PUBLIC WORKS ENGINEERING

IVOR H SEELEY

Public Works Engineering

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Public Works Engineering

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Engineering is a creative activity involving imagination, intuition and deliberate choice

Ove Arup

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Preface

Public Works Engineering embraces the many aspects of civil engineering and associated building work which are of use and benefit to the public and they may be undertaken by public, private or statutory undertakings. In general, civil engineers change the natural environment, preferably in a sympathetic way, for the benefit of humanity, and provide, operate and maintain the infrastructure of structures and services which are so essential to the survival of a modern civilisation. The infrastructure is the fabric of a nation, forms the foundation on which the standard of living is built and serves the essential needs of industry and commerce.

The range of activities is enormous from transportation and highway and traffic engineering through to wastewater engineering, solid waste management and water engineering. Conservation work, the building of new towns, enhancement of the environment and the provision of major recreational facilities all fall within its scope. Flood relief work, coastal and river engineering, harbour regeneration and construction, offshore works and energy generation all form vital areas of public works engineering, and are all explored in such depth as the reasonable size of the book permits. There are many references for readers who wish to pursue particular aspects in greater detail.

Widely dispersed, challenging and informative examples have been selected as case studies to illustrate the problems encountered in many parts of the world and how they have been overcome, preceded by an analysis of the principal design, construction, management and maintenance aspects. These schemes are of great benefit to those who use the facilities or are served by them.

Special emphasis has been placed on the provision of supporting photographs, to give a better comprehension of the nature and scope of projects and to help bring the text to life, using colour where this will be of particular benefit to the reader. There are also more than 100 diagrams showing details of projects to assist the reader in appreciating and understanding the more important features incorporated in the selected schemes.

The book commences with a study of the organisational, financial, legal, management and marketing aspects of public works engineering, which it was felt would provide a useful backcloth to the subject. This introductory chapter is followed by seven self-contained chapters each encompassing important and far reaching facets of public works engineering.

Many aspects of transportation are considered and compared, including the provision of major highway and motorway projects and bus stations in the UK. Other topical highway aspects examined include the relief of traffic congestion, forecasting traffic flows, park and ride schemes, road pricing and private sector initiatives. A comparison is made of UK, French and Australian railways with their different objectives, followed by an analysis of the civil engineering problems associated with the electrification and modernisation of railway networks. The importance of modern mass/light rail transit systems to help combat severe urban congestion is illustrated by reference to London Docklands Light Railway, Tyne and Wear Metro, Greater Manchester Metrolink, Hong Kong Mass Transit Railway and Singapore Mass Rapid Transit System. The principal civil engineering works associated with the extensive UK canal network are examined together with interesting major projects at Limehouse Tidal Lock, Llangollen Canal, Stanley Ferry Aqueduct and Blisworth and Netherton Tunnels. The design, construction and possible problems in the operation of the Channel Tunnel are explored. The selection of airport sites and the design and maintenance of airfields are followed by a comparative study of recent airport projects at Heathrow Terminal 4, Gatwick North Terminal, Stansted, Changi (Singapore) and Mount Pleasant (Falklands Islands).

Highway planning, design, construction, management, widening and maintenance are all considered, together with their practical implications and the provision of major road junctions and intersections in the UK, Hong Kong, Oman, Singapore and Australia. Extensive and exciting bridge projects are examined in the UK, Hong Kong, South Korea and Japan. Road safety, lighting and parking also receive attention.

Sewer and manhole design, construction and rehabilitation, together with the provision of long sea outfalls and associated headworks, to reduce pollution of beaches, are examined and described. Major wastewater schemes at Cairo and Shanghai are analysed and compared, and the design and construction of sewage pumping stations are illustrated by reference to projects at Portland, Royal Docks and Ameria (Cairo). The main wastewater treatment processes are investigated and treatment plants in the UK, Middle East and Hong Kong are described and illustrated.

Solid waste management processes, including collection and disposal methods, are analysed together with the nature and purpose of solid waste transfer stations, incineration, waste derived fuel and composting plant, with supporting examples. The Rechem Pontypool hazardous wastes disposal plant and the disposal of radioactive wastes are also examined.

Water supply management processes are becoming increasingly important and these are examined and described with reference to the UK and developing countries. The methods of construction of reservoirs and dams are investigated with illustrated descriptions of the impressive Mudhiq Dam in Saudi Arabia and the vital Queen's Valley Reservoir in Jersey. Boreholes and wells, with their associated pumps, and water supply networks and services, including the London ring main, are suitably detailed. Water treatment processes are analysed and compared and a variety of water treatment plants in the UK, Sicily, Bombay, Iraq and Malaysia examined in some detail. Attention is paid to the important aspects of leakage control and metering, and the provision of service reservoirs, water towers and pumping stations, with detailed case studies of two complex pumping stations in Hong Kong.

A comparative study, with practical examples, is made of housing development and new towns in the UK, Hong Kong and Singapore, and an analysis of modern commercial and industrial developments, including business and science parks. The increasing importance attached to conservation work is recognised and studies embrace the Albert Dock, Liverpool and the current Singaporean policy in a multi-racial country. Urban renewal projects, which are becoming increasingly urgent with such large areas of derelict land in the UK and many other countries, centre around London Docklands, Swansea Maritime Quarter and Darling Harbour in Sydney.

Flood relief schemes include the Thames and Barking Barriers and two projects in Yorkshire, while sea defence and coastal and river management systems are examined and supported by practical examples. Port and harbour construction and regeneration schemes embrace Aberdeen, Felixstowe, Umm al Qaiwan (United Arab Emirates), and the Hebrides and Shetlands. The design and siting factors of container terminals are considered with case studies of Bahrain and Indonesia. Extensive reclamation processes in Singapore and Hong Kong are examined together with their important after-use. The importance of irrigation in dry regions, including the re-use of sewage, is examined supported by relevant examples in the Middle East and Madeira. The main characteristics and hazards of offshore works are investigated and a study made of the Magnus Oilfield and other North Sea projects.

A variety of recreational facilities are considered ranging from water based sports to swimming pools and sports stadia, illustrated by noteworthy examples such as the Holme Pierrepont Water Sports Centre and Toronto's Sky Dome. Other famous recreational structures investigated include the Sydney Opera House and Sydney Centrepoint Tower. The study of recreational facilities also encompasses national parks and associated recreational features, garden festivals and Sentosa Island, Singapore.

Energy generation involves extensive civil engineering works and particular attention is paid to the design and construction of power stations, with practical examples taken from China and Hong Kong. The importance of hydroelectric schemes is recognised and the study includes major schemes in Malaysia, Java and Kenya. The final chapter concludes with a comparison of the Severn and Mersey Tidal Barrage schemes and the use of wind energy systems.

The book is designed to meet the needs of a wide range of readers in the UK and overseas, ranging from practising civil engineers and civil engineering students, to consultants, contractors and clients. There is much within its pages of interest to a wider readership including structural engineers, architects, surveyors, builders, planners and environmentalists, and also lay persons who wish to know more about the provision, operation and maintenance of a country's infrastructure.

The preparation of the book has involved the author in extensive research and the text has benefited enormously from the contributions made by the numerous persons and organisations listed in the *Acknowledgements* section of the book and throughout the various chapters. They have all given so freely and so willingly of their time and resources.

Abbreviations are used extensively and they are listed in the Appendix at the end of the book for ease of reference.

IVOR H. SEELEY

Acknowledgements

A great debt of gratitude is owed to the many persons and organisations who gave so much assistance in such a willing and helpful way. It is not possible to mention them all personally, but the following are specifically listed as supplying plates and/or diagrams or in giving permission for their reproduction, and these have done much to enhance the quality and usefulness of the book. I have also drawn readily from technical publications listed in the references at the end of each chapter for which my grateful thanks are due to the authors and publishers respectively.

Proceedings of the Institution of Civil Engineers and Thomas Telford Publications: figures 2.5, 2.6, 2.7, 2.10, 2.11, 2.14, 2.15, 2.16, 2.23, 2.31, 3.1, 3.2, 3.3, 3.10, 3.11, 3.12, 3.13, 6.11, 6.12, 6.13, 6.14, 6.15, 6.16, 6.17, 6.18, 6.19, 6.20, 8.9, 8.10, 8.23, 8.37, 8.38 and 8.39.

Municipal Engineer and Thomas Telford Publications: figures 2.2, 2.3, 2.4, 3.9, 4.15, 4.16, 4.17, 4.18, 8.6, 8.13, 8.14, 8.25 and 8.26.

New Civil Engineer and Thomas Telford Publications: figures 3.5 and 4.4.

ICE/Thomas Telford Publications. Long Sea Outfalls: figures 4.6, 4.7, 4.8, 4.9, 4.10, 4.11, 4.12 and 4.13.

ICE/Thomas Telford Publications. Port Engineering and Operation: figure 8.12.

W.S. Atkins, Consultants Ltd: figures 2.1, 4.26, 5.2 and plate 1.

Binnie & Partners, Consulting Engineers: figures 4.3, 4.20, 4.22, 4.24, 4.25, 6.3, 6.7, 8.5 and 8.35 and plates 15, 17 and 42.

Sir W. Halcrow & Partners, Consulting Engineers: figures 2.28, 2.29, 4.19 and 8.36 and plates 2, 5 and 43.

L.G. Mouchel & Partners, Consulting Engineers: figures 3.16 and 8.34.

Ove Arup, Consulting Engineers: figures 7.10, 8.27, 8.28, 8.32 and 8.33.

Ove Arup, Consulting Engineers and Arup Associates, Architect/Master Planners: figure 7.9.

Rendel Palmer & Tritton, Consulting Engineers: figures 3.14, 3.15, 8.1, 8.2, 8.3, 8.11, 8.15, 8.16, 8.20 and 8.40 and plate 41.

Scott Wilson Kirkpatrick, Consulting Engineers: figures 3.4 and 3.6 and plate 10.

Travers Morgan, Consulting Group: figures 2.8, 2.9 and 3.8 and plates 8 and 9.

Watson Hawksley, Consulting Engineers: figures 4.5, 4.14, 6.8 and 6.9 and plates 13, 16 and 18.

W.A. Dawson Ltd, Civil Engineering Contractor, Luton: figures 4.23, 8.7 and 8.8 and plates 3, 4, 12, 32 and 33.

Shepherd Construction Ltd (copyright): figures 2.12 and 7.12 and plates 23 and 39.

Ministry of Transport: figure 4.1.

Sports Council: figure 8.24.

Greater London Council: figures 5.3, 5.4 and 7.1.

Isle of Wight County Council: figures 5.10, 5.11 and 5.12.

London Docklands Development Corporation: figure 2.13.

Merseyside Development Corporation: plates 25 and 26.

Milton Keynes Development Corporation: figures 7.17 and 7.18.

North London Waste Authority: figures 5.5 and 5.6

Swansea City Council: figure 7.15.

British Airports Authority: figures 2.32 and 2.33.

BAA (Heathrow Airports Ltd): plate 6.

British Waterways: figures 2.22 and 2.25 and plate 37.

Eurotunnel: figures 2.26 and 2.27.

Greater Manchester Passenger Transport Executive: figures 2.20 and 2.21.

Holme Pierrepont Water Sports Centre, Nottingham: plate 38.

Severn Trent Water: figures 6.1, 6.2, 6.4, 6.5 and 6.6 and plate 14.

Thames Water: figure 8.4.

Transmanche-Link: figure 2.30.

Tyne and Wear Passenger Transport Executive: figure 2.19.

Hong Kong Territory Development Department: figures 3.7, 7.2, 7.8 and 7.19 and plates 19, 20, 21, 30, 34 and 35.

Singapore Housing and Development Board: figures 7.3, 7.4, 7.5, 7.6, 7.20, 8.17, 8.18 and 8.19 and plates 22 and 31.

Singapore Mass Rapid Transit Corporation: figures 2.17 and 2.18.

Singapore Public Works Department: figures 2.35 and 2.36 and plates 7 and 11.

Singapore Urban Redevelopment Authority: figure 7.14.

Sentosa Development Corporation, Singapore: plate 40.

Brent Walker Group plc: plate 36.

East Sussex Enterprises Ltd: figure 5.9.

London and Metropolitan plc: figure 7.11 and plate 24.

Norwich Union: figure 7.7.

Olympia and York Canary Wharf Ltd: plate 29.

Rechem: figure 5.15.

Walcon Marine Ltd: figure 8.21.

Concrete Pipe Association: figure 4.2.

The publications of the Institution of Civil Engineers and Thomas Telford Publications Ltd have been invaluable sources of technical data, and I am very much indebted to the authors and publishers respectively. My discussions with civil engineers in widely dispersed locations have proved most enlightening.

As with previous publications, I would like to express my sincere thanks to Malcolm Stewart of Macmillan Education for his continual help and advice and to my wife for her background assistance and understanding.

Colour Plates (all located near middle of book)

1

General Background to Public Works Engineering

This chapter is introductory in nature and describes the type of activities embraced by the term *Public Works Engineering*; the various parties involved, the possible effect of the European harmonisation arrangements in 1992; financing, management and marketing; use of computing aids; whole life costing; contractual arrangements, communications; liabilities; quality assurance; safety, and environmental aspects.

General Introduction

For the purposes of this book the term *Public Works Engineering* embraces the many aspects of civil engineering work which are of use and benefit to the public, and they can be undertaken by public, private or statutory organisations. The main activities will be discussed later in this chapter. In general, civil engineers change the natural environment for the benefit of humanity, and provide and maintain the infrastructure of structures and services which are so essential to the survival of civilisation.

The Confederation of British Industry aptly described how 'the infrastructure is the fabric of the nation. It is important to us all. It is the foundation on which our standard of living is built. It is important to industry and commerce because it provides the essential support for the endeavours in the creation of wealth'.[1]

The majority of persons concerned with the design and execution of major schemes of public works engineering are corporate members of the Institution of Civil Engineers, and are frequently supported in their work by technician engineers. The Institution of Civil Engineers – civil means civilian as opposed to military – was founded in 1819, and has a royal charter to work for the benefit of society. In 1989 it had 72 000 corporate members serving the communities of 146 different countries. The Institution has three main roles – learned society (to facilitate the advancement of the engineering science and the acquisition of knowledge), qualifications (to ensure members are appropriately prepared for and competent in the profession) and public affairs (including giving advice to government).

It would be appropriate at this stage to give the definition of the profession of a civil engineer as stated in the Royal Charter of the Institution of Civil Engineers, namely 'the art of directing the great sources of power in Nature for the use and convenience of man, as the means of production and of traffic in states for both external and internal trade, as applied in the construction of roads, bridges, aqueducts, canals, river navigation and docks, for internal intercourse and exchange, and in the construction of ports, harbours, moles, breakwaters and lighthouses, and in the art of navigation by artificial powers for the purposes of commerce, and in the construction and adaptation of machinery, and in the drainage of cities and towns.' This wide ranging definition needs to be interpreted in the light of changed technologies and the establishment of the Institutions of Electrical and Mechanical Engineers.

The Institution of Municipal Engineers merged with the Institution of Civil Engineers in 1984 based on the large degree of common interest, to reduce the amount of fragmentation already existing amongst the chartered engineering bodies and to form a cohesive force dedicated to furthering the interests of the profession as a whole. The essential traditions and aims of the Institution of

Municipal Engineers were preserved by the creation of the Association of Municipal Engineers. The Association has welcomed into membership civil engineers who carry out work for municipal authorities but are not employed by them. Professionally, municipal engineers have been at the forefront of change and from daily experience develop a sense of social conscience irrespective of personal political preference.

The main aims of the Association of Municipal Engineers are as follows:

1. to influence and promote the needs and benefits of public sector engineering both within the Institution and outside the profession;
2. to develop engineering and management excellence in public sector engineering; and
3. to promote a corporate identity for public sector engineers in the divisions and the United Kingdom as a whole.

The Association forms a focus and forum for those members of the Institution of Civil Engineers who are involved in the provision, operation, development and maintenance of municipal and public services. It seeks to develop among civil engineers an awareness of the needs of the community, to encourage knowledge of relevant legislation and to promote excellence in the art of public administration and management. It issues a lively and informative journal, arranges an annual conference, debates and seminars and awards prizes for published papers. In 1989 it had a membership of about 11 000.

Nature and Scope of Public Works Engineering

The range of public engineering works is extremely wide and covers a great diversity of projects of varying size and complexity and located worldwide. The following schedule lists most of the main projects making up this field of activity:

highways with associated bridges and tunnels, and traffic management schemes
airports, railways, rapid transit systems, canals and navigable rivers
sewerage and sewage disposal (waste water engineering)
waste disposal
water supply, treatment and distribution
urban development and redevelopment, renewal and conservation
recreational facilities
flood relief
irrigation
port and harbour works and marinas
marine and coastal engineering
land reclamation
power generation
barrages
offshore engineering.

Many of the projects have become more sophisticated such as the Mass Rapid Transit network in Singapore and the Channel Tunnel, large environmental engineering projects, vast motorways with their complex intersections and large extensions to major airports, all of which feature in this book. The problems of urban decay, deprivation and dereliction have become ever more widespread and require urgent and substantial resources for their alleviation.

The comparative poverty of many third world countries is generally caused by inadequate water supply, irrigation and transport systems, and insufficient energy and poor housing; and all aggravated by rapid population growth, coupled with reduced productivity engendered by endemic ill health, mainly caused by impure water supplies and inadequate sanitation. Unless these major deficiencies are remedied they could become the cause of serious strife in the years ahead. Hence it is vitally important to increase investment in public works engineering throughout the world,[2] and particularly in Africa and Latin America. Unfortunately, in the early 1990s the poorest nations, weighed down by debt, were becoming poorer and the infrastructure development which must form part of any strategy for economic growth was not taking place.

The United Nations Centre for Regional Development (UNCRD) initiated a cross-national research project on Managing Urban Development: Focus on Services for the Poor. The Centre has organised expert group meetings to discuss concept papers commissioned by the Centre; and to prepare a research format for undertaking comparable case studies of urban projects. The publication*Urban Services in Developing Countries*[3] includes the revised version of these concept papers and examines both policy issues and actual experiences with pioneering programmes in developing countries, and focusses on the roles of government, community organisations and international agencies such as USAID, the World Bank and UNICEF. Problems of organisation and management, finance, social services, housing, slum upgrading and credit provision for small scale businesses are highlighted.

Another important concept facing civil engineers has been their role in society and they responded by setting up the Infrastructure Planning Group (IPG) in 1981 with the remit of reviewing, establishing and recommending the infrastructure needs of the United Kingdom until 2000. The IPG produced two reports, the first in 1984 giving an overall picture of the infrastructure,[4] and the second in 1986 concentrated on transport and water supply.[5] The IPG has also sponsored a number of major debates on such topics as capital investment and the water industry, the future of railways, the Channel Tunnel and the consequences of the government's airports policy.

Effect of European Community Harmonisation Arrangements on the Construction Industry

General Implications

A single European market in 1992 embracing 320m consumers will result in fundamental changes to the British construction industry. It poses a threat to those who cannot adapt but will provide tremendous opportunities for those who are willing to expand into the world's largest market.

To make the most of the changing situation, each construction company needs to examine its own strategic plan, decide where its main expertise lies, and then proceed to build a European business based on these. It may be that the best way forward is by joint ventures with other European companies. The poorer European countries like Spain, Portugal, Italy and Greece, who are the main recipients of the European Community's structural adjustment programme for infrastructure development, may provide schemes to which UK contractors could be attracted. Projects like the Channel Tunnel, which brought together five British and five French contractors, could lead to continuing associations for work on future schemes.

It is evident that companies with European ambitions need to undertake extensive market research to understand the mechanism of the construction industry in each EC member country, as only by knowing specific client requirements and their competitors will they be able to compete effectively. They will also need to consider the likely shape of their business organisation in Europe, the number, size, nature and location of production and distribution units, the recruitment and training policies with special emphasis on linguistic abilities and the alliances, joint venture, merger and acquisition policies.[6]

Consultants will also recognise the attraction of a single European economy, based on their substantial experience in so many branches of construction work. They will also need to carry out similar investigations and activities to those described for construction companies. This could result in the amalgamation of firms and a substantial reduction in their total number.

Qualifications are subject to two different approaches. A general directive for professional qualifications came into force in January 1991, whereby chartered bodies are obliged to recognise equivalent qualifications in other EC countries. At craft level, vocation qualifications in the EC will be linked to mutually agreed job descriptions.

An examination of the role of civil engineers in other EC countries and the way in which they operate is also needed. For example, in France the engineer is the most dominant person in the construction industry. He supervises work on site for the client and contractors, is heavily involved in design work, and undertakes many of the functions that in the UK would often be carried out by building and quantity surveyors. The architect is normally only responsible for the conceptual design of a building with little involvement in detailed and working drawings which are usually produced by the contractor.[7]

EC Directives

A number of directives have been issued with radical implications for the UK construction industry. For example, public works directive 71/305 has been in existence since 1971 and requires national public works authorities to advertise all tenders for construction over the stated value in the *European Journal*. It also permits engineers/contractors from other member states to submit alternative tenders. This directive has since been revised to raise the level of contract values and to require public works authorities to accept for consideration alternative tenders based on European codes and standards.[8]

Other important directives with construction implications include the construction products directive, which applies to all products for permanent inclusion in building and civil engineering works. On large public sector contracts the materials will have to be specified and advertised in the *European Journal* to enable manufacturers from other member states to bid for the contracts. Yet another impending directive at the time of writing this book required the advertising of consultants' appointments on large projects, although this carries with it a number of problems, including the possible difficult administration of competitions.

Further controversial proposals include the establishment of a standard form of construction contract for Europe. This fails to recognise the impossibility of considering a legal document in isolation from the legal systems in which it operates. European legal systems vary fundamentally. In some countries the law of contract is paramount; whereas in others, such as France, Belgium, Spain and Italy, the civil codes are stronger than contract provisions. Anglo Saxon countries have no civil code but common law based on precedent, which again can take precedence over a contract. Liability for construction works also varies considerably making for problems in harmonisation.

Eurocodes and Related Standards

Eurocodes are intended to cover the design rules for all types of structure, except certain very specialised forms such as nuclear reactors and long span bridges. The first nine Eurocodes encompass common unified rules; concrete structures; steel structures; composite steel and concrete structures; timber structures; masonry structures; foundations; structures in seismic zones; and actions.

The Commission intends that these design codes will have the following objectives:

(a) to promote the functioning of the Common Market by removing obstacles arising from differing rules, and the regulatory authorities of member states will be expected to give equal status to the European codes and national codes
(b) to provide common technical rules for the efficient application of the Council directive 71/305 on the co-ordination of procedures for the award of public contracts, which can be applied as an alternative to the national rules
(c) to reinforce the competitive position of the European construction industry and allied professions in countries outside the Community – future EC contracts are likely to require that the work be in accordance with European codes and standards
(d) to establish a basis for the common rules intended for building products – the construction products directive will refer to interpretive documents in the context of establishing criteria for the design of products; and for structural products Eurocodes will fulfil this function.

The format of the Eurocodes draws a distinction between principles and application rules.

The principles relate to matters for which there is no alternative; they are therefore mandatory in the context of Eurocodes. The application rules are those which satisfy the principles. The designer has the freedom to use other equivalent methods of satisfying the principles, but the basis of any such method will have to be justified by the designer to a regulatory authority where appropriate.[8]

The preparation of the documents has been carried out by drafting panels of experts appointed by the Commission. They have used as their starting point the technical base/model codes prepared by relevant European technological associations. In the UK the Department of the Environment (DOE) is the body primarily responsible for matters of policy concerning the Eurocode programme and for the provision of funds for the necessary design and safety studies required when the national comments are being developed. The DOE relies on the British Standards Institution (BSI) to provide the technical response from industry.[8]

The intentions of the Commission concerning the use of Eurocodes as design codes are as follows:

(a) Their use should be optional and they should be permitted to exist in parallel with national codes.
(b) When the final draft has been approved by the member states, the Eurocodes shall be offered to the Comité Européen de Normalisation (CEN) – the European committee for standardisation and the European equivalent of BSI – as a basis for harmonisation of national codes of practice.
(c) The European Free Trade Association (EFTA) countries should be given the opportunity to comment on and to participate in the approval process, so that the Eurocodes can be accepted throughout Europe and not just within the EC.
(d) The European code on actions together with the design codes and key material standards shall form a European operational package.

However, the ultimate objective is that the European codes shall replace BSI codes when finally approved and after an appropriate transition period, although there is a significant input from BSI in their formulation.

The principal objective of the Eurocode is to facilitate trade in professional services across the member states. UK consultants will generally find it easier to obtain local approval of their designs in other member states when they use Eurocodes. However, in practice the problem of code approval is only one factor in the difficulty of operating in other European countries, and another is language, as British engineers are rarely fluent in other languages.

Other engineers in the Community may see the UK as a new market for their services and will have no language problem.[8]

In the early 1990s it was probable that many more British engineers worked in overseas contracts outside the Community than in the other member states, which are incidentally now becoming part of the home market. Furthermore, the Community has a significant annual investment in contracts in Third World countries. In future it seems inevitable that the Commission will insist that such contracts be based on European codes and standards. This will have significant implications for those engineers who are currently used to designing in accordance with British codes. In addition, in most engineering contracts the materials are specified on the basis of the standards to which the design codes refer. A change of code could therefore have significant implications for material manufacturers.[8]

When completed the Eurocodes will reflect the civil and structural engineering technology across the EC, and with the active co-operation of the EFTA countries, over the whole of Europe. Bartle and Thorburn[8] have described how as the codes are updated not only will they reflect the latest technology, but also generate new technology which will enhance the quality and image of the European construction industry. There will be an increasing need for greater European collaboration in civil engineering research and development, with substantial financial assistance from EC funds.

Nature, Role and Terms of Engagement of Public Works Engineers

The Engineer

In *Civil Engineering Procedure*,[9] the Engineer is defined as 'the person representing the organisation which provides professional advice on the investigation for, and the design and construction of, civil engineering works.' Consulting engineers usually practise in the form of partnerships but may practise as limited liability companies or as individuals. Alternatively the Engineer may be an employee of the Promoter. The Contractor can also employ engineers to carry out civil engineering duties on the sites of projects.

It is usual for the functions of the Engineer to include the development, design and technical direction of the Works, preparation of specifications, bills of quantities and other contract documents. During the execution of the Works, his duties include the inspection of materials and workmanship and a variety of administrative duties such as the measurement and valuation of the work and the pricing of varied work, in which he may be assisted by a quantity surveyor.

Promoters include central government departments, local authorities, national or public industries or corporations, incorporated companies, and other organisations, both in the United Kingdom and overseas. In 1987 public new construction spending on infrastructure in the United Kingdom amounted to £351m on water and sewerage, £220m on electricity and coal, £732m on roads, £193m on railways and air transport and £108m on harbours and waterways.

Consulting Engineers

The Association of Consulting Engineers was formed in 1913 to promote the advancement of the profession of consulting engineers (not exclusively civil engineering) and to ensure that its members advising on engineering matters are fully qualified engineers in their respective fields and at the same time willing to be bound by a strict code of professional rules. The Association also provides for the information of the public a list of independent engineers who are not directly or indirectly connected with any commercial or manufacturing interests which might affect their professional judgement. It affords a means by which the profession can confer with government and public departments as well as other professional bodies, and recommends conditions of engagement between the client and the consulting engineer.[9]

The International Federation of Consulting Engineers (FIDIC) was also founded in 1913 by five national associations of consulting engineers within Europe, and since the last war has expanded substantially to embrace thirty countries within its membership. Its objects are to disseminate information of interest to its members and promote their professional interests. Probably the best known of its publications is the FIDIC Conditions of Contract which are used internationally.

Initially, consulting engineers tended to specialise in activities such as roads, bridges, tunnels, dams and maritime works and their reputations were built on major projects constructed both in the United Kingdom and abroad. One major success story is the establishment and high reputation of British consulting engineers in respect of their overseas work which provided a valuable source of earnings.[10]

As the workload increased, firms of consulting engineers grew in size and although they may have been founded on specialist activities, many firms have merged and diversified in the range of their work. In the UK in 1990 there were about 12 firms with a staff in excess of 1000 employees. Most of these undertake the whole range of civil engineering work, of which public works engineering forms a dominant part, and many of them provide specialist services such as electrical and mechanical engineering, geotechnical engineering, transportation, and planning and environmental work.

Large firms of consultants frequently structure their activities by regions or types of service often on a divisional basis. For example, Watson Hawksley who specialise in water, wastewater, and environmental engineering and science, have structured the group into three regional divisions in the UK, a European division and four overseas divisions, together with three specialist divisions based on the head office covering earth science and dams, mechanical and electrical, and process design. By comparison, Binnie and Partners who specialise in water resource development, have formed twelve specialist groups and departments embracing such activities as computer aided draughting, geological, geotechnical, hydrology, marine, wastewater, and water treatment.

The very large Travers Morgan Group has formed three main divisions which are then further subdivided into a variety of both regional and specialist activities, ranging from railways, civil engineering, electrical and mechanical to planning and environment, and landscape. The three main divisions are also supported by three others covering international work, computing, and a service company to the Group. There is no universal structure and each one is designed to suit the individual needs of the particular consultant. It is emphasised that the examples have been taken at random.

Furthermore, the range of services offered by the leading consultants has become much more comprehensive and sophisticated and can encompass such diverse activities as formulation of alternative strategies, investment appraisal, sensitivity analysis, risk analysis, project finance, planning and programming, life cycle costing, quality assurance and advice on a whole range of contractual and cost related matters. Most of the consulting engineers have highly efficient marketing departments and issue an excellent selection of high quality, informative and very well presented and illustrated brochures giving the potential client a valuable introduction to the range of services offered by the practice.

Engagement of Consultants

The Association of Consulting Engineers formulated recommended fee scales and is of the opinion that competition in quality of service or by innovation based on research is a much better form of selection than price competition. The Association also felt that price competition was fraught with dangers such as the employment of less competent staff, the preparation of inadequate or extravagant designs, possibly resulting in high maintenance and operating costs. However, the Monopolies and Merger Commission was not convinced of the validity of this argument and concluded that the imposition of rules which prevented competition on the basis of fee scales was against the public interest.

By the mid-1980s most public sector financed work given to consulting engineers was awarded on a competitive fee basis. It could be argued that the fee structure yielded windfall profits in times of inflation and that savings could be possible with the more extensive use of computer-aided systems for survey plotting, and drafting bills of quantities and specifications and the development of more efficient and economical working practices. But there still remains the fear that minor savings in fees are no real substitute for much higher maintenance costs resulting from over-economising and insufficient attention to detail at design stage.[11]

If fee competition is to be applied to professional design and supervision services, it is essential that consultants receive adequate briefs and the following four conditions have wisely been suggested as desirable requisites:

(a) the services to be supplied should be adequately specified in advance of competition
(b) only firms capable of carrying out the services should be invited to compete
(c) there should be a means of ensuring that the services are correctly supplied as stipulated
(d) the supplier of services should be reasonably expected to remain financially sound and have relevant insurance, continuing until the expiry of the relevant legal limitation period.[11]

Municipal Engineers

Municipal engineers are responsible for the provision of much of the infrastructure for society, despite the privatisation of some of the municipal services. They are heavily involved in transportation, highways, urban development and redevelopment, coastal protection, ports, harbours, airports, cleansing, waste disposal, land reclamation, building control and recreational facilities. Moreover, working in a local government environment demands a variety of skills to be employed in the political and democratic processes, relating to the promotion and administration of technical services, apart from the exercise of expertise in civil engineering.[12]

By the late 1980s the municipal engineering profession was facing an unprecedented amount of external pressure, particularly from central government. Issues such as the crumbling infrastructure, privatisation, officer/member relationships and financial restraints imposed by central government, combined to compel the municipal engineer to adopt different and versatile approaches to many of his functions.

A local government officer has a duty to his employer who is generally represented by the controlling group on the council. He also has a professional duty to give his professional advice without fear or favour, and he needs to know that he has an absolute right to report a dissenting opinion. Having done that he has a duty to act on the decision finally made by the Council.

Councillors are politically aware of the needs and actions required in caring for their wards and districts. They have a vision of what they want but the reality of the situation does not always match their aspirations with regard to time, cost and/or quality. Ideally, the councillors will rely upon the engineer to advise them on the practicalities and economics of alternative proposals. The engineer often needs to consult with other officers of the council when matters arise which have legal and financial implications and, on occasions, it is necessary to prepare joint reports.

Rogers[10] points out that in future, to ensure full accountability, it is probable that engineers will need to separate the work of the design team from client activities, and to complete timesheets for the design work in the same way as consultants. This is essential for monitoring expenditure on specific schemes or elements of such schemes, to determine whether or not the operation is profitable and as a basis for future bid proposals. From completed timesheets it is possible to ascertain the amount of productive time of the design team. A common target in consultants' offices is around 82%; the unproductive time being taken up by leave, sickness, office administration and sometimes waiting between projects.

Another important element to be included in the costings is that of overheads, which consist of such items as:

(a) rent, rates and other expenses of the upkeep of offices, their furnishings, equipment and supplies
(b) insurance premiums other than those recovered in payroll costs
(c) administrative, accounting, secretarial and financing costs
(d) cost of keeping abreast of advances in engineering
(e) cost of preliminary operations for new or potential projects
(f) loss of productive time of technical staff between assignments.

Future of the Municipal Engineer

It is possible that significant changes could take place in the role and activities of the municipal engineer by the mid-1990s. He could conceivably become part of a more general technical services department, embracing architects, engineers, quantity surveyors, estate and planning officers and environmentalists. In this situation, the engineer will need to compete with other professionals for the leadership of these major spending departments. Furthermore, chief officers may be recruited without previous local government experience and engineers aspiring to top posts may have to be prepared to transfer between private and public sectors in the development of their careers.

Engineering departments are likely to be smaller and to concentrate their in-house work on smaller capital schemes and revenue expenditure. Major capital projects are more likely to be undertaken by specialist consultants supported by highly computerised facilities, with the commissions awarded in competition. There could be increasing emphasis on direct government funding and control of major infrastructure projects.

The engineer could provide an important service as 'enabler' or client adviser to other departments whose technical work is undertaken by consultants. The provision of engineering services is likely to be subject to increasing budgetary controls and cost monitoring and must be highly cost-effective.

Implementation of Public Works Engineering Projects

Contractors

The bulk of public works engineering projects are undertaken by general contractors who, on account of their extensive knowledge and experience, are able to accept responsibility for the construction of the whole of a project. They are usually limited liability companies. Many of the larger contractors carry out both building and civil engineering work; many public works engineering contracts contain some building work and the demarcation line between the two classes of work is, on occasions, rather blurred. As for example structural steelwork and chimneys on power station contracts.

The larger public works engineering projects require considerable technical knowledge, skill and ingenuity in their construction. The use of new materials, plant and techniques is continually changing the nature and methods of construction, and the increasing size and complexity of the works, often coupled with difficult site conditions, call for ever greater expertise and skill on the part of contractors, who carry very heavy contractual responsibilities.

Contractors who confine their activities to selected classes of work are generally referred to as specialist contractors. They carry skilled staff and plant particularly suited to their sphere of work and can therefore undertake the work economically and efficiently, to the advantage of promoters and general contractors alike. A specialist contractor may perform his work by sub-contract to a general contractor who will act as co-ordinator. Alternatively, the specialist contractor may carry out his work by direct contract with the promoter. Specialist work encompasses such activities as demolition, earthworks, piling, tunnelling and marine work.

The Federation of Civil Engineering Contractors was formed in 1919 with the following main objectives:

1. to further the interests of its members
2. to establish amicable arrangements and relations between its members and their work people and to regulate wages and working conditions in the industry
3. to maintain a high standard of conduct
4. to combat unfair practices and encourage efficiency among its members
5. to settle and secure the adoption of standard forms of contract embodying equitable conditions.

Local Authority Direct Labour Organisations

The method of operation of local authority direct labour organisations changed significantly in the 1980s as central government introduced measures aimed at ensuring greater accountability and increased value for money. Municipal engineers have generally responded well to the changed situation and recognised the need for competition in the provision of local government services. Carter[13] described how these requirements sharpened the approach to, and the appreciation of, the need to review constantly whether or not methodology and operations were achieving objectives and value for money. The fact that a service has historically been provided by directly employed personnel does not in itself justify claims that it cannot be provided at least equally by other means.

The Local Government Planning and Land Act 1980 and the associated statutory instruments contained five major requirements relating to direct labour organisations (DLOs):

1. to maintain and publish promptly separate accounts on a trading account basis for each of four main categories of work, giving a true financial picture of their operations (general highways and sewer works, other works of new construction exceeding £50 000, ditto not exceeding £50 000, and other works of maintenance)
2. to obtain tenders for work above prescribed limits in each category
3. to achieve a rate of return on all capital employed (initially 5%)
4. provision and publication of reports
5. power of Secretary of State to close down DLOs in certain circumstances.

In preparing estimates and tenders a DLO must include a fair proportion of local authority administrative charges, which are comparable with contractors' oncosts. It is frequently argued that DLOs could operate more cheaply if they were not subject to inhibiting local authority conditions, such as higher than average safety and training standards, and committee structures and cycles, or the dependency on other local authority departments for advice and service, although it should be borne in mind that the larger contractors also have to pay for legal, accounting and personnel advice.

The Local Government Act 1988 placed further restrictions on local authorities by requiring them to invite bids from both private companies and staff to operate seven services, namely school meals, other catering, refuse collection, street cleaning, building cleaning, grounds maintenance, and vehicle maintenance.

The quality of the service provided by private contractors will be influenced by the adequacy of contract documents, the manner of selection of tenderers and the standard of supervision of the contract.[14] A common local authority assertion that putting out work to the private sector will of necessity result in a worse service is unsustainable, although there are certain activities, particularly emergency works, where DLOs can often offer the best service. One major weakness is that all too frequently the work of DLOs is shared between committees and sub-committees which are not responsible for achieving satisfactory rates of return.

Green[14] has described how local authority committee and departmental structures are generally ill-suited for running a business. Lines of communication are too long, decision making is too centralist and too slow, accountability is not clearly defined, there is inadequate delegation, overlapping of roles between members and officers and an abundance of incompatible objectives. Standing orders are generally designed to protect the local authority as an employer of contractors rather than a contractor in its own right.

An Audit Commission report in 1989[15] claimed to have found strong evidence that in many local authorities the costs of building maintenance direct labour organisations were far higher than they need be and that not enough attention was paid to the quality of service. The Commission recommended better management and control of overheads, improved incentive and bonus schemes and better training schemes.

The changing climate has produced the need for the municipal engineer to change from his role as a trusted public servant to a thrusting commercial manager, concerned with identifying needs and developing performance standards. In some cases this has involved a complete review of operations which were based on outdated customs and practice.

All activities need to be kept under constant review and alternative procedures costed and compared. The use of computer technology can assist in assessing the operational and financial consequences of alternatives, whether provision is by contract or direct labour. The various elements constituting the service, such as transport, equipment, labour and accommodation, require detailed assessment. This analysis, coupled with investment decisions and the establishment of realistic productivity levels, will help in promoting the more efficient direction of future operations.[13]

Financing Public Works Engineering

Local Authority Finance

Local authorities may finance capital expenditure from a number of sources of which the main ones are borrowing, capital receipts embracing income from the sales of assets such as surplus land and council houses, grants from central government and poll tax or other local tax. The principal source of funds still remains government grants, which were progressively reduced in real terms during the 1980s.

Problems in the planning and implementation of public works projects have often been exacerbated because of conflicting objectives between central and local government. Despite the original intentions the grant system offers little or no flexibility. Even the option of using finance raised through capital receipts has been progressively reduced by a central government whose main preoccupation is to keep spending within annual cash limits. Operating on an annual basis creates the worst possible conditions for promoting capital projects which often span two or more financial years. It is necessary to plan on a longer term and the Audit Commission[16] has advocated a minimum of three years.

Government Financial Policy

The medium term government financial strategy is designed to curb inflation and create the environment for a reduction in interest rates, which in 1989 rose to an unacceptably high level. The public sector borrowing requirement (PSBR) is based on the difference between government revenues and public spending, and no distinction is made between capital and revenue spending. This form of cash accounting can result in incorrect spending priorities.

The Infrastructure Planning Group (IPG) of the Institution of Civil Engineers has criticised the essentially *ad hoc* nature of government policy and suggested that there should be a continued development of knowledge on the state of assets and a clearer link between this knowledge and national considerations. The government should ideally encourage and participate in the assessment of the adequacy of services and the financing of essential works. Major government initiatives in the funding of urban renewal was in the 1980s restricted to the two development corporations in Liverpool and London.

Private Finance

Private sector money can be used to finance schemes of public works engineering where the user pays directly for the service. Typical examples are the Tay road bridge, the third Dartford crossing and the Channel Tunnel. The latter project, described in chapter 2, highlighted some of the major difficulties with the financial institutions being reluctant to loan the £5b required to finance the project and the uncertainty regarding the future return on investment, highlighting the need to develop suitable guarantee systems. Eurotunnel was a company with no trading history and it eventually secured a project finance agreement with almost 200 international banks providing, in six tranches, loans and letters of credit facilities equivalent to £5b.

Partnership schemes between local authorities and private enterprise have become quite common in large scale town centre redevelopment schemes and other urban renewal projects. The local authority has powers of compulsory acquisition which are vital if the best pattern of development is to be achieved. The local authority also meets certain basic costs apart from land acquisition, such as site clearance and the provision of roads and services and execution of other public improvements. The private developer often has a vital role to play with regard to availability of capital, knowledge of the market and ability to exploit commercial opportunities.[17]

Financial Assistance from the European Commission

In 1989 the European Community established a revised set of articles covering the distribution of the European Regional Development Fund. The greater part of the fund, approaching 80%, is now reserved for projects within the objective one list and will be allocated to the less developed southern areas of Europe in Greece, Spain, Portugal and Italy. While objective two areas, which include the United Kingdom, will be competing for a smaller proportion of the fund than hitherto, although the fund was doubled in size.

The European Regional Development Fund is essentially about civil engineering projects. The United Kingdom has received millions of pounds for infrastructure projects, especially road schemes. There is a considerable amount of flexibility in the management of the fund and any developer should argue his case strongly and with conviction. The history of the Birmingham Convention Centre, a £120m project which eventually received a 35% grant, is an object lesson in perseverence and ingenuity.

Financing Overseas Work

There is ample evidence of the significant benefits for the British economy from overseas construction projects with a major UK input. The Greater Cairo wastewater scheme in Egypt, described in chapter 4, is estimated as providing employment for UK personnel amounting to 10 000 man years for the duration of stage one contracts and contributing £200m to the balance of payments, for an initial Overseas Development Administration grant of £50m.

Companies operating overseas face considerable difficulties in finding funds for schemes, particularly in poorer countries. Some form of government assistance in helping to find or underwrite sources for these funds is needed as well as back up funds when conventional finance is unavailable.

Consultants, contractors and bankers all have an important role to perform in generating successful international contracts. Consultants must be prepared to produce innovative designs, while contractors need to maintain a sustained presence in areas in which business is to be won and to actively market themselves entailing heavy speculative expenditure. There is an acute need for cofinancing schemes involving the World Bank and other multilateral bodies. Private sector investment plays a major role in financing third world development and this could increase significantly in the future.

Management and Marketing of Public Works Engineering

Principles of Management

The principal management objectives can be summarised as follows:

1. to secure the future survival of the organisation developing appropriate and timely innovation
2. to achieve an effective and efficient organisation based on highly motivated and committed employees
3. to identify and implement the management techniques which are best suited to the particular organisation
4. to secure the effective breakdown of very large organisations to prevent the stifling of entrepreneurial drive, creativity, adaptability and innovation
5. to achieve the optimum mix of rational, logical decision-making and problem-solving activities and intuitive, judgemental activities.[18]

Staff Development

Staff development is concerned primarily with improving a person's performance in work, by reference to the organisation's objectives and needs, and based on an effective appraisal system. The gap which exists between present and required job performance should be identified as appraisal and action can then be taken to remedy the situation. Many methods are available for continuing staff development, including in house training, guided reading, undertaking projects, attending courses, seminars and conferences, site visits and job rotation.

Good staff need satisfactory long term career prospects if they are to be effectively motivated and retained. Annual appraisals of staff are customary following which the future career development of each member of staff can be considered.[19]

Contract Management

Most contractors train their staff in contract management techniques in accordance with established policies and practices, but ideally embracing a reasonable amount of flexibility in operation. The contractor has two main objectives:

1. completion of projects to the reasonable satisfaction of the promoter, i.e. on programme, to an acceptable standard and within the budget price
2. to carry out the work efficiently, smoothly and safely, with a reasonable profit margin.

The engineer for the contract also has some involvement in contract management to ensure that the project is completed on time and within the budget cost.

Marketing Local Government Services

Marketing can be defined as the management process responsible for identifying, anticipating and satisfying customer requirements profitably. An analysis of the current position leads naturally to the development of a marketing plan, preferably based on a market-led approach. The challenge of change needs to be met in a positive way. Identifying the needs of the public may reveal the desirability of providing new products and services or dealing with existing provision in a different way which relates more closely to the wishes of the consumer.[20]

Publicity will help to make people more aware of local government, of the way it can affect their lives, of the policies and objectives of the council, and of the extent to which they are being successfully achieved. Corporate image is important and local authorities and other relevant organisations need to be positive about its implementation.

Marketing strategies are the means by which the marketing objectives are achieved. The proposed strategies are reviewed with respect to product-service, price-cost, place and promotion, which must all be considered as an integrated package.[20]

Marketing Professional Services

The marketing of the professional services of consulting engineers is becoming increasingly necessary in a commercially oriented society. The marketing momentum is usually initiated by the principal or partners and is achieved through the application of marketing strategies employing diverse marketing tactics and techniques from the extensive use of the media to the circulation of sophisticated and impressive brochures and other publicity material, such as newsletters, video films, synchronised slide/tape presentations and exhibitions. This approach is being encouraged by the erosion of traditional markets, changes in client expectations and competition from other practices adopting the latest marketing techniques.

It is understandable that there can be some reluctance from partners in traditional, well established professional firms to the marketing concept as being incompatible with the dignity of a profession. The counter argument is that marketing makes use of proven activities from a highly developed field of communication and creative effort. The specialised marketing activities encompassing research, planning, promoting, distributing, selling and pricing, generally require consultation with or employment of professional marketing personnel. Common terms of reference include public image, competitiveness, specialisms, markets, fees, market trends, profitability, pathways to growth, strategic planning, strengths and weaknesses and risk factor. The marketing mix ensures that appropriate skills, techniques and price are matched as closely as possible to market needs.[21]

Computing Aids in Public Works Engineering

Computer Applications

An Institution of Civil Engineers conference[22] in 1985 gave a broad overview of the role of computers in the construction industry, and it embraced such activities as:

(a) estimating and cost control
(b) design and construction (including analysis)
(c) information management
(d) office systems
(e) computer-aided draughting
(f) quality assurance
(g) expert or knowledge-based systems.

A number of these applications will be considered in later chapters. They have enabled many calculations to be performed much more quickly and the storage and speedy retrieval of large amounts of valuable data.

Pilgrim[23] while accepting that the computer has brought wide ranging benefits to engineering research, including carrying out investigations which without it would have been impossible, believes that it does nevertheless have some drawbacks. The main emphasis has been on office based research at the expense of field or laboratory research. A danger lies in the tendency of researchers to develop and apply complex models of what they assume or imagine to happen in reality, based on limited data, and then to publish the results of their research. Similarly with large data banks, the user often does not have access to and contact with the original data in the form in which they were gathered and is, in consequence, unable to get the feel of the data and to assess their characteristics and accuracy.

Database Management Systems

All the main manufacturers of computers offer database management systems, designed to make the development of custom software easier and to allow a wide range of screen enquiries and print-outs to be obtained to satisfy users' specific requirements, with considerable flexibility in operation. The database approach also gives the opportunity to develop common information systems requiring fewer programmes, using more advanced software and providing greater flexibility and consistency of information.

A Central Computing Service

The Local Authorities Management Services and Computer Committee (LAMSAC) is the central local government organisation providing specialist services in management, information technology, purchasing, research and energy to all local authorities in the United Kingdom. LAMSAC was established in 1968 and is sponsored by the local authority associations and is managed by a board of elected members who are representatives of these bodies.

The organisation:

(1) provides an advisory service for local authorities on computing, developing technology and associated management sciences
(2) acts as a focus for the collection and dissemination of good management practice and value for money initiatives
(3) offers a consultancy service to local authorities and others
(4) undertakes sponsored research projects into areas which will improve the economy, effectiveness and efficiency of local authority operations
(5) provides appreciation seminars, workshops and conferences to promote awareness of developments in the fields of information technology and management sciences.

In addition to its annual grant from the associations and project funding from central government and other bodies, LAMSAC earns income from consultancy fees and software product sales. These activities are not confined to local government and LAMSAC is active in the wider public sector and internationally.

Whole Life Costing

Whole life costing entails the consideration of all costs, embracing initial construction, and operation and maintenance throughout the life of the project at the design stage, in order to secure the optimum long term solution.

Major Civil Engineering Schemes in Developing Countries

In developing countries new investment is often aimed at meeting growing demand, and is rarely an alternative to adequate operation and maintenance. Poor operation or maintenance of major civil engineering projects in developing countries can result from inappropriate design, inadequate resources or confused allocation of responsibility, but there are also broader issues to be considered such as:

(a) economic pressure to adopt low initial cost solutions
(b) political pressure to give preference to high profile projects
(c) career pressure on local engineers to be involved in new works rather than operation and maintenance
(d) inadequate attention to handover from designers to operators.

Two principal remedies have been suggested, namely:

(1) forging closer links between those responsible for implementing new schemes and those concerned with operation and maintenance
(2) whole life management of schemes, whereby maintenance, replacement and rehabilitation is planned, implemented and monitored throughout the life of a scheme, with external funding better distributed between new works and operation and maintenance.[24]

Application to Roads

Garrett[25] has aptly described how in recent years decisions in the United Kingdom concerning the design and maintenance of road schemes have been made principally on the lowest initial cost rather than whole life costs, and this has often been the case with most other types of public engineering works. This strategy has exacerbated the current conflict between need and budget. The situation is becoming increasingly acute because many of these lowest initial cost road schemes, which were constructed during a more affluent period, are now having to be maintained during a time of economic restraint. Indeed, the problems faced by highway authorities of providing and maintaining the road network are not dissimilar to those encountered by managers of other elements of the infrastructure. To solve the present crisis and to prevent the problem from occurring in the future, it is essential that whole life costing of alternative strategies for road projects and their component parts is carried out to provide optimum long term value for money.

This concept is encompassed in the term 'terotechnology' or physical asset management, which is defined in BS 3811[26] as 'a combination of management, financial, engineering, building and other practices applied to physical assets in pursuit of economic life cycle costs.'

Using the system devised by Garrett in Figure 1.1 in which road maintenance costs in addition to road construction and road user costs are incorporated in a cost–benefit analysis, schemes exhibiting optimum whole life costs and value for money are likely to result.

As a typical example, changes in the frequency of road sweeping can affect the drainage of a road, which in turn can affect the structural strength of the road and the safety of the user and hence road user costs. Hence what appears to be savings because of lower initial expenditure against a particular budget can result in greater overall costs. With the central reservations of motorways, bituminous pavings are likely to be the best long term cost alternative to soiling, seeding and grass cutting. In like manner plastic grooving of concrete road surfaces is likely to provide a cheaper whole life alternative than the commonly used brushed finish with its limited life.[25]

Discounting future costs to current values is generally carried out when combining costs incurred at different times. Discount rates of 7 to 8% are commonly employed. The use of high discount rates favours low initial cost options by suppressing future costs. This approach is further complicated by the fact that maintenance/user costs do not remain constant at current values because of the direct and indirect effects of deterioration and traffic growth. Hence there is a need to refine the discounted cost technique as applied to schemes of public works engineering.

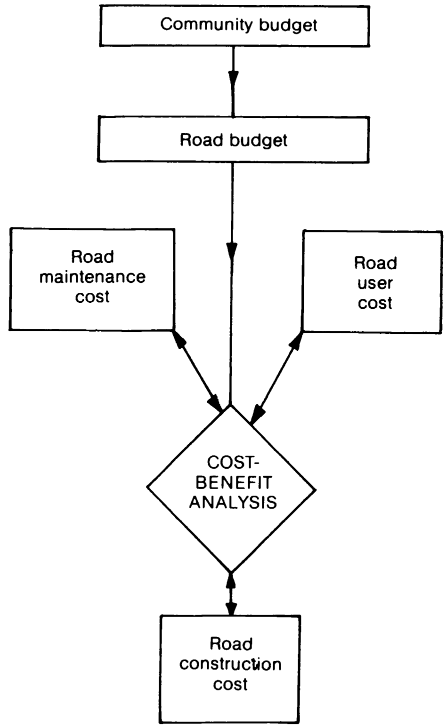


Figure 1.1 *Proposed financial system for roads (Source: C. Garrett[25])*

General Contractual Arrangements

Purpose of Contract Documents

Contract documents form the basis on which a civil engineering contractor will prepare his tender and carry out and complete the contract works. It is therefore essential that the documents shall collectively detail all the requirements of the project in a comprehensive and unambiguous way. These documents also identify all the rights and duties of the main parties to the contract – the employer, engineer and contractor. Collectively they constitute a binding contract, whereby the contractor undertakes to construct the works in accordance with the details supplied by the engineer and the employer agrees to pay the contractor in stages during the execution of the works in the manner prescribed in the contract.[27]

Form of Contract Documents

The documents normally used in connection with a measurement contract are listed in *Civil Engineering Procedure*,[9], and consist of the following items, which are all mutually operative:

(1) The Conditions of Contract which in the United Kingdom and the Commonwealth are normally the ICE Conditions[28], which define the terms under which the work is to be undertaken, the relationship between the employer and the contractor, the powers of the engineer and the terms of payment, and are designed to protect the interests of all parties. *The Conditions of Contract (International) for Works of Civil Engineering Construction*,[29] known as the FIDIC contract are recommended for works of civil engineering construction which are the subject of international tender, and these are used in many countries throughout the world. They have evolved from the ICE Conditions of Contract and there is provision for the insertion of the ruling language in which the contract is to be construed and interpreted.

(2) Drawings are prepared by the engineer to depict clearly the nature and scope of the contract works, and should be as com-

prehensive as possible to assist the contractor in compiling his tender, including particulars relating to soils and groundwater. During the progress of the works, the engineer or his representative often finds it necessary to issue further drawings in amplification of those issued at the tender stage. In a design and build contract the detailed drawings will be prepared by the contractor.

(3) The specification is another important document in a civil engineering contract. It describes in detail the work to be executed, the character and quality of the materials and workmanship, and any special responsibilities of the contractor that are not covered by the Conditions of Contract. Useful guidance on the preparation of civil engineering specifications can be found in *Civil Engineering Specification*.[30]

(4) Bills of Quantities are generally prepared in accordance with *The Civil Engineering Standard Method of Measurement*,[31] which defines a bill of quantities as a list of items giving brief identifying descriptions and estimated quantities of the work comprised in a contract. An explanation of its contents and applications are given in *Civil Engineering Quantities*.[32] The bill of quantities enables all contractors to tender on the basis of the same information.

(5) Instructions to tenderers aim to assist tenderers in the preparation of their tenders, and to ensure that they are presented in the form required by the employer and engineer and typical clauses are given in *Civil Engineering Contract Administration and Control*.[27]

(6) The form of tender is the tenderer's written offer to carry out the work in accordance with the other contract documents. It incorporates the total tender sum, the time for completion and other matters pertaining to the offer. Normally the tenderer submits a tender complying fully with the specification, but in certain instances he is permitted to offer alternative forms of construction. The employer's written acceptance of the offer is binding, pending the completion of the agreement.

(7) The form of agreement is also incorporated in the ICE Conditions and constitutes a legal undertaking between the employer and the contractor for the construction of the works, both permanent and temporary, in accordance with the contract documents, and for the maintenance of the permanent works. The employer covenants to pay the contractor at the times and in the manner prescribed by the contract. Temporary works are often very extensive and costly.

(8) The performance bond is a document whereby a bank, insurance company or other acceptable guarantor undertakes to pay a specified sum if the contractor fails to discharge his obligations satisfactorily. The amount of the bond is usually 10% of the tender sum and the contractor is almost certain to include the cost of providing the bond in his tender. Hence, where the contractor on investigation is found to be in all respects satisfactory, the bond requirement can be omitted and the employer saved the additional costs.

Operation of the Contract

The engineer is normally represented on the site by his representative, often described as the resident engineer, whose main functions are to watch and supervise the construction, completion and maintenance of the works. While the contractor is made responsible for all aspects of the construction, completion and maintenance of the works as specified in or can be reasonably inferred from the contract. He is fully responsible for the adequacy, stability and safety of all site operations and methods of construction, but excluding the design and specification of the permanent works, and is deemed to have inspected and examined the site prior to tendering.

The contractor has to supply the engineer with a programme of work, set out the works, provide all necessary superintendence and relevant insurance, give the necessary notices and pay the requisite fees, meet all statutory requirements, avoid damage to highways, provide facilities for other contractors, provide samples and carry out tests, remove improper work and materials and clear the site on completion.

The engineer has the power to vary the works and is required to consult with the contractor prior to determining the value of variations. Where the engineer considers it necessary or desirable the work can be executed on a daywork basis. The procedure for dealing with contractor's claims is detailed in the contract, as are also the arrangements with sub-contractors and the issue of certificates and payments to the contractor, normally monthly, less the prescribed retention. The contractor is required to submit a statement of final account with all supporting documents not later than 3 months after the date of the maintenance certificate, issued at the expiration of the period of maintenance. There is an optional contract price fluctuations clause which is normally included in contracts of over two years' duration.

Readers requiring further information on tendering and contract arrangements are referred to *Civil Engineering Procedure*[9] and *Civil Engineering Contract Administration and Control*.[27] The latter two books also cover the altenative methods of civil engineering procurement or types of contract, such as lump sum contracts, schedule contracts, cost reimbursement contracts, all-in contracts, negotiated contracts, serial contracts and management contracts.

Communication

Factors Affecting Communication

Poor communication has often been a problem in the construction industry and this stems in part from the way in which the industry is organised. Site personnel come from different backgrounds and have varying contributions to make at a variety of levels. A large amount of information passes between them and this creates the need for a well organised and effective communication network. Even with a well established network, problems of communication can still arise because the information conveyed may be difficult to understand, inaccurate or misleading.[33]

Public works engineers have first to consider the type of audience to be addressed. When communicating with engineers and other professionals it is customary to use technical language, but reports to local authorities covering such matters as a major transportation proposal must be couched in terms that can be understood by lay persons. Experience in dealing with the media and the public have taught engineers and public relations officers that short and simple messages are always the most effective in publicity disseminated in consultation exercises.[34]

Choice of Written Style

As described by Scott,[35] a tradition has developed in civil engineering of using verbs in the passive tense, which if used excessively can lead to a mediocre style. For example, 'Observations have been received from the employer' is better expressed in the active tense as 'The employer has made observations'. In the past engineers almost invariably wrote in the third person, such as 'It is recommended that...', while the modern trend is to adopt a more direct use of the first person pronoun, such as 'We recommend...'.

The four main variations in writing style are:

(1) length of sentences, paragraphs and sections, desirably kept to a reasonable length;
(2) choice of words, preferably kept simple and avoidance of technical jargon as far as possible;
(3) use of verbs, with the active tense generally preferred; and
(4) use of pronouns – first or third person.[35]

Appointment of the Engineer and the Employer's Brief

The engineer will need to clarify the terms of his appointment in writing to avoid any future problems. Most civil engineers use a standard appointment form which simplifies the procedure and reduces the risk of omissions.[27]

Large public and private employers normally prepare a written brief before they engage the engineer for a project. The brief should be carefully prepared and be as precise and comprehensive as possible, as it is a very important document. It forces the employer thoroughly to think through his ideas about the project and this prevents the engineer from wasting time considering matters on which the employer has already made up his mind.

Some engineers invite the employer's representatives to attend meetings of the design team to promote greater understanding and speed up the decision-making process. However, other engineers argue that it can inhibit designers in the performance of their work, lead to premature decisions and can be wasteful of time.

Preparation of Reports to the Employer

Many reports require a firm recommendation and this is always to be preferred to a list of options which leaves the reader to make the choice. Conclusions and recommendations should be kept separate and presented in that order. As a recommendation constitutes the personal advice of the engineer, he should write in a positive and discerning way and endeavour to convince the reader of the need to accept his advice.

The report should be written in clear and correct English as behoves a professional person. The impact of the report can often be enhanced by relevant illustrations, which may consist of photographs, diagrams and/or artists' impressions, covering aspects which are difficult to describe in words. The illustrations should be restricted to major items in the report to avoid their excessive use.

The use of appendixes to a report is a valuable method of providing technical data without fragmenting the body of the report. A long report, or one which is based on research undertaken by others, often requires a list of references. These should be selected carefully, giving full details and annotated in the text often by superior numbers.

Site Documents and Records

The keeping of continuous and comprehensive site records provides an effective means of controlling and monitoring all activities on the site. They have a vital role to play in the assessment and settlement of disputes and can take a wide variety of different forms, of which the following are some of the most important.

(1) Correspondence includes letters, telexes, fax documents and drawings which should be recorded as soon as they are received or despatched, and all incoming documents should be date stamped. Verbal instructions to the contractor should always be confirmed in writing and also telephone conversations where they convey instructions or important information.

(2) Reports often summarise information and are the principal method of conveying information on site matters to head office, the employer and other parties. Daily reports by inspectors, supervising the constructional work on site, form an important part of site communications.

(3) Labour and plant returns constitute another commonly employed form of written record which forms the basis for monthly returns to the engineer.

(4) Drawings provide an effective and convenient way of recording the progress of construction work on site.

(5) Photographs of the main features of the project taken from the same positions at regular intervals, often monthly, provide a good record of progress throughout the project.

(6) Laboratory reports and other test results are normally entered on standard forms and filed on a subject basis.

(7) Diaries are indispensable as they provide a complete narrative of the progress of the

works and the activities of the engineer's site staff. The diary entries collectively supply comprehensive information on all aspects of the work and also permit cross-checking to clarify disputed statements.

(8) Variation orders may be required to deal with variable site conditions, non-availability of materials or for other causes.

Purpose and Conduct of Meetings

During the course of a contract, a variety of meetings will take place in site offices, on specific parts of the works and in suppliers' premises. Some may be arranged at short notice to resolve a problem on the site, while others will be formally arranged at regular intervals and are generally concerned with co-ordination and progress. The main objective of all meetings is to come to a decision, although supplementary aspects such as the exchange of information, generation of ideas and discussion of problems may also be important. Meetings can, however, fail to achieve these objectives through over-formality, ineffective chairmanship, failure to concentrate on key issues or an antagonistic attitude by one of the parties.[27]

The most important meetings on a public works engineering project are the regular project meetings, sometimes termed site meetings or progress meetings. They are normally held at monthly intervals and provide the opportunity for a regular, comprehensive reappraisal of the project.

The usual method of conducting such meetings and the form of the agendas and minutes are well described and illustrated in *Civil Engineering Contract Administration and Control*.[27]

Liabilities

Professional Engineer at Risk

Engineers, like other professionals, have become increasingly at risk through actions in law being brought against them for negligence. In the past insurance has generally provided adequate protection but is now becoming very expensive and sometimes difficult to obtain.[36] Insurance payments by civil engineers in 1990 were stated to be in the order of 6–10% of fee income.

The increased risk to the professional engineer arises because of the following causes:

1. The courts have extended the scope for actions in negligence in recent years through a number of leading cases, and there is a greater expectation by the public for compensation where a defect or action has occurred.
2. The courts have allowed greater scope for actions to be pursued in tort, as opposed to contract, which has benefited plaintiffs by extending the period of liability, facilitating actions against third parties and, in some cases, widening the scope for damages.
3. The law relating to negligence has become extremely complex and, with its development through the courts, uncertain in outcome.

Where an error or defect comes to light at the end of the maintenance period resulting in the claiming of damages, the professional engineers or architects in the case of building work are likely to find themselves involved in any dispute that may arise for the following reasons:

1. Their design and inspection function is likely to embrace all aspects of the project and to have entailed a duty of care.
2. As they normally carry insurance, they can be expected to meet claims whereas the contractor's position is far less certain.
3. In order to release insurance funds, it is necessary to prove liability against the engineer for an act or omission covered by his policy.[36]

When a claim arises, the action will be brought against the engineer, who will have to bear any stigma associated with the allegations that are made. The insurer conducts the case but will only be liable personally if the case is proved against the engineer or some settlement is agreed. Should the insurance prove insufficient the engineer will be liable for the balance and the sums involved may be more than most firms can bear.[36]

Limitation Law and the Latent Damage Act 1986

The law provides a number of complex tests for determining when a plaintiff should be considered to have knowledge of a defect and there is uncertainty in establishing the date in construction work when the 15-year long stop period is to begin and the true meaning of the term 'deliberate concealment' in section 32 of the related Limitation Act 1980. The last item is of considerable importance because such operations as covering up foundations could have the effect of nullifying the long stop.[36]

The main disadvantages of professional indemnity insurance are that some defects arise from causes that do not involve negligence; that a considerable proportion of the total cost of premiums, often approaching 60%, is spent on legal and administrative costs, as opposed to recompense for damage; and the procedures are time-consuming and uncertain. Moreover, they provide little feedback, few records and small incentive for improvement in standards and quality.[36]

Abbeystead Accident

The Abbeystead accident in 1984 highlighted the extreme vulnerability of consultants, even those of international repute, and how unfortunate and questionable decisions can result from court cases.

The case was brought by a consortium representing 31 of the relatives and victims of the explosion which occurred after pumps of the Lancashire water transfer scheme were switched on for a demonstration, and vented methane into the underground valve house at Abbeystead. After the accident, Binnie and Partners, the project designer, undertook months of intensive investigation and a seismic survey and established that the gas had been locked in a reef about 1 km below the tunnel. This unusual source of methane was not foreseeable and would not have been discovered by extended site investigations and additional boreholes carried out prior to the design stage as advocated by the plaintiffs. Furthermore, no one could have foreseen that 44 members of the public would have been invited to the valve house.

The majority two to one judgement in the Appeal Court in 1988 found Binnie and Partners solely to blame for the disaster, although this was countered by a lengthy dissenting opinion that absolved the firm of any negligence. This strong divergence of legal opinion called into question the function and suitability of the Appeal Court when dealing with complex engineering issues.

The unfortunate consequences of the lengthy and costly legal action were:

1. Binnie and Partners found themselves wholly and solely liable for the explosion in 1984, facing huge costs and a devastating slur on their professional reputation. Few civil engineers whatever their view of Binnie's culpability would consider this a fitting penalty.
2. In such cases there remains an abiding suspicion that the courts feel that they must always find someone guilty so that the victims can obtain compensation.[37]

Readers requiring further information about engineers' professional liability are referred to the ICE publication *Professional Liability*.[38]

Quality Assurance

Quality Management Systems in Civil Engineering

There has been considerable discussion concerning the applications of quality assurance (QA) within civil engineering, and in 1988 it was generally believed that the time was right for the adoption of quality assurance by the civil engineering industry. There is a growing international commitment to QA with BS 5750, *Quality Systems*, being updated and reissued to incorporate new international standards. QA through a formal quality management system provides the opportunity to review, improve and co-ordinate the systems in operation. This improved quality of operation can help to reduce costs and can identify areas that require concentration of effort to improve quality. The work involved in correcting deficiencies in quality can be expensive in both cost and time, particularly when problems are discovered at a late stage.

Sanderson[39] considered that a quality management system needed to be applied to all aspects of a company's organisation that affect quality, and must be clear in meaning and concise in definition. The quality management system within a company is invariably controlled through formal documentation. This documentation should set out the requirements of the system and provide facilities for auditing. The documentation for a quality management system would typically comprise a primary, company-wide manual supported by second tier or departmental control manuals and procedures. Setting up a quality management system involves most departments within a company.

The requirements and benefits of a quality management system should be demonstrated as widely as possible to all concerned, using promotional material, such as that produced by the National Quality Campaign, operated by the Department of Trade and Industry. The British Standard for quality systems is a broadly based conceptual document which covers many varying applications. Sanderson[39] has wisely recommended checking and registration by a recognised third party to demonstrate that the quality management system meets a recognised standard. This helps to standardise assessments and reduce the need for individual client audits. The use of consultants and contractors who operate quality assurance systems and have been independently assessed and registered, gives some protection before the event, rather than after it, when the damage has already occurred.

Benefits of Quality Assurance

Clients with large and complex projects where safety or reliability are of paramount importance, such as nuclear power stations and oil terminals, are now applying QA to all aspects of construction. Workmanship and supervision are unfortunately often below standard on many projects. Any system which reduces the chances of error or inferior work going unchecked justifies serious consideration.

QA is a management discipline aimed at anticipating problems and creating attitudes and controls which prevent problems arising. QA ensures not only that work and procedures are carried out correctly but that they are also clearly demonstrated to be correct, with invaluable consequences for the client who requires his structures to perform well over long periods. The system also has beneficial side effects as, for example, the client is obliged to decide his precise requirements before work is started and to commit the necessary resources to ensure that his wishes are met.

A number of benefits can accrue from the appropriate QA system properly applied, such as fewer failures, less remedial work, more precise specifications, improved planning, better and more structured form of communication, more chance of completing on time, easier settlement of claims, a full record for each contract, and a sounder basis on which to select main contractors, suppliers and sub-contractors.

Johnson[40] has rightly emphasised that the client should have a quality system to control his brief and define his requirements. The designer needs a quality system to control the design process and to ensure that the client's brief is satisfied. While the contractor needs a quality system which can satisfy the requirements of the designer and execute the project in accordance with the specified details. Finally the operator must proceed in accordance with a quality system to ensure the structure or plant is used correctly.

Quality Assurance and Local Authorities

Quality assurance has been identified as an essential tool for local authority works directors in their changing role as client to ensure a reasonable level of service from contractors. Works directors will increasingly request private contractors and direct labour organisations competing for contracts for municipal services to obtain QA certificates.

For example, Westminster City Council has written a quality assurance clause into its street cleaning and refuse collection contract documentation, with the emphasis on performance specification rather than detail specification.

Safety Aspects

Safety in Civil Engineering

Civil engineering is an industry which, in terms of safety, does not possess the controlled environment of the factory or a manufacturing workplace, and hence is beset by numerous hazards and requires the exercise of greater care and precautionary measures. Furthermore, changes in the construction industry in recent years, with a steady growth in management contracting and the use of labour only sub-contractors and self-employed workers, have led to an increasingly casual approach by the workforce, a reduction in the number of experienced skilled operatives, and increasing difficulty in limiting the number of accidents.

Civil engineering works and working methods can always be made safer with the expenditure of more money, but there is always great pressure to reduce construction costs. However, a study of the economics of improved safety measures might well show overall cost savings. Derrington[41] has postulated that if the professional team could authorise additional safety measures, where needed, from a provisional sum in the bill of quantities, a marked improvement in the accident statistics would result.

It is emphasised in *Civil Engineering Procedure*[9] that the safety of all personnel working on building and civil engineering sites is a major responsibility of those involved, whether they be management or operatives, and the Health and Safety Executive considers all parties to the contract to be implicated in safety aspects. The construction industry is one of the most dangerous in the UK, accounting for nearly 20% of all serious accidents and 40% of all fatalities at work, at enormous cost to the industry and the country. Most of these accidents could be prevented with careful planning and forethought at the start of a project to identify the hazards and minimise their dangers, and all concerned owe a special duty of care to site operatives.

Major Causes of Accidents

The largest cause of accidents is the fall of a man or a material from a height. About 80% of all fatal accidents and 40% of all other accidents are in this category. These can be further subdivided into the following main groups:

1. falls from inadequate scaffolding and working platforms
2. falls through and from roofs
3. falls from structural frameworks during erection
4. falls resulting from the collapse of structural frameworks during erection, demolition and refurbishment operations, as well as by the failure of temporary works
5. falls of materials from heights
6. burial by the fall of material from the sides of excavations
7. collapse and overturning of lifting equipment and machines such as cranes.

The risk to safety through structural failures can result from alkali–silica reaction in concrete; corrosion of reinforcement and pre-stressing tendons on concrete bridges; structural damage caused by gas explosions; damage to bridges by impact of vehicles; structural failures resulting from inadequate design or construction; and changes in engineering design practice.

Statutory Requirements

The construction industry falls within the ambit of the *Factories Act 1961* and the *Construction Regulations 1961* and *1966*. Subsequent legislation in the form of the *Health and Safety at Work, etc. Act*

1974 provided the legislative framework within which to promote, stimulate and encourage high standards of health and safety at work. It aims to persuade all those involved in the construction industry, including employees, to promote an awareness of safety during the construction process, and to do all that is necessary to avoid accidents and occupational ill-health.[27]

The main objectives of the 1974 Act, the responsibilities of employers and the specific duties of employees are detailed in *Civil Engineering Contract Administration and Control*.[27]

Practical Applications

Earthworks

Most public works engineering projects encompass extensive earthworks and the following precautions should be taken to eliminate or reduce the accidents which can occur:

(1) The failure of temporary slopes is a common cause of accidents and all batters should be cut to a safe angle or shoring provided.
(2) Neither heavy plant nor excavated material should be sited near the edge of batters.
(3) When excavating from the base of a working face, care should be taken to ensure that the face is not overhanging nor excessively high.
(4) Open overnight excavations that could be a hazard to the public and site personnel, should be protected with barriers and hazard warning lights.
(5) Explosives should be handled only by experienced personnel, satisfactorily stored and adequate precautions taken when blasting.[42]

Site Handling and Demolition Work

Care must be taken to ensure that plant operators and banksmen are properly trained, competent supervision provided, and that all involved in handling operations are adequately briefed as to requirements.[43]

The proportion of fatal accidents in demolition work is many times higher than in construction work generally. Unless urgent corrective steps are taken these numbers are likely to increase with the more difficult problems imposed by removing complex structures such as off shore oil platforms and decommissioning nuclear power stations.

Tunnelling

Safety in tunnelling is the subject of BS 6164[44]. There are special hazards arising from the nature of the work, the confined space and problems of access. Contingency planning should be undertaken prior to construction to prevent unexpected hazards becoming catastrophes. Natural hazards arising from ground conditions include collapse, inundation and gas.

The most vital safety measure is to be aware of these dangers at all times and to take appropriate corrective action before serious problems occur. A first line of defence is to restrict the excavated area and to ensure the availability of materials for immediate support.[45]

Sewers and Other Underground Structures

Men working in foul and surface water sewers, manholes and other underground confined spaces need to be highly trained, provided with appropriate protective and safety clothing and equipment, and to follow closely standardised procedures because of the risks involved from flammable, asphyxiating and poisonous gases, and possible flooding. The dangers of gases in confined spaces were highlighted in the serious accidents at Carsington reservoir in 1983 and Abbeystead outfall station in 1984. These disasters have shown the pressing need for a reassessment of design criteria and operating procedures for all existing and future underground works, and a greater appreciation by all engineers of the dangers of gases in confined spaces.

The standard precautions relating to sewer inspection work are extensive and range from erecting barriers and warning signs around three manholes, opening them up and checking for unusual conditions. The nearest telephone should be checked to ensure that it is operational and a strict procedure followed on entry to the sewer by a team with lookouts posted at both top and bottom of the access manhole. In the event of possible rain the men are recalled and in situations when the normal five minute call is not received from the working team, the rescue service is called.[46]

Environmental Aspects

Introduction to Environmental Issues

Duffell[47] argues logically that civil engineers need to embrace whole heartedly a conservation ethic to ensure humane physical surroundings in which people can develop and lead contented lives, and where technology and environment are in balance. There is ample evidence of extensive public concern embracing environmental pollution matters. However, while scientific analysis may confirm the public's view on pollution, the method of determining what constitutes a satisfactory or adequate level of necessary activities is more difficult.

Social and Political Trends at National Level

There is now a greater environmental awareness, understanding and concern that in the two previous decades, largely through the medium of television, coupled with a much more rational debate on environmental excesses and acceptabilities.[47]

The physical and biological environment now assumes greater importance in the social fabric of towns and in 1985 central government supported a conference on the greening of cities. The faith in the city report[48] highlighted the plight of those in inner cities, and the alienation and hopelessness that many feel in neither being involved in their own destiny nor feeling that anyone else cares. Riots in Handsworth and Tottenham had their roots partly in the physical quality of people's surroundings as portrayed by Birch,[49] and the concern of Prince Charles concerning the inner city has been well publicised, culminating in the publication of *A Vision of Britain*.[50] Many others are now supporting his stand in the field of community architecture.

The interest and enthusiasm generated by such groups as Friends of the Earth and Greenpeace have gathered momentum and respectability, coupled with the pioneering work of such agencies as the Nature Conservation Council, local conservations trusts and the Council for Environmental Conservation.[51]

The Council of Europe statute, on the mandatory undertaking of environmental impact assessments (EIAs) on major projects such as airports, reservoirs, power stations and motorways, was implemented in 1988. On lesser projects EIAs will be carried out by agreement or persuasion.

Furthermore, increased consideration is being given to the vital global issues of acid rain, toxic waste, the ozone layer and tropical rain forests, highlighted by the Environment Week 1989. A principal aim was to make more people aware of the importance of the quality of their surroundings. The Environment Week was titled *Operation Eyesore* to encourage people to remove unsightly scars on the local scene, comprising such aspects as making parks on small unwanted plots of land; paving and providing seats on waste sites; planting shrubs and bulbs on roundabouts; painting out graffiti on underpasses; bringing abandoned ponds back to life; repairing or replacing broken steps or railings; painting bus shelters and removing flyposters.[52]

Environmental Conservation in Practice

Duffell[47] introduced several typical case studies including the following informative examples:

(1) River Engineering

In the field of river engineering the Water Act 1973 required water authorities to deal with the needs of nature conservation, while the Wildlife and Countryside Act 1981 introduced a statutory requirement to further the conservation and enhancement of natural beauty. A good example is the Severn Trent Water Authority that adopted a new attitude to the functional and aesthetic aspects of rivers. When river improvements are contemplated, the design process incorporates conservationists and landscape architects, and the approach includes non-trapezoidal sections, working from one bank only where possible, constructing berms or revetments where flora and fauna can become established, and retaining by-passable meanders. If the marginal cost of this treatment of about 2% of the capital cost of the engineering solution cannot be met then it is questionable whether the scheme was justified in the first instance. At no diminution of the engineering function of flood alleviation, a balanced environment of aesthetic value is obtained.

(2) Treatment of Polluted and Derelict Land

An excellent example is the extensive environmental improvement of derelict, polluted and contaminated land arising from industrial dereliction in Stoke on Trent, following the demise of the coal, pottery and steel-making industries. About 10% of the area of the city occupied such land and was characterised by toxic waste dumping, tar lagoons, colliery waste mounds, asbestos, sewage slurries and substantial subsurface structures.[53] Of particular interest was the area formerly occupied by the Shelton Steelworks which formed the site of the National Garden Festival in 1986. Half the site area of 66 ha (150 acres) was reclaimed at a cost of £7.5m (1983 prices) for industrial, commercial and public open space. Another £9m was spent at the behest of the Department of the Environment to create the festival site. When the festival finished in October 1986, 40 ha was made available to the local authority for commercial and industrial use, and the remainder became permanent open space to improve the quality of the environment.

Costing of the Environment

Economists are seeking ways of costing the environmental damage caused by new road projects. In 1989, the Department of Transport commissioned a research study to examine how countries such as the United States and Norway have attempted to evaluate financially the costs of scarred landscapes and loss of plants and wildlife.

This was followed in the same year by the Pearce report commissioned by the Environment Secretary on sustainable development and which recommended pollution taxes to pay for environmental damage. It also argued that environmental damage caused by development projects should be costed and included in cost–benefit equations. It was believed that a society could not begin to follow such an objective unless it was prepared to place a cash value on environmental issues, so that a rational trade off could be made between economic gain and environmental damage.

Environmental aspects will be examined in more detail in chapter 8.

References

1. Confederation of British Industry. *The Fabric of the Nation* (1985)
2. D.G.M. Roberts. Presidential Address 1986. *Proc. Instn Civ. Engrs, Part 1, 1987, 82, Feb.*
3. D.A. Rondinelli & G.S. Cheema (Eds). *Urban Services in Developing Countries: public and private roles in urban development.* Macmillan (1988)
4. Institution of Civil Engineers. *First Report of the Infrastructure Planning Group.* ICE (1984)
5. Institution of Civil Engineers. *Second Report of the Infrastructure Planning Group.* Telford (1986)
6. University of Reading, Centre for Strategic Studies in Construction. *Building Britain 2001* (1988)
7. CIRIA. Special publication 66. *The French Construction Industry: A Guide for UK Professionals* (1989)
8. P.R. Bartle & S. Thorburn. A strategic view of the European Community in the context of civil

engineering codes and standards. *Mun. Engr, 1988, 5 Dec., 281–90*
9. Institution of Civil Engineers. *Civil Engineering Procedure*. Fourth Edition. Telford (1986)
10. D. Rogers. Design in the private sector. *Mun. Engr, 1988, 5, Dec., 319–22*
11. I.J. Rowdon & N.R. Mansfield. What price professionalism? *Proc. Instn Civ. Engrs, Part 1, 1988, 84, Feb., 85–93; Part 1, 1989, 86, Feb., 217–22*
12. P.H. Elwell. Municipal engineer – a profession at the crossroads. *Mun. Engr, 1986, 3, Feb., 45–53*
13. C.E. Carter. Competition: the process and issues. *Mun. Engr, 1988, 5, Dec., 313–18*
14. D.F. Green. Competition in a large public sector department. *Mun. Engr, 1989, 6, Apr., 109–14*
15. Audit Commission. *Building Direct Labour Organisations – A Management Handbook*. HMSO (1989)
16. Audit Commission. *Capital Expenditure Controls in Local Government in England*. HMSO (1985)
17. I.H. Seeley. *Building Economics*. Third Edition. Macmillan (1983)
18. D. Lock & N. Farrow (Eds). *The Gower Handbook of Management*. Gower (1988)
19. S. Martin & F. Glover (Eds). *Managing People*. Telford (1988)
20. D.R. Pigg. Marketing and the municipal engineer. *Mun. Engr, 1988, 5, Dec., 291–99*
21. B. Katz. *How to Market Professional Services*. Gower (1988)
22. Institution of Civil Engineers. *Computer Technology in Construction*. Telford (1985)
23. D.H. Pilgrim. Trends and tensions in engineering research. *Proc. Instn Civ. Engrs, Part 1, 1989, 86, Apr., 255–68*
24. M.J. LeGouais. Developing countries: maintenance and rehabilitation or new investment. *Proc. Instn Civ. Engrs, Part 1, 1989, June, 581–2*
25. C. Garrett. Whole life costing of roads. *Mun. Engr, 1985, 2, Aug., 223–32*
26. British Standards Institution. *Glossary of Maintenance and Management Terms in Terotechnology: BS 3811: 1984*
27. I.H. Seeley. *Civil Engineering Contract Administration and Control*. Macmillan (1986)
28. ICE, ACE and FCEC. *Conditions of Contract, Forms of Tender, Agreement and Bond for use in connection with Works of Civil Engineering Construction*. Sixth Edition (1991)
29. Fédération Internationale des Ingénieurs Conseils and the Fédération Internationale Européenne de la Construction. *The Conditions of Contract (International) for Works of Civil Engineering Construction (1977)*
30. I.H. Seeley. *Civil Engineering Specification*. Macmillan (1976)
31. ICE and FCEC. *Civil Engineering Standard Method of Measurement* (1991)
32. I.H. Seeley. *Civil Engineering Quantities*. Macmillan (1987)
33. B. Fryer. *The Practice of Construction Management*. Collins (1985)
34. A.R. Thurston. Selling public authority services – public relations aspects. *Mun. Engr, 1988, 5, Apr., 85–91*
35. B. Scott. *Communication for Professional Engineers*. Telford (1984)
36. D.R. Culverwell. The professional engineer at risk. *Proc. Instn Civ. Engrs, Part 1, 1989, 86, June, 553–66*
37. Abbeystead: a case for 'no blame' compensation. *New Civ. Engr, 25 Feb. 1988*
38. Institution of Civil Engineers. *Professional Liability* (1989)
39. J.D. Sanderson. Quality management systems in civil engineering. *Proc. Instn Civ. Engrs, Part 1, 1988, 84, Aug., 847–9.*
40. K. Johnson. QA can lead to better results. *New Civ. Engr, 2 March 1989*
41. J.A. Derrington. Engineering for safety. *Proc. Instn Civ. Engrs, Part 1, 1987, 82, Feb., 171–221*
42. P.C. Horner. *Earthworks*. Telford (1988)
43. J.R. Illingworth. *Site Handling Equipment*. Telford (1982)
44. British Standards Institution. *Code of Practice for Safety in Tunnelling in the Construction Industry: BS 6164: 1982*
45. T.M. Megaw. *Tunnelling*. Telford (1982)
46. A. Wignall. *Roadwork: Theory and Practice*. Heinemann (1988)
47. N.R. Duffell. A balanced environment – civil engineering in its social and political context. *Mun. Engr, 1987, 4, Feb., 45–8*
48. The Archbishop of Canterbury's Commission. *Faith in the City – A Call for Action by Church and Nation*. Church House Publishing (1985)
49. R. Birch. The urban shadows – a police perspective. *Proc. IME Annual Conference, Torquay, 1982*
50. HRH The Prince of Wales. *A Vision of Britain*. Doubleday (1989)
51. J.R. Duffell. Environment, engineering and employment. *Mun. Engr, 1988, 5, Dec., 301–7*
52. *Environmental Week, 22 Apr. – 1 May, 1989. AME Brief, Apr. 1989*
53. R.W. Hampson. Treatment of polluted and derelict land in Stoke on Trent. *Mun. Engr, 1984, 111, Mar., 95–9*

2 Transportation

This chapter embraces the broad spectrum of transportation facilities which have become so important in sustaining the economic and social well-being of a country. It commences with general transportation characteristics and implications and then proceeds to examine the major elements comprising motorways, railways, rapid transit systems, rivers and canals, the Channel Tunnel, and airports.

Transportation Characteristics and Implications

The characteristics and implications of transportation arrangements are very wide ranging and have been broken down into manageable sections for ease of identification and assimilation.

General Statistics

The transport statistics for Great Britain for 1974 to 1984[1] show that by tonne-kilometres, 62% of freight went by road in 1984, 7% by rail, 25% (almost wholly petroleum products) by water, and 6% (again petroleum) by pipeline. With regard to passenger transport, measured in passenger kilometres, 92% went by road, 7% by rail and 1% by air. In 1984, £54b was spent on transport in the UK, and taxes on expenditure (almost entirely motoring and road freight transport) amounted to a further £11.4b, and public expenditure on transport totalled £5.6b.

Bendixson[2] has described how investment in roads and, to a lesser extent, railways reduced drastically all across western Europe between the mid-seventies and mid-eighties, as the rise in oil prices and the ensuing economic recession forced governments to cut their budgets. When the economies began to improve in the mid-eighties transport problems began to arise because of congested roads and old-fashioned railways. Fortunately the InterCity 125s in Britain and, even more so, the French *Trains à Grande Vitesse* (TGV) have brought about the rebirth of railways in Europe. Indeed, the TGV has shown that 150 mph (240 kph) trains can attract former air passengers and so reduce airport and air traffic congestion.

Increasing traffic congestion is resulting mainly from economic growth with its rising levels of car ownership and increased suburban and exurban living. Car trips have grown substantially in number and length and have exceeded the ability of highway authorities to cater for them.

Traffic Congestion

It is common knowledge that the failure of transport investment in south east England to keep pace wih dramatic increases in road, rail and air travel, has resulted in poor accessibility in some areas and serious congestion and overcrowding in others. This undoubtedly adversely affects economic performance and the region's future development.

One day in March 1989, an accident on the M4 flyover near Brentford coupled with a series of relatively minor incidents scattered throughout central London caused chaos in the capital's road traffic and came close to bringing the entire city to a halt. Three harrowing disasters on British Rail's Network Southeast and the King's Cross fire, apart from the innumerable train failures and delays, showed that the surface and underground railway systems were also under severe strain.

Congestion itself is now acting as a regulator of traffic and this is wasteful, costly and damaging to economic growth, the environment, convenience and, increasingly, public safety.[3] While the same ICE report[3] pointed out that in 1989, 15 sections of the London Underground were critically congested, and about 25 stations were choked at peak hours in ticket halls, escalators or platforms. These numbers are bound to rise if no action is taken. Buses could undoubtedly be developed to take a much more important role if reliability, speed and passenger confidence could be improved.

A CBI report[4] in 1989 estimated that the inadequacies in London's transport infrastructure were costing industry as much as £15b per annum, based on returns from a selection of members, although this figure should probably be treated with caution. The report contains various sensitive proposals, including park and ride interchanges wherever rail or tube lines meet radial motorways; removal of yellow lines that are not needed or policed; and tougher and more consistent enforcement in locations where illegal parking causes congestion.

The ICE report[3] also contained a number of remedial proposals of which the most important were to make maximum use of all forms of transport and for major investment in public transportation, possibly backed up by road pricing controls, to improve the speed of travel in crowded city centres. Other recommendations included increased staggering of working time and holidays, stronger measures for dealing with illegal parking such as towing vehicles away, and permanent reinstatement by statutory undertakers. The Transport Secretary was also considering measures to reduce the interference with traffic caused by statutory undertakers' roadworks.

Transportation Planning

Yu[5] aptly describes how an urban transportation system consists of many parts and performs many functions. Properly planned, it can make the environment more attractive, strengthen the town/city centre, widen the range of employment, assist in guiding and stabilising land use patterns, and improving all forms of traffic movement. Thus the urban transportation plan should encompass almost every aspect of urban life. It should be sufficiently rigid to provide the necessary direction and control over future growth, yet flexible enough to adapt to the constantly changing urban environmemt.

As long ago as 1963, Buchanan in *Traffic in Towns*[6] believed that comprehensive redevelopment of extensive areas of many towns and cities was needed to secure satisfactory traffic arrangements. He quoted 'unless the public accepts that there has to be comprehensive redevelopment over large areas, then the opportunities for dealing imaginatively with traffic will all be lost, and in the end this will severely restrict the use that can be made of motor vehicles in built-up areas. Even now the opportunities are slipping past as the old obsolete street patterns are being 'frozen' by piecemeal rebuilding, and will remain frozen for another half century or longer.'

One of the greatest deficiencies in transportation planning is the frequent lack of realisation that planning and transportation are inextricably linked. When a new housing estate, shopping centre or business park is built, more traffic is generated. Conversely, build a new transport link, like the M25, and new development will be attracted around it. Hence development and transportation must proceed hand in hand in order to avoid future problems.

Forecasting Traffic Flows

One of the major activities in transportation planning is to forecast future traffic growth, in which recent developments in the UK have been widely inaccurate. Abercrombie[7] was commissioned during the last war to report on the future of London, and he predicted that Greater London would need five ring roads to cope with the projected traffic. Nearly 50 years later London has one substandard half ring road (North and South Circulars) and one complete ring road (M25) finished in the late 1980s, which was overloaded as soon as it was opened. In 1989 engineers were considering the need to widen the road from a dual three lane to a dual six lane motorway to provide adequate capacity, indicating that a more sophisticated approach to forecasting is required.

The authoritative House of Commons Public Accounts Committee report in 1989 contains some very critical but justifiable statements concerning the action taken by the Department of Transport, which are of sufficient significance to deserve repeating.

They read: '...we are not convinced that in its planning and monitoring the department has taken sufficient account of wider and more strategic consequences of building major motorways and trunk roads. For example, it did not draw successfully on the early experience of the Chertsey to Egham section of the M25 in planning other sections which were to open some years later. It seems to have failed to make full use of the experience of the Midland Links motorways dating back to the early 1970s.

'We therefore consider that the department should give much deeper consideration to the results of its "before and after" monitoring and make sure that the information and analyses provided are fully taken into account in future planning ... and not allow short term considerations or unduly conservative estimates of likely traffic flows to result in an under-provision of capacity.

'It is difficult to have confidence in present forecasting methods when traffic flows on some roads have so quickly and so substantially exceeded the forecast on which design standards were based.'

Road Network in Milton Keynes

It would be helpful at this stage to briefly examine the road network of the latest new town in the UK, whose design was based on extensive analyses of different modes of transport, distances and costs. It was established that a good bus service might attract 20 to 30% of travellers using small 25 to 30 passenger buses with a typical journey time to work of 25 minutes.

The road network at Milton Keynes is unusual for new towns, in that the main roads are at ground level with no multi-level flyover intersections, and the main roads are on a grid layout at roughly one kilometre intervals. The spacing of these roads is crucial as it determines the volume of traffic entering the road network. The prescribed spacing generates the need for dual carriageway main roads with colour-light-controlled intersections and a peak hour traffic flow not exceeding 250 vehicles per hour, involving no real conflict with pedestrian movement. In most town road networks the most dangerous roads for pedestrians are the collector roads (intermediate between main and local roads) and these have been eliminated in Milton Keynes.[8]

A typical journey by car to work takes about 15 minutes. The road system was relatively cheap and flexible to build, allows free movement by car to and from all points in the town by a choice of direct routes, and the simultaneous use of good and cheap public transport.

Park and Ride Schemes

As described earlier in the chapter, increased affluence and the inherent advantages of cars have caused critical traffic conditions in the centres of most towns and cities. The principal aim is generally to maintain the accessibility of the central area and yet, at the same time, provide satisfactory environmental conditions, and one way of helping to achieve this is to introduce formalised park and ride schemes.

These schemes provide public car parks conveniently located around the periphery of the town or city with a frequent and efficient bus service connecting the car parks to the town/city centre. The charges are often based on a flat return bus fare and need to be competitive. The service needs full local authority support with ample publicity and good direction signs to the car parks. The schemes may serve seasonal shoppers, non-seasonal shoppers or non-seasonal shoppers and commuters.

Bixby and Bullen[9] identified the following factors as determining the effectiveness of a park and ride scheme:

(1) Overall travel time, particularly excess time such as walking and waiting.
(2) Whether an exclusive bus service is provided.
(3) Frequency of bus service.
(4) Convenience for drivers.
(5) Capacity of park and ride car park.
(6) Location of park and ride car park.
(7) Bus priority measures.
(8) Parking policy in centre.
(9) Charging method and overall cost compared with central area parking.
(10) Publicity and marketing.

Fifteen towns and cities are operating or have operated park and ride schemes. They range from some of the largest urban areas (Birmingham, Leeds, Manchester and Nottingham) to smaller, historic centres such as Cambridge, Colchester, Norwich and Oxford. Despite their undoubted merits, they are currently making only a minor contribution to easing urban traffic congestion on a national scale. They have, however, received support in recent traffic reports.

Road Pricing

Another method of reducing the volume of road traffic, albeit radical and controversial, is road pricing. For instance, a system of stickers displayed by cars wishing to use certain inner city roads is operated in Singapore, and its effect was to cut the number of cars entering the city core by 44% overall and 65% at peak times.

A number of different methods have been suggested in the UK but objections to the general principle have been raised on the grounds that the poor will be penalised and commuters will simply pass the cost on to their companies rather than stay out of the controlled area. It is generally considered that a network of toll booths would be too expensive to operate and would disrupt traffic. Automatic vehicle identification systems, analogous to telephone bills, are expensive and could infringe a driver's privacy. But meters, which could be read like gas or electric meters, or work on prepayment, like a phonecard, could overcome this objection.

Oldridge and Humber[10] introduced a novel system in 1989 known as 'congestion pricing', which could overcome many of the complex cordoning, tolling and billing drawbacks of conventional road pricing. Equipment to monitor motor vehicle movement was estimated to cost about £50 per car, without any burden on the public purse.

Under this system, motorists would have a prepaid, rechargeable, programmable smartcard inserted in the dashboard and units would be deducted according to time and distance travelled in heavily congested traffic. No charge would be made to free flowing traffic or to vehicles which were stationary for more than a certain length of time. Microelectronics would sense the movement of the vehicle and prevent engines being started without units on the card. If a card ran out in transit, the vehicle would continue but when next started would need a new card from which overdue units would be debited. Cards could be purchased for a few pounds or 'reloaded' at petrol stations using either credit cards or cash. Each card could have a keypad and each owner their own identification number. It was claimed that the system could pay for itself on increased car security and reduced insurance premiums alone.

Private Sector Transport Projects

In the future private money is likely to play a much larger part in providing transport facilities if the Conservative Government's wishes in the late 1980s and early 1990s were to be carried out. Developers are among the key groups targeted to pay for road improvements sought as a way of raising the value of their land. Little headway has been made so far with private infrastructure projects, apart from the Trafalgar House deal for a new Thames crossing east of London and the possibility of a privately developed rail link between Paddington station and Heathrow.

To make more progress, it seems that privately financed infrastructure projects require backing by the Treasury, in order to generate investor confidence in projects which may not show a profit for several years. Ideally, the Treasury should provide a safety net for projects by agreeing to underwrite short term equity issues in advance if necessary.

In 1989, a National Economic Development Council private finance working party proposed setting up a task force in 1990 to act as a focus for debate on private finance issues, and suggested that pilot projects be developed to test proposed procedures. The task force would be composed of any groups with an interest in the infrastructure, such as government, local authorities, contractors, developers, banks and consultants.[11] The working party recommended setting up a fund to provide risk sharing between the public and private sectors for the initial development of ideas to the stage of outline feasibility.

Exclusivity has emerged as one of the most serious obstacles to increasing private sector involvement in infrastructure development. Contractors have complained that they can spend large sums of money developing ideas which could be wasted if the concession or contract was awarded to another bidder. The private sector needs to be convinced that the return on capital employed in infrastructure justifies the risks involved.

Another proposal in 1989 embraced a 50 km length of private toll dual carriageway aimed at improving communications between Scotland and England, linking the M8 and the M74, with completion planned for the mid-1990s, and which could eventually lead to a new bridge over the River Forth, perhaps also financed by the private sector.

Studies had shown that the proposed road, which would be used largely by commercial and industrial traffic, could be an economic proposition. One national contractor responded that although many road schemes in the United Kingdom had been suggested as private sector projects in the late 1980s, the majority clearly were not viable, but that the latest proposal warranted serious attention.

Co-ordination of Transportation

The Transport Act 1985 laid emphasis on competition between operators, but Simpson[12] has rightly pointed out that co-ordination will often have precedence over free competition for the following reasons:

1. the need to run a network rather than routes
2. the need for stability to ensure a return on large capital investments
3. the possible effect of externalities
4. the need to share facilities such as bus stops, shelters, stations, and booking halls.

A good example of a well designed co-ordinated transport facility is the Bury bus/road/rail completed in 1980 at a cost of £2.65m. It is situated in the town centre with good road access and consists of the following elements:

1. bus station containing stands for 24 buses
2. island platform for six-car railway trains at low level, with lift and escalator connections to the booking hall and bus station
3. car park with taxi rank and provision for motor cycles and spare buses
4. ancillary offices and operational accommodation.[13]

Unfortunately, transport problems are largely treated on an *ad hoc* basis in the UK. Solutions are generally sought for each bottleneck in turn, with little regard for the causes or the wider transport issues involved. All too frequently problems are created by planning decisions taken with little or no regard for their transport implications. Sound, comprehensive long term planning is necessary to overcome these weaknesses.

The ICE congestion report[3] in 1989 identified three main reasons for the lack of positive government action with regard to co-ordination:

1. Reluctance by British governments to carry out any serious long term planning of investment of any kind.
2. Conservative governments of the 1980s considered that public expenditure had to be kept to a minimum until the economy improved.
3. A conviction that the type of comprehensive

planning which would be involved, for example in the creation of a national transport plan, would result in bureaucratic inaction.

Smith[14] made some interesting and instructive comparisons between transport policies in Britain and other west European countries. Britain has an overcrowded urban road network, alarmingly congested London underground and British Rail commuter trains, money being taken out of the public transport system and substantial sums being allocated for new major road schemes. By contrast other European countries are spending large sums on new conventional and light railways, developing tramways, closing car parks and abandoning inner city road building schemes.

The key difference in approach is that most European countries have a clear national policy for transport which recognises the critical importance that it plays in the quality of life and economic well-being, and establishes priorities to meet these objectives. In addition to the national policy, major European cities have their own transport authority to handle the city's needs.

By comparison, Britain has no coherent national policy for transport and no established authority with responsibility for the specific transport problems of its capital city. Britain, alone of the countries in Western Europe, relies on market forces to establish transport priorities.

The CBI transport in London report[4] recommended the establishment of a central task force, comprising a high-powered, free-standing regional transport authority, because the operation of the present 33 different transport authorities in London gives rise to confusion and lack of co-ordinated decision making. Having abolished the Greater London Council and the metropolitan counties, it seems unlikely that a Conservative Government would favour the establishment of a new regional authority.

The ICE congestion report[3] also recognised the need for a national transport co-ordinating group representing users of all modes and responsible to the Secretary of State. It emphasised that the consequences of further neglect could be extremely serious. For example, increasing road and rail congestion in south east England creates a real danger that, with the opening of the Channel Tunnel, the rest of the UK will be largely cut off from access to European markets.

Motorways

Historical Background

By 1938 members of the former Institution of Municipal Engineers were contemplating whether there should be a national system of motorways, doubtless influenced by the alarming toll of road accidents and the construction of the German *Autobahnen*. The subject was chosen for the Institution's Richard Pickering prize, and in the prize-winning paper a national system with spur motorways penetrating deep into cities was proposed. Some fears were however expressed about motorways, concerning the spoiling of the countryside by railway-like cuttings and embankments and the generation of additional traffic which could lead to further congestion and accidents in towns and cities.[15]

In the same year, the County Surveyors' Society prepared a plan for 1000 miles (1600 km) of motorway. However, it was not until 1959 that the first motorway, the Preston Bypass, opened to traffic.

European Comparisons

It is interesting to compare the road network of Britain with that of some of its European neighbours. For example, in 1986 Britain had 3081 km of motorways while West Germany had 8350 km of *Autobahnen*, although the two countries are of similar size, population and industrial culture.[16] These statistics do however deserve further analysis, as car ownership is lower in Britain than in Germany and in parts of Britain, such as the West Midlands and South Lancashire, there are few motorways but many dual carriageways, trunk and principal roads, which seem to have no parallel in Germany. Also Britain has many inter-urban dual carriageways that in Germany would be classified as *Autobahnen*.[2]

Bendixson's research in 1989[2] showed that in the Low Countries and, to a lesser extent, Germany and Italy, governments were taking the view that the years of construction were past and that it remained to add links, widen existing roads where capacity was needed, and build bridges or tunnels where rivers or other barriers caused bottlenecks. They were also concerned about the rising cost of road maintenance, an issue which becomes ever more pressing with the progressive increase in lorry weights. (A 38-tonne lorry does pavement damage equivalent to 250 000 cars.) Britain and France announced major motorway programmes in 1988, but in 1989 Britain road widening became the preferred method of reducing traffic congestion and this will be described later in this section of the book. An extensive but largely overloaded and fast deteriorating network of motorways exists in Britain, with the oldest about 30 years old and requiring increasing and costly maintenance and replacement resulting in substantial delays and danger to road users.

M25 London Orbital Motorway

The first London orbital motorway, the M25, located about 30 km from the centre of the city, was full to capacity on completion in 1986. Consultant Rendel, Palmer and Tritton reported to the Department of Transport in 1989 on the measures needed to alleviate congestion on the M25.

Widening is made more difficult because of the need to reconstruct bridges, cuttings and embankments. The report proposed short term congestion relief by narrowing existing lanes by repainting white lines to provide four lanes on crowded sections until the permanent widening to dual four lane is carried out. Narrower lanes can be introduced with partial loss of hard shoulder while a lower speed limit of 80 km/h could be introduced to maintain driver safety.

Improved driver information, displayed on closely spaced overhead signs which are served by electronic traffic detectors buried in the carriageway was also recommended, together with more lighting and improved junction layouts. However, the report did not mention the consultant's once strongly favoured scheme of closing junctions or restricting access to the motorway, although further studies of possible closures of busy access points were recommended.

Probably Rendel, Palmer and Tritton's main achievement was to persuade the Department of Transport (DTp) to widen the M25 along its whole length, as announced in the 1989 Roads White Paper.[17] The consultant proposed full dual four lane widening and a feasibility study into further expansion to dual five or six lane carriageway.

In late 1990 traffic flows on the overloaded 8 lane section near Heathrow reached the highest count ever on a British motorway, at 166 000 vehicles/day. The M25 carried 14% of all motorway traffic on only 6% of the network and traffic is expected to double by the year 2010. Hence the Transport Secretary announced the widening of nearly all of the M25 to four lanes in each direction between 1992 and 1996, and to widen it to five lanes in some areas by the year 2000. Over 190 structures required examining to see if they could be adapted, but some will probably have to be demolished and rebuilt.

Figure 2.1 shows the junction of the M25 and the M4, and some technical details of the construction of the south-west quadrant of the motorway between Westerham and Heathrow follows by courtesy of W.S. Atkins who planned, designed and supervised the construction of this section, to illustrate the various techniques involved in modern motorway construction.

This section of the motorway was built under eleven main contracts, with a total of 51 km of dual three-lane carriageway, 8 km of dual four-lane carriageway, and 9 interchanges. Much of the route passed through pleasant rolling countryside and so the environmental impact was reduced to a minimum by the use of cuttings and screening banks in sensitive areas and acoustic fences adjoining housing.

For most of the main contracts, alternative pavement designs were prepared so that contractors tendered for either concrete or bitumastic construction with the selection depending on the underlying soil conditions. There are three free-flow interchanges where other motorways crossed, being four level at M23 and M4 (see Figure 2.1), and braided at M3. The remaining six interchanges are of the conventional two or three level roundabout type.

The 120 bridges embrace most of the more usual forms of construction including steel box girder, steel plate girder, prestressed *in situ* and prestressed precast concrete, and reinforced concrete. Standardised designs were used as much as possible to minimise cost. The type of piling was dictated by the soil conditions. Lighting, mostly of the catenary type, was installed over the more heavily trafficked parts of the route. Overhead sign and signal gantries feature at the major interchanges as shown in Figure 2.1.

Figure 2.1 *Motorway junction (M25 and M4) (Source: W.S. Atkins Consultants Ltd)*

UK Road Programme 1990–2000

General Proposals

In 1989 the Transport Secretary published a White Paper *Roads for Prosperity* which set out a major expansion of Britain's trunk roads over a 10 year period.[17] The White Paper costed the additional work at over £6b and the total trunk roads programme at £12b with a further £1b for Scotland and Wales. To put this in perspective, a few months earlier the County Surveyors Society had proposed investment of £8829m on trunk roads and £10285m on major local authority roads. Furthermore, even if the programme is fully implemented, it is unlikely that Britain will reach the same standards as Germany, Italy or France.

Some 790 km of existing motorways are to be widened, concentrating on the M25, M1 and M6. Many existing trunk roads are to be upgraded to dual carriageways each of two or three lanes. In all a total of 2700 miles (4345 km) of new or extended roads were in the Department of Transport's programme for England alone. In addition, consultants were commissioned to undertake a series of corridor studies for about £2000m of new roads whose construction costs were left out of the the White Paper, which could include a new trans-Pennine motorway. Assessment was also to be made of the orbital capacity around London which could lead to the construction of a 300 km long outer orbital motorway as described in the next section of this chapter.

The 1989 White Paper was dominated by motorway widening or improvement to existing A roads, which made up 90% of the programmed work. Upgrading was seen as less harmful to the environment than building new roads in virgin countryside, and widening is a quicker method of increasing capacity on account of the simpler planning procedures. Lengthy planning procedures for new routes are caused by the need to compulsorily purchase land, hold public consultations and introduce parliamentary legislation, which means that a new orbital could take 10 to 15 years to implement.

Despite speedier planning, widening will be complicated by the need to adapt bridges and earthworks while design will often be restrained by the difficulty of acquiring additional land where developments are immediately alongside. The three principal methods of full quality widening are described and compared in chapter 3.

London Outer Orbital Motorway

Rendel, Palmer and Tritton advocated the provision of high standard trunked outer orbital route of at least dual two lane standard. Airports at Luton, Stansted and Gatwick should all be served by the new road. Proposals to build half of the proposed ring road or to implement corridor studies were included in the 1989 Roads White Paper,[17] but not as a proposal for a new outer orbital. The White Paper included the consultant's proposals for a study of a new lower Thames crossing at East Tilbury.

A new orbital must have sufficient lanes to cope with traffic for 30 years or more either by initial construction of excess capacity or by designing earthworks and structures with provision for later widening. Re-using existing transport corridors is likely to be an important feature of the new orbital and incorporating bypasses to congested towns could be advantageous, but even so substantial lengths of tunnel could be needed.[18]

It is important that any new orbital should only be built with the likely environmental impact in mind. Careful choice of alignment will allow picturesque towns to be bypassed and allow the pressure for development to be directed into targeted areas where jobs are needed.[18]

Bus Services

Origins

The origins of urban passenger transport systems date back to the 1870s with the tramways, which have now been reintroduced in a modernised form in many towns and cities throughout the world. The first trams were hauled by horses, then driven by steam engines and subsequently by electricity. The original tramways gave towns and cities a characteristic appearance which is often associated with the Victorian period.

Two electric systems operated, one with overhead lines and the other with a conduit between the track. It was generally considered that the overhead system was the best, although the network of wires strung between columns was acknowledged to be unsightly. The conduit system was susceptible to dirt and dust entering the slot, but improved design subsequently overcame this.

Bus Deregulation

The latest development in respect of bus services has been the deregulation of local bus operations outside London under the Transport Act 1985, which permitted private operators to compete with municipal bus services often on the same routes. The Transport and Road Research Laboratory monitored the impact and provided some useful data of which the most important findings are now reproduced.

Service levels, as measured by vehicle kilometres registered, increased steadily after deregulation in October 1986, and the increase was reflected in both subsidised services and those operated commercially. There were initial reductions in services in most metropolitan areas but these had generally been more than recovered by 1988. Fares generally moved in line with inflation, although there were some heavy fare increases in metropolitan areas, mainly resulting from reduced expenditure limits rather than deregulation. The number of operators increased after 1986, with small operators being particularly successful in winning subsidy contracts. Operating subsidies have however decreased significantly but opportunities have been taken to extend concessionary fares schemes. Innovation has been mainly in the form of minibus services. There has been no evidence of any significant

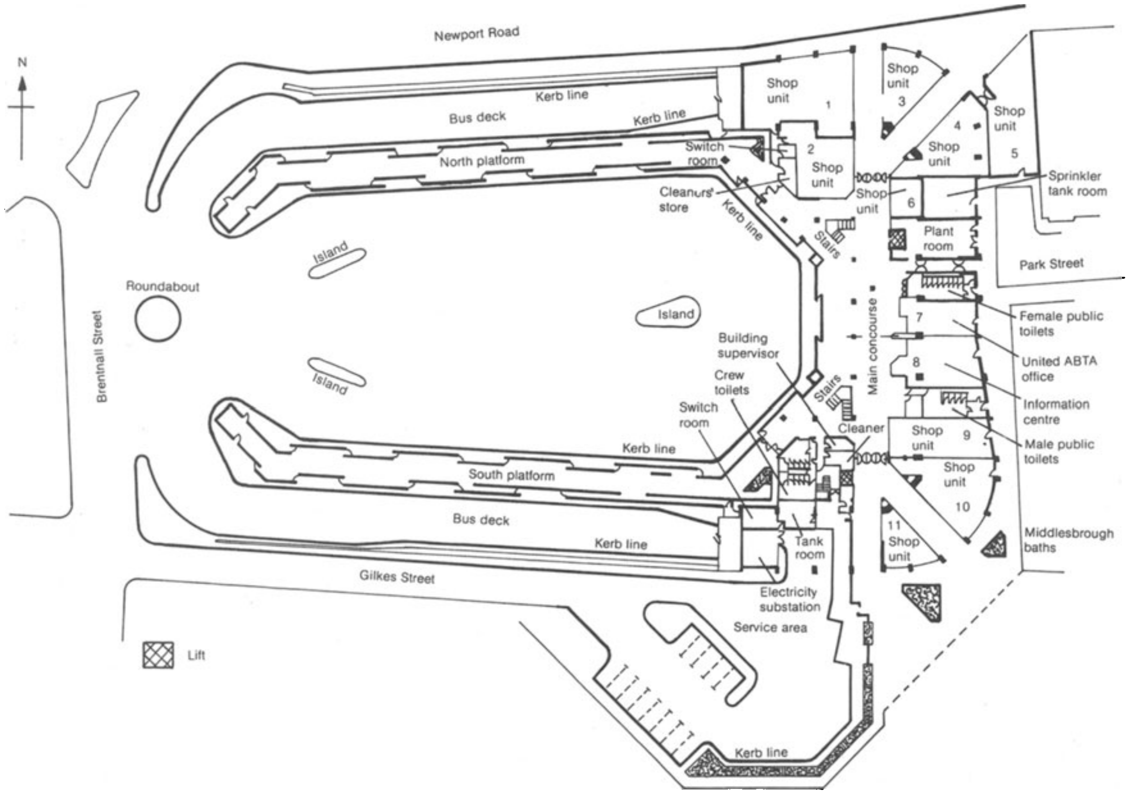


Figure 2.2 *Middlesbrough bus station: ground floor plan (Source: J. T. Ratcliffe)*

change in standards of bus safety or maintenance.[19] However, it must be appreciated that the review period is comparatively short and is not conducive to making constructive long term assessments.

Bus Stations

The major works in connection with bus services with direct impact on the public works engineer are the design, construction and maintenance of bus stations, which have undergone radical changes in layout since 1970. Two municipal bus stations built in the 1980s have been selected for study as they are both attractively designed but based on entirely different concepts.

Middlesbrough bus station, opened in 1982, provided interchange facilities for all licensed transport operators within the Cleveland conurbation. The Middlesbrough Borough Engineer and Surveyor was appointed project co-ordinator for the development, management and maintenance of the project. The bus station's horseshoe design enables passengers to be completely segregated from the buses within the extensively glazed, climate-controlled waiting areas. There are 26 bus stands at two levels around the edges of the waiting area. The bus station is built astride a main pedestrian route and a number of small shops, toilets and information centre have been provided on the pedestrian mall.

The ground floor level, as illustrated in Figure 2.2, caters mainly for short journeys within the Cleveland conurbation. The outside edge of the horseshoe incorporates a ramp rising to the first floor from where express services depart to destinations throughout Britain, and which is shown on Figure 2.3.

The principal design objectives were to provide the highest level of passenger comfort and convenience; complete passenger–vehicular segregation with no reversing buses or passengers crossing bus lanes, ensuring public safety; one-way bus lanes with 'run through' bus stops; low maintenance building materials and finishes; and closely integrated passenger-related facilities.[20]

The following statistics relating to the Middlesbrough bus station could be of interest to the reader.

Cost £5.3m (construction period 1978–82)
Departures 1600 per day approximately (1984)
Passengers 39 000 per day approximately (1984)
Shop units 9, total area 941 m^2
First floor offices area 560 m^2
Enclosed passenger areas (ground floor) 1873 m^2

The Leicester municipal St Margaret's bus station was rebuilt in 1985 at a cost of £1.45m using the concept of a single enclosed passenger concourse with local services parking in echelon pattern within the bus station and express services parallel parking in adjoining Gravel Street. Total segregation of passengers and buses was encouraged by using the layout shown in Figure 2.4. Facilities include a waiting room, cafeteria, toilets, a baby feeding room, left luggage facility and a newsagent's kiosk. The design and construction was co-ordinated by the Leicester City Engineer.[21]

The pavement design at Leicester bus station assumed 850 bus movements per day with zero growth, based on an analysis of existing and projected usage. For the heavily trafficked areas the total construction thickness was 1 m, including 150 mm of lean mix road base and 80 mm of concrete blockwork. The concrete block paving used for the trafficked areas complemented the effect of the large flagged areas within the concourse. Charcoal grey was chosen as the predominant block colour in an attempt to minimise the visual effect of inevitable oil stains. Bus bay markings are in a natural coloured block.

The existing pedestrian footbridge over the adjoining Burleys Way, which forms part of the city central ring road, was extended to a raised planting/seating area to the east of the concourse. Landscaping has been included to create an interesting environment and a soft edge to the bus station, as shown in Figure 2.4.

The passenger concourse, although enclosed by a glass curtain wall to protect passengers from inclement weather, is not temperature-controlled. A steel frame of lattice beams on 200 x 200 RHS columns supports the roof. The beams have a span of 17 m with a 5 m overhang to each side. Column spacing is based on a 4.95 m grid along the length of the building; this spacing being determined by the bus bay module.

Considerable thought went into the design process to make the bus station as vandal-resistant as possible. To assist bus station staff, closed-circuit television was installed.

To supplement the traditional methods of timetabling information, television monitors were provided, similar to those used at airports. To aid the bus station manager, a monitor shows from the timetabling information fed into the computer whether any bay is occupied or due to be occupied. This helps in the allocation of excursions and intermittent arrivals at the bus station.

Railways

General Introduction

British railways in the pre-war years were operated by private companies who operated a reasonably efficient service but encountered difficulties in making significant profits. After the war the railways were nationalised to provide a rationalised national network but were subsequently subject to the Beeching review which resulted in many of the uneconomic rural lines being closed. In the late 1980s a number of these lines were reopened often with financial assistance from local authorities.

High capital cost and acute environmental considerations prevented significant lengths of

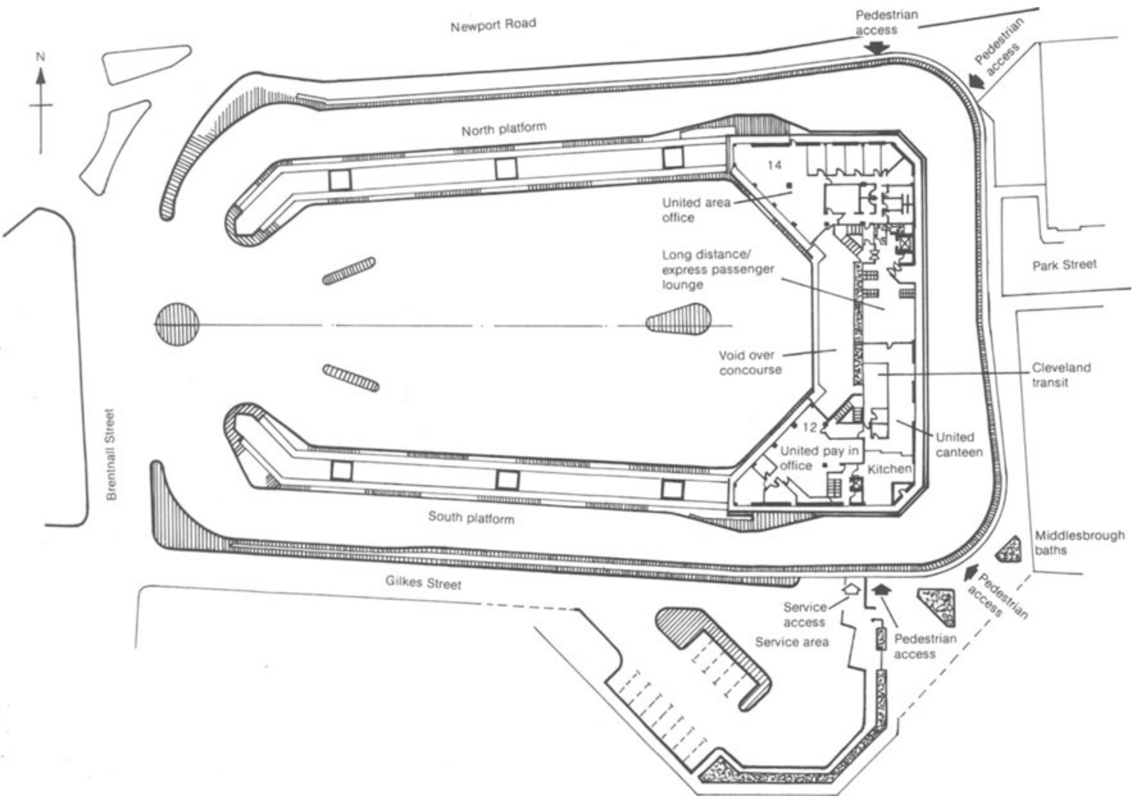


Figure 2.3 *Middlesbrough bus station: first floor plan (Source: J. T. Ratcliffe)*

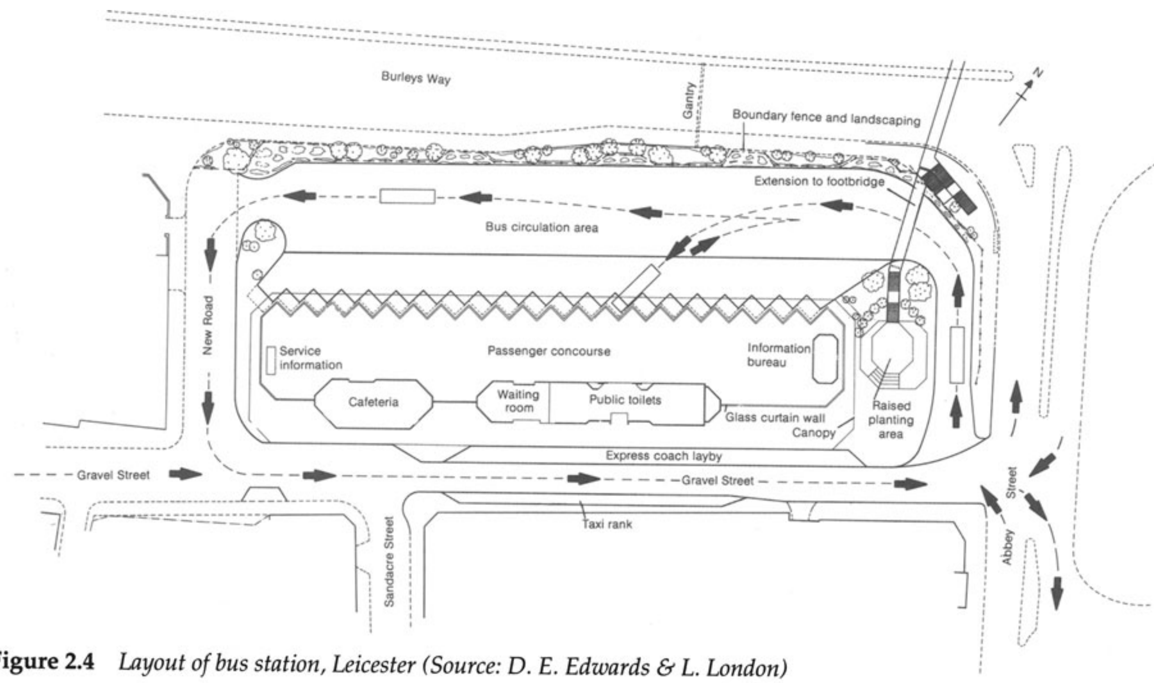


Figure 2.4 *Layout of bus station, Leicester (Source: D. E. Edwards & L. London)*

new track being laid. However successive acceleration of the East Coast main line resulted in the dramatic increase in the speed limit at Peterborough from 24 to 160 kph, and the Crewe modernisation works, described later, produced an increase from 24 to 128 kph. The introduction of diesel powered High Speed Trains (HST) reduced the London to Edinburgh journey time from six to just over four and a half hours, and in 1991 electrification of the line produced a further reduction to four hours. O'Brien[22] suggested that two hours would be an attractive target for the journey time from London to Manchester, but that it would require new traction and a mix of expenditure on infrastructure and new rolling stock, possibly tilting coaches in part derived from APT technology and experience.

InterCity business grew significantly both in real income and in passenger volume in the 1970s and 1980s, in one of the fiercest transport market places in the world. While British trains cannot beat the speed of the Japanese and French modern dedicated routes, they do run at faster average speeds than anywhere else in the world over infrastructure which has been in use for up to 150 years.[22]

Gotch[23] described how Britain led the European railways with its APT technology and then watched France's TGV settle into regular service, as described later, before APT could be successfully introduced. However, Britain has more sophisticated systems of freight movement than its European neighbours and uses its freight rolling stock more intensively with such innovations as merry-go-round coal trains, TOPS computer control, Freightliners and Speedlink, yet the strict financial targets imposed on the railway could force the closure of lines and services which are uneconomical in the short term and leave the long term system the poorer for their loss.

The Channel Tunnel, which is described later in this chapter, creates an excellent opportunity for British Rail to expand its freight business, and reduce congestion on the overloaded roads. In 1990, Britain's short haul railways carried only about 9% of the country's goods traffic. By comparison, continental railways, with longer hauls, carried about 20% and American ones, crossing a continent, nearly 60%.[24]

Track Design

Purbrick[25] has described how British Rail's track layout is the legacy of the history of the development of numerous private railway companies in the 19th century. Very little of the system was designed with high speeds in mind and much of the length of the routes has a high percentage of curves, which limits the maximum speeds. Despite these limitations, British Rail developed those lines which were geometrically suitable for 200 kph operation by High Speed Trains. These trains have two diesel power units of 2250 HP one at each end of a train of 7 or 8 carriages, and more distance is travelled annually at 200 kph, using the existing railway, than in any other system anywhere in the world.

The operation of a train around curves causes wear on the rails and increases train resistance. Curve resistance increases in direct proportion to the degree of curve and amounts to about 0.36 kg/t per degree of curve. It has been estimated that a 12-degree curve approximately doubles the train resistance likely to occur on a straight level track.[26] Wright and Ashford[27] have classified 1 to 3-degree rail curves as relatively flat and 8 to 10-degree curves as relatively sharp. Curves greater than 10 degrees are seldom used for main lines, except in mountainous areas. France's TGV high speed railway is designed with a normal minimum radius of 4000 m (less than 0.5 degrees), and this system is described later.

General Constructional Details

The main components of a railway network are now described in order to identify their main characteristics and uses.

1. *Ballast.* Selig[28] has listed the most important ballast functions as restraining ties against forces from train and track; reducing stress on the weaker subgrade; facilitating maintenance; providing immediate drainage of water from the

track structure; and providing resiliency to the track.

To achieve these functions gravel-sized crushed hard, durable rock with particles in the 20 to 65 mm range are often considered the most suitable. In practice, crushed stone, washed river or pit run gravel, or furnace slag with a grain size varying between 38 and 45 mm are commonly specified. Where a sub-ballast layer is provided, this can be a less openly graded material meeting less stringent quality requirements.[27].

The depth of the ballast may vary from 150 to 750 mm or more depending on wheel loads, traffic density and speed, and the type and condition of the foundation. The thickness of the sub-ballast may also vary, but good results have been obtained with a thickness of about 300 mm[29]. Currie[30] provides some useful further information about ballast characteristics and requirements.

2. *Sleepers.* The traditional imported softwood sleepers with baseplates were expensive and relatively short lived. Hardwood sleepers gave a longer life but had a higher initial cost than softwood, as did also steel sleepers. Hence they have been largely displaced by concrete sleepers which have a cost advantage and give improved lateral stability.[25]

In Britain and most other countries concrete sleepers are pretensioned by the long-line method in which the tendons are fully bonded and give good control and distribution of prestress. A typical British rail sleeper (F27BS) is 2.515 m long, 203 mm deep under the rail, 264 mm wide at the base and weighs 280 kg. Spacing in British track is usually 700 or 650 mm, although 600 mm spacing is used with sharp curves. Prestressed concrete sleepers have an average life of 40 to 50 years.[30]

Purbrick[25] has described how British Rail evaluated 33 different fastenings to be used with concrete sleepers. The two fastenings considered to be most suitable were the Pandrol clip and the Spring Hoop Clip (SHC). The Pandrol clip was adopted by British Rail as it is installed parallel to the rails and can be used in baseplates, on timber and steel, and in switches and crossings.

3. *Track.* The flat bottom, or Vignole, rail is now almost univerally used and so the bull head rail of past British practice can be ignored. In Britain the rail section is normally made from BS 11 normal grade steel, conforming to BS 110A and weighing 56.5 kg/m, whereas in Europe rails up to 60 kg/m are used and up to 70 kg/m in the United States. Most of the rail bought by British Rail is depot-welded by the Flash-butt Welding process into lengths up to 305 m. After conveyance to site by train it is welded again, by the Thermit Skv-F process, to form Continuously Welded Rail Track (CWR), which now accounts for over 50% of all UK track.[25]

4. *Switches and Crossings.* All railway switch and crossing work is made up of three basic units: (1) switches; (2) common or acute (angle) crossings; and (3) obtuse (angle) or diamond crossings. These are all fully described and illustrated by Currie in *Civil Engineer's Reference Book.*[30]

In switches and crossings greater use is made of high grade steels in locations such as some of the London Terminals, where intensive suburban services operate on sharp curves. On high speed lines and very heavily worked freight lines most crossings are cast Austenitic manganese steel (AMS). This material is difficult to weld to BS 11 steel rail and so fishplate joints were commonly employed, but this method produced a point of weakness. The former BR Research Department at Derby overcame this problem using bainitic steel inserts or hearts, which have excellent wearing properties, are fracture tough and can be welded to BS 11 rail.[25]

Track Maintenance and Renewal

Use of Direct Labour or Contract Civil engineering work on track maintenance must comply with statutory and legal requirements, railway rules and regulations and track standards, to ensure safety of traffic and personnel. It must be cost effective and engineers must be always seeking improved methods of working, accommodating peak workloads and the use of specialist contractors where necessary.

Herring[31] described how in the UK it has been the practice for virtually all track renewal and maintenance work to be carried out by railway staff using railway owned plant and equipment, except for specialist activities such as rail grinding, weedkilling and plant hire. The move towards privatisation could however change this approach in the future. Contracts for most relaying work outside Britain were usually negotiated with established contractors on five year terms, in order to provide the contractors with adequate assurance of future work to justify investment in expensive specialised plant. To remain aware of the realistic costs of the classes of work put out to contract, most railway administrations retained some of this work in-house.

In the UK, maintenance contracts were mainly for private sidings ranging from standard gauge depots to single sidings and crane tracks. However, contractors were major suppliers of track components to British Rail, especially for point and crossing work, where contracts commonly required the contractor to provide a complete fully timbered prefabrication of the layout.[31]

Civil Engineering Aspects of British Rail Cooper[32] described how 25% of InterCity working expenses were on civil engineering, of which this sum was approximately equally divided between track renewal, track maintenance and indirect costs of civil engineering work. The latter expenses resulted from week day temporary speed restrictions (TSRs) after renewals, weekend delays and diversions during renewal work and reliability problems associated with civil engineering. This led to pressure to reduce both these losses and direct unit costs.

Reynolds[31] described how the main strategy for weekends was avoidance of diversions by using simplified bidirectional signalling (SIMBIDS). Engineers worked principally on the line under renewal, the adjacent line being open under reversible signalling. Trains lost time in crossover movements and in travelling under a TSR past the site, but less than in a diversion. Greater discipline was required of staff working next to an open line. Weekday journey times were reduced, weekend timetables were closer to weekday standards and the better quality track obtained showed sustained improvements in geometry and reliability. This was greatly assisted by laser levelling control of reballasting depth and by using a dynamic track stabiliser (DTS) to consolidate new track instead of leaving it to be done by rail traffic under a TSR. Line opening speeds of up to 200 kph (125 mph) have been secured using the DTS. Although a longer possession was required to allow the tamping and DTS working, costs were reduced by completing the work in one long possession and eliminating weekday manual follow up.

Effect of Adverse Weather Conditions Railways are usually less affected by bad weather than road users. However, in summer high temperatures can cause expansion and, in severe cases, buckling of the track, but this is now usually overcome by allowing expansion gaps or, more likely, by laying continuous welded rails which will withstand considerable heating without causing problems. Heavy rain, apart from causing flooding, can adversely affect the electric wires of the signalling system, while lightning can disrupt power supplies to electrified lines.

Gales affect overhead electric lines, especially on exposed upland moorlands, and can blow trees, fences and sheds across the track causing delays, as happened after the October 1987 gale in South East England. In addition, electrified lines were also put out of action for a time by power cuts. Snow, when it drifts, can cover low-lying sections of track and in severe cases fill a cutting. Exposed routes in Scotland, across Shap Fell and the Settle to Carlisle line crossing ground over 300 m high create the worst hazards. In moderate cases the snow can be cleared by ploughing.

Ice is a problem with electric lines around London which use the third rail system of electrical pick-up. A good contact must be maintained between the conductor rail which is about 150 mm above the ground and the metal of the pick-up shoe. Ice on the conductor rail can prevent this contact and cause jerky running, damage or even a standstill. De-icing trains can be used to prevent or disperse ice build-up but they are expensive. Frozen points can also cause train delays.

Crewe Railway Modernisation Scheme

Crewe has been selected as a large scale railway station modernisation scheme. The original track layout and platform arrangements at Crewe main line station, as shown in Figure 2.5, were remodelled to meet future rail traffic and business requirements. Alterations to the track layout reduced the number of point ends from 229 to 109 and diamond crossings from 56 to 4. The number of operational platforms was reduced from 17 to 11, giving an indication of the extensive scale of the rationalisation achieved. The new layout as shown in Figure 2.6 incorporated a revised alignment for the through lines raising their line speed from 32 to 130 kph (20 to 80 mph).

Barwell and Cutting[33] described how to undertake the civil engineering work using traditional weekend possession would have required a period of up to three-and-a-half years, with consequent disruption to train services. This was unacceptable for business reasons and works were accordingly divided into three stages, as follows.

Stage 1 started on 15 April 1984, and encompassed track works on the fringes under weekend possessions and other preparatory works for stage 2 including station building and platform works.

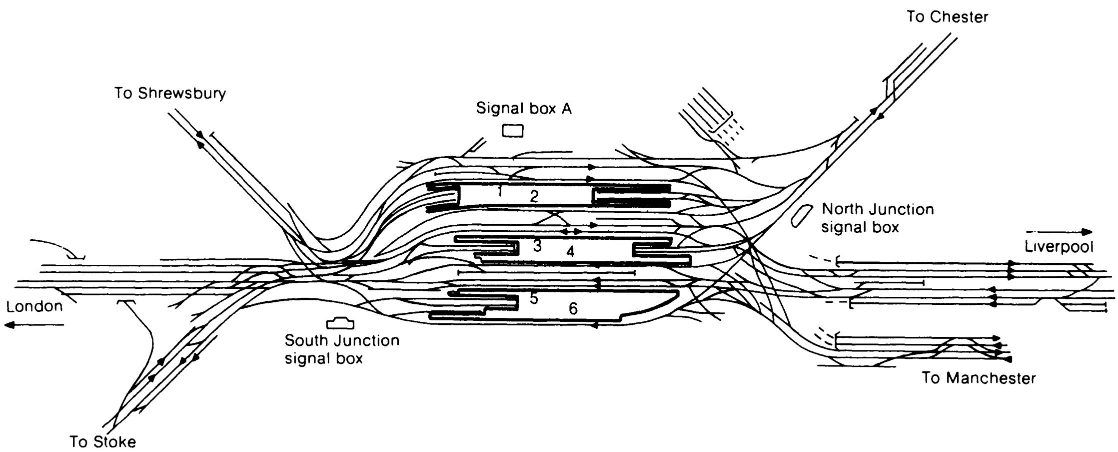


Figure 2.5 *Layout before April 1984 at Crewe railway station (Source: A. P. Barwell & W. G. Cutting)*

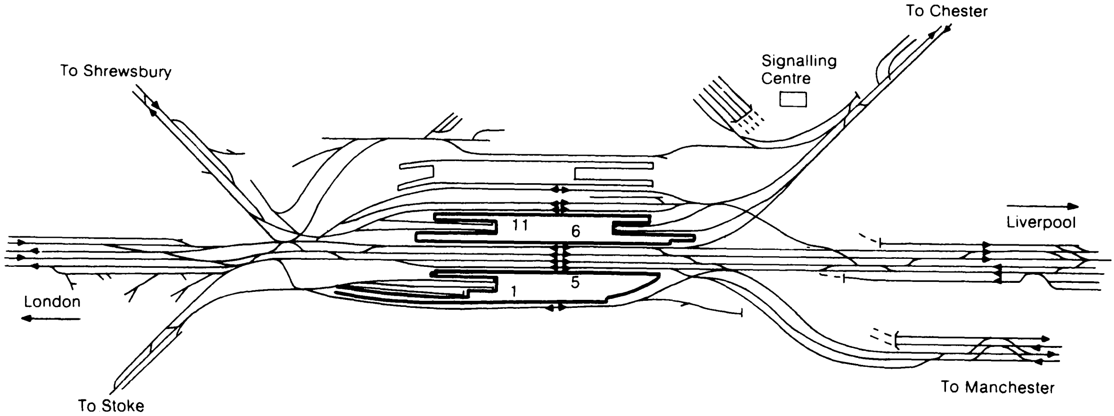


Figure 2.6 *Layout after July 1985 at Crewe railway station (Source: A. P. Barwell & W. G. Cutting)*

Stage 2 involved a shutdown period of 49 days of the station area from 5 June 1985 to carry out the major remodelling works, and a programme was formulated, as shown in Figure 2.7, with each department having a prime user period.

The Crewe site was unique with the existence of independent lines for the diversion of the main rail services. Furthermore, there was good road access to the site with land available beside the railway which could accommodate large mobile cranes and new materials. It was these key issues which determined the operation of a shutdown period for stage 2.

Stage 3 consisted of the residual completion of works in the traditional manner.

For stage 2, the site was divided into four sections with the boundaries of each determined by the physical limits required by the large 200 or 300 t road cranes. The formation was protected with a geotextile fabric (terram 4000) and polythene and areas of soft clay were cut out and backfilled with sand and a minimum depth of ballast of 375 mm. The track was BS 11 113A normal grade rail on jarrah sleepers and switches and crossings were of BS 11 113A wear resistant grade A rail with manganese or semi-welded crossings, all on jarrah timbers.

The simplified track layout permitted the installation of automatic tensioning equipment necessary for the proposed line speed of 130 kph, and this was based on the use of MK1 equipment using cadmium–copper conductors to maintain compatability with the existing equipment entering the Crewe station area. A total of 140 working drawings were produced for the installers.

To give an indication of the scope and speed of the works a few interesting statistics supplied by Spilletts and Wilkinson[33] have been included. In the six month period preceding stage 2, a total of 9.6 km of overhead equipment was removed, 11.3 km reinstated and 86 structure foundation bases installed. With the diversion of the main line trains by way of independent lines during stage 2, a buffer zone was created in the equipment running on the remodelled site to overcome isolation problems. In stage 2, 30 km of overhead line equipment was removed in three days and 19.3 km of overhead equipment installed in eight days. A further two days was required for checking of equipment during energisation and the renewal of the overhead equipment was completed three days ahead of schedule.

The signalling specification included for four aspect signalling, DC single rail track circuits point operation by clamp lock with electrical point heaters. The interlocking was BR free wired standard design with the operating console a combined NX panel with processor control

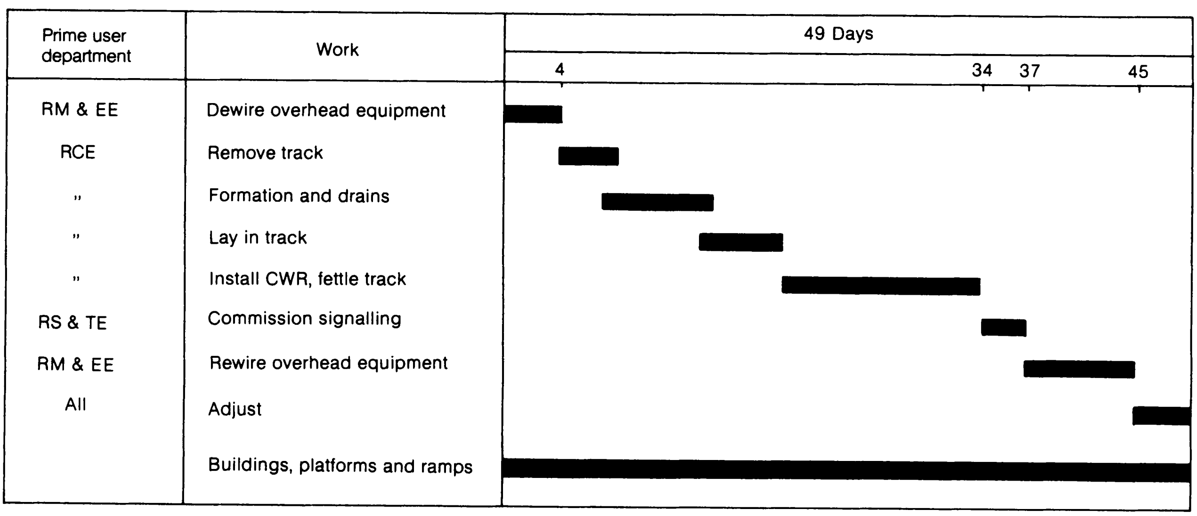


Figure 2.7 *Programme of work on Crewe railway modernisation (Source: A. P. Barwell & W. G. Cutting)*

buttons and indications, chosen to minimise the number of physical connections between the interlocking and the panel. A modular standard steel building was constructed to house the interlocking and control room.

Railway Electrification

A considerable amount of electrification of railway lines has taken place in the United Kingdom over the last three decades, and the latest project, at the time of writing this book, was the extension of the East Coast route north to Edinburgh in 1991, and the travelling public would like to see many more schemes implemented. However, the selected example is the civil engineering work required to convert the diesel hauled rail service from London (Liverpool Street) to an electric service to Harwich in 1986 and to Norwich and Cambridge in 1987.

The Anglia East project from Colchester to Norwich and a spur to Harwich cost £24.2m at 1982 prices, including £10.5m of civil engineering work. While Anglia West from Bishops Stortford to Cambridge cost £9.3m at 1984 prices and included £3m for the provision of improved clearance to bridges and structures and alterations to the track. Both projects were completed to time and were underspent.

Overbridges Lewis and Clark[34] have described how the East Anglian electrification was by the overhead wire system operating at 25 kV AC, requiring increased vertical clearance height between rail and bridge soffit. This could be obtained either by raising the bridge or possibly lowering the track. Sixty-four bridges were involved, and where a bridge could not be demolished and abandoned, it was raised by jacking the bridge span upwards or by reconstructing the bridge. This work took 3½ years to complete.

On earlier electrification projects from Liverpool Street, engineers replaced brick arch bridge spans with pre-tensioned, prestressed beams, and with three span bridges, diaphragm walls were often erected to support the side arches and the central arch replaced by beams. Experience over 30 years showed that this could produce a relatively cheap solution and hence it was used, where appropriate, on Anglia East.[34]

The electrification from Euston to Glasgow made use of precast concrete arch units to give the required improved track clearances and to preserve the arch shape, reducing the rise required on road approaches and the amount of abutment raising that would have been needed for beams. The computer program was updated to standardise design, and this speeded checking and estimating of the precast concrete works and reuse of expensive moulds. Precast arches were used for 25 of the 64 bridges.[34]

The highway authority influenced the method of carrying out the work, which could take the following forms:

(1) total closure of the road with diversion of traffic to adjoining bridges
(2) provision of a temporary Bailey bridge during reconstruction
(3) demolition of half the arch with traffic using one half while the other half was being reconstructed
(4) bridge widening with the widening being completed before reconstruction to carry traffic.[34]

Lewis and Clark[34] have described how interference to the running of trains must be kept to the shortest acceptable time. The track was protected with polythene sheeting and a layer of wood sleepers to receive the demolished brick arch, and from which the rubble was loaded. The fill above the arch was removed before demolition. Demolition was usually performed by breaking through the arch and dropping it, but explosives were also employed.

For demolishing an arch over a double line railway, the time available was usually limited to an 8 hour blockage of both tracks (midnight on Saturday to 8 am Sunday morning). During the subsequent 8 hours rail traffic operated on one track while the second was made available to the engineer for disposal of rubble. The only other major track occupation requirement was for road cranes lifting the prefabricated units, and this was usually done by special arrangement with the railway operating manager who closed the line between the passage of trains.

Parapet walls to bridges were strengthened with reinforced concrete surrounded by brickwork, in accordance with Technical Memorandum (Bridges) BE5,[35] to preserve the traditional appearance.

Footbridges New footbridges were constructed in either prestressed concrete or steel and concrete composite construction, to carry a load of 5 kN/m^2. Over the tracks, glass reinforced concrete panels were provided in blues, browns and greys, to avoid colours with signalling significance. Drainage holes could not be provided in the floor of the bridge span as contact could be made with the 25 kV overhead wires or the earth return wire, and so the rainwater had to be conveyed along the span to downpipes at the supports.

Planning Approach Roads and Services Where reconstruction of a bridge was necessary, the highway authority was consulted at the planning stage about road widening, improvement to alignment or gradients of bridge approaches, and appropriate road loadings. A substantial cost chargeable to electrification, amounting in one case to 30% of the total cost of bridge reconstruction, resulted from the need to maintain public services in the roads passing over bridges. Early consultation was needed with the gas, water, electricity and telephone authorities in order to liaise with any of the undertakers' planned works.

Station Alterations The increased clearance required from the rail, made necessary the removal of the part of any station structure lying within the space required for the locomotive pantograph and the specified clearance to it. To satisfy this requirement at Stowmarket Station, the platform awning was set back but care was taken to maintain the appearance of the original station. One typical method of reconstruction was to place prestressed, precast concrete planks on the support walls and *in situ* concrete, reinforced with steel fabric, placed on top to carry an assumed loading of 5 kN/m^2. Precast concrete copings were placed at the exact standard distance from the track, and mastic asphalt was found to be a satisfactory surfacing material.[34]

Rail Track Lewis and Clark[34] described how rail track improvements were undertaken at the approaches to many curves, to achieve the correct rate of build of cant or superelevation of the high rail over the low rail. This increased from zero on the straight to full superelevation on the curves. This involved appreciable earthworks, as the railway was repositioned to lengthen the transition curve, made necessary by the planned increase in route speed from 153 to 160 kph (95 to 100 mph).

Tunnel Work In the Ipswich tunnel, the restricted clearances were optimised permanently, by replacing the original flat bottom rail on timber sleepers by track in which the rail was fastened directly on to a concrete slab cushioned by a pad. The paved concrete track comprised a profiled, continuously reinforced concrete slab. The rails were supported on 10 mm thick resilient pads consisting of 9 mm of rubber bonded cork with a 1 mm PVC topping supplied in 2 m lengths and laid end to end, to form a continuous support.

The rails were held by a form of Pandrol fastening, consisting of Pandrol E1809 clips, shot peened and sheradised, with composite nylon and malleable iron insulators and galvanised, malleable iron shoulders, fixed in holes in the concrete slab by epoxy or polyester resin. It was necessary to incorporate drainage outlets at intervals from the concrete into the tunnel drainage system, to prevent water lying on the surface of the slab.[34]

Channel Tunnel Rail Link

British Rail's choice of route for the dedicated high speed rail link from London to the Channel Tunnel and its implementation proved to be a most controversial matter. Mounting pressure from strong environmental groups resulted in delayed publication of proposals and subsequently in substantial changes and then a further one year's delay in presentation to Parliament to allow time for further revisions to be made. These problems were accentuated by funding difficulties as the estimated cost of the project rose from £1.2b to £3.61b between March and November 1989.

Kent County Council's official position was that it accepted the need for a new dedicated line but wanted it to benefit the people of Kent as a whole, by improving commuter services and diverting freight from road to rail. Main environmental objections by the council centred around noise and visual intrusion across the Kent countryside. This implied putting lines into cuttings or cut and cover tunnels, avoiding embankments and keeping to existing transport corridors, such as rail lines and the M20.

In 1988 British Rail publicised three alternative routes each with extensive environmentally sensitive sections above ground. In March 1989 the Prime Minister requested British Rail to make substantial amendments to the chosen rail link option, which was believed to be the route running north of Maidstone and coming into London through Sidcup, and to increase considerably the terms for compensation payable to those whose property was blighted by the project. Despite renewed calls for a public inquiry, British Rail planned to press ahead with the introduction of a private bill in November 1989, permitting work to start in 1991 and the line to open in 1997 at the earliest, four years after the opening date for the Channel Tunnel.

The revised proposal, whereby about one third of the new rail link would be tunnelled through London and Kent, had raised the cost from £1.2b to £1.7b, with a consequent reduction in maximium track speed from 300 to 225 kph (186 to 140 mph). This also resulted in greater funding problems as money had to come from private sources. Under section 42 of the Channel Tunnel Act, the Government could not give any grant to British Rail to help it provide, improve or develop international rail services relevant to 'the carriage of passengers or goods by way of the tunnel system.' Most commentators and analysts agreed that international passenger traffic alone could not justify the £1.7b cost.

By May 1989 extreme difficulties were being encountered in obtaining central London construction sites for tunnel headings and permanent access shafts. The problems were compounded by the Railways Inspectorate requiring an extra 15 to 20 large diameter access shafts, costing between £25m and £50m, at 1 km intervals along the route to provide an entry for emergency services and an exit for passengers in case of fire or other accident. In addition, in most cases, lengths of horizontal tunnelling were required from shafts to connect to roads and emergency services.

In September 1989 the chairman of British Rail admitted that even with help from the private sector, British Rail could not raise the finance to meet the escalating costs of the link and to meet the 8% return on the investment required by the Government. A detailed estimate of British Rail's preferred route had now been costed at £3.61b, including 5% per annum inflation up to 1997. This estimate included four terminals (King's Cross, Waterloo, Ashford and Mid Kent Parkway), tunnel engineering works, property purchase, and international passenger and high speed commuter trains.

At the same time an alternative link to Stratford was proposed by a consortium at a cost of £2.2b. It was further claimed that this route would be almost completely free of environmental disturbance and would provide better opportunities for future expansion. However, this proposal was rejected by British Rail in November 1989.

At the same time, British Rail postponed its plans for the high speed rail link for a further year and announced that the EuroRail consortium led by the Trafalgar House group, would be its private sector partner in the project. Both parties announced that the scheme would not be economically viable if they were forced to excavate a continuous tunnel under south east London, from Swanley in Kent to King's Cross station. Passage of private bills through Parliament takes 2½ years, so the earliest construction start is 1993 and the project is likely to take up to seven years to complete.

The partners intend to build an international station near the M25 at Swanley, and an intermediate stop on route to London. The additional year will be spent working on different solutions to connecting Swanley to King's Cross. These could include upgrading existing rail tracks and tunnels to carry international trains, as well as possibly a new line to handle the increased volume. It appears likely that high speed trains will have to run on existing tracks into London for the rest of the century. To make matters worse, in June 1990 the Transport Secretary formally rejected a £3.5b proposal from the EuroRail consortium, insisting that a planned investment of £1b in the existing BR routes would provide adequate service until capacity was reached at the turn of the century.

This is not a successful outcome and highlights the major problems resulting from the absence of government financial support for transportation schemes of national importance, the strength of the environmental lobby and the fears of residents whose properties are likely to be blighted by the proposals. However, in October 1991 the Government approved a northerly route approaching King's Cross from the east, which would help in regenerating the lower Thames area.

French High Speed Railways

French high speed railways have been examined on account of their great success in implementing advanced technology and in competing with air travel, which is very desirable having regard to the serious airspace and airport congestion over much of Europe. The United Kingdom can learn from the French achievements, despite its much more densely populated terrain.

France's second high speed railway entered service in 1989, comprising the Paris to Le Mans branch of the TGV Atlantique, with the branch to Tours completed in 1990. The TGV (*train à grande vitesse*) travels at speeds up to 300 kph (186 mph) on its own dedicated track, and by 1992 the TGV Atlantique was expected to carry 21m passengers a year. It builds on the phenomenal success of the first TGV line, the Sud Est route between Paris and Lyon, which has made substantial inroads into Paris–Lyon air traffic since it opened in 1981. In 1987 it carried 4.8m passengers, ten times the number flying between the two cities.

These latest lines have taken about 11 years from initial planning to completion and the Paris–Le Mans branch cost about £920m for a length of 180 km. The French government contributed 30% of the cost of the line, with French Railways (SNCF) funding the remainder and the full cost of rolling stock. SNCF expects to secure a 12% return on its investment.[36]

Fowler[36] has described how the high speed line consists of 285 km of new track, with 12.4 km of bored tunnel and 8.4 km of cut and cover (mainly in the Paris suburbs), and there are 30 viaducts totalling 3.4 km in length. The maximum gradient is 2.5% (reduced from 3.5% on the Sud Est line), which trains can climb without reducing speed. The maximum curve radius is 6000 m, or 4500 m in exceptional cases. Trains can run at up to 200 kph to within 6 km of the modernised Montparnasse station in Paris.

Civil engineering work along the route was divided into eleven sections and involved most of the French major contractors. The first 75 km of the route from Le Mans crossed virgin countryside, the next 85 km followed existing transport corridors to reduce environmental disturbance (A10 motorway and Tours railway line), and the last 20 km through the suburbs of Paris, was largely underground in a succession of cut and cover and tunnelled sections. This provided the opportunity to create an 11 km *coulée verte* or garden throughway above the line landscaped by local authorities to provide gardens, paths and cycle tracks for local residents.

The track is conventional except for a greater than usual minimum thickness of ballast of 350 mm. The rails are continuously welded and pretensioned to give a neutral temperature – at which thermal stresses are zero – of 25°C. Sleepers consist of twin 840 mm reinforced concrete blocks connected by a metallic brace beneath the ballast. Around 10% of the total cost of the line was spent on environmental works. Noise barriers have been provided extensively where the line runs above ground near towns or villages. A number of wildlife bridges were provided in woodland areas to enable animals to cross the track safely. These consist of grassed structures 12 m wide at the centre and widening at each side to 'funnel' animals across them. Culverts were installed to ensure that the line did not interfere with the natural drainage of the land.[36]

Acceptance of the line was helped by the provisions of French law whereby anyone whose land is compulsorily purchased receives 25% above market value for it. Where agricultural land is severed by the line, plots affected are reallocated or regrouped to give farmers the same area of land which they had before, all on the same side of the line. Fowler[36] pointed out that environmental opposition is becoming more vociferous and environmental spending on the later Nord line which passes through more highly populated areas could amount to 15% of the total cost.

The train has undergone considerable changes since the TGV Sud Est entered service. It has a white and blue livery in contrast to the previous orange. Mechanically, it will have AC instead of DC motors, air suspension, and improved aerodynamics reducing its drag coefficient by 10%. Its 300 kph maximum speed is 30 kph greater than the TGV Sud Est. Each trainset has ten cars to the TGV Sud Est's eight, and carries 485 people, 25% in first class accommodation. The trains are provided with telephones, a stationery and tobacconist's shop and a nursery.[36]

SNCF's in-cab signalling system allows trains to run at three minute intervals at peak periods, with signalling for the entire line controlled from Montparnasse. Initially SNCF planned to run 10 trains per day in each direction, rising eventually to 120 per day on the common section of track, diverted equally between the two branches.

Fowler[36] describes how high speed trains are more fuel efficient than most other forms of transport and the track requires less land than a road. Most European railway engineers envisage a rail network which will eventually link all the major centres of Europe, with overall travel times comparable to those by air with all its consequent advantages. Unfortunately, London may not be one of the centres in the network, largely because of the difficulties of forging dedicated high speed rail lines in a densely populated island and also because of the lack of integrated transport planning in Britain.

Australian Railways

The study of the French railways was directed towards the high speed passenger routes and, by contrast, in looking at Australian railways there is great emphasis on long distance rail freight transport. The five government railway systems in Australia developed jointly with assistance from UK consultants Travers Morgan developed INTRANS, which stands for the Railways of Australia Intersystem Transport Operating Plan. This is a plan to improve the services offered by long distance interstate rail freight transport in Australia.

The objectives of the plan are noteworthy as they aim to identify and meet the needs of customers spread over a very large country with a high standard of service reliability. The key element is the streamlining of intersystem freight services, with transits planned from departure to delivery throughout the country. Furthermore, under the INTRANS plan trains will be remarshalled at fewer points, there is a standard train examination procedure for all systems and terminal performance is being steadily improved.

Concurrent with the implementation of INTRANS was the adoption of a system of centralised intersystem wagon transit monitoring, administered by CENWAG based in Melbourne. A computer system was installed by CENWAG to keep track of the transit progress of the 13000 intersystem wagon fleet. The monitoring system is fed and updated continuously with the information from intersystem train movements and intermediate yard reports telexed to CENWAG by all railway systems.

Figure 2.8 shows the Australian Rail network connecting the largest centres of population. It shows the three different types of track (standard, broad and narrow gauge). Hence it is possible to travel directly from Perth to Sydney and from Sydney to Melbourne on the same standard gauge, 1435 mm wide. However, the track from Adelaide to Melbourne is broad gauge, 1600 mm wide, and for a train to pass from one system to the other a fast, high capacity bogie exchange is performed at Adelaide (Dry Creek).

A variety of train types are in use from very long trains made up of innumerable wagons carrying long distance bulk freight and diverse commodities to trains of 'piggyback' wagons on which many road transport operators load their complete rigs at Adelaide and Port Augusta (to the north of Adelaide) for the long hauls to Alice Springs or Western Australia, or a record breaking 8400 tonne quadruple-headed coal train in New South Wales. There are also different types of passenger train such as the dual locomotive Australian–Pacific train probably hauling some 14 carriages, used on the Perth to Sydney route, to the interurban double-deck passenger train illustrated in Figure 2.9. In 1990 increased competition was arising from the high powered two-trailer road transport units, coupled with improved highways.

An efficient and well monitored system of track maintenance is required to cover such long lengths of track and the associated structures, and the stated aim is to achieve a high quality of service.

Travers Morgan have advised Australian railways on many important matters ranging from computerised wagon tracking procedures for interstate traffic to major marketing studies and economic feasibility studies of rail electrification schemes.

Railway Bridges

New and reconstructed bridges must be built to provide at least the mandatory clearances to the kinematic envelope prescribed by the Department of Transport. For British Rail, this requirement gives a standard structure gauge 4.640 m high (above rail level) and 2.340 m clear laterally from the centre line of the nearest track, although additional lateral clearance is necessary alongside curved tracks.

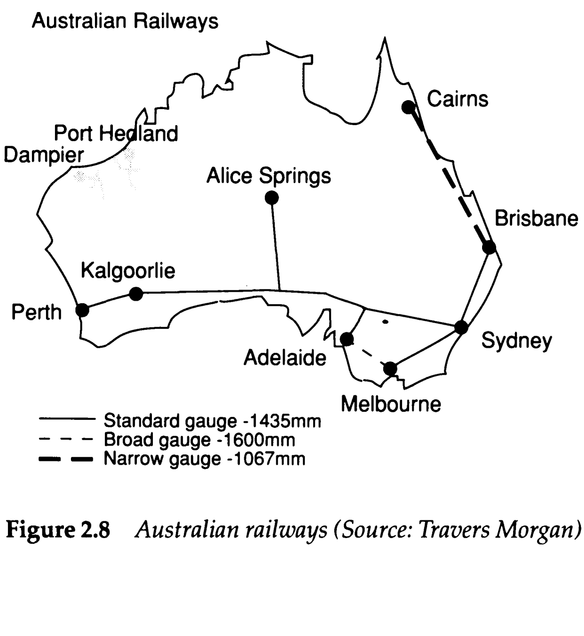


Figure 2.8 *Australian railways (Source: Travers Morgan)*

Atkins and Wigley[37] have identified four main influences on railway underline bridge design as: the introduction of the bridge code BS 5400,[38] the development of new materials and techniques, the requirements of the Health and Safety at Work Act 1974, and the more commercially oriented management of British Rail. Some bridges, because of their size and accessibility, have been built alongside the railway track and slid into place or have been built in line with the existing track during a temporary track diversion.

The general design principles on which railway bridges are based encompass simplicity of erection, durability and ease of maintenance. The bridge code contained in BS 5400 led to more consistent designs and higher standards. Bridge decks are waterproofed normally using a proprietary membrane or paint. These generally require protection from ballast and must be impervious to the oils often encountered near railway depots.

Atkins and Wigley[37] have emphasised the great advances that have been made in the development of craneage, which are of great benefit when working to strict time limits; 54 hours being the average time allowed for the reconstruction of an existing bridge deck. Whole superstructures may be lifted in to reduce erection times. Furthermore, in multi-span bridge construction, rough terrain cranes with capacities of up to 70 t have been used to transport and place bridge deck units. For larger span concrete bridges, where the weight of the structure precludes lifting techniques, the bridge has to be built beside the track and slid or moved into position under the track, using a variety of methods. Complete bridges have also been thrust under the tracks in the form of large boxes using jacking techniques, while portals have been slid into place on previously prepared foundations, sometimes with trailing wing walls attached.

Figure 2.9 *Australian Inter Urban Train (Source: Travers Morgan)*

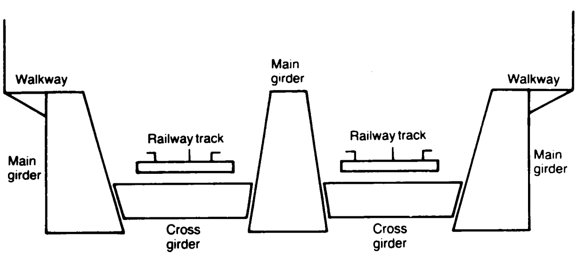


Figure 2.10 *Standard box girder design for bridges (Source: F. E. Atkins & P. J. G. Wigley [37])*

One of the most widely used *steel bridges* is the British Railways standard box girder type developed by the Western Region. This bridge was originally designed as a single track two girder bridge or a double track three girder bridge for spans of 8 to 25 m, as illustrated in Figure 2.10. The main advantages over similar half-through type bridges with I-section main girders are easier erection and reduced depth of main girders.

For smaller spans up to 5.5 m where construction depth permits, the most economical solution is likely to be unconnected *precast reinforced concrete slabs*. Two units per track is the optimum arrangement commensurate with ease of placing and minimising site waterproofing.

Prestressed beams are used on longer spans and are generally connected together to provide an effective slab deck. A common practice is to adopt transverse post-tensioning with the *in situ* concrete between the beams cast at the concrete works during the trial erection. An inflatable rubber ductube is threaded through the post-tensioning ducts to ensure no grout ingress and a suitable releasing agent is applied to one side of each beam. The beams are carefully marked once the concrete is set to ensure that they are erected in the correct positions. This leaves only the post-tensioning and subsequent grouting to be carried out on site. This technique can be used for spans up to 20 m and is illustrated in Figure 2.11.

On the 630 km East Coast main line electrification scheme from London to Edinburgh, completed in 1991 at a cost of £306m, the infrastructure works accounted for £157m. The civil engineering work included increasing clearance on 111 bridges to take the electric locomotive's pantograph, by straight jack up, track lowering or reconstruction. The choice of bridge solution was determined by cost. For example, to lower the track by taking 10 mm off the ballast was easy but expensive for a 50 mm drop requiring the relaying of 600 m of track. With one bridge, 20 mm was chiselled off the stone face to obtain the clearance for the pantograph. High capacity cranes can be a cost effective method of raising bridges, possibly carried out in two halves.

On the East Coast route, BR civil engineers were responsible for the design work on rebuilding bridges with contracts let by competitive tender. Rebuilds were usually in single span precast, prestressed concrete beams or precast concrete saddles, but for large spans steel proved the most economic. Other work on bridges included high parapet walls with pointed tops to meet safety regulations covering the 25 000 V line beneath.

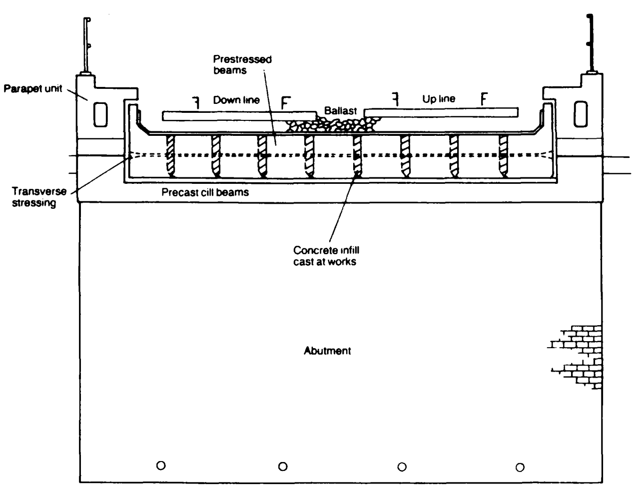


Figure 2.11 *Cross section of bridge using precast prestressed concrete beams (Source: F. E. Atkins & P. J. G. Wigley [37])*

Railway Stations

Station platforms should be long enough to accommodate the longest train and have a non-slip surface. The clear width should not be less than 2 m, and for important stations and island platforms a minimum width of 4 m over the greater part of the length is desirable. Columns and other structures should not extend to within less than 2 m from the platform edge and a clear minimum headway of 2.5 m is required over the platform. The stepping distance between the platform edge and the footboards of passenger rolling stock should not exceed 275 mm laterally and 250 mm vertically. Copings should overhang the face walls at platform edges by 300 mm.

All station premises used by passengers and staff during hours of darkness shall be adequately illuminated and provided with adequate and conspicuously displayed name plates, illuminated at night. Stairways and ramps shall be of adequate widths and suitable grades. The structures shall be suitably fire resistant and there shall be adequate fire extinguishing equipment.

York station is probably one of the most attractive railway stations in the British Isles with its sedate Victorian splendour and has, accordingly, been selected for closer examination. It was completed in 1877 to a design by the North Eastern Railway's architect, Thomas Prosser, and is a listed station. Its 16 platforms, ranging in length up to 516 m, are protected by an elegant curving trainshed roof 244 m long and 72 m wide, and the largest span over the through tracks is 25 m. The wrought iron roof ribs rise to 12.8 m above platform level and spring from wrought iron girders resting on cast iron columns. The massive colourful side walls are built from yellow Scarborough bricks with stone dressings. The station is illustrated in Figure 2.12, although it will be appreciated that the InterCity 125 diesel locomotive was replaced in 1991 with an electrified high speed train.

Figure 2.12 *York railway station (Source: Shepherd Construction Ltd)*

In 1988 one of the most complex track remodelling schemes was undertaken at York station at a cost of £18m. There was no diversionary route around York and so it was necessary to relay some 10 km of mainline track and drastically reduce the number of points and crossovers, but still keep the trains running through the station on schedule.

York's track layout, with its dozens of superfluous points, crossovers and sidings and a signalling system from the 1950s was due for renewal, as it was cumbersome in operation and included extensive duplication. Electrification provided the opportunity for modernisation and rationalisation but all the work had to be carefully planned and be cost effective.

The number of main lines through the station was reduced from six to three, coupled with the removal of at least three quarters of the 160 points and all but two of the two dozen diamond crossings. This halved the number of end bay, terminus platforms and allowed simplification and removal of much of the adjoining freight yards. Main lines had to be relaid for a distance of 2 km on each side of the station and a highly sophisticated computer controlled solid state nterlocking signalling system was installed reducing the 3000 wires to a mere handful.

Using the conventional 12 to 18 h weekend possessions would have involved a 2½ year completion period, but this was unacceptable on this busy high speed line. Hence, at York, engineers obtained unprecedented possessions occupying weeks rather than hours, enabling them to carry out major 1 km long track relays by day and night without interruption, and trains passed alongside the possession areas. With possessions lasting up to six weeks each, the work was completed in 25 weeks, although it was preceded by four years of discussion and one year of intensive planning.

Track relaying in short possessions requires up to seven trains repeatedly bringing in materials for a few hours' work, while at York all trains and necessary materials were kept nearby or on the site. With short possessions it takes one to three hours before work can commence, while at York the mainline track was being dismantled 10 minutes after the last high speed train had passed.

Double the usual volume of ballast was laid in one operation, with laser levelling dozers positioning 500 t of stone in a single 1 km length. An extremely complex crossover section was remodelled by removing seven diamond crossings and all but three of the 28 points in 56 hours, providing further evidence of the very fast execution of this project.

The £85m reconstruction of *Charing Cross station* was carried out in the late 1980s with most of the office development suspended from a series of bowstring arches assembled at roof level, and almost the entire weight of the 100×50 m superstructure hangs from the arches and is supported by 21 columns, each carrying up to 2700 t on huge caissons, excavated by hand beneath the original station vaults. The impressive floodlit arched gable end provides a distinctive new landmark on the north bank of the River Thames.

Mass/Light Rail Transit Systems

Introduction

The increasing congestion of many European central urban areas has resulted in considerable emphasis being placed on modern light rail systems. New lines were opened in the late 1980s in Nantes, Grenoble and Utrecht, and modern street tramways developed in Amsterdam and Basel. In Britain, this approach developed from the Tyne and Wear Metro, through the Docklands Light Railway to the later schemes planned for Manchester, Sheffield, Bristol and various other cities.[39]

Light rail schemes incorporate driver only; standard gauge; wholly or partially segregated rights of way; closely spaced stops; minimum signalling; and light vehicles capable of negotiating sharper bends and curves and steeper gradients than conventional rail vehicles. A largely segregated service is more reliable and quicker and light rail transit (LRT) can achieve this at less cost than a suburban railway or metro, albeit with a lower maximum capacity, and operates at a level between local bus services and longer distance rail services. It is likely to cater for passenger flows between 1000 and 20 000 passengers per hour with a route length unlikely to exceed about 25 km (15 miles). The accepted international standard for systems involving street running is 750 volts DC with overhead supply, while the third rail is only feasible in totally segregated situations such as the Docklands Light Railway. Although London Underground and British Rail trains share tracks on occasions, this is not generally practicable because of differing wheel profiles, buffing loads and power supply systems, and it requires the approval of the Railway Inspectorate.[39]

London Underground

General Characteristics Parts of London Underground are over 160 years old, it carries over 3m passengers per day, the network occupies 400 km with around 260 stations and has long lengths of deep, small bore tunnels. During the period 1980–90, passengers travelling on London Underground increased by almost 50% on a rail system much of which was becoming increasingly outdated and dilapidated with extensive overloading at peak periods, and with escalating repair and maintenance costs. For example, expensive grouting work was required to prevent water seepage prior to major underground station renovation works. Vibrations from passing trains over the past 100 years, coupled with the age of the tunnels, has resulted in the grout infill cracking and causing fatigue of lead caulking in the cast iron tunnel lining joints.

Rising groundwater levels in London can adversely affect the drainage of the underground track and the risk of flooding is likely to increase. Drainage arrangements on some parts of the system are in need of substantial improvement and replacement and in 1987 a seriously defective section was identified on the Circle line where the 450 mm brick culvert, dating back to the 1860s, was suffering from encrustation, deposits of silt and debris and partial collapse. Collapsed drains can lead to the formation of cavities leaving the track unsupported. Drain cleaning is normally carried out by water jetting, followed by closed circuit television inspection, which shows the structural condition of the drains and the position of pipe entries and 'lost' manholes. Remedial works include the installation of steel ductile iron or spun concrete pipes where complete replacement is necessary, or the use of polyethylene flexible liners pulled through the existing drains using winches from enlarged manholes.

The tragic fire at King's Cross Underground station in November 1987 brought sharply into focus the dilemma facing London Regional Transport, namely how to match limited investment funds to the often competing objectives of increasing efficiency, attracting more passengers and improving safety standards. The Health and Safety Executive recreated the circumstances of the tragedy and concluded that the fire was started by a lighted match igniting grease and fluff below an escalator, and was transformed into a terrifying inferno by flames being funnelled up the wood lined escalator trench into the booking hall igniting everything they touched, and killing 31 people in the process.

The absence of leaky feeder radio systems was unfortunate, as they allow communication underground and are deemed essential in the mining industry and in the Channel Tunnel. This equipment was provided in 48 underground stations the following year and successful trials had taken place at one station over an eleven year period preceding the fire. After the tragedy fire safety policy was urgently reviewed and many deficiencies were identified including the extensive use of flammable materials. More funds were directed towards installing new fire safety equipment such as heat detectors, sprinklers, fire doors and fire breaks, and the phasing out of wooden escalators. But even with additional funds the task of dovetailing modern technology into a system designed and installed in a bygone age is formidable.

Extensions to the Underground System In 1989 the Minister of Transport announced the approval of the extension of the Jubilee line from Green Park to Stratford, via Westminster, Waterloo, London Bridge, Surrey Quays, Canary Wharf, Canning Town and West Ham, thus helping to open up intensively developed sections of London Docklands. The estimated cost was £1000m, of which the private sector developers who will benefit considerably from the line, mainly Olympia and York, agreed to contribute £400m, which was much less than the government was anticipating, and was further reduced to £100m in 1990. The extension, which forms the first new section of underground line in London since the early 1970s, will not become operative until 1995 and the final cost is likely to be very much in excess of the estimated figure. It was, however, feared that about 100 buildings of special architectural and historic interest could be damaged by dust, ground settlement and the introduction of new structures, because of their proximity to the line, including buildings around Parliament Square.

However, the developers, agents and occupiers in London Docklands were very concerned at this time about the area's transport problems. They felt that the planned improvements were insufficient to keep pace with the development, let alone ease congestion, and that the government seemed much more interested in avoiding spending money than finding ways of solving the problems. As described earlier in the chapter, the country suffered from the absence of a clearly defined and efficiently co-ordinated transport policy.

Another London rail proposal was announced in 1989 and comprised a £235m link between Paddington Station and Heathrow, funded 80% by Heathrow Airport, a wholly owned subsidiary of British Airports Authority (BAA), and 20% by British Rail. The line is expected to become operative in 1994 and will run on existing lines from Paddington to Stockley Bridge and then underground to Heathrow; the journey time being 16 minutes to Terminals 1, 2 and 3, and 20 minutes to Terminal 4.

Two other underground lines under consideration in 1989 were to cross London from Chelsea to Hackney and from Paddington to Liverpool Street. Work on these rail tunnels would involve the excavation of between 10 km and 15 km twin bore drives at depths of up to 40 m, to avoid building foundations and existing underground tube and rail lines. The estimated cost at that time was around £1500m each, but they were not approved by the government.

London Docklands Light Railway

The Docklands Public Transport Strategic Plan (DPTSP) discussion document published in 1988 stated: 'The current public transport system for Docklands is inferior to that of central London and also inferior to many areas of inner London at a similar distance from the centre'. Furthermore, the scale of development exceeds that anywhere else in central London, with 2.38 million m^2 (25m sq ft) of new commercial space becoming available between 1988 and 1996, and by year 2003, the number of households is expected to double from 25 000 to 50 000 and the number of jobs from 40 000 to 200 000, but in the late 1980s and early 1990s problems were being experienced in the disposal of certain properties.

The Docklands Light Railway (DLR) is the cornerstone of the London Docklands Development Corporation commitment to increasing and improving public transport in Docklands. It commenced with the opening of the 12 km computerised light transit system in 1987, linking Tower Hill to Stratford and Islands Gardens, carrying 3500 passengers per hour in each direction through the Isle of Dogs, and jointly funded by the Government through the Corporation and London Regional Transport (LRT). DLR is a wholly owned subsidiary of LRT. It was however evident from the outset that the capacity of the railway was inadequate.

Subsequently the railway was extended westwards to Bank Station in the heart of the city and work was carried out to upgrade and strengthen the network to meet the increasing demands of developments such as Canary Wharf, and by 1991 trains had doubled in length and could carry up to 15 000 passengers per hour in each direction on the section of railway between Bank and Westferry Stations. The DLR western extension was funded by Government, through LRT, and the developers of Canary Wharf, Olympia and York. The DLR eastern extension between Poplar and the Royal Docks was opened in 1992, with a capacity of 7800 passengers per hour and was funded by the Corporation. The route of the Docklands Light Railway is shown in Figure 2.13.

Docklands Light Railway uses fully automatic rail services and was the first of its kind in Britain. Much of the track has been designed to use existing British Rail rights of way. The attractively designed light rail vehicles illustrated in Plate 1 use an unobtrusive third rail system. By using lightweight overhead structures, DLR avoided road intersections and the creation of isolated pockets of land, cut off by the railway. The ability to cope with gradients of up to 6% (1 in 17) and curves of 40 m radius, or 25 m on short sections, also minimised land requirements and reduced capital costs and disruption.

Hong Kong Mass Transit Railway

It is worth considering briefly the very popular and world famous Peak funicular railway opened in 1888, in which the cars are hauled by cable up the 1350 m long tramway to a height of 395 m at slopes of up to 27°. Today, one half of the passengers carried annually are overseas tourists, 40% are local sightseers, and only one tenth are

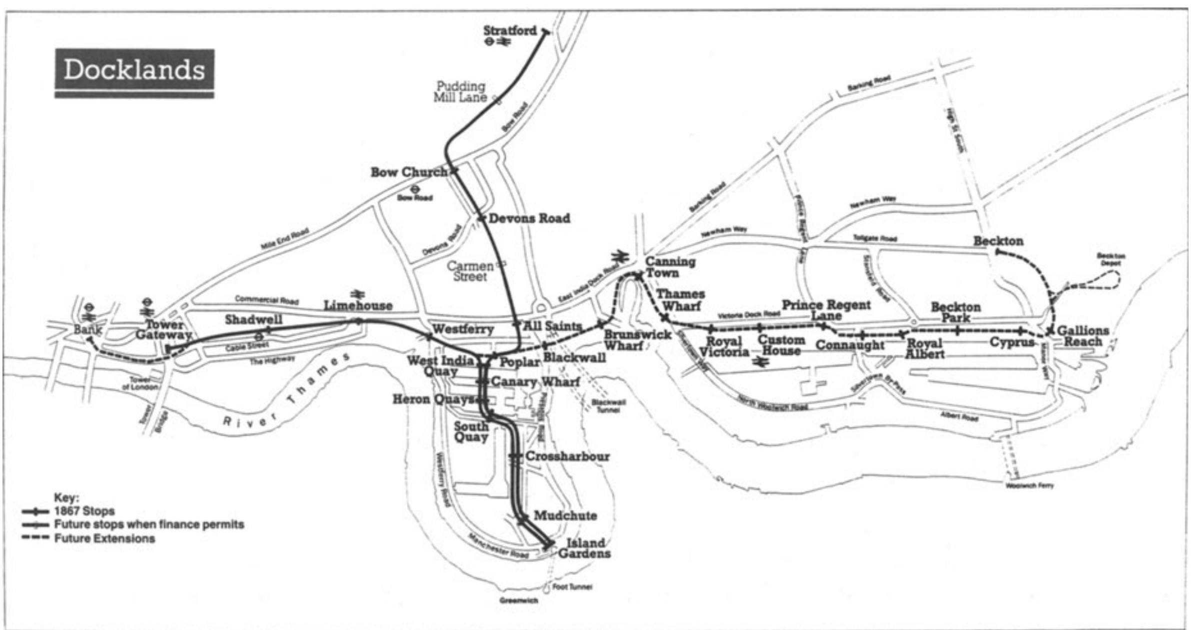


Figure 2.13 *Docklands Light Railway (Source: Docklands Light Railway Ltd)*

commuters. There have been four generations of tramcars, and extensive refurbishment of everything except the track was undertaken in the late 1980s, with larger cars travelling at higher speeds and doors on both sides, increasing the number of passengers per hour in each direction from 600 to 1400. This will allow 3m passengers per year to enjoy the spectacular views of Hong Kong and the harbour from the top terminal.[40]

The Mass Transit Railway Corporation of Hong Kong was established in 1975 as a public statutory body for the principal purpose of constructing and operating an efficient and commercially sound mass transit railway. All of the issued capital was held by the Government of Hong Kong. MTRC constructed and operates a 38.6 km railway system, comprising the Tsuen Wan, Kwun Tong and Island Lines, together with a further 5 km in the second harbour crossing. The three lines were completed in phases between 1979 and 1986 at a total cost of HK$25b, and the second harbour crossing between Cha Kwo Ling and Quarry Bay, 5 km long, and containing both road and rail tunnels to relieve morning peak hour traffic congestion, was completed in 1989. These three lines open up much of Hong Kong Island, Kowloon and the New Territories.

There were basically four constructional methods used, namely:

(1) Immersed tube – by sinking and joining together 14 prefabricated tunnel segments.
(2) Underground stations – by cut and cover, using diaphragm, pack-in-place, sheet pile, secant pile/caisson, soldier pile, reinforced concrete and steel king pile, and reinforced concrete retaining walls.
(3) Tunnels – mainly bored including work under compressed air, with small sections of cut and cover.
(4) Overhead stations and running line – similar to flyover construction using continuous prestressed concrete viaducts.

The 39 stations comprised 30 underground (9 in bored tunnel), 8 overhead and one at ground level.[41]

During the peak construction period about 8100 workers were employed by contractors, comprising about 12% of the total construction work force in Hong Kong. The approximate division of contracts between countries, spread over the three lines, consisted of Japan 46%, United Kingdom 22%, Hong Kong 16%, France 11%, West Germany 3%, Sweden 1% and USA 1%.

The railway employs computerised systems with the trains themselves being controlled automatically with regard to the regulation of acceleration, braking and coasting and to the control of speed on each specific section of track. The ticketing system is fully automatic with both single journey and stored tickets available. The eight car trains are air conditioned and each car is 22.5 m × 3.2 m, and can carry 2500 passengers per train at two minute headways during the peak rush hour. The passenger capacity of each car is 48 seated and up to 265 standing, and trains have a scheduled speed of 33 kph (20 mph) and a maximum speed of 80 kph (50 mph). The average station stopping time in peak hours is 30 seconds and the trains operate from 6 am to 1 am the following day (19 hours daily). The passenger volume on the three lines in 1990 was 2m per day (two thirds of the London Underground numbers but on only one tenth of the total length of London route).[41]

In conjunction with the railway construction and operation, MTRC has undertaken joint venture developments of large residential and commercial properties above stations and depots, which in 1987 produced an income of HK$113m.

Singapore Mass Rapid Transit System

Planning Although Singapore is only the size of the Isle of Wight, it has a population of 2.6m, and boasts a mass rapid transport system that rivals the largest in the world in terms of sophistication and innovation. Hence it was considered necessary to examine the system in considerable detail as there are so many lessons to be learnt from it. A metro is the most difficult form of infrastructure that any city can undertake and Singapore faced many challenges with differing ground conditions, water problems and dealing with hundreds of underground pipes and cables that had to be carefully diverted to ensure that utility services remained operative.

The Singapore Mass Rapid Transit System, as illustrated in Figure 2.14, became fully operational in 1990 and consists of 42 stations over a 67 km route, connecting the central business district, various new towns and major industrial areas, and taking seven years to construct. Fifteen of the stations are underground, twenty-six are overhead and one is at ground level. In the early stages action was taken by government agencies to prevent inhibiting development occurring along the preferred routes. There was also considerable attention given to the feasibility of an all-bus system, as opposed to feeder buses serving MRT stations. In 1982 the government opted for the MRT system and announced that it would finance the initial capital cost (approaching S$5000m), but that the revenue accruing from the railway operation should be sufficient to cover all operating, maintenance and replacement costs. The Mass Rapid Transit Corporation was established to plan and organise the works.[42]

Design It was decided that the system was to be the most modern available compatible with the use of components that had been tried and tested in service under conditions similar to those anticipated for the Singapore system. The design life was stipulated as 75 to 100 years, coupled with a requirement that design should reduce maintenance to an absolute minimum.[43]

It was considered that a maximum train frequency of 32 per hour was comfortably within the capabilities of modern signalling systems, with a maximum train load of 2/3 of the crush capacity of 1800 and an average speed of 40 kph. Train cars are 23 m long and 3.2 m wide with a six car formation and a train is shown in Plate 2 emerging from the elevated three track Ang Mo

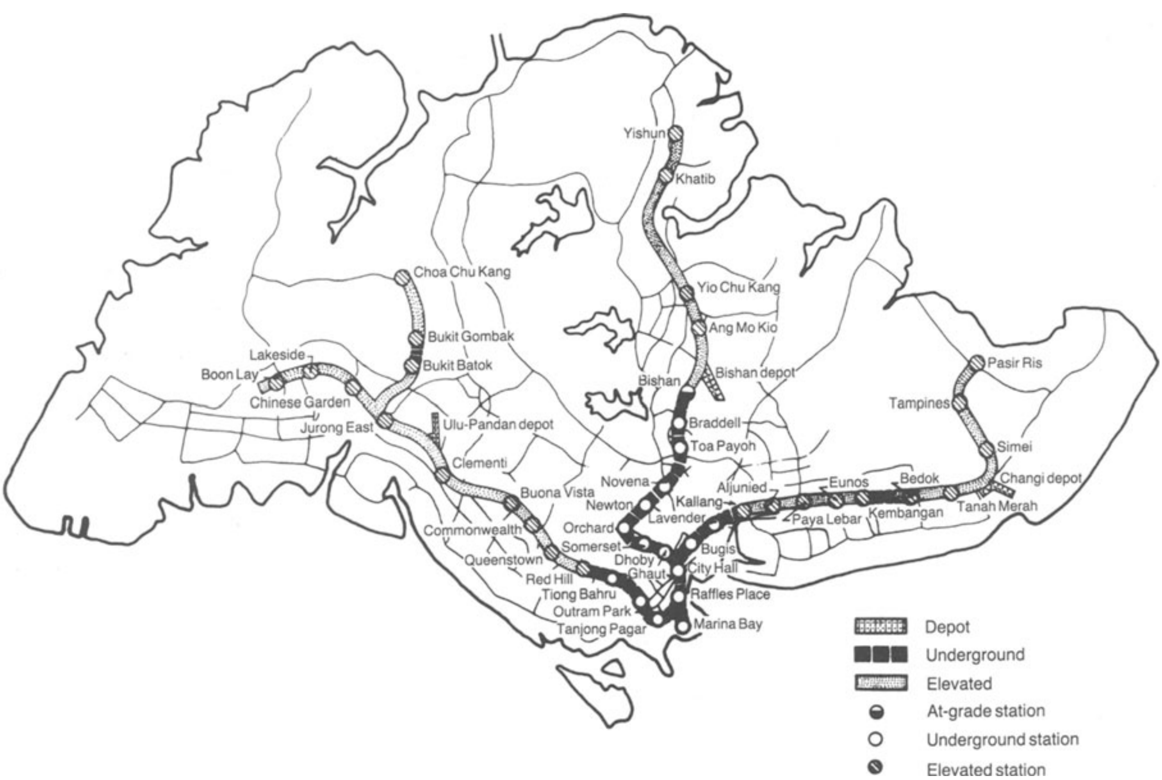


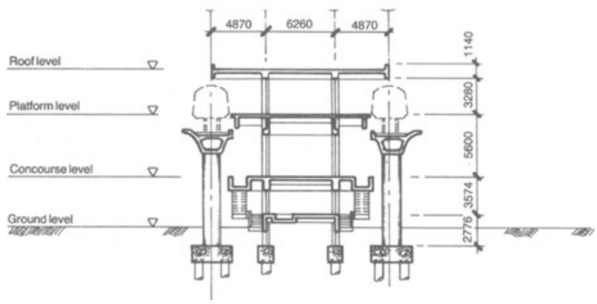
Figure 2.14 *Singapore Mass Rapid Transit System (Source: T. W. Hulme et al[42])*

Kio station. A 750 V DC third rail traction supply system was adopted to avoid a proliferation of support standards and wires.

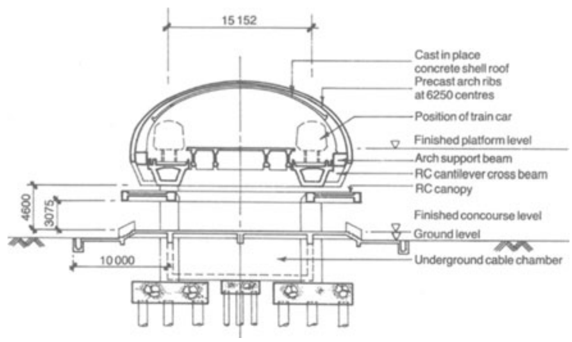
The Singapore MRT was the first to be fully air conditioned throughout the year and environmental energy costs are high in relation to traction power. Studies in the final phase showed that economies of up to 50% of the operating costs of a conventional system could be achieved by installing platform edge screen doors to separate the air conditioned stations from the tunnels. In the event of this innovation proving impractical, the conventional system could still be used.[43]

The *stations* have a platform length of 138 m to accommodate the six car trains. Elevated stations, required only minimal air conditioning of non-public areas, and were relatively simple in layout. Off-street stations were two level with the upper island platform served by escalators and stairs from a ground level ticket concourse. Stations in the road medians generally had three levels: plant rooms at ground level, ticket concourse at first level with direct passenger access by overhead bridge from the road sides and island platform at second level. At three stations – Ang Mo Kio (shown in Plate 2), Jurong and Tanah Merah – three tracks are provided with two island platforms, as these stations are all adjacent to depots or stabling sidings. The third track is to allow the intermediate reversing of services and the passage of trains to and from the depot without disruption to the service. Most underground stations have been strengthened for civil defence purposes and have gas and blast proof closure devices.

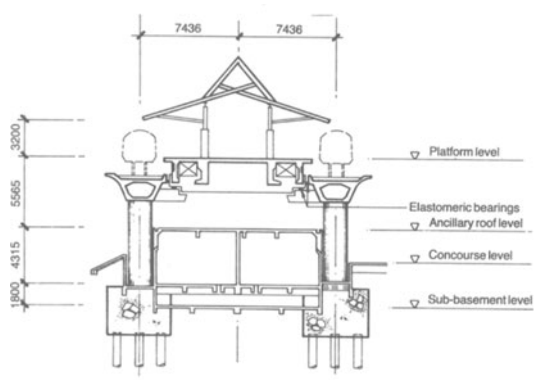
In all the elevated stations the structural elements are designed in reinforced concrete and prestressed concrete, but the structural frame arrangements differ. In phases I and IA the station structure was completely separated from the viaduct structure, whereas in phases IIA and IIB the platform main beams were supported off the viaduct columns with elastometric bearings for vibration isolation. There are also three different roof styles. Phase I and IA stations were of conventional beam slab construction, although phase IA had a lattice type extension overhanging the track to provide increased protection against the heavy rains encountered in Singapore. Phase IIA stations had a reinforced concrete barrel arch roof of 23.6 m span, while phase IIB stations were designed with attractive Chinese and Malay type roofs built off structural steel frames. All three station designs are illustrated in Figure 2.15.[43]



Cross-section of phase I and IA station



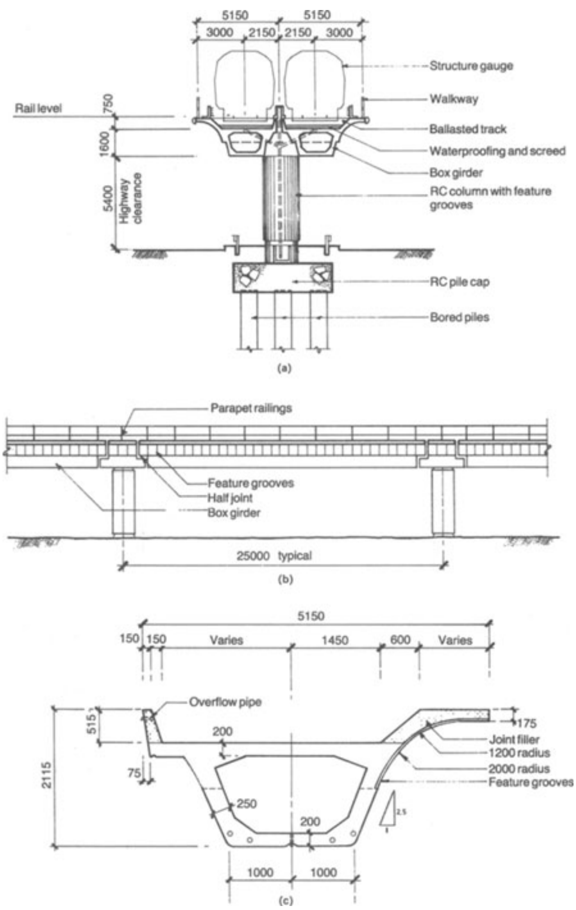
Cross-section of phase IIA section



Cross-section of phase IIB station

Figure 2.15 *Singapore Mass Rapid Transit System: station designs (Source: J. P. Copsey et al[43])*

Viaducts were a dominant feature as there were nearly 50 km in all and so appearance was an important factor. They were constructed of precast prestressed concrete box girders with 25 m spans, as illustrated in Figure 2.16. This heavy concrete construction assisted in the suppression of noise, made use of techniques familiar to the local construction industry and minimised future protective maintenance as compared with steel. Each track was supported independently, thus limiting damage caused by derailment or other incident to one track, simplifying erection work and assisting with the division of tracks at island stations. A clean horizontal surface was provided for aesthetic reasons with a curved profile on the outside edge of each girder to give a slender appearance and a softening shadow effect. A graded waterproofed protective screed to girders drained to 150 mm downpipes at each column.[43]



Viaduct structure: (a) section; (b) elevation; (c) box girder section

Figure 2.16 *Singapore Mass Rapid Transit System: viaduct structure (Source: J. P. Copsey et al[43])*

The *permanent way* was of standard gauge (1435 mm) because of its worldwide use and consequent expansion of the market for the supply of equipment. The design criteria included 16 t axle load, minimum 200 m curve radius, maximum gradient of 3%, maximum cant 150 mm for concrete track and 125 mm for ballast track, and maximum cant gradient of 1:500. In curves with radii smaller than 500 m, high wear resistant steel grade 110 with a tensile strength of 1080 N/mm^2 and about 1% chrome content was selected, with grade 90 rails with a tensile strength of 880 N/mm^2 for all other lines.[43]

Ballast track was used in at-grade sections and on viaducts as it was relatively inexpensive, insensitive to differential settlement at viaduct columns, had good electrical insulation properties and allowed easy maintenance of cross levels, alignment and regrading at soft ground areas. Kempass wooden sleepers from Malaysia and Indonesia were selected as they were easier to handle, readily available and could accommodate easily the third rail brackets and guide rail features. When correctly impregnated their life was considered equal to concrete sleepers. Continuously welded rail was used throughout.

For tunnel sections, fixed slab track was used as it provided lasting alignment in the narrowly confined tunnel envelope, required minimum maintenance, eased drainage and cleaning, incorporated cables and service crossings, and reduced the depth by 120 mm compared with ballasted track. Where the route crossed densely populated areas and commercial districts, floating slab track was used to eliminate vibrations and secondary airborne noise inside buildings. The minimum tunnel size was 5.2 m internal diameter with reinforced concrete segmental lining. However, contractors opted for tunnel diameters ranging from 5.23 to 5.4 m. The only successful sealing material identified for use with the concrete segments was a non-soluble but water expansive resin and synthetic rubber product.

The underground stations were built on the cut and cover principle using a variety of cofferdam techniques, including diaphragm walls, sheet piles, bored pile walls, and soldier piles and ground anchors. The depth of excavation varied from 13.5 m (sheet piles) to 25.2 m (Raffles Place – largest station, using soldier piles, timber lagging and ground anchors). In addition, tunnels under the Singapore River and Telok Ayer Basin were designed as cut and cover tunnels, and the work under construction in part 1 of the river crossing, near Empress Place, is illustrated in Figure 2.17. Figure 2.18 shows sections of underground railway under construction in central Singapore using the cut and cover technique.

Tyne and Wear Metro

In the United Kingdom in 1989 Parliamentary Bills were lodged to permit the construction of rapid transit systems in Manchester, the West Midlands, Sheffield, Leeds, Southampton and Bristol/Bath. In addition, various kinds of rapid transport schemes were proposed for implemetation in the 1990s in other British towns and cities, including Edinburgh, Cardiff, Belfast, South Hampshire, Nottingham, Norwich, Chester and Gloucester. The forerunner was the Tyne and Wear Metro which entailed close collaboration with British Rail, was completed in 1984, and will now be examined.

The Tyne and Wear Metro has a total route length of 55 km, using 42 km of converted British rail line and 13 km of new track, including sections in tunnel constructed under Newcastle and Gateshead central areas and connected by the Queen Elizabeth II bridge across the Tyne. Other new sections of track included diversions from the former BR alignment to link local centres

Figure 2.17 *Singapore Mass Rapid Transit System, construction of first phase of tunnel under Singapore River near Empress Place (Source: Singapore Mass Rapid Transit Corporation)*

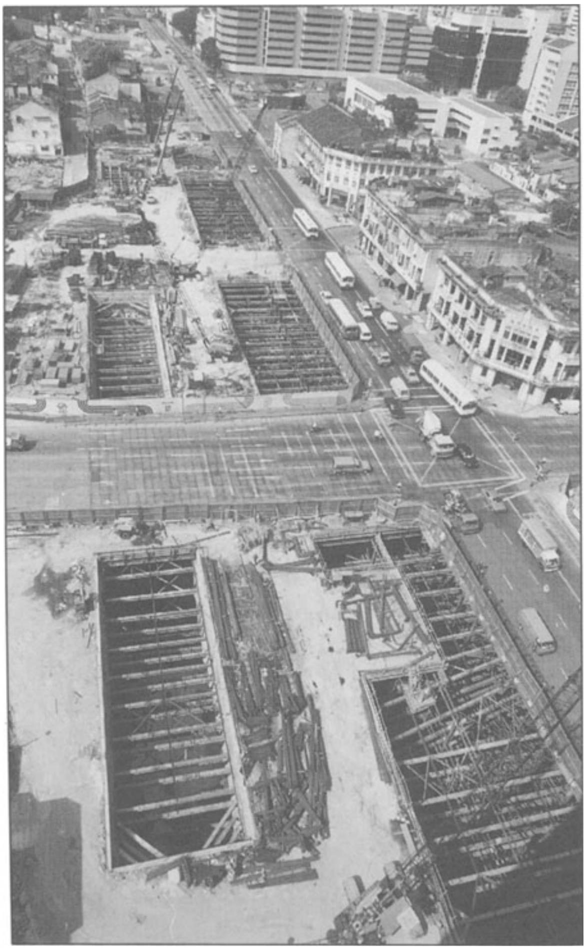


Figure 2.18 *Singapore Mass Rapid Transit System, sections of underground railway under construction in Singapore City using cut and cover principle (Source: Singapore MRTC)*

and new housing areas. The old route linked towns such as Monkseaton, Whitley Bay, Tynemouth, North Shields and South Shields to Newcastle. It has 44 stations.

The Tyne and Wear system integrated the Metro with bus services, the British Rail line from Newcastle to Sunderland, and the ferry connecting North Shields and South Shields. Parking areas at the interchanges and at some local stations also allow car users to link into the system. Most bus services now fulfil the dual service of feeding the Metro system and meeting local travel needs, following their restructuring and rationalisation.[44]

The Tyne and Wear Metro is operated by Tyne and Wear Passenger Transport Executive and comprises a driver operated light rail system and accounts for around 47 million passenger journeys annually. The track is standard 1435 mm gauge and is mainly continuously welded 54 kg/m FB laid on concrete sleepers set in deep stone ballast, except in tunnels where there are concrete block sleepers set in concrete. The overhead 1500 V DC power supply was chosen for three main reasons:

(1) The Chief Inspecting Officer of Railways ruled on safety grounds that an unprotected third rail system would be permissible only for extensions to existing railways. A standard third rail system would also be foul of main line structure gauge for the joint use BR/Metro sections.
(2) Third rail systems are more prone to icing problems than overhead.
(3) Overhead provides a technically better and safer system at depots and level crossings.[45]

At peak periods there are 18 trains per hour passing through the central area north/south tunnels and a minimum 12 minute headway to outlying stations in evenings and on Sundays. Trains are manually operated but the signalling and route setting for each journey are automatic. Once the train's route is set by the driver, the route code is fed by wire pick up loops located between the rails to route setting equipment at South Gosforth Control Centre. The lineside signalling and route setting on the journey is then controlled automatically. System controllers based at South Gosforth are in radio contact with drivers and can manually override the computer operated signalling and route setting if required.[39]

Stations are unmanned and most are adapted from old British Rail stations or comprise a basic design of a shelter with seats and covered in ticket machine area. Central area stations and purpose built interchanges are constructed on a larger scale. All stations have a public address system and are equipped with CCTV, with video recording facility, and passenger information display systems were being developed in the late

1980s. The stations are fully accessible to wheelchair users. Automatic ticket issuing machines and ticket operated entry barriers are provided at all stations. The Metro participates in the Tyne and Wear Public Transport Operators Travelcard Scheme with through ticketing to bus services and British Rail.[39]

The Metro *train* is an articulated lightweight two section vehicle, each section being 27.4 m long and 2.65 m wide, and carrying 84 people seated and 200 people standing. The door bay areas are also available for wheelchair passengers and prams, with ease of boarding being assisted by the absence of steps from the platform to the metrocar. The fleet of 90 cars was built by Metro Cammell and Figure 2.19 illustrates all the main components.

The preferred extension route is to Newcastle Airport, 3.5 km long with two new stations. It was planned for completion in 1992 at a cost of about £10m, to be shared between the Government (DOE under s56 of the Transport Act 1968): 54%; Tyne and Wear Passenger Transport Authority: 23%; and the Airport Company: 23%. A further extension to Sunderland was being examined for possible completion during the period 1994 to 2000.

Greater Manchester Metrolink

Greater Manchester is a conurbation of 2.6 million people, and has in the past been served by buses and suburban services of British Rail, which do not link across the city centre, hence the perceived need to provide a light rail transit system (LRT) termed 'Metrolink' to rectify the transport deficiencies. Greater Manchester became the first of the new generation light rail schemes in the United Kingdom to incorporate street running, and is likely to be followed by many more. In 1990/91 South Yorkshire Passenger Transport Executive (PTE) were constructing a line from Hillsborough to Mosborough and crossing central Sheffield, and were seeking powers for a second line along the Lower Don Valley from Sheffield to Rotherham. At the same time, West Midlands PTE were seeking powers to construct a line between Snow Hill in Birmingham and Wolverhampton, while Avon Metro were proceeding with a privately

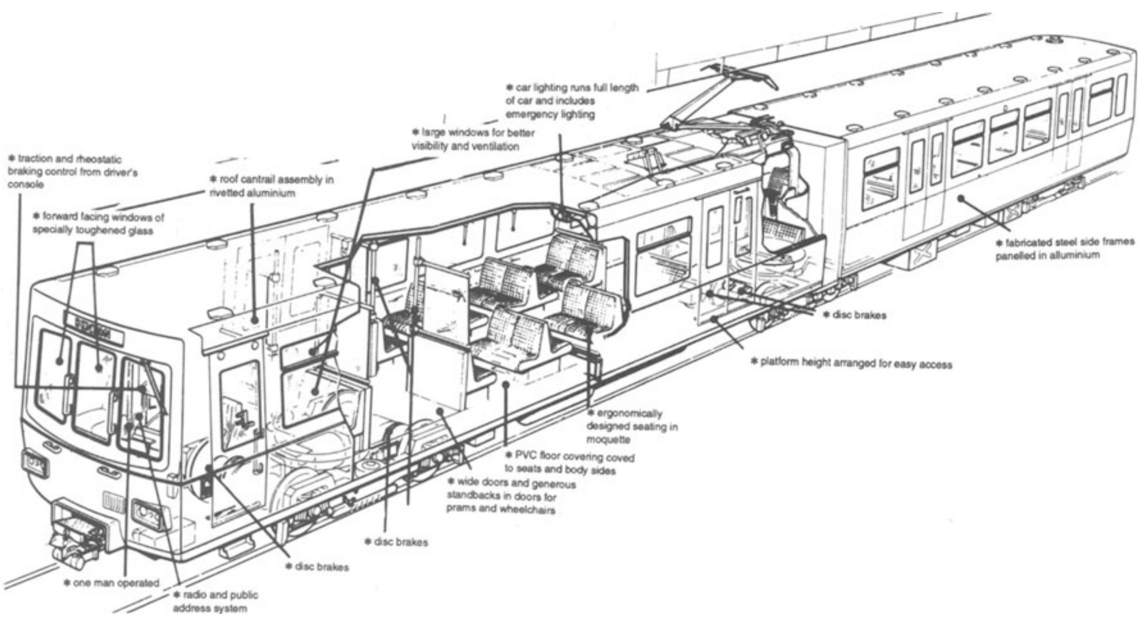


Figure 2.19 *Sketch of Tyne and Wear Metro train (Source: Tyne and Wear Passenger Transport Executive)*

sponsored scheme in Bristol. As described earlier in the chapter Tyne and Wear became Britain's first new light rail system and met the recognised criteria with regard to rolling stock and geometric standards but was fully segregated and could not exploit LRT opportunities to the full.

The main aims of Metrolink as identified by Greater Manchester PTE[46] were to:

(1) improve passengers' journeys to and across Manchester city centre
(2) link together the northern and southern rail systems
(3) offer overall financial and economic benefits for the area
(4) reduce the revenue support needed for local rail services
(5) improve access to shops and businesses
(6) encourage development of vacant land, including housing
(7) assist development of leisure, recreation and tourist facilities
(8) provide better links with British Rail's local and InterCity networks
(9) help create jobs in local industry.

Parliamentary approval was obtained in 1988 for the first phase of the Greater Manchester Metrolink at a cost of £140m and it was completed in 1992. It comprised 29 km of converted British Rail track on two of the busiest commuter lines from Manchester to Bury in the north and Altrincham in the south, linked by 3 km of largely on-street new track through the city centre as illustrated in Figure 2.20. It will link for the first time Manchester's two British Rail main stations at Victoria and Piccadilly, together with Deansgate station, Piccadilly Gardens, the G-MEX Exhibition Centre, Town Hall, Arndale shopping centre and other main shopping and business centres.

About 45% of the cost was borne by the Greater Manchester PTE, 45% from the Government under s56 of the Transport Act 1968, and the remaining 10% from the GMA consortium, who designed, constructed, operated and maintained the system and receive all fares for a 15 year concessionary period, although the assets including rolling stock remain in PTE ownership. It

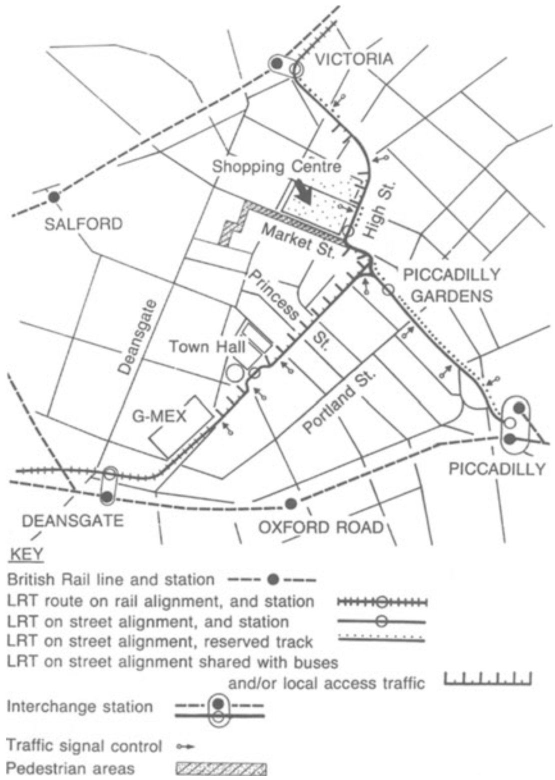


Figure 2.20 *Manchester City Centre: existing British Rail lines and proposed Light Rapid Transit line (Source: Greater Manchester Passenger Transport Executive)*

was possible that a European development fund grant amounting to a third of the cost could be made.

The overall scheme encompasses a 100 km network covering six BR suburban lines and future phases are planned to connect Salford Quays, Langworthy, Oldham, Rochdale, Glossop and Marple, for completion in the 1990s, with priority routes covering Salford Quays, Trafford Park, Oldham and Rochdale to be constructed as an early extension of phase 1. This network will provide a substantial boost to the local economy, creating new jobs and assisting in establishing Greater Manchester as a focal point for North West England. It has the support of all ten district councils in Greater Manchester and the business and commercial sector.

Each *light rail vehicle* comprises a two section articulated unit and each vehicle can carry 80 seated passengers and up to 100 people standing. Because they are lightweight with powerful electric motors they have fast acceleration with a maximum operating speed of 80 kph (50 mph) on converted existing railway lines, but at normal traffic speeds when on the new on-street tracks through the city centre. The light and clean grey livery of the supertrams with the orange Metrolink logo has been designed so that the supertrams are visible for street running but are not an over-dominant feature of the urban scene. A new design of profiled street platform was developed to give level access at the front door of the train and a relatively easy two step access at other doors with a single automatic retractable step. An artist's impression of a supertram passing through central Manchester is given in Figure 2.21.

Off-street the overhead wires are supported by gantry type structures, while with on-street sections through the city centre, wires may be supported by poles placed between tracks, from transverse wires slung between buildings, or slung from poles on either side of the track when they will also carry street lighting, street signs and traffic lights. Two types of rail are used: a standard British Rail type for ballasted track sections and for on-street a wide based grooved rail finishing flush with the street surface.

Five new *stations* were built in Manchester city centre to serve Metrolink and all station features and colour schemes were designed to blend in with the varied surroundings but to retain their own unique style. The stations are shown on figure 2.20 and are as follows:

(1) High Street/Market Street – serving Market Street area, Arndale shopping centre and other principal shops.
(2) Piccadilly Gardens/Mosley Street – serving city centre and Piccadilly bus station.
(3) St Peter's Square (near the Town Hall) – serving the Central Library, Free Trade Hall and Town Hall area.
(4) G-Mex – serving G-Mex Exhibition Centre and linked to Deansgate station.
(5) Piccadilly Undercroft – situated below Piccadilly railway station and providing interchange for local and main line services.[47]

All stations on the Bury and Altrincham lines were refurbished to make them more open and accessible, particularly for elderly and disabled people and those with prams and pushchairs. In addition, a large viaduct was built near G-Mex and a BR underbridge at Old Trafford to separate BR and Metrolink tracks. Little co-ordination with bus services was possible because of deregulation.

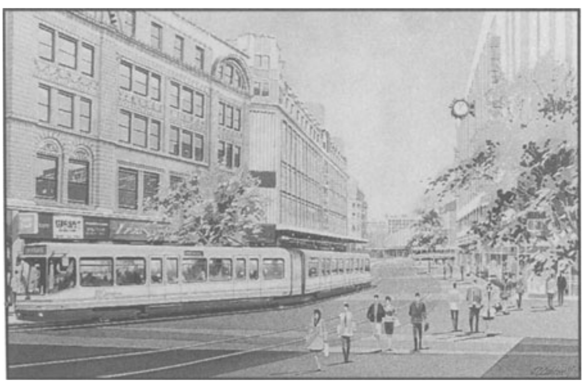


Figure 2.21 *Artist's impression of Metrolink super tram in Manchester city centre (Source: Greater Manchester PTE)*

Navigable Rivers and Canals

General Characteristics

An extensive network of navigable rivers and canals exists in Britain. The navigable rivers and some of the larger canals carry significant quantities of freight while the majority of the canals are used mainly by pleasure craft. The largest navigable rivers in Britain are the River Thames and the River Severn, but other rivers, such as the Rivers Tyne, Mersey and Trent have an important role to play. Admittedly, these rivers are small compared with many of the world's great rivers but they do provide excellent outlets from ports to the sea.

Freight Transport

The south west of England has been taken as a typical example of the extension of freight facilities being made available by British Waterways. The Gloucester and Sharpness Canal and the River Severn together provide a significant water highway from Stourport to the Bristol Channel for the transport of freight. Wharves along the route provide cargo handling services and there are major docks at Sharpness and Gloucester. The Gloucester and Sharpness Ship Canal is 25.75 km (16 miles) long with unrestricted headroom, connects Gloucester to the Bristol Channel and links with the River Severn, and sea-going ships of 1000 t deadweight can navigate throughout its length. While barges up to about 350 t can navigate to Worcester. In 1990, British Waterways Board were formulating plans to improve the Gloucester and Sharpness Canal and the River Severn to enable vessels of 2500 dwt to reach Gloucester and 1500 dwt to reach Worcester.[48]

Gloucester Docks have undergone extensive modernisation and improvement and can handle import and export cargoes for industry in the south west and midlands of England and Wales, which have good road and rail links to the docks. Ships carry goods to and from EEC countries, the Iberian Peninsula, Scandinavian and Baltic ports. Transit warehouses are available on a number of quays and all operating berths and transit sheds are approved by HM Customs.

General Canal Characteristics

A typical cross section of a canal is shown in Figure 2.22 with its watertight bed of puddle clay, which could be as much as 600 mm deep. Brick or dry stone walls, often supported on timber piles, were sometimes provided on the towpath side of the canal, which followed contours around hillsides, to protect the banks from erosion caused by wash from vessels particularly on sharp bends. Where provision was made for vessels to moor on both sides of a canal it was customary to protect both banks with masonry. In canal restoration work precast concrete piles and light steel sheet piling have been used.

John Rennie specified brick locks on the Kennet and Avon Canal in 1795, 24.4 m (80 ft) long by 4.53 m (14.84 ft) wide at the top and 4.22 m (13.84 ft) at the bottom and 2.75 m (9 ft) deep, with wing walls at each end extending 5.50 m (18 ft) from the gates. The bottom of the lock consisted of an inverted brick arch, 215 mm deep, laid in water cement on rammed clay or marl. A large fir sill, row of 100 mm grooved sheeting piles 2.4 m deep, with 1.50 m of puddle in front of the sheeting, was provided at the lower end of the arch. The side walls were of best burnt bricks with a

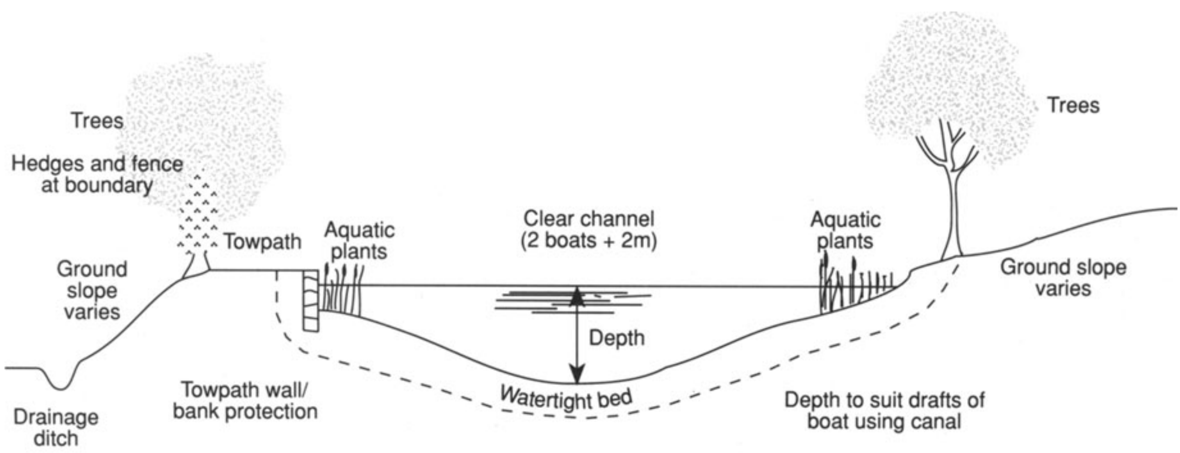


Figure 2.22 *Typical cross section of canal*

battering face built off the inverted arch and backed with further brick walls and counterforts tied to the walls by oak ties. Quoins and copings were constructed in stone. Substantial fir sills were provided under the upper gates with a cast iron plate in the centre of the sill to prevent damage by boats. The heavy beam under the lower gates was supported by two rows of piles. The gates were formed of large oak members all securely jointed with large iron plates and bolts and faced with oak planking 56 mm thick. The soundness of the design and construction is evidenced by the very long life of most of the locks.[49]

The Kennet and Avon Canal was completed in 1810 and is exceptional in that throughout the 140 km between Reading and Bristol there are 104 locks, including the spectacular Caen Hill flight of 29 locks west of Devizes which rises 72 m in 4 km. Rennie also installed a reservoir and two pumping stations to provide adequate water to the summit of the canal and designed simple but attractive bridges and viaducts. Initially it carried large quantities of freight but the opening of the Great Western Railway and the purchase of the canal by GWR in 1852 resulted in declining use of the canal and its increasing state of disrepair. The largely derelict canal was closed to navigation in 1951 but its restoration was initiated by the Kennet and Avon Canal Trust in 1962. Full restoration was completed in 1990 with substantial assistance from British Waterways and Berkshire County Council. The restoration of locks and replacement or modification of low level bridges involved considerable costly civil engineering work. The reconstruction of locks, such as Woolhampton, with attractive brick chambers on concrete floors with new gates, and brick paved surrounds and suitable landscaping, has been undertaken with considerable care and skill.[50] A typical canal lock at Cowley near Uxbridge on the Grand Union Canal is shown in operation in Plate 37, by courtesy of British Waterways, with a canal hump back bridge in the background.

Plate 3 shows an aerial view of the new Sprotbrough Lock on the South Yorkshire Canal, near Doncaster, under construction in 1980, adjoining the original lock, while Plate 4 shows the lock after completion, taken upstream. The main works comprised constructing a much enlarged replacement lock 77 m long × 7 m wide with the walls formed of Nr 4 Frodingham steel sheet piling, 13 m long, supported by 381 × 102 × 55.1 kg rolled steel channel walings connected by 75 mm diameter high yield steel tie rods at every sixth pile, through filling on each side to connect with further steel piling on the waterside and Nr 3 Frodingham anchor piles on the landside. The piling to the lock was backed with puddle clay 1 m thick. There is further sheet piling downstream of the new lock to protect the bank. The lock gate chambers and the base to the lock were constructed in reinforced concrete. The waterway beside the lock was blocked off opposite the downstream lock gates and the canal realigned to pass across the line of the original lock, which was demolished, and the original lock house replaced by a new control cabin. The project was designed by British Waterways, Engineering Department, Rickmansworth, and the works cost £0.67m.

General Responsibilities of British Waterways

British Waterways are statutorily responsible for a large portion of the canal and river navigations in England, Wales and Scotland. Their responsibilities include operating, maintaining, renewing and improving the canal track and its associated engineering structures and features. They also own extensive land and property holdings with responsibility for the upkeep of numerous canal related buildings, and the infrastructure at commercial docks. It is not generally appreciated that British Waterways administer 3200 km of waterways, 1549 locks, 60 tunnels, 89 reservoirs, 397 aqueducts, 983 public road bridges, 2612 accommodation bridges, 1715 listed buildings, 130 ancient monuments and 50 sites of special scientific interest.[51]

Organisation of the Engineering Function within British Waterways

The organisation of British Waterways was restructured in 1989, whereby the canal network was split into six manageable regions, each under the control of a Regional Manager, assisted by Waterway Managers who are responsible for all functions on individual lengths of canal. They manage the direct labour force whose primary tasks cover water control, operating locks, attendance at docks, agricultural works, dredging, bank protection, replacement of lock gates and the smaller repair and maintenance tasks.

Within each region there is a small central engineering team responsible for ensuring engineering standards, safety and the integrity of canals. Each has a small design team which prepares, designs and plans for small works to be undertaken by direct labour or contract. They also check and approve any third party works affecting BW's property, and works of canal restoration and improvement being undertaken by volunteers or through Employment Training Schemes. Building work is dealt with by separate regional estates teams.

Almost all major engineering works are constructed by contract for most of which a central engineering division either undertakes the investigation, design, letting of contracts, and supervision of construction work or, alternatively, instructs and monitors the work of Consulting Engineers.

Public Works Activities on British Waterways Canals

These encompass a wide range of activities which can be subdivided into the following categories, as so ably and fully detailed by Neil Maxwell, British Waterways Special Projects Engineer (Gloucester).

(i) *Operating:* This includes attendance at locks, bridges, docks, basins and pumping stations, controlling water supply and flood waters, inspections, attending to customers using the canal network and day to day dealing with adjoining landowners. These tasks are mainly undertaken by BW's own labour force.

(ii) *Agricultural Work and Environmental Management*: This work includes cutting hedges and grass on the towpath, cutting back trees overhanging the water, clearing undergrowth on slopes to cuttings and embankments, cleansing ditches, clearing excess aquatic vegetation from the canal and keeping weirs and overflow sluices free from obstructions. Most of this work is carried out by direct labour possibly supplemented by small works contractors. Where possible tractors and machines are used but their size and use are often limited by the narrow towpath and access to it and by structures alongside the canal.

Dredging is also a major task normally undertaken by direct labour using BW's own special floating dredgers and crane barges. Where access is possible, land based hydraulic excavators or draglines are often used, although transporting and disposing of the dredgings can present problems.

(iii) *Structural Maintenance*

(a) *Daily and Minor Works*

British Waterways' direct labour force undertake a variety of tasks to keep the canals operational, including minor repairs to masonry, regular painting, and regular attendance to and replacement of moving parts in sluices, locks and movable bridges. Except for emergencies, canals can only be dewatered during winter stoppages, at which times repairs and renewals are made to chamber walls, sills, and gates to locks, to culverts and weirs, and to underwater parts of canals. Erosion protection of the banks is an ongoing task, often using light sheet piling or geotextiles on the smaller canals with heavy sheet piles or stone pitching on the deeper commercial canals. Contracts are sometimes let for these latter works.

(b) *Emergency and Third Party Works*

The direct labour force has a major role in dealing with incidents such as breaches, leakages and damage to the canal and its structures. There is a regular requirement to inspect canals for signs of impending damage and to check, approve and supervise any third party works over, under or alongside the canal. It is necessary to keep a lookout for dangers arising from subsidence in areas of mining and brine operations, where British Waterways may become involved in the construction of major protective and remedial works.

(c) *Major Works*

These can arise from the failure or long term deterioration of the canal and its structures, many of which were built some 200 years ago. Such works can include repairs to and rebuilding of culverts, weirs, locks, bridges and aqueducts, relining the channel, remedial works to earth slopes in cuttings and embankments, and works at reservoirs to meet the requirements of Inspecting Engineers. These works are usually undertaken by contract to designs prepared inhouse or by Consultants.

(iv) *Improvements*: The need for major engineering investigations and works can result from proposed commercial freight and property developments and from changes in legislation. An example of commercial freight development in the late 1980s was the enlarging of the Sheffield and South Yorkshire Navigation, including the replacement of locks. In the early 1990s British Waterways were exploiting the property value of much of their canalside land with major developments planned in London, Leeds, Gloucester and Sheffield.

There is a continual programme of strengthening canal walls, replacing locks, strengthening or rebuilding road bridges and remedial work to reservoirs, to meet latest standards and Health and Safety legislation. This is accompanied by an increasing programme of minor works to improve the amenity aspects of the canal, such as the provision of moorings and angling facilities, and clearing and reforming towpaths in both rural and inner city locations. Some of this latter work is undertaken by contract or direct labour, but much of it has been carried out using MSC and Employment Training Schemes, often in conjunction with local authorities.

(v) *Restoration*: Prior to nationalisation in 1948 and up until the 1960s, there was regrettably a policy of closing down canals. Some were legally abandoned and frequently filled in and built over, while others were left to deteriorate into a derelict condition. However, mainly through pressure applied by volunteer societies and trusts, with active support and encouragement from local authorities, this process has since been halted and many of the lengths have or are being restored for pleasure navigation and amenity use, which is further examined in chapter 8. A major restoration scheme on the Kennet and Avon Canal was described earlier. Other notable restoration schemes included the Basingstoke Canal (not BW), Huddersfield Narrow Canal and the Lowland canals in Scotland. Tribute must be paid to the valuable work undertaken by the MSC and Employment Training Schemes with some general assistance and supervision from British Waterways, which totalled £34m over the period 1983–89.

Major Public Works Carried out by Contract

Major engineering contract schemes for which final accounts were paid between 1985 and 1989 at a total cost of £35.5m, included Preston Brook Tunnel (£1.34m), Boddington Reservoir (£1.36m), Netherton Tunnel (£1.31m), Beeston Weir (£1.30m), Blisworth Tunnel (£4.22m), stages 2 to 4 of Llangollen Canal (£3.69m), Combs Reservoir (£1.03m) and Regents Canal Repair (£1.17m). A further set of schemes completed in 1991 amounted to £20.6m and included the later stages of the Llangollen Canal, the restoration of the original Stanley Ferry Aqueduct and many other worthwhile projects. A selection of the more unique engineering projects are described later in the chapter.

All these schemes were financed by grants from the Department of the Environment, to cover the cost of major arrears and renewals that have built up over the years. Additionally, there are many small contracts and direct labour works administered by British Waterways and paid for out of grant-in-aid and operating revenue, further monies spent on properties, and works on restoration and improvement schemes most of which are joint schemes with local authorities and volunteer societies with only comparatively small contributions from British Waterways' funds.

Types of Plant Used

Various types of land and water based plant are used for canal works, with the actual choice being governed by the size of the individual waterway and its bridge holes and the means of access to individual sites. British Waterways own a considerable fleet of purpose built floating craft, including bucket dredgers, tugs, crane and lifting barges, piling barges and boats, hoppers, work boats and weed cutters. These range from boats of 2.15 m (7 ft) beam for use on narrow canals to those of 6.7 m (22 ft) or more used on the larger commercial canals and river navigations.

Land based plant includes the usual categories of construction and small plant such as road vehicles, tractors, dumpers, cranes, pumps and compressors, although many of these often have to be restricted to smaller or mini-sized equipment. Mini-tractors and hand equipment such as mowers and strimmers are used for grass cutting, while tractor mounted flails and hand methods are both used for hedging. Around the country there are a number of repair and plant yards, some with dry docks, where plant is built and maintained. These yards also build and install lock gates.

Problems and Constraints Associated with the Maintenance of Canals

Most of the canals were built some 200 years ago using materials that were locally to hand. With increasing competition from the railways from the mid 1800s onwards, little money was available for maintenance and repairs, except that needed to cater for essential commercial traffic. Hence major works were usually confined to a few days at bank holidays when commercial traffic could be halted. The position deteriorated steadily as the railway companies bought out many of the canals. It was not until the start of pleasure boating in the 1960s that monies eventually became available for their upkeep and gradual improvement. Consequently many of the canals and associated structures are in poor condition and there is still a large backlog of work required on the limited budgets available, although much has been achieved since 1970.

Furthermore, the change from horse drawn to propellor driven boats has created more erosion of the banks, damage to structures, and an increase in the need to dredge. Likewise, the change from full-time commercial boatmen whose livelihoods depended on the canals together with frequently manned locks and bridges, to the present day mostly inexperienced holiday boaters with very few lock and bridge keepers to assist them has increased the incidence of damage.

With the gradual deterioration of the puddle clay linings and the banks, leakage becomes more of a problem. Apart from causing nuisance to adjoining landowners, it can weaken and cause earth support structures to fail and it increases the rate of disfiguration of brick and stone structures. The bridges, attractive though they are, were constructed to support the traffic of the day, and not the present day traffic and farm vehicle loadings. Increasingly, more attention is being directed to the rich environmental and heritage aspects of the canals with consequent changes to management and maintenance practice.

Constraints in the Design and Construction of Works

Often very little is known about the original construction, and this can hamper the planning and construction of repairs, restoration and improvement work. Most of the planned work has to be constructed in the winter months, if prolonged stoppage of pleasure boating and financial damage to hire boat operators is to be avoided. During construction works, it is still necessary to maintain the land drainage role of the canal and possibly the water supply along the canal. Where works are to be undertaken with the canal in water, then care has to be taken to avoid breaching the canal, and to maintain restricted passage for boats where feasible.

Because of the linear nature and often difficult location of canals, ready access to and along the canal may be very restricted. This may result in prolonged negotiations with adjoining landowners to obtain access over their land as well as logistic problems and limitation on size and type of plant. Adequate attention must also be paid to the environmental and historic value of the canals and their structures.

Limehouse Tidal Lock

In 1989 at Limehouse Basin in London, a new high-tec lock was opened, whereby the large ship lock was replaced by a smaller lock designed by British Waterways' staff, which is more suited to leisure craft. The new lock was constructed inside the 90 m by 20 m chamber of the former 120 years old ship lock. The new lock is 30 m long by 8 m wide, consuming one tenth of the water used by its predecessor, and built of concrete walls with the spaces between them and the original lock walls suitably filled.

A problem experienced at Limehouse is a reversal of water level at high tide in the River Thames and it was therefore decided to install sector gates that can withstand water pressure from either side without movement. The sector gates resist the inflow of silt from the river at high tides and they avoid the need for an independent system of levelling sluices. Each gate weighs 20 t, but the operating cycle is automatic, operated solely by one BW member of staff at Limehouse Basin from 8 am to 6 pm daily. The sector gates were developed by Biwater Hydro Power Limited over the years and have been used successfully at other locations on the Thames.

The London Docklands Development Corporation contributed £1.5m to the cost of the lock. Because of its proximity to the River Thames, LDDC considered that it would aid significantly the use of waterborne transport of large volumes of bulky materials during the construction of the Limehouse Link Road in tunnel from Butchers Row under Limehouse Basin, Limekiln Dock and Dundee Wharf to the Isle of Dogs. This form of transport offered both environmental and functional advantages.[52]

Reconstruction of Llangollen Canal

General Characteristics

The Llangollen to Chirk part of the canal system is probably the most attractive of the many canals built in Great Britain during the 18th and 19th centuries. The Pontcysyllte aqueduct, which carries the canal 37 m above the River Dee in a 307 m long continuous structure, is Telford's masterpiece on the canal system. For much of its length in the Vale of Llangollen, the canal, lined with puddle clay, is benched into hill slopes and is founded on glacially derived materials. Major breaches occurred in 1945, 1960, 1982 and 1985. Hence a detailed examination was carried out of the ground conditions, behaviour of groundwater and performance of some of the traditional materials used in the construction of the canal, including the provision of many boreholes and the monitoring of piezometers, inclinometers and V-notch readings. This particular length of canal has a history of deformations, hillside slippages and water issues from the embankment, in a complex geological environment. As a result, this 8320 m length of canal was completely reconstructed over the period 1982 to 1992 at a cost of about £8m.

As a result of these investigations it was concluded that the 1960, 1982 and 1985 breaches were caused by leakages resulting from a combination of unusually steep slopes and the presence of an upper silt layer. The 1945 breach was attributed to a combination of a steep gradient leading to a very close unused railway running parallel to the canal and the high gradient of the groundwater.

Apart from being a popular boating waterway

(4000 return trips annually), the canal is a major conveyer of water. About 45 Ml of water are supplied daily through the canal to the Hurleston Reservoir for drinking water supplies.

Reconstruction Works

In general, canals were built in locations where leakage, although undesirable, was unlikely to cause structural failure and silt deposition was inevitable. Puddle clay in these cases was and continues to be an ideal lining material, particularly where it conforms to the BW standard specification. Dredging must be carried out with care and kept a little shallow to allow siltation to protect the puddle clay. The natural structure of the clay provides flexibility, can be easily repaired and is relatively inexpensive.[53]

Haider[53] has described how for locations where structural failures could be caused by leakage of water, the risks are much greater when using puddle clay as a lining material. Absence of a deposit of silt over the lining further exposes the puddle clay to wear and tear. When the canal is narrow, steering a boat can be difficult and canal users frequently use poles to push the craft forward and may easily puncture the puddled clay in the process. For these reasons, puddle clay was considered unsuitable for the lining in the reconstruction work, and other asphaltic and butyl linings were found unsuitable. The alternative of moving the alignment away from the slopes of the hillside required the promotion of a parliamentary bill and was unacceptable.

Hence a reinforced concrete cross section to BS 8007 with suitable outside drainage, as illustrated in Figure 2.23, was used throughout the reconstruction. Generally the width of the channel was kept to 6 m to allow two boats to pass each other with reasonable tolerances on each side. In some parts, however, it was necessary to reduce the width and to provide passing bays. The rectangular cross section provides a better section for navigation and also for the flow of water, which is significant for water supply purposes. Contraction joints were provided at 7.5 m centres and expansion joints at 30 m centres.[53]

It was considered that a rectangular cross section with straight sides required hand-holds to provide an escape route for people falling into the canal. Stepped cattle escapes were also provided to allow cattle access to and from the canal as many farmers depend on the canal water for their cattle and sheep. Ground cover plants will be grown adjoining the concrete copings to improve the appearance. Opportunity was also taken to straighten the canal bank where possible, thereby increasing the width of the canal in several places.

Haider[53] has described how access for con-

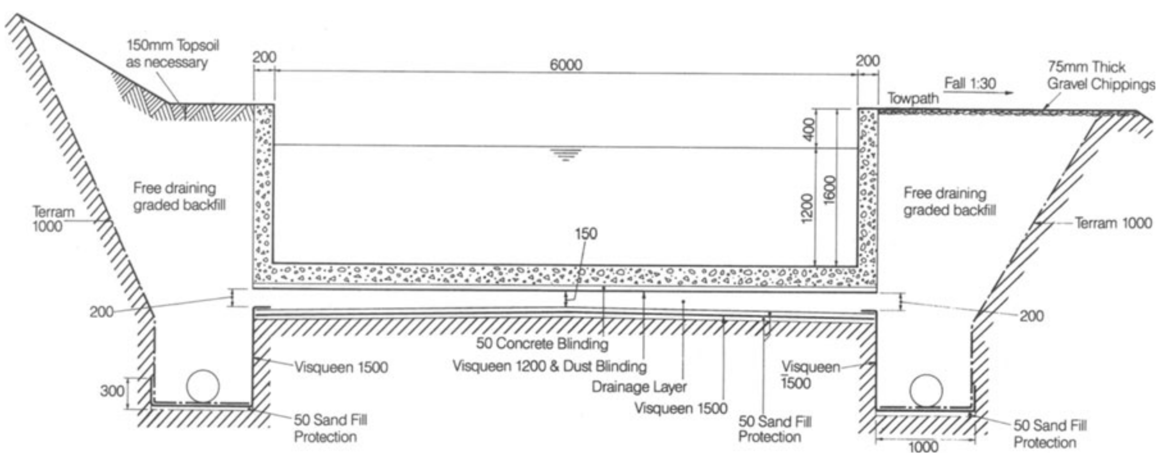


Figure 2.23 *Typical cross section of Llangollen Canal reconstruction (Source: G. Haider[53])*

struction work on a canal site is often an expensive part of the project. Invariably materials have to be handled two or three times. Backfilling material had to be tipped at a central point and then transferred by dumpers to either side.

The transverse and longitudinal drainage system incorporated in the new construction, as shown in Figure 2.23, collects water flows from the upper water table. Continual monitoring has shown that the drainage system is providing the required relief to the perched water table with the water flows corresponding to the rainfall in the area.

Stanley Ferry Aqueduct

General Background

Stanley Ferry Aqueduct is a three span prestressed concrete structure at Stanley Ferry near Wakefield. It carries a canal waterway across the River Calder alongside the original 1839 aqueduct, which comprises a cast iron trough of 50 m span suspended on wrought iron hangers from twin cast iron arches and is a listed structure. Repairs and renovative work were carried out to the original structure in the late 1980s, as it had been subject to progressive corrosion and damage by barges.

To overcome difficulties arising from the flash flooding characteristics of the river, the replacement aqueduct was constructed in the early 1980s in a cofferdam on the southern approach to the canal and then launched across the river on hydraulic supports as one complete unit weighing 2300 t. Cable stays were used to provide temporary support to the aqueduct during the launching.

Aqueduct Design

Cost comparisons were carried out on three alternative designs involving the use of steel, reinforced concrete, and prestressed concrete. Prestressed concrete was chosen as it had a small cost advantage and better long term durabilty. The structure is basically a concrete trough, consisting of a main central span over the River Calder of 42.7 m and cantilever spans of 16.25 m, thus ensuring adequate unobstructed width of river and economy of design by equalising moments.[54]

In the design the structure was treated as a bridge that had to be watertight and resist loads from water and barge impact, as well as self-weight. In addition, special features had to be incorporated to take account of the effect of the river during flood conditions, when in severe cases the river water could rise to the top of the aqueduct walls. Special flood relief valves, as shown in Figure 2.24, were installed on the upstream side of the aqueduct, and these will remain open during the period of any drain down to prevent flotation problems with the trough and overturning of the pier foundations.[54]

A typical cross section of the aqueduct is shown in Figure 2.24 giving details of the post-tensioning tendons, most of which were stressed from both ends prior to the launch. The level of water in the aqueduct was assumed to be to the top of the walls, 600 mm above normal water level to allow for the bow wave effect. Expansion joints were provided at each end of the trough, consisting of a continuous neoprene rubber section, 8 mm thick, nylon reinforced, preformed to the profile of the trough and clamped to the concrete by galvanised steel plates and stainless steel bolts.

Simpson[54] described how timber squat boards were provided at each abutment 250 mm above the bottom of the trough, to control the approach speed of barges and to ensure that any squat impact was transferred to the reinforced concrete abutments. It was anticipated that barges up to 700 t could use the aqueduct with a speed limit of 4 kph, as compared with a normal canal speed of 9.65 kph. The fendering system comprised two continuous rubber sections, 100 mm square, sandwiched between two hardwood timber baulks. Two bridge rails provided the rubbing contact to prevent wear, as shown in Figure 2.24.

The vertical loads of the trough were transmitted on to two piers by four Glacier spherical sliding bearings, protected by a butyl rubber skirt. The cross section of the reinforced concrete piers was 15.4 m by 2.5 m, with the end faces approximately parabolic in shape to

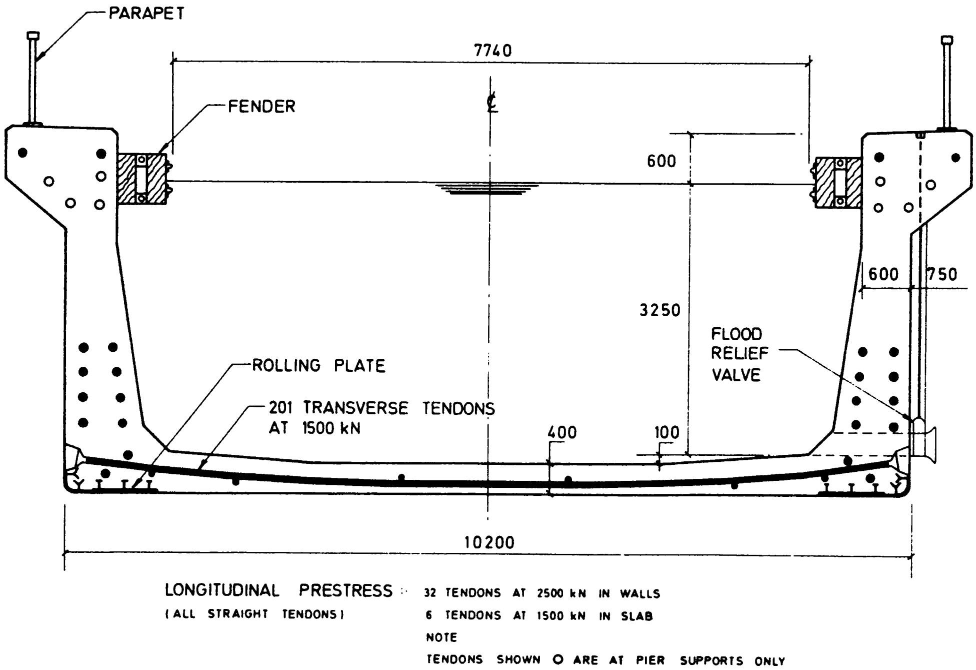


Figure 2.24 *Typical cross section of Stanley Ferry Aqueduct (Source: J. L. Simpson[54])*

reduce the obstruction to the flow in the river. The pier foundations were designed to bear on mudstone and siltstone rock and be constructed within cofferdams. However, the foundation to the south pier was modified during the contract to reinforced concrete bored piles to take advantage of a 2 m thick band of firm sandstone.[54]

Blisworth Tunnel Reconstruction

Modern advanced engineering techniques were used to restore the 180 years old Blisworth Canal tunnel, which was one of the oldest and longest navigable tunnels in Britain and had been closed to the public since 1980 because of its dangerous condition. It is situated on the Grand Union Canal between the villages of Blisworth and Stoke Bruerne, south of Northampton, and approximately half way between London and Birmingham. Engineers using clay bricks made on site built the magnificent tunnel 2.8 km long and 5 m wide and opened it for two-way traffic in 1805. From as early as 1820, major repairs and frequent patching were required, yet it carried extensive water traffic between cities as far apart as London and Manchester for over 150 years.[55]

Dangerous bulges in the brick lining and floor were evidence of the complex geological forces to which the tunnel had been subjected. A comprehensive survey in 1980 confirmed that problems were most serious in the middle third of the tunnel, where it had cut along the junction between clay and sandstone layers. The survey also recorded vital details such as concealed construction shafts and water inflows, with pressure building up on the wet brick lining from the surrounding clay, which expanded when waterlogged.

Early in 1982, finance was allocated to the project and the restoration was completed in August 1984 at a cost of £4.3m. The entire brick lining in the middle third of the tunnel, some 1000 m long, was replaced with precast concrete segments. A specially constructed machine was built into a cylindrical steel shield assembled inside the tunnel. The shield moved along the

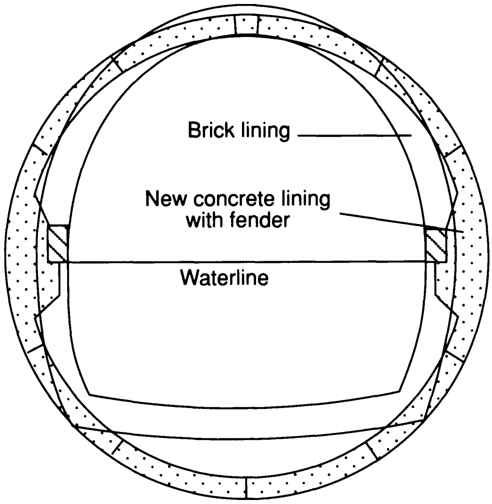


Figure 2.25 *Cross section of work in Blisworth Tunnel (Source: British Waterways Board[55])*

tunnel as work progressed, providing protection to both men and machinery. Brickwork in the adjoining sections had suffered much less deterioration and were repaired and repointed.

The first operation was to dam the northern two thirds of the tunnel, empty it of water and lay a concrete road on the tunnel floor to enable vehicles to reach the central section. The brick extracting machine consisted of an hydraulic excavator mounted within the steel shield, with a cutting edge at the front. A conveyor system moved the old bricks and soil back behind the machinery for loading on to articulated dump trucks. These reversed down the tunnel to unload concrete segments, and drove forwards out of the tunnel when reloading with excavated bricks and waste.

The precast concrete lining segments unloaded in the tunnel were laid flat and fed through to the construction area on the conveyor. There was no space to change their order, neither were they always identical, hence it was vital to load and unload them in order of assembly. The shield formed a working chamber inside which the workforce could put the segmented concrete rings in place, using sophisticated, laser controlled alignment techniques. A cross section showing the work in outline is illustrated in Figure 2.25.

As each ring was completed, the steel shield and its mechanical contents moved forward to prepare for the next ring – not only protecting the workforce but also supporting the tunnel until the new lining was in place. For some metres ahead of the shield, steel arches were erected to support the old brickwork – and then moved down the tunnel as the shield progressed, eventually achieving an advance of some 15 m each day.

Throughout the work, old ventilation shafts and drainage systems were prepared for reconnection. The gap behind the new concrete lining was filled with cement grout. Timber-faced fenders were positioned on each side of the tunnel, as shown in Figure 2.25, to prevent damage to boats and the new lining. On completion of the work, the machinery was dismantled and taken out of the tunnel but the steel shield could not be removed. Finally, the ventilation shafts and drainage systems were reconnected, brick portals at each end of the tunnel renovated, the concrete road and dams removed, and the tunnel flooded ready for use, six months ahead of schedule.[55]

Netherton Canal Tunnel Repairs

General Background

Netherton Tunnel was the last major tunnel to be built and was opened to traffic in 1858 by the Birmingham Canal Navigation Company, to relieve the congested Dudley Tunnel which was carrying over 40 000 boats annually at that time on a one-way system. In 1975, a localised invert heave was evidenced by boats grounding in one section of the tunnel. Side wall convergence and invert heave continued to increase and, as a result, the tunnel was closed to public traffic in 1979. Although monitoring and detailed studies were initiated at the time, no repairs could be undertaken owing to lack of funds. Fortunately, the Board received a grant in 1982 which made it possible to carry out substantial repair work and reopen the tunnel in 1984. Three lengths of invert totalling about 300 m were repaired at a cost of about £1.3m.

The dimensions of the tunnel were impressive: 2777 m long, 8.32 m wide and 7.42 m high, with a waterway width of 4.6 m designed for two-way narrowboat traffic and with towpaths on either side. The thickness of the brick lining varied according to the conditions encountered during tunnelling, and the lower part of the tunnel was provided with a puddle clay lining off which the towpath walls were built. The tunnel was constructed with 17 construction shafts at distances varying from 150 m to 185 m, of which seven were retained for ventilation. Tunnelling was carried out by driving small pilot tunnels at invert level from the shafts and subsequently enlarging these to the full cross section.[56]

Repair Work

A detailed site investigation of the failed section was carried out in 1982, and 30 cored boreholes were drilled to depths ranging from 2 m to 80 m. Standpipe piezometers installed in four of the boreholes indicated stable water levels at about the same elevation as the canal water level. As a result of these investigations, the main problem was considered to be failure of the weak mudstones around the tunnel leading to high compressive stresses in the lining. The relatively flat invert was particularly susceptible to failure under the likely loading.

The new invert was designed to withstand horizontal thrusts of 3 N/mm^2 and upward radial forces of 0.3 N/mm^2. Following dewatering, and during puddle clay and towpath removal, temporary support of the lower side walls was required to produce a pressure comparable with that of the water and fill within the tunnel. Excavation of the failed invert was carried out in short transverse bays at a minimum spacing of two tunnel diameters until specified concrete strengths had been attained.[56]

Haider and Richards[56] described how for practical considerations, a mass concrete invert with a depth to span ratio of 0.10 was chosen. This gave slightly greater curvature than the original invert but did not involve significant excavation below the original invert profile. The new invert was tied into the existing side walls by reinforced concrete footings and the replacement towpaths were provided in mass concrete. A detailed account of the methodology used in the complicated repair process is described and illustrated in the comprehensive paper by Haider and Richards.[56]

Other Examples

It would be pertinent to look at canals in one or two other countries for purposes of comparison. For example, in Bangkok there are over 500 km of canals, termed klongs, in a closely knit network connected to the Chao Phya River which flows through the middle of the city of 5m population. They are principally used by commuters and even school children on long narrow fish tail speedboats, and these also carry fruit and vegetables to residents, to avoid the heavily congested roads. They provide a relatively speedy means of transport, supplemented by converted rice barges.

In Holland, the larger canals carry a considerable amount of freight while the more domestic ones, as in Amsterdam, carry many commuters and sightseers in water buses.

The Channel Tunnel

Introduction

The first scheme for a tunnel linking the UK and France was thought to have been conceived in 1802. Tunnelling was twice commenced in 1882 and in 1974/5, but abandoned on both occasions. In the early 1980s, the two governments commissioned studies to report on the feasibility of constructing a fixed link financed solely by private capital. In 1985, the two governments invited bids for the financing, construction and operation of a fixed link across the Channel without recourse to government funds. As a result Eurotunnel, a partnership between the Anglo-French Tunnel Group (CTG) and France

Manche (FM), was granted the right to build and operate the Tunnel for 55 years from 1987.[57]

The construction contract was signed in 1986 between Eurotunnel and Transmanche-Link (TML) and was anticipated to cost about £4.8b by its completion in June 1993, but by 1990 it was evident that the final cost would be nearer £7.5b. TML is a consortium of ten leading British and French contractors, including Balfour Beatty, Costain, Tarmac, Taylor Woodrow and Wimpey. The construction work was monitored by an independent organisation, the Maitre d'Oeuvre, an Anglo-French joint venture comprising two firms of consulting engineers – W.S. Atkins and Partners and Société d'Etudes Techniques et Economiques (SETEC), with Sir William Halcrow & Partners and Tractebel as sub-consultants. Hence this unique, complex and vast civil engineering project was a joint operation involving many leading British and French companies.

The Channel Tunnel provides an all weather, 24 hours a day, channel link constructed with modern proven engineering techniques and will be free from navigational hazards. It provides combined facilities for both road and rail traffic, new employment opportunities and offers the user the choice of an alternative to sea ferries. It should be able to handle the forecast freight and passenger traffic well into the twentieth century, and should stimulate trade between Britain and mainland Europe.

Transport Facilities

The project aimed to provide a fast, convenient and reliable system joining the road and rail transport networks of Britain, France and the rest of mainland Europe. It comprises twin tunnels, connected to a smaller central service tunnel, each containing a single standard gauge railway track. Two types of train will use the tunnel:

(1) purpose-built Shuttle trains, owned and operated by Eurotunnel carrying passenger and freight road vehicles together with their drivers and passengers

(2) passenger and freight trains operated by European railways using the Tunnel to link the railway networks of Britain, France and continental Europe, with their passage controlled by Eurotunnel.

On opening the nominal capacity of the Tunnel was estimated as 20 train paths per hour in each direction, but with future upgrading of signalling equipment and the introduction of automatic train operation, the capacity is expected to increase to 30 train paths per hour in each direction.

The Railways plan to provide frequent high speed train services between London and Paris and London and Brussels, sleeper trains over longer distances, and through services between cities north of London and in mainland Europe. Direct freight trains will also run between cities in the UK and continental Europe.

While the Shuttles will use the same track as through trains, their loading gauge will prevent them travelling on British and European railways (see Figure 2.26). Each terminal incorporates a 'return-loop' so that Shuttles do not need to reverse, and the loops will be multi-tracked to permit maintenance.[57]

At both terminals new road connections are being provided to give direct access to and from motorways. Vehicles driving off the motorway will pass through Tunnel toll booths and then undergo the necessary frontier formalities of the two countries.

A normal passenger Shuttle consists of two 'rakes' each of 13 carrier wagons, with a loading wagon at one end and an unloading wagon at the other, coupled with electric locomotives. Double deck wagons carry cars and vans less than 1.85 m high, while single deck wagons carry vehicles up to 4.2 m high. A 'rake' of double deck wagons can carry up to 120 standard size cars, while a 'rake' of single deck wagons can carry 65 cars. Each freight Shuttle has 25 carrier wagons with a loading and unloading wagon, marshalled between electric locomotives. Each wagon is designed to carry one commercial vehicle with a maximum weight of 44 tonnes.[57]

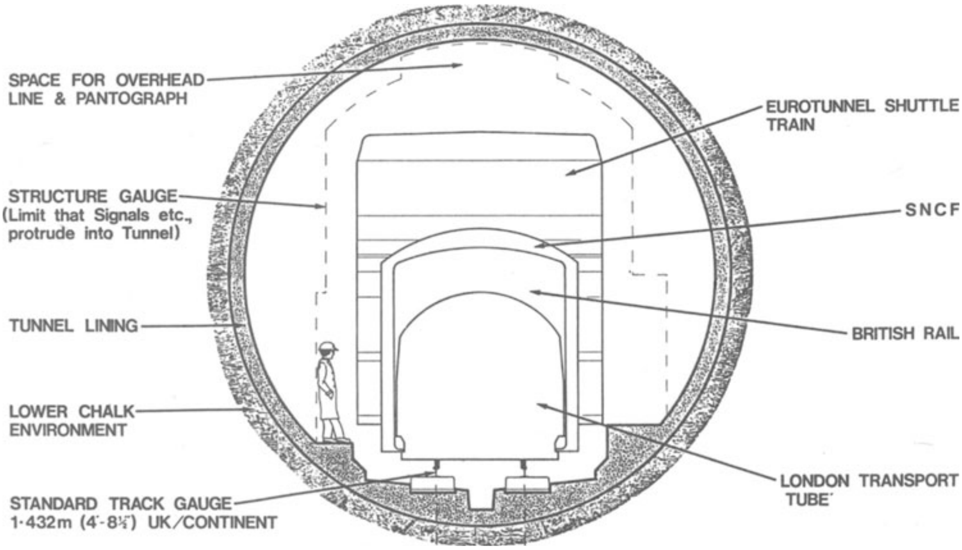


Figure 2.26 *The Channel Tunnel Project: comparison of loading gauges (Source: Eurotunnel)*

There are Tunnel control centres at both British and French Terminals and traction power will be supplied from the Terminals.

The Tunnel System

Main features The rail link is provided by two 7.6 m diameter tunnels with their portals near Folkestone in the UK and Sangatte in France. Each tunnel is approximately 50 km long, of which 38 km is under the seabed. The centres of the running tunnels are 30 m apart and a 4.8 m diameter service tunnel runs centrally between them. All three tunnels are interconnected for operational and safety reasons. Transverse passages 3.3 m in diameter connect the rail tunnels with the service tunnel at 375 m intervals, thus ensuring that any Shuttle stopping in a tunnel is adjacent to at least two cross passages for passengers having to disembark. In addition, there are 2 m diameter piston-effect relief ducts between the running tunnels at 250 m intervals, allowing the pressure pulse in front of a train to dissipate to reduce aerodynamic drag. The general arrangement is shown in Figure 2.27.

At two points along the tunnel length there are crossover chambers, to allow trains to transfer between running tunnels as for example when maintenance is being carried out.

Most of the tunnel is located in favourable Chalk Marl at a depth of approximately 100 m below sea level, giving a normal thickness of rock above the tunnels of 40 m, reducing to about 17 m near the French coast.

Construction The tunnels were driven from both sides of the Channel simultaneously, using six tunnel boring machines on the UK side and five on the French side. The central service tunnel was bored first, to act as a pilot tunnel and to allow investigation and confirmation of ground conditions, before boring the running tunnels.[57]

On the UK side tunnels were excavated by 14 m long TBMs of the open face type but with the facility for closing down the face should the need arise. Shield advancement was achieved by the use of hydraulic rams and gripper pads acting on the surrounding ground or by jacking off the completed lining. The critical operation was the speed of lining erection rather than cutting rates, coupled with component reliability. The Markham machine, assembled at the Chesterfield works, made extensive use of computerised

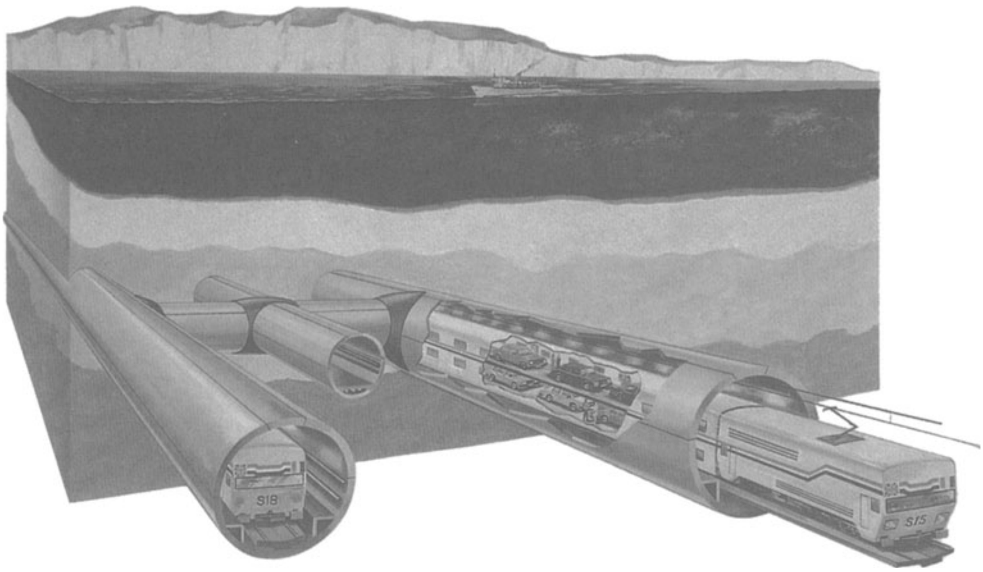


Figure 2.27 *Channel Tunnel: arrangement of main components (Source: Eurotunnel)*

control with nine separate computers carrying out and recording 300 checks ranging from oil pressure monitoring to advising on the speed of conveyors.[58]

Figure 2.28 shows a TBM in action in the tunnel with 20 rams located behind the 2 m deep cutting head. Normal cutting was achieved by some 160 single and double acting picks arranged on a star shaped eight arm head, with the spoil falling directly on to a conveyor. The TBM incorporated two lines of defence against flooding and tail shutters could be extended to cover the 1.50 m wide exposed ring of chalk prior to the lining erection.[58]

On the UK side, primary and secondary conveyors attached to the TBMs loaded trains of muck skips hauled by electric locomotives, as illustrated in Figure 2.29. This figure also shows the assembled concrete lining in a running tunnel. The trains travelled to an underground chamber at the foot of Shakespeare Cliff, where the spoil was discharged into transfer bunkers. From these

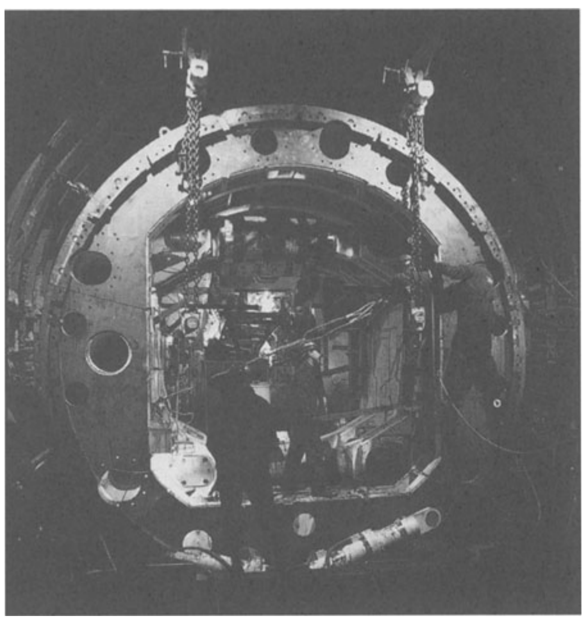


Figure 2.28 *Channel Tunnel, tunnel boring machine in action (Source: Sir W. Halcrow & Partners)*

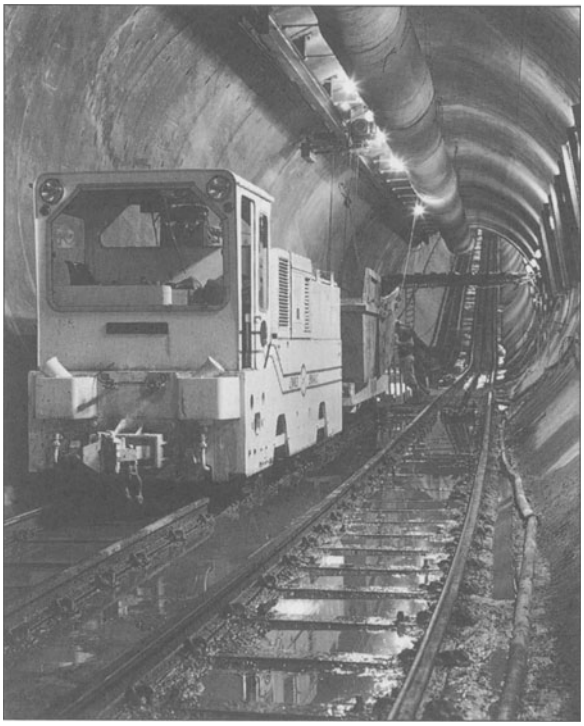


Figure 2.29 *Channel Tunnel, electric locomotive hauling muck skips in tunnel (Source: Sir W. Halcrow & Partners)*

bunkers, the spoil was carried to the surface by inclined conveyor and the bulk of it deposited in the reclamation area behind the new sea wall, as shown in Plate 5, which also illustrates vividly the night working in progress on this 24 hours per day contract. Some spoil from the landward tunnels was used in the terminal area.[57]

Tunnel linings consisted mainly of precast concrete segments produced in dedicated precasting yards at the Isle of Grain in the UK and Sangatte in France. Where difficult ground conditions were encountered and at junctions for crossovers, ductile iron bolted lining sections were used. Within the tunnels both concrete and iron lining sections were taken to the faces by special rail wagons and then passed through the TBMs by conveyor and erected mechanically. The segmental rings of reinforced concrete were of the expanded type with wedge shaped key segments. Pads separated the outer faces of the segments from the surrounding ground to form a 20 mm annulus which was subsequently grouted. The cast iron rings had machined faces butting together, while the concrete segments relied on neoprene gaskets recessed into the joint faces, and all suitably grouted externally to ensure watertightness.[57]

Figure 2.30 shows a typical cross section through a running tunnel looking into the normal direction of travel. The concrete walkway has a minimum width of 800 mm and is 650 mm above rail level. These walkways can be used for the evacuation of passengers in an emergency and for the inspection of trains' running gear. A second lower inspection walkway was incorporated on the other side. The 1435 mm standard gauge track was laid with continuous welded rail secured to concrete slab track or discrete sleepers by resilient steel fastenings to a design speed of 200 kph.

Also shown in Figure 2.30 are the railway safety systems to detect hot wheels or axleboxes and equipment dragging below a train. To the side of the tunnel are the leaky feeder and UHF aerial for direct train-to-control and personnel-to-control communications and emergency telephones. The tunnels and cross passages are equipped with both normal and emergency lighting. Ventilation of the running tunnels is achieved by maintaining the air pressure in the service tunnel at a higher level, and this is vented into the running tunnels through adjustable grilles with non-returnable dampers in the doors providing access from the running tunnels to the cross passages. An additional ventilation system can provide air directly to the running tunnels under emergency conditions. Fire fighting equipment in the tunnels is supplied from a freshwater main in the service tunnel, capable of supplying four nozzles simultaneously at any location, supported by portable extinguishers. During construction, innovative water fog sprays were incorporated into the safety arrangements along with the extensive use of fire resistant materials at considerable additional cost. The system is supplied with sophisticated signalling, communications and control arrangements which are aptly described in *The Channel Tunnel: A Technical Description*[57], from which much of the data in this section has been obtained with the

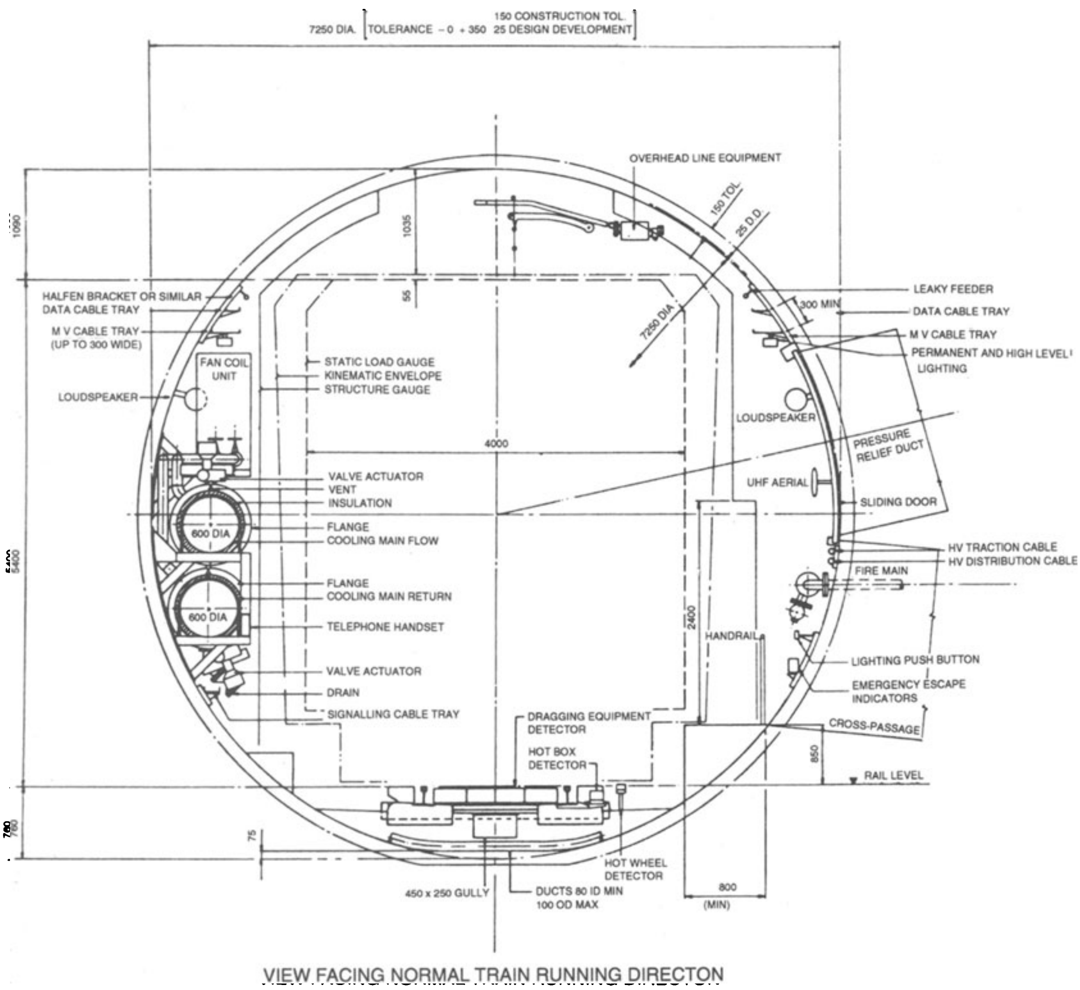


Figure 2.30 *Channel Tunnel: running tunnel cross section (Source: TML)*

kind permission of Eurotunnel.

Terminals The UK terminal, occupying 140 ha, is sited at Folkestone adjoining the M20 motorway and the Folkestone-London main railway line. Dedicated slip-roads are provided between the terminal and the M20 and there are suitable rail connections and new sidings. To minimise environmental impact, the road and rail networks are routed along the M20 corridor, and the area landscaped and planted to merge with the surrounding countryside as far as practicable. The Shuttle rail loop tracks taking in-bound Shuttles from the Tunnel portal to the loading platforms run in a 1 km long cut-and-cover tunnel. The terminal layout is based on the principle of 'free exit' traffic flow and is well provided with terminal facilities and adequate access control.[57]

Tunnel Problems As with any civil engineering scheme of this magnitude and complexity, problems were almost inevitable, and the Channel Tunnel was no exception. The major problem centred around the escalating cost of the scheme and major disputes between Eurotunnel and TML in 1989/90. The seriousness of the situation is evidenced by the need for Eurotunnel and TML to hold 54 meetings in the last three months of 1989 and the reluctance of the 22 instructing banks and the other 186 consortium members to fund Eurotunnel's estimated additional costs amounting to about £1.5b, over and above the extra £1b already provided by the sponsors.

There were three main areas of cost:

(1) The lump sum cost for fitting out the tunnels with power, ventilation equipment, railway track and signalling. The two parties agreed on a basic cost but in 1989/90 TML claimed an additional £300–400m from Eurotunnel for cost overruns resulting from the higher specification required by both governments and Eurotunnel's commercial department.

(2) TML were paid a fee for procurement items for designing and ordering large items of equipment such as the Shuttle trains and Eurotunnel wanted TML to reduce the fee.

(3) The target price works covered the cost of excavating the tunnels and the associated civil engineering work and this was the main area of dispute. The two parties originally agreed to share the costs up to a 6% cost overrun. Beyond this 6% figure Eurotunnel was to pay for everything and, with costs soaring out of control, the two parties were unable to agree whether the final figure should be £1.5b or £2.1b. Eurotunnel wanted to put a cap on its liability.

In early 1990 it was necessary to reach agreement to prevent the project coming to a halt. For example the lump sum works were then estimated at £1860m as against the original figure of £1140m and this was referred to arbitration. On the tunnels, the contractor agreed to meet 30% of the price of cost overruns over a revised target of £1580m at 1985 prices, with no limit being put on the amount. TML's fee on procurement costs was capped at £60m, which meant that with the costs of rolling stock and other equipment doubling to £600m, the estimated maximum fee was £60m as against the £73m which could have been earned previously.

It was agreed that the contractor could earn a £20m bonus if the tunnel opened on schedule but would pay a £20m penalty if the deadline was passed. Cost savings totalling some £100m were identified, largely by reducing the speed of shuttle trains from 160 kph to 120 kph. Over £100m was also saved by rolling stock design changes and from signalling and track costs. For example, heavy goods vehicles will be carried on open carriages instead of in enclosed trains as previously proposed. Eurotunnel also agreed to cut project supervision costs by 25% and was looking to TML to make substantial savings under this head. All in all many difficult decisions had to be made and some compromises implemented.

Thus in 1990 some estimates suggested that TML could only make a maximum profit of around £250m which, split ten ways between the consortium's members does not amount to much over a five year construction period for such a risky and high profile project. Furthermore, any prestige associated with the project has probably been largely offset by the involvement in acrimonious disputes.

Some questioned the dangers of accidents and even sabotage within the tunnel itself and still seemed less than convinced about the adeqacy of the safety measures incorporated in the scheme. Additionally two explosives experts believed that the tunnel could conceivably be fractured by explosives from the seabed.[59] In 1990, the continual passage of cooling water through the tunnel was considered necessary to dissipate the heat generated by passing trains and Eurotunnel were requested by the Channel Tunnel Safety Authority to incorporate additional safety measures to make the tunnel more resilient to earthquakes.

Airports

Forecasting Airport Needs

Halcrow[60] has described aptly how the dominant factor in air transport is explosive and continuing growth, which was highlighted in 1990 when Singapore International Airlines (SIA) placed an order for 50 new aircraft, while Quantas Airways was spending A$4.7b to almost double its fleet between 1990 and 1993. In 1988, the world's airports handled over 1000m passengers and this figure could conceivably double by year 2000. The larger airlines were also seizing the initiative to increase their share of the market and extend the range of their services, such as SIA linking up with Swissair and Delta Airlines (US) and British Airways (BA) with Japan Airline (JAL).

The growth of air travel offers great opportunities for those airports ready and able to grasp them, of which Changi Airport, Singapore, described later in the chapter, is a prime example. The growth also raises problems, not only for airport owners and managers, but for airlines, local communities and governments. The means of solving the capacity problem include a wide range of options. In a small number of cases, building completely new airports will offer the best long term solution. Elsewhere, runways, aprons, terminal facilities and surface access systems will need to be expanded and upgraded.

In some situations, Halcrow[60] identified the desirability of STOLports close to city centres or short runways alongside full length runways. For other airports, new or improved operating techniques will allow better use of existing facilities.

Only with a thorough appreciation of the market overall, of the airline structure seeking to serve that market, of the characteristics of the aircraft which are to be used, of the national and international regulatory frameworks within which such services are to be provided and of the environmental constraints likely to be imposed, can airport planning meet the needs of future travellers.[60]

As stated by BAA, British Airport Services,[61] planning an air transportation system fit for the 21st century, or even developing an existing one, is a highly complex operation. With the substantial scale of investment involved it is vital to know exactly when the new capacity will be needed, where it should be located, who will use it and whether it will be financially viable. The Roskill Commission's Report on the third London airport using cost benefit analysis techniques to cost all the intangibles relating to the four sites and arriving at total figures in excess of £4m, with the cheapest site at Cublington only 5% less than the most expensive at Foulness, and then deciding many years later to proceed with Stansted, serves to highlight some of the difficulties involved.

A key element in transport planning is the ability to produce accurate traffic forecasts. Equally important is the ability to do so consistently so that management can make major investment decisions using those forecasts with confidence. Such confidence was demonstrated by BAA during the construction of Gatwick's North Terminal in the early 1980s. Despite the worldwide recession, BAA had faith in its predictions and continued with a major construction programme even though traffic was declining. Management were confident that the downturn would be short-lived and the additional terminal capacity, produced on a long construction programme, was ready when the traffic upturn came in the latter part of the decade.[61]

However, in the late 1980s the UK was entering a more demanding era in air transport with a projected annual growth rate of 5 to 8% in passenger numbers, and the three extended London airports could conceivably reach saturation point by 1994. Admittedly, it was announced in 1990 that it was intended to upgrade Terminal 1, following the refurbishment of Terminal 3, and to subsequently provide a new Terminal 5 at Heathrow Airport, but a decision was awaited with regard to the building of two new runways at one of the three London airports to avoid a crisis occurring before the end of the 20th century. It has been estimated that air traffic worldwide will double between 1990 and 2005, despite the 1990/92 recession.

Selection of Airport Sites

An airport comprises a wide range of facilities from the road and rail access arrangements, and the passenger and cargo terminal facilities through to the aircraft taxiways and runways. There are also numerous support functions that have to be catered for and these include aircraft and vehicle maintenance, emergency services, flight catering, bonded stores and apron and office accommodation. Case studies of four recently constructed airport projects at Heathrow, Gatwick, Stansted and Changi, Singapore detailing and comparing the main elements are included in this chapter.

The principal factors to be considered in the selection of an airport site are as follows:

(1) Passenger catchment area – to serve a populous area and often on outskirts of a major city, with normal travelling time to airport ideally limited to 45 minutes for regional airports.
(2) Availability of land and its cost – a major international airport may require 5000 ha with 450 ha sufficient for a modest regional airport. Highly priced land should be avoided if at all possible.
(3) Accessibility for both passengers and freight with good communications.
(4) Social and environmental factors – minimise nuisance from noise and provide adequate landscaping.
(5) Economic and financial appraisal – need for full feasibility study.
(6) Airspace – ensure in-flight safety, avoiding interference with traffic from adjacent airports.
(7) Topography – relatively flat site with effective natural drainage.
(8) Obstructions to aircraft operations – free from towers, tall buildings, mountain ranges and excessive bird hazards.
(9) Meteorology – acceptable visibility and cloud base height, with freedom from fog, smoke, snow or glare.
(10) Design and layout of airport – avoid making major departures from desired layout and design to fit a particular site.
(11) Engineering factors – suitable ground conditions and runways of adequate length and oriented so that aircraft may land at least 95% of the time without exceeding the allowable crosswinds.
(12) Utility services – accessible and adequate capacity water, sewerage, gas, electrical and telephone services.
(13) Co-ordination with other airports – where more than one airport is required to serve a metropolitan area.[62]

Airfield Pavement Design in the United Kingdom

The Property Services Agency (Civil Engineering Services)[63] has described how the design of an airfield pavement requires realistic methods of assessing the loading characteristics of aircraft and the structural response of the pavement. The severity of load-induced stresses in a pavement and subgrade depends on the gross weights of the aircraft and the configuration, spacing and tyre pressures of their undercarriage wheels. The response of the pavement in resisting these stresses depends on its thickness, composition, the properties of the materials used and the strength of the subgrade.

These basic concepts have been further developed and extended to include the effects of fatigue, environmental factors, mixed traffic and overload operations. Furthermore, major developments in aircraft designs have required a continuing review of existing pavement designs.

The Department of the Environment's previous guide in 1971[64] introduced the concept of Load Classification Groups (LCG) which categorised the Load Classification Numbers (LCN) into seven groups, thereby simplifying the design and evaluation of pavements. Although the LCG system was included in the 1977 edition of the International Civil Aviation Organisation (ICAO) *Aerodrome Design Manual*[65] as one of the recommended methods for reporting pavement strength, it did not become popular outside the Department of the Environment.

The 1989 Guide[63] superseded all design and evaluation documents previously published by the Department of the Environment. It is considerably enlarged in comparison with its predecessor and includes guidance on the subgrade, material specification, construction practice, aircraft use, overload operations and design methods for stopways and shoulders. An extensive section has also been incorporated on pavement evaluation and strengthening.

The major change is the adoption of the ICAO Aircraft Classification Number – Pavement Classification Number (ACN-PCN) method as the classification system linked to the design and evaluation methods. The flexible pavement design model used in the Guide is still based on the CBR method[66], but by using Equivalency Factors account can now be taken of the improved pavement performance given by cement and bitumen bound base courses.

Airfield Pavement Maintenance

Airfield pavement maintenance has assumed greater importance and become more sophisticated resulting from the larger and heavier aircraft now in service. For example, with flexible pavements as constructed at Changi Airport, Singapore, there are many types of pavement distress, encompassing ruts, corrugations, depressions, alligator cracks, block cracks, bleeding, oil spillage, swelling, rubber deposition, jet blast, potholes, water seepage, ponding and sunken airfield lighting. It is usual to carry out a daily inspection with a thorough inspection on foot twice monthly, with reports being prepared and remedial action taken. The most common repair is to apply a tack coat of bitumen emulsion, followed by a coat of asphaltic concrete laid at a temperature of 135–160°C with a paver with sensor shoes on both ends and then rolled.

Heathrow Airport Terminal 4

General background Planning Terminal 4 at Heathrow commenced in 1973 and four years later the British Airports Authority (BAA) submitted a planning application to the Greater London Council for a site on the south side of the airport. After a public inquiry and further Government deliberation BAA received clearance subject to obtaining detailed planning approval from the three local authorities concerned. It took a further eighteen months to reach agreement with these authorities on the major environmental issues of noise, appearance of the building, road traffic and related matters.[67]

Additional terminal capacity was required to accommodate the increasing number of passengers generated by the introduction of wider bodied aircraft. Plate 6 gives an aerial view of Heathrow with Terminal 4 and its road access in the foreground and the remaining terminals and runways in the background. The Terminal became operational in 1986 and the total cost was £200m.

Following the opening of Terminal 4, all British long-haul flights were transferred from Terminal 3 and some other long-haul carriers moved to Terminal 1. This created space in Terminal 3 and provided the opportunity to undertake a major redevelopment and refurbishment programme costing £73m between 1987 and 1990. This resulted in the provision of modern and much improved facilities for passengers, with an two-thirds increase in floor area, and an impressive external facelift.[68]

In assessing capacity, BAA uses a measure known as the 'busy hour rate' (BHR), defined as the hourly rate at or below which 95% of the traffic in a year passes through the terminal and equates to about the hundredth busiest hour. With the addition of Terminal 4 with an annual capacity of 8 million passengers, the total capacity of Heathrow was increased to 38 million. However, the Government's consultation document *Airport Strategy for Great Britain part I* states 'that apart from the provision of Terminal 4 within the southern boundary, a terminal complex handling 15 million passengers could be constructed on the Perry Oaks site'. This would be Terminal 5 and is supported by British Airways.

Contractual Arrangements Terminal 4 was a unique project in many ways having regard to its size and complexity, but also being built under the largest management contract in Europe. It was completed on time, within budget and to the required quality within 49 months, following the appointment of Taylor Woodrow Construction Ltd as management contractors with responsibility for planning, programming, procuring and supervising the work. The Terminal construction work was divided into some 80 major works packages and 200 smaller ones, ranging in value from £15m down to £50 000.

BAA believed that traditional forms of contract were not viable and that management contracting, which is becoming increasingly popular in Britain, offered the best approach. It involves the client paying fees to a contractor who agrees to oversee construction on the client's behalf, subletting all the works to other contractors. The client can take full advantage of the contractor's expertise and it is possible to overlap design with construction, thus compressing the overall contract period. The management contractor promotes the buildability of the project and closely controls and monitors the work of all subcontractors. Over 40 000 drawings and revisions were generated during the project and these were monitored by a computer controlled drawing registry.

Thus the management contracting route provides the necessary flexible approach in controlling a large multi-discipline project, where many problems can be expected to arise which have the effect of slowing down the original planned activities. If the traditional contracting route had been followed then the client could have been faced with considerable prolongation claims and/or acceleration costs and, quite possibly, would not have achieved the required completion date. The client also employed a project manager to coordinate the work of the various professionals and to generally safeguard his interests.

Design The project was conceived around certain key functional elements which are now listed:

(1) Total airside segregation of departing and arriving passengers.
(2) Ability to connect the maximum number of terminal served stands.
(3) Creation of a flexible airside concourse, 650 m by 25 m, serving as a combined lounge, circulation, shopping, catering and boarding area, being a major departure from the normal enclosed gate rooms in which passengers wait prior to boarding their aircraft.
(4) Maximum economy in operation through centralised controls.

Simplicity of design and speed of construction were the two vital elements in the design of the Terminal. The arrivals concourse is at the lowest level with baggage handling and customs. Offices and landside catering together with incoming immigration controls are housed on the intermediate levels, while the upper levels are devoted to departing passengers with the landside concourse, security and immigration controls, airside shops and catering. Departing and arriving passengers follow separate routes at different levels through the building, and there are sophisticated baggage handling arrangements.

The design incorporates lightweight demountable aluminium panelling both inside and out, while the external system is based on a repeated module of glazing and panelling providing a highly efficient acoustic and thermal performance. The rectangular steel structure was selected for speed of construction and to house the horizontal services between ceilings and upper floors. The majority of elements were self-finished and produced off-site.

The essentially silver rectangular exterior is softened with a mansard roof, while the silver theme is reflected on interior panelling. The roof design for the airside concourse provides natural light through an angled glazed section running the length of the concourse. This is balanced by stainless steel ducting for services, which provides a high-tech, space-age effect, together with contrasting terracotta coloured structural roofing.

There are 18 aircraft stands immediately accessible from the concourse, all of them large enough to take wide-bodied jets and eight capable of accommodating the stretched Boeing 747s. Five more stands are a short distance from the terminal, making 23 stands in all.

However, British Airways found it necessary to spend £14m to meet the airline's own requirements, together with de-icing and nitrogen storage facilities and motor transport depots because of the relative remoteness of Terminal 4 from central airport facilities. The airline also considered the provision of special lounge areas inadequate and the demand for these facilities is on the increase. Many of the difficulties could have been overcome had BAA known which airlines were to occupy the terminal at the planning stage. In the event the Authority did not receive this information until 1985, following three years of consultation.

As whole life costing is now assuming greater importance among civil engineers, it is apposite to consider the depreciation periods selected by BAA for the main airport components which are as follows:

terminal buildings: 30 years, probably with a major refurbishment during their lives
runways, taxiways and aprons: 40 years
airport plant and equipment, including runway lighting: 15–25 years
motor vehicles and office equipment: 4–8 years
furniture and fittings: 5 years.[69]

Structure The structural steel bay sizes are 10.8 m by between 7.2 and 18.0 m. Over the departures and airside concourses, the roof is supported on 2.6 m deep welded tubular trusses up to 42 m long. The steel frame to the building, designed by Scott Wilson Kirkpatrick & Partners, was given the 1985 European design award for steel structures by the European Convention for Constructional Steelwork. Floors are constructed of concrete on permanent steel soffit shuttering, which had the advantage of providing a clear space below throughout the construction sequence, and are covered with terrazzo tiles or carpet.[70]

The external envelope consists basically of a curtain wall system supported at each floor level and tied back to the roof trusses, and consists of extruded mullions and transomes which are silver anodised. It was designed to accept double glazed units and heavy duty acoustic and thermal panels. The main roofs are of concrete on 'Holorib' permanent decking, covered with precast concrete slabs, extruded polystyrene insulating boards and two coats of mastic asphalt.[70]

Mechanical Engineering Services are extensive and consist of ventilation (20 km of ductwork), air conditioning, heating, fire protection, domestic services and associated central boiler (14 250 kW) and refrigeration plant (9500 kW) for the terminal building, multi-storey car park and the airside passenger vehicle station. Mechanical engineering equipment includes the baggage handling systems, conveyors (2000 m departures baggage and 500 m passengers), 29 lifts, 15 escalators, and 17 aircraft loading bridges.

Electrical and Electronic Equipment is provided in abundance in Terminal 4. Apart from the more common main power supply and general lighting, there is the public address system, aircraft fixed ground power, car park control equipment, fire alarms, flight information systems and telephone network. There are 600 m of cable tunnels and nearly 3 km of suspended access walkways to allow maintenance of the building and services without interfering with passengers.

Civil Engineering Works cover a wide range of facilities from underground railway , noise barriers and landscaping to roads, car parks, aircraft taxiways, aprons, and foul and surface water drainage.

A six km single loop links Heathrow Central and Hatton Cross Piccadilly line underground stations via Terminal 4's own station. It was driven by the Thyssen-Taywood joint venture with the tunnelling completed in 15 months, thereby becoming the fastest driven tunnel on the London underground network.

Noise barriers, 1.3 km in total length and 7 m high were erected in the form of precast concrete walls consisting of four horizontal units with a chevron profile to give an out of plane surface to dissipate reflected noise. The units span between precast concrete triangular buttresses at 6.5 m centres between which there is an area of ground for planting to relieve the landside expanse of wall elevation. The exposed aggregate finish was obtained by using a retard and wash off process. They cost £1.2m and were awarded a commendation in the 1985 Concrete Society Awards.

Drainage The built up and paved areas

covered nearly 0.5 million m^2 and an additional 1.8 m diameter sewer was required to take the run off. The tunnel sections were pipe jacked using a full face tunnelling machine and intermediate jacking points in the 150 m long drive under rivers. The flood effects of a 1 in 2 year and 1 in 5 year storm were allowed for in the design. The surface water is collected either in continuous *in situ* reinforced concrete box gutters or proprietary galvanised steel slot drains, discharging through parallel carriers to the main outfall balancing pond. A new 300 mm diameter foul sewer was constructed to connect the new terminal complex to the existing outfall sewer.[70]

Groundwater exclusion The new finished ground levels and construction excavation levels were generally below maximum groundwater level. To exclude groundwater during construction and from the permanent works a continuous cut-off wall was built around the main terminal building, the service yards, the short term car parks and the underground railway station. Where the cut-off wall was required to also act as a retaining or load bearing wall, it was a conventional reinforced concrete diaphragm wall, but elsewhere it was either a lightly reinforced concrete diaphragm wall or a semi-rigid bentonite-cement-gravel cut-off. A subsoil drainage system was constructed of porous drains laid within either the natural gravel or in a replacement layer of graded gravel 300 mm thick.[70]

Roads A gyratory road system in front of the terminal allows movements between the departures and arrivals forecourts and provides direct access to and from the A30 trunk road and, via the airport road system, the M25 and M4 motorways. The road layout incorporates a grade separated quarter clove leaf at the A30 junction and an elevated roundabout with slip roads to the southern perimeter road. A three span reinforced concrete bridge with suspended centre span of pre-tensioned precast U-beams crosses the A30 dual carriageway trunk road. The supporting piers are founded on 600 mm diameter bored piles and the skeletal abutments are carried down to the gravel founding layer. The original south perimeter road was improved to link with the M25 spur west of the airport.

Car Parks A multi-storey car park with 1150 spaces is approached from the departures forecourt. Additionally, new surface car parks provide 1800 spaces for passenger long term parking and 800 spaces for staff. The construction incorporates the technique of *in situ* cement stabilisation of the natural gravels to provide a base for the asphalt parking areas and the concrete circulatory roads.

Taxiways and Aprons The aircraft pavements were designed in-house by BAA's Engineering Department. Some 150 000 m^2 of taxiways and 170 000 m^2 of aprons were constructed of plain slab, unreinforced, undowelled, pavement quality concrete (PQC). The pavement was designed for unlimited use by LCGII (Load Classification Group) aircraft and resulted in a 350 mm depth of PQC laid on a 150 mm lean concrete base course supported on a finished formation having a modulus of subgrade reaction (K30) of 80 $MN/m^2/m$.[70]

Joints were formed in the concrete to create 5.25 m square bays, expansion joints being provided generally at 60–80 m centres dependent upon any incorporated ancillary feature. All joints were sealed with elastomeric sealants resistant to aircraft fuels and oils.[70]

Prefabricated steel louvred blast deflection screens, 2.9 m high, were provided at the ends of each cul-de-sac to protect vehicles and pedestrians from direct jet blast. Proprietary cellular precast concrete paving blocks capable of supporting vegetation in entrapped topsoil have also been used as protection against blast erosion from manoeuvring aircraft.[70]

Other Works Service ducts are either 90 mm or 150 mm clay ducts laid with a concrete surround. Fuel mains consisted of 450, 500 and 600 mm steel pipes serving two 150 mm risers on each aircraft stand.

Landscaping Landscaping was considered to be very important and consisted primarily of strategically located grassed banks and some 60 000 shrubs and trees to provide a natural noise barrier and improve the environment.

Gatwick Airport, North Terminal

General Background Gatwick's North Terminal was opened in 1988 in the latest stage of what is now the second busiest international airport in the world, exceeded only by Heathrow. British Airports Authority (BAA) invested over £200m in the North Terminal and its support buildings, services and infrastructure. Gatwick's role is to remain a single runway airport supported by two passenger terminals and other facilities capable of ultimately handling up to 25m passengers and 500 000 tonnes of cargo annually.

Principal design aspects Gatwick has a total area of 760 ha which is adequate for all its foreseeable requirements, but is small compared to many airports, and resulted in the compact design of the North Terminal. Another major element in design was that of flexibility, both to allow reorganisation of North Terminal's internal layout to meet short term demands and to enable the building to expand to its longer term capacity of 9m passengers annually.[71]

The terminal building is of three storeys to economise in the use of land and to provide maximum passenger convenience. The piers to the aircraft are grouped around the terminal for the same reasons, while further saving in land was achieved through the provision of an elevated road to the departures level and the rapid transit system linking the North Terminal with the South Terminal and Gatwick's main line railway station, the latter being described later in the chapter.

Main building features The building contains a very strong prefabricated steel skeleton which allowed very large public areas and an extremely adaptable layout and speedy erection. Externally about 75% of the exposed area of the main building is covered with dark blue vitreous enamel prefabricated panels, in contrast to the silver finish of Heathrow, backed by honeycombed aluminium and mineral wool to give good sound and thermal insulation. The remaining 25% consists of either silver aluminium louvres or smoked glass. The terminal is lit by these glass panels and through skylights. The main aircraft piers are clad in aluminium panels, painted contrasting silver, and the rapid transit station and the nodes of the aircraft stands are clad in dark blue enamelled panels.[71]

Partition walls based on the grid of steel columns can be moved quickly and easily to meet changing requirements. In addition to the steel columns there are four reinforced concrete cores carrying services. There is a concealed basement road running under the centre of the building, for use by supply vehicles that feed their loads up through the two main service cores. Hidden above the ceilings on each main level is a complete network of walkways giving access for maintenance. The internal finishings and facilities for passengers are of a very high standard.[71]

Aircraft stands. Aircraft stands are equipped with advanced Azimuth Guidance Nose-In Systems (AGNIS) and Parallax Assisted Parking Aids (PAPA), in addition to fuel and power ground hydrants. Seven stands were equipped in the first phase of development, which together cater for eleven of the largest aircraft at a time.[71]

Road access Passengers travelling by car reach the departures concourse via the elevated roadway, while incoming passengers pass to road transport at ground level. Access roads lead road passengers directly from the A23 and the spur of the M23 motorway. There is a short term multi-storey car park connected to the terminal, with a capacity of 1200 cars, and there are 3000 long-stay car parking spaces, with a further 1600 spaces available for employees. A second multi-storey car park is planned for the later stage of development of the terminal, increasing the number of long term parking spaces to 6700.[71]

Transit link between terminals As this civil engineering component is unusual and embraces some novel features, it was decided to give a brief description of the construction. It comprises two fully automatic three-vehicle trains running on a dual elevated trackway over a length of about 1.25 km. The vehicles complete each journey in 2 minutes, reach a maximum speed of 42 kph, can each carry a peak load of 375 passengers and their luggage and have adequate capacity for future needs. Following detailed evaluation of all available options, a Westinghouse system employing conventional rubber tyred wheels and electric traction was selected.

Macleod and Harding[72] have described how each vehicle is supported by two bogies which incorporate the traction, braking, suspension and guidance assemblies. Each bogie contains an automotive type axle with differential gearing and dual pneumatic tyres which run on the concrete running surface of the trackway, which gives good structural performance and a high rate of level tolerance. Four foam filled lateral guide tyres are rigidly mounted on each bogie so that they hold the web of the central guide beam as shown in Figure 2.31.

The vehicle receives three-phase AC power at a nominal 600 V from a power rail mounted above the guide beam. Power is collected by pick-up shoes and fed to two series DC motors, one mounted on each bogie. The automatic control system is divided into three functions: automatic train protection (ATP), automatic train operation (ATO) and line supervisory control (LSC). [72]

The superstructure consists of a simply supported span of 22 m incorporating steel beams with a composite concrete running surface, supported on contractor-designed *in situ* concrete auger bored piles with pile caps, which in turn supported portal columns comprising reinforced concrete columns and beams. The spans were formed by using two 914 × 305 UB rolled sections

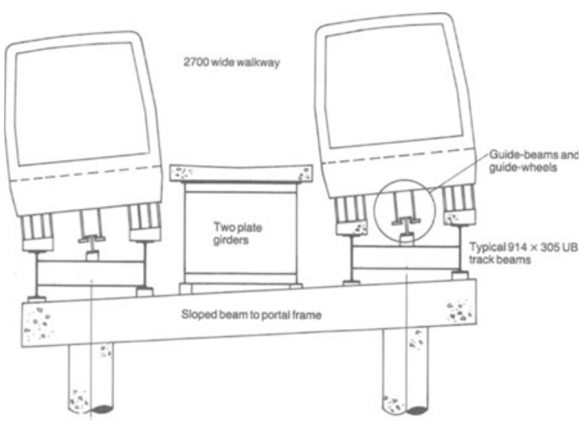


Figure 2.31 *Gatwick Airport, transit link between terminals: cross section of track (Source: D. J. Macleod & C. G. Harding[72])*

spaced 2.03 m apart with a 610 × 200 mm concrete running surface cast compositively on the top flange. Cross diaphragms with structural tee bracings were fitted between the track beams to give lateral stability. The vehicle guide beam was fitted centrally to the trackway and welded to each diaphragm.[72]

A central walkway runs continuously between the two tracks and provides an emergency passenger escape route at vehicle floor level and a service corridor for power and communication. The walkway is formed of 150 mm precast units spanning between 1.96 m deep plate girders and topped with a 100 mm *in situ* air-entrained concrete pedestrian way.[72]

Stansted Airport

General introduction Stansted Airport was planned as the third London international airport with an ultimate design capacity of 15m passengers per annum (pax) and the first phase was opened in 1991 and will cater for 8m passengers per annum by 1996. It was selected for study being the latest large airport constructed in the United Kingdom, and differs from the terminals described at Heathrow and Gatwick with all passengers on the same floor. It also permits an examination of the construction of an unconventional hangar with CUBIC Space Frame, environmental aspects, runways, modern developments in the treatment of deicing water, new rail access and transit system.

Terminal building The brief called for a design which would be economical, provide optimum passenger comfort and convenience, allow internal flexibility for future modifications with the minimum of disruption and be intrusive in the generally rural landscape.[73]

All public facilities are provided on a single concourse floor with arrivals and departures facilities planned side by side, producing a compact building thereby reducing walking distances for passengers, enabling them to move through the building on essentially linear routes. The terminal was also designed with full integration of all transport links, with all landside vehicles at the same level as the main concourse and the British Rail station located below the forecourt in the undercroft as illustrated in Figure 2.32. Lifts, escalators and ramps bring passengers from the railway station, coach station and car parks, directly up to the concourse level.[73]

In addition to accommodating the British Rail station, the undercroft houses the baggage handling systems, engineering plant for the building, vehicle servicing area and associated storage. There are no engineering services at roof level in the terminal, thus permitting the roof to be of simple form, free of mechanical plant housings or equipment.[73]

The structural columns at concourse level are positioned on a 36 m square grid, to satisfy the functional requirements of the terminal and the need to provide maximum flexibility of layout at passenger floor level. The supports for the roof comprise clusters of four interconnected tubular steel columns. The roof consists of lattice shell domes which obviate the need for dominant roof trusses or beams. Furthermore, all distribution equipment for heating, ventilation, air conditioning and lighting serving the concourse is contained within the steel columns.[73]

To provide ample opportunity for future alterations and modifications, all enclosed passenger facilities at concourse level, such as shops, banks, kitchens, left luggage, lavatories and medical facilities, were designed as free-standing demountable enclosures, 3.5 m high, and served by independent environmental engineering systems located in the undercroft.[73]

Internally natural light for the concourse is provided by both glazed cladding and rooflights in the lattice domes. After dark, the concourse is lit indirectly by light reflected from the internal surface of the roof, providing a gentle glow when viewed from the outside. The same indirect lighting system is used to illuminate the landside passenger set down area in the forecourt and transit track stations, as shown in Figure 2.33. Externally, deep canopies provide sun shading and serve to eliminate strong reflections in the glass walls, making them transparent rather than reflective.[73]

The building has a heat recovery air conditioning system. This uses heat generated inside the building, by lights, equipment and people, to offset heat loss through the walls and roof, which are insulated to very high standards.[73]

Unique jumbo hangar The 27 m high, unconventionally shaped hangar/aircraft maintenance facility for Qualitair Aviation Ltd included the latest and largest application in 1989 of the CUBIC Space Frame and provided a novel approach to hangar design. The design was so exceptional that it obtained the supreme award in the British Construction Industry Awards Scheme for 1989, the main objective of which is to recognise excellence in the engineering design of building and civil engineering works. It was described by the judges as 'engineering of the highest standard'.

On plan the hangar is diamond shaped with two equilateral triangles of 98 m placed side by side to give a maximum clear span of 170 m, sufficient to fully accommodate two Boeing 747, 400 series jumbo jets, including their tail fins which are usually left uncovered. Aircraft enter through two electrically operated steel doors, 72 m wide by 21 m high, and stand nose to nose

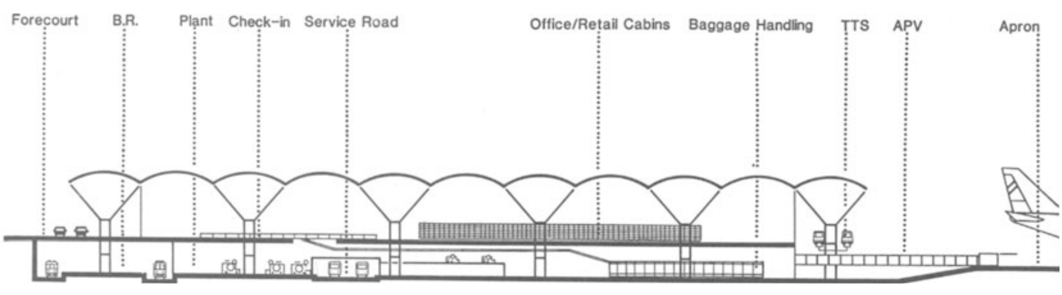


Figure 2.32 *Stansted Airport: north-south section through terminal (Source: BAA[73])*

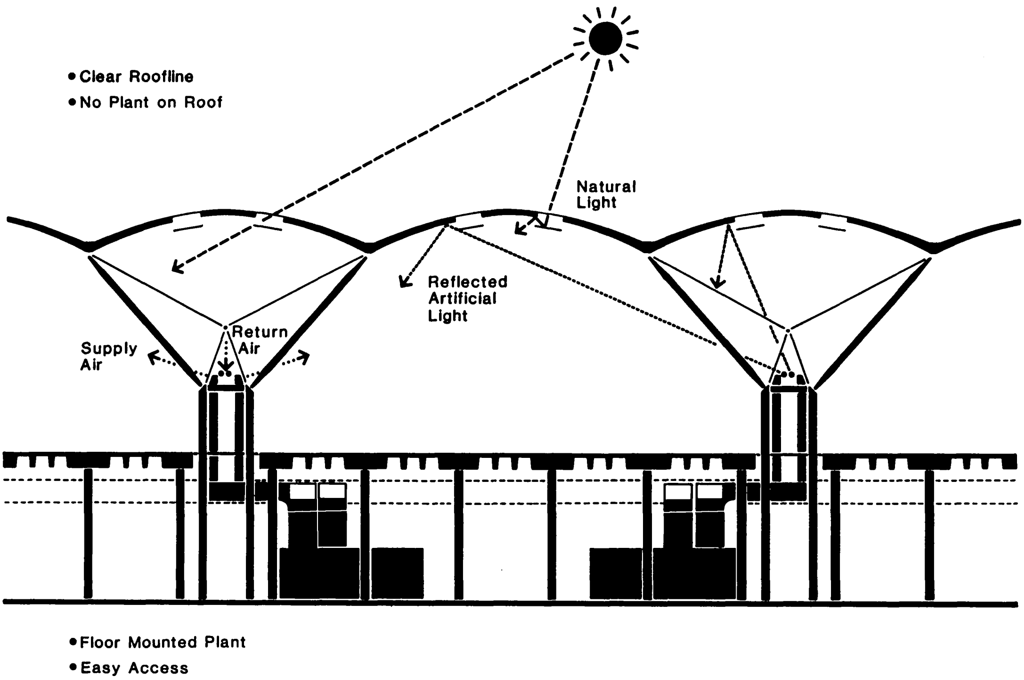


Figure 2.33 *Stansted Airport: air conditioning and lighting of terminal (Source: BAA[73])*

at 60°, thereby saving considerable space over a conventional rectangular hangar. The hangar roof is designed to support two 30 tonne radial overhead travelling cranes for aircraft maintenance, each with a lifting capacity of 3.5 tonnes.[74]

There are 950 tonnes of structural steelwork in the roof consisting of 1200 fabricated steel CUBIC Space Frame modules which are each 4 m high by 3.5 m by 2 m and weighing between 0.5 and 1 t. The roof void is free from obstructing diagonals and can be used to house plant rooms, services or even office accommodation. The roof is drained with a two way camber and was approximately 2 m less in depth than the alternative structural types which were investigated. Fixed based stanchions in each of the four corners of the hangar transfer wind forces from the roof to foundations. The CUBIC Space Frame is a proprietary structural system invented by M.L. Kubik of Nottingham Polytechnic and developed in conjunction with Dr L.A. Kubik of Burkes Green and Partners, Consultants of Newark.[74]

Environmental aspects The environmental implications of the development were thoroughly researched at the outset of the design programme. Extensive ecological survey work and visual impact studies were undertaken by independent consultants. As a result, extensive new planting was carried out around the development, much of which was well established when the airport was opened in 1991. Extensive groundshaping also took place to help reconcile the new civil engineering works with the adjoining landscape, and this applied particularly to the new access roads and balancing ponds. Steep cuttings and embankments were replaced wherever possible by more smoothly contoured landforms.[75]

Runways BAA, British Airports Services kindly supplied basic information on the design and construction of runways on their airports, which is very informative. It has been included under Stansted as the studies of Heathrow and Gatwick were confined to the latest terminals.

The length of a runway depends on a number of factors such as the type of aircraft, payload, required range and cost. In general, they vary between approximately 1200 and 3600 m. The standard width is 45 m, but provision may be made for extension to 60 m in the future to accommodate larger aircraft.

The construction of a typical rigid runway is as follows:

400 mm pavement quality concrete laid as a single slab with no dowels
300 mm dry lean concrete
300 mm granular sub base

This would be suitable for high frequency use by critical aircraft (over 250 000 coverage during the design life of 30 years) on a low strength subgrade. The design is based on achieving a flexural strength for pavement quality concrete of 4.5 MN/m^2 at 28 days.

Treatment of deicing waste The capacity of Stansted Airport will increase from the original 0.5m to 8m passengers per annum by 1996. The large resultant increases in apron and taxiway areas and aircraft movements will give rise to large amounts of deicing chemicals being used, and regulatory bodies have identified this factor as a cause for serious concern, as the stream receiving drainage from the runway, taxiways and new terminal complex comprises parts of the headwaters of a river which is used for potable water abstraction. Hence the control and treatment of glycol based materials is being exercised, as these currently constitute the bulk of the de- and anti-icing chemicals.[76]

British Airport Services[76] have described how in the past airport surface water drainage design teams have worked to two main criteria:

(1) to prevent flooding of operational areas
(2) to provide measures to control the rate of runoff so that the often relatively small receiving watercourses did not become overloaded and flood.

These systems have proved efficient in removing water from airfields but do not permit the ready separation of contaminated from uncontaminated flows, which was considered a necessity at Stansted because of the restrictions on discharge quality.

This third design constraint has been satisfied by providing three separate drainage systems, two of which will carry glycol contamination, while the third remains essentially clean. The three subcatchments are:

(1) urban areas – roads, car parks and landside areas (uncontaminated waste)
(2) aprons – cargo and passenger terminal stands (contaminated waste)
(3) runways and taxiways (contaminated waste).

Each of the subcatchments drain to a common automated flow splitting chamber, diverting contaminated flows to a storage pond and permitting the free discharge to the river of non-contaminated flows, after flood prevention storage and oil removal. A dedicated pumping main conveys glycol waste from the on-airport storage area to a drainage authority treatment plant, where adequate aeration capacity has been provided. Stansted is the first airport in the UK to undertake the separation and treatment of glycols.[76]

It is interesting to note that a new range of chemicals based on aqueous acetate solution and manufactured by BP may be used in the future. First indications are that this substitution will not affect the treatment processes and will have the advantage of reducing organic loading.

Access A substantial new dual carriageway network provides good road access from the M11 Motorway. In addition a new rail line has been provided to link with the London to Cambridge main line.

The new rail link provided some challenges because of the need to avoid previous construction works and to conceal the route from adjoining villages in the flat Essex countryside. Over one third of the 5.4 km spur is tunnelled to carry the track under the Stansted runway and an underbridge had to be constructed through the embankment to the M11. In addition, environmental factors resulted in the construction of one of the largest retaining walls in the UK to conceal the new airport terminal together with its built-in basement railway station and approach track. The cost of the project was £30m.[77]

Rapid transit system An innovative rapid transit system has been provided at Stansted, similar to the one described for Gatwick. It carries passengers in just over two minutes from the new terminal building to the satellite departure points, and has the capacity to carry

8m passengers per annum but can readily be expanded to 15m. It consists of twin concrete parallel tracks, partially elevated and the remainder in tunnel.

The elevated section consists of a 1.8 m deep precast concrete trough supported by cantilevered concrete portals at 18 m intervals, with 1.4 to 1.7 m deep crossheads, carried by 1.05 m diameter columns 3 m apart founded on conventional pad foundations. The running tracks and guide beams are positioned inside the trough which also has a central precast concrete walkway.[78]

The twin box section tunnel, 13 m wide by 5.5 m high, was constructed by the cut and cover method using watertight reinforced concrete. The outer walls, floor and roof are 400 mm thick and the central dividing wall is 300 mm thick. The tunnels have been built without a waterproof membrane and rely entirely on the impervious nature of the concrete. Only at the movement joints was additional waterproofing provided.[78]

However, because it is the most northerly system of its kind in the world, the above ground section is equipped with a special heating cable. Other innovative features include a sophisticated smoke extraction scheme for the tunnels. There are interconnecting doors at 50 m intervals between the tunnels to aid the evacuation of passengers in the event of fire. The smoke will then be drawn out of the affected tunnel while fresh air is pumped into the other. All the cables in the tunnel are halogen free so that, in the event of overheating, they will not emit smoke.[78]

Changi Airport, Singapore

Main airport facilities Changi Airport is situated on the eastern part of the Island Republic of Singapore covering some 1663 ha of land, half of which has been reclaimed from the sea. The site was chosen because it was well removed from centres of high density population. The approaches to the airport are over the sea to reduce the noise and air pollution over populated areas. It was selected for detailed study as it is one of the most modern, attractive and efficient airports in the world, situated in a most progressive country.

As with most large airports, development of the airport was undertaken in phases. Phase I covering the Passenger Terminal Building I, one runway, 45 aircraft parking places, the control tower, road access, car parking facilities, cargo and maintenance complex and the large SIA hangar, was completed and became operative in 1981. While phase II incorporating the second runway and 23 additional aircraft parking places was completed in 1984 and phase IIA comprising Passenger Terminal Building II and two multi-storey car parks was completed in 1990, expanding the capacity of the airport to 14m passengers per annum.[79]

An aerial view of the airport showing the runways, taxiways, terminal buildings and cargo and maintenance complex is provided in Plate 7, by courtesy of Singapore Public Works Department, Airport Development Division (Civil Engineering).

In 1990 a conceptual plan was in an embryo stage for a further phase in the development of the airport to provide for a forecast throughput of 60m passengers per annum by the year 2010. This future development was to be built on land to be reclaimed from the sea to the north of the present site and would replace all existing development. This proposal would permit all aircraft to fly in and out of the airport over the sea at all hours without causing any annoyance to residents of Singapore. It is likely that it would be built on the cluster pattern as used in O'Hare International Airport, Chicago[80], as illustrated in Figure 2.34, as this gives a more compact layout with facility for duplication.

Access to the airport The airport is linked to the central business district and commercial area by the East Coast Parkway built on land reclaimed from the sea along the south eastern coast. The 20 km distance can be covered in approximately 20 minutes. A second expressway (Pan Island Expressway) joins the first at a grade separated interchange some 2 km from the airport and links the airport to a large section of the remainder of the island. Shortly before entering

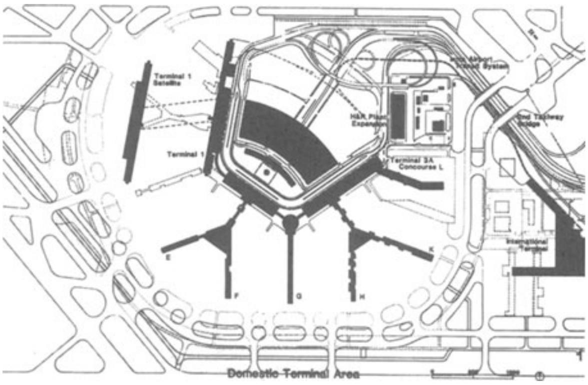


Figure 2.34 *O'Hare International Airport, Chicago: layout plan (Source: M. Suloway & J. M. Stevenson[80])*

the main airport complex, the expressway has a branch running along the eastern boundary of the airport for use by cargo traffic. Hence congestion in the terminal area is eased by the removal of the heavier and slower moving cargo carrying vehicles.

To the north, the airport is accessible from the sea and a jetty has been provided for the delivery of aviation fuel with a direct pipeline connection between the fuel tanker and the fuel farm. Space is also reserved for a future connection of the mass rapid transit (MRT) system to the centre of the airport.

Runways, taxiways and aprons The airport master plan, as illustrated in Figure 2.35,[81] provided for two parallel runways and these have been constructed with a general N–NE orientation and a 1643 m separation, catering for simultaneous aircraft operations on both runways. The first runway (02L–20R) was completed in 1981 with a total length of 4000 m and width of 60 m with a 3 m wide shoulder on each side. In 1984, the second runway (02R–20L) was completed of the same width and 3355 m long. High speed exit to the 30 m wide taxiways is possible at four points on each runway with an additional two perpendicular exits at each end of the runways which also serve as holding areas.[79]

Together the two runways can accommodate up to 80 aircraft movements an hour. The northern half of runway I was a former 2000 m long military runway which was widened from 45 m to 60 m and strengthened to cater for heavier aircraft. Pavements for both runways are of the flexible type consisting of a 750 mm thick granite stone basecourse supported on a prepared earth subgrade compacted to 98% modified AASHTO maximum dry density. A 150 mm thick asphalt concrete surface overlies the basecourse. This type of pavement construction was used as there is an abundance of granite in the region.[79]

Taxiways totalling 17.3 km in length link the two runways with the aprons, cargo complex,

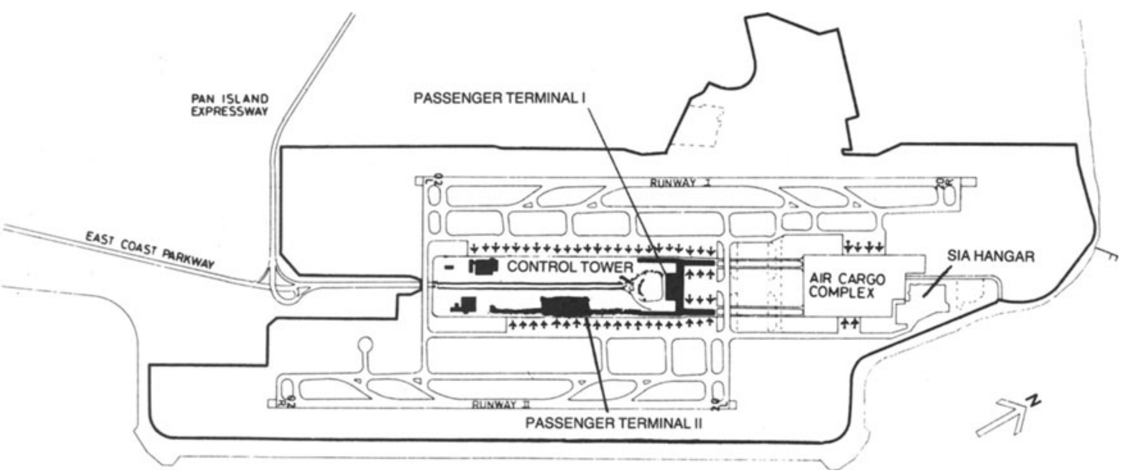


Figure 2.35 *Changi Airport, Singapore: master plan layout 1986 (Source: Singapore Public Works Department)*

hangar and each other. Two cross-taxiways link the two airfield systems and also the eastern and western aircraft parking aprons thereby increasing the capacity of both runways. Taxiways are also of flexible pavement construction and are 30 m wide with a 3 m shoulder on each side, except at turnings where they widen to 35 m.

Aprons or *aircraft parking bays* totalled 68 in all in 1990, and included 3 in the maintenance area, 6 at the cargo complex and 59 passenger aircraft bays. Apron pavements are constructed of a 360 mm thick concrete slab on a 150 mm thick concrete base slab. The top slab is of pavement quality concrete (PQC) with a minimum 28 days working flexural strength of 4.15 MN/m^2, which is understandably lower than the 4.50 MN/m^2 adopted for runways on the larger UK airports but in the middle of the range prescribed in the PSA publication *A Guide to Airfield Pavement Design and Evaluation*[63]. The bottom slab had to maintain a minimum flexural strength of 2.5 MN/m^2. The concrete was laid by slip forming in 6 m lanes and subdivided into 6 m × 6 m panels with premoulded self expanding cork as joint sealer material.[79]

Passenger terminal buildings These were planned on the basis of simplicity of layout, flexibility in operation and maximum convenience for the passengers, which is assisted by bringing the aircraft as close as possible to the Passenger Terminal Buildings. Terminal Building I was system built using precast concrete units with a floor area of approximately 220 000 m^2 and can handle up to 10m passenger movements annually. The main concourse is a five storey block, 204 m by 120 m with a basement, connected to two parallel fingers each approximately 580 m long and having a total of 22 fixed gates. The facilities for passengers are of an extremely high standard with exceptionally spacious, comfortable and well designed and finished accommodation.

The Passenger Terminal Building II was completed in 1990 and is shown under construction in Figure 2.36, which provides a clear indication

Figure 2.36 *Changi Airport, Singapore, passenger terminal building II under construction (Source: Singapore PWD Airport Devepment Division)*

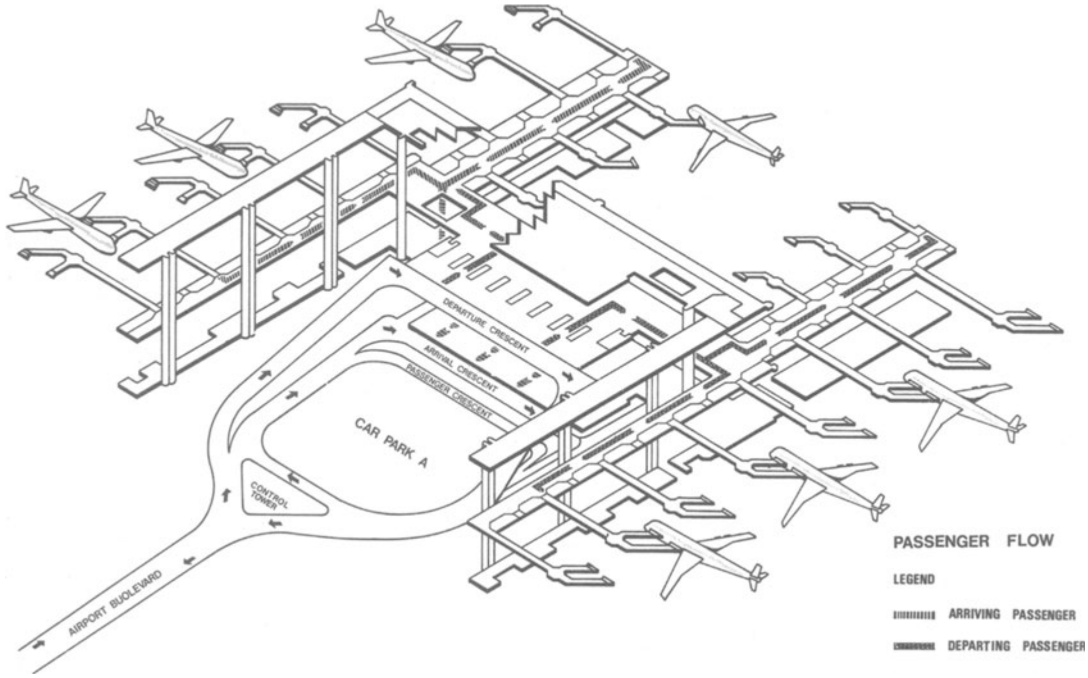


Figure 2.37 *Changi Airport, Singapore Terminal Building I: passenger flow (Source: Chua Hua Meng[82])*

of its large size, being 300 m long and having 30% greater floor area than terminal building I. The departure and arrival halls are duplicated, and baggage is conveyed by rail in tunnel under the terminal building. The building is constructed of *in situ* concrete and aluminium cladding with a high standard of finishes as, for example, the columns clad in Italian marble. There is a monorail connecting the two terminals and two multi-storey car parks adjoining the latest terminal. It is provided with extensive travellators and landscaping.[81]

Passenger flow pattern The passenger flow pattern in terminal building I is well illustrated in Figure 2.37,[82] which shows clearly the separate arrangements for arriving and departing passengers, and their easy access to and from all types of transport. City-line buses are accommodated in the basement bus station from which passengers can proceed by moving sidewalks or lifts to departure level. There are ample flight information boards, TV monitors, public address system and an excellent central waiting lounge for use by passengers prior to proceeding to finger pier holdrooms by moving sidewalks. There are well designed arrangements for arriving and transfer and transit passengers and a well tried and tested baggage handling system.

Air traffic control tower This tower located at the centre of the airport rises to 78 m high and is probably the most impressive feature of the airport, and closes the vista when approaching the airport along Airport Boulevard very effectively. It consists of a three-tiered cabin, a cylindrical shaft and a low rise building encircling the base. The low rise building accommodates all the supporting facilities for the operation of the air traffic control tower. A fountain pool and landscaped garden further enhance this attractive structure.

In the core of the reinforced concrete cylindrical octagonal shaped shaft of 7 m diameter, constructed using the slip form and heavy lift up technique, are the staircase, service ducts and lifts. A column of windows runs longitudinally down the sides to provide natural lighting for the core. Supported on the slender shaft is a polygonal glass structure of sealed insulated double glazing with a white bubble fibre glass dome on the top. The sixteen sided glass and reinforced concrete structure weighed 1350 t, was assembled at ground level and raised by a 95 m crane. It contains three floors, with the control cabin on the top floor, the equipment room in the middle and the emergency operations room on the lower floor, as illustrated in figure 2.38.[83] The whole structure is a remarkable feat of engineering.

Taxiway and vehicular bridges Another prominent landmark at the airport is the Taxiway Bridge which spans the commencement of Airport Boulevard on the approach to the airport, together with adjacent twin vehicular bridges, which together form a gateway to the airport. The taxiway bridge supports part of the southern cross taxiway, one of three taxiways linking the two runways. It has a clear height of 5 m above the road and is 143 m long by 50 m wide. The bridge was built and designed with full consideration given to aesthetic, cost and loading aspects (up to 682 t). The bridge has six spans supported on tied arch piers and with a box girder section deck.[79]

Soil improvement under pavements Large sections of the runways, taxiways and apron pavement are built over soft marine clay which required treatment to accelerate the settlement before the overlying pavement was constructed. The compressible clay strata was usually located from 2 to 4 m below proposed subgrade level and varied in thickness from 2 to 30 m. Because of the heavy aircraft loads, it was essential that post construction settlement was eliminated. Hence costly improvement works had to be undertaken and the following methods were used.

(1) complete replacement of soft marine clay up to 4 m deep from ground level
(2) consolidation by precompression or surcharging using the weight of earth
(3) installation of vertical sand drains together with earth surcharge to provide effective and shorter drainage paths for the relief of pore water pressure in the marine clay strata

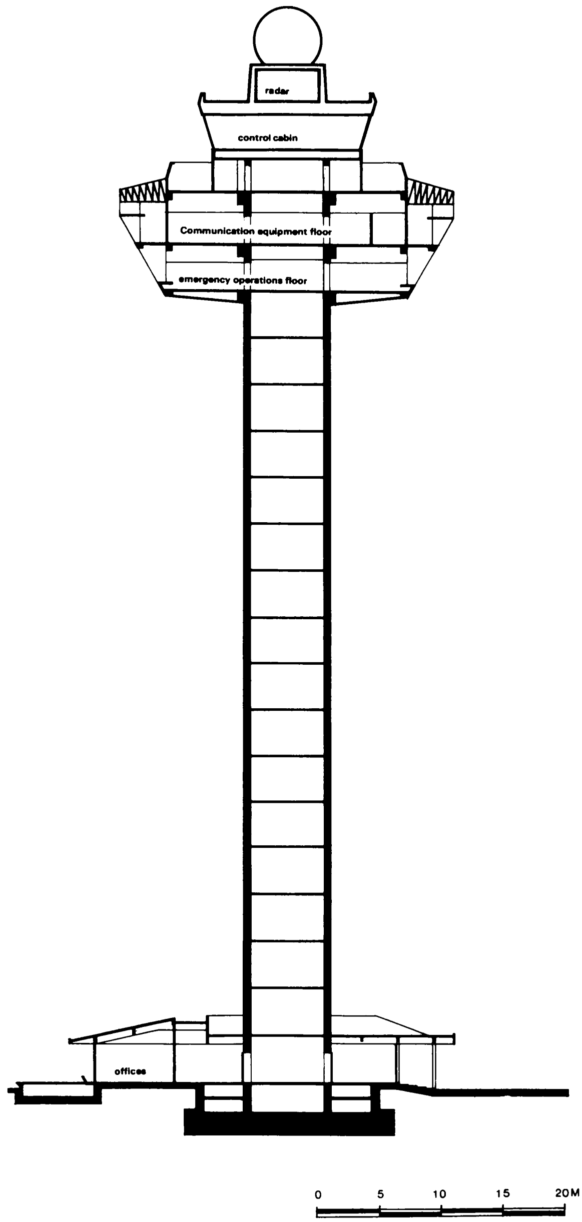


Figure 2.38 *Changi Airport, Singapore: section through control tower (Source: Journal of the Singapore Institute of Architects[83])*

(4) installation of band drains where, instead of sand, bands made of synthetic material together with earth surcharge were used
(5) dynamic consolidation involving the use of a heavy weight dropped from a height to compress the soft marine clay below the subgrade.[79]

Reservoirs Two reservoirs are situated at the northern and southern most ends of the airport, to which all the main drains within the airport complex are chanelled. Hence rainwater can be collected for reuse in building airconditioning cooling systems, industrial usage and fire fighting. The northern reservoir has a water depth of 2.8 m and storage capacity of 80 000 m^3, while the southern reservoir has a depth of 4.1 m and a capacity of 320 000 m^3.

Road system and car parks within the airport complex A comprehensive network of internal service roads and public approach roads link the various facilities located throughout the airport complex. Ample parking spaces have been provided for private cars, goods vehicles and service vehicles at the various centres of activity. For example, fronting passenger terminal building I are two landscaped public car parks accommodating 1741 cars. Additional parking facilities are provided for coaches, taxis, rental cars and cars of airport employees, and there is a VIP car park and two multi-storey car parks associated with passenger terminal building II.

The main approach road to the terminal buildings, known as Airport Boulevard, is 1.6 km long with dual carriageways each of three lanes. The road is well landscaped and the 11 m wide central reservation is lined with blue juniper trees interspersed with colourful shrubs. The Cargo Approach Road is a four lane two-way single carriageway, 8.2 km long, to carry the slower moving cargo vehicles and it also serves the newly created beach.[79]

SIA hangar This giant hangar for Singapore International Airlines (SIA) is worthy of study as when completed in 1982 it was the world's largest span column-free hangar, 218 m long, 92 m wide and 25 m clear height. The main aim was to provide maximum flexibility in the disposition of aircraft being serviced and to cater for engineering needs well into the 1990s. It is possible to accommodate three B747s at one time, but alternatively there is space for four DC10s or six B727s.

Lim Boon Liang[84] describes how in practice, the hangar is divided into three main bays. One bay is used for heavy maintenance of B747 aircraft with a comprehensive docking system, while the other two bays are used for the servicing of other aircraft types, such as the DC10, B727 and Airbus A300B4, using a combination of fixed and mobile docks. To supplement the aircraft docks, one 10 tonne travelling hoist and two teleplatforms were installed on the underside of the hangar roof.

The hangar roof comprised a tubular diagrid space frame weighing over 2500 t and was prefabricated on Batam Island (Indonesia) in four sections, which were then transported to Changi by barge one at a time, unloaded and towed into the hangar area by an 'aero-go' system. The system employed compressed air to lift the space frame unit so that a frictionless air film was created between the unit and the temporary steel plated roadway to permit towing from point to point. The assembled roof was then hoisted into position in a single lift by means of jacks and cables at 12 lifting points.

The support of such a large and heavy roof structure without columns called for walls of great strength on the three enclosed sides of the hangar building. These three walls comprised a U-shaped nine storey annex building, part of which houses the corporate headquarters of the SIA Group. The annex structure was designed to support the weight of the hangar roof at ten points by means of heavy steel box beams that cantilevered beyond the ninth floor, with loads transmitted through bridge bearings to the support columns within the annex structure. During the lifting of the roof, special sliding bearings and hydraulic jacks enabled the beams to move in a lateral plane so that the roof could be precisely aligned and bolted to the supports. The total site area of the hangar complex is 58 000 m^2. Of this area, the hangar itself occupies 20 000 m^2 and the ground floor of the annex building some 14 500 m^2, while most of the remaining area of

23 500 m^2 is devoted to an aircraft parking apron.[83]

Mechanical and electrical systems Sophisticated mechanical systems include passenger loading bridges; baggage handling facilities; moving sidewalks, escalators and lifts; aircraft fuelling system facilities; and air conditioning. The very extensive electrical power and telecommunication systems incorporate:

(1) airport electrification network consisting of high voltage switchgear cubicles, cables, power transformers and standby generators
(2) electrical installations in the passenger terminal buildings consisting of lighting and standby generator
(3) airfield lighting system consisting of lighting configuration, cabling, taxiway guidance system, control gear and standby power system
(4) parking apron floodlighting
(5) apron approach road lighting
(6) car park lighting
(7) security fence lighting
(8) telecommunication system.

Cost of development It is interesting to analyse the costs of the main components and to see their interrelationship.

Changi Airport – Cost of Government Projects

	Component	Phase I (S$m)	Phase II (S$m)	Total (S$m)
1)	Land reclamation	242.90	150.50	393.40
2)	Runway	110.00	157.90	267.90
3)	Aircraft parking aprons	122.50	69.30	191.80
4)	Roads, car parks and drainage	38.00	56.20	94.20
5)	Passenger terminal building	299.80	500.00	799.80
6)	Multi-storey car parks	—	50.00	50.00
7)	Airport ancillary buildings	66.50	5.80	72.30
8)	Utility services	21.10	-	21.10
9)	Navigational aids/ communications	67.70	15.70	83.40
	Totals	968.50	1005.40	1973.90
				(approx. £600m)

Note: Non-government projects were valued at S$549.30 million (approx. £166m)

Mount Pleasant Airport, Falklands Islands

This chapter would not be complete without the inclusion of a brief account of the contract for the construction of the Mount Pleasant Airport on the Falkland Islands, for use by both civil and military aircraft, to be constructed in this isolated location, in record time and in severe weather conditions.

The task was to design and build a new airport complete with supporting accommodation and services. This included a main runway 2590 m long; a secondary runway 1500 m long; hardstandings for passenger and military aircraft and helicopters; a hangar for a wide-bodied jet; an air traffic control tower; power stations; water supply; associated airport operational buildings; and domestic accommodation for the personnel needed to operate the airport. Property Services Agency (PSA) retained full responsibility for the airport layout and design while Sir Alexander Gibb and Partners designed all other civil engineering works.[85]

The consortium of Laing - Mowlem - Amey Roadstone (LMA) was awarded the contract for the works in 1983 to a value of approximately £190m, to which must be added the cost of the road from Mount Pleasant to Stanley and a separate MOD contract for communication and navigational aids, making a total of around £215m, for full completion by early 1986.[85]

The main problems affecting the successful completion of the contract were:

(1) The organisation of an efficient and timely supply of materials.
(2) Provision of an attractive employment package for the large UK labour force working 12 870 km from home in exceptionally adverse weather conditions (at the peak 2000 men were working a minimum 60-hour, 6-day week).
(3) The need to provide adequate accommodation and welfare facilities.
(4) The necessity to locate sufficient quarry sites and thereafter to obtain large quantities of aggregates to meet the enormous con-

struction requirements (over 1.5m tonnes of stone were quarried).

In 1984 LMA were awarded a further contract to construct a permanent port at Mare Harbour, and storage and living accommodation for the army at a cost of £119m, which together with the expanded airport contract brought the total value of work to £395m at September 1984 prices.[85]

References

1. Department of Transport. *Transport Statistics: Great Britain 1974–1984*. HMSO (1985)
2. T. Bendixson. *Transport in the Nineties: The Shaping of Europe*. RICS (1989)
3. Institution of Civil Engineers, Infrastructure Policy Group (IPG). *Congestion*. ICE (1989)
4. Confederation of British Industry. *Transport in London, Task Force Report: The Capital at Risk* (1989)
5. J.C. Yu. *Transportation Engineering*. Elsevier (1982)
6. C. Buchanan. *Traffic in Towns*. HMSO (1963)
7. P. Abercrombie. *Greater London Plan*. HMSO (1945)
8. Lord Llewelyn Davies. Changing goals in design: the Milton Keynes example. *New Towns: The British Experience*. Ed. H. Evans. Knight (1972)
9. R W. Bixby & D.P. Bullen. Park and ride – the Oxford experience. *Mun. Engr. Vol. 110, Jan. 1983*
10. P. Bishop. 'Congestion pricing' attracts DTp interest. *New Civ. Engr, 13 July 1989*
11. NEDC. *Private Participation in Infrastructure Projects* (1989)
12. B.J. Simpson. *Planning and Public Transport in Great Britain, France and West Germany*. Longman (1987)
13. I.C. Lord. Bury bus/road/rail interchange. *Ch. Mun. Engr, 1979, 106, Oct.*
14. M. Smith. Always jam tomorrow. *The Guardian. 23 Oct. 1989*
15. T.H. Shillam & W. Skellern. The municipal engineer and transportation – 100 years of change. *J. Instn Mun. Engrs, 1973, 100, Feb., 57–62*

16. Department of Transport. Transport Statistics: Great Britain 1977–1988. HMSO (1988)

17. Secretary of State for Transport. *White Paper: Roads for Prosperity, CM 693*. HMSO (1989)
18. H. Jones. Vicious circles. *New Civ. Engr, 1989, 10, Aug., 22–23*
19. W.S. Clough. Bus deregulation. *Mun. Engr, 1988, Oct., 247–55*
20. J.T. Ratcliffe. Middlesbrough's new bus station – putting the passenger first. *Mun. Engr, 1984, Aug., 129–38*
21. D.E. Edwards & L. London. The reconstruction of St Margaret's bus station, Leicester. *Mun. Engr, 1986, Oct., 263–73*
22. J.J. O'Brien. Rail passenger transport. ICE. *European Transport*. Telford (1987)
23. J.M.B. Gotch. Rail freight meets the challenge. ICE. *European Transport*. Telford (1987)
24. Institution of Civil Engineers. Congestion: kill or cure? Briefing notes: *Seminar of Infrastructure Policy Group, London, 6 March 1989*
25. M.C. Purbrick. Track for the next decade – the mixed traffic railway. ICE. *Track Technology*. Telford (1985)
26. W. H. Hay. *Railroad Engineering*. Wiley, New York (1982)
27. P.H. Wright & N.J. Ashford. *Transportation Engineering: Planning and Design, pp. 456–70* Wiley (1989)
28. E.T. Selig. Ballast for heavy duty track. ICE. *Track Technology*. Telford (1985)
29. American Railway Engineering Association. *Manual for Railway Engineering* (1986)
30. D. S. Currie. Railways. *Civil Engineer's Reference Book*. Butterworths (1989)
31. K.G.A. Herring & E.C. Harrison. Track maintenance and renewal – direct labour or contract? *Proc. Instn Civ. Engrs, Part 1, 1987, 82, Oct., 1043–6*
32. A.J. Cooper & M.G. Reynolds. Engineer's role in rail journey time management. *Proc. Instn. Civ. Engrs, Part 1, 1989, 86, Oct., 1043–6*
33. A.P. Barwell *et al.* Crewe track and station remodelling scheme. *Proc. Instn Civ. Engrs, Part 1, 1987, 82, Aug., 887–95*
34. W.M. Lewis & P.J. Clark. Railway electrification: Anglia civil engineering projects. *Proc. Instn Civ. Engrs, Part 1, 1987, 82, Apr., 247–68*
35. Department of Transport. Technical memorandum. *Design of Highway Bridge Parapets*. HMSO (1982)
36. D. Fowler. French make the connection. *New Civ. Engr, 7 Sept. 1989, 28–35*
37. F.E. Atkins & P.J.G. Wigley. Railway underline bridges: developments within constraints of limited possession. *Proc. Instn Civ. Engrs, Part 1, 1988, Oct., 989–1007*
38. BSI. *BS 5400:1978. Steel, concrete and composite bridges*

39. Passenger Transport Executive Group. *Light Rail Transit* (1988)
40. D. Fowler. The peak of performance. *New Civ. Engr, 20 April 1989*
41. Hong Kong Mass Transit Railway Corporation. *Fact Sheet* (1988)
42. T.W. Hulme *et al*. Singapore Mass Rapid Transit System: planning and implementation. *Proc. Instn Civ. Engrs, Part 1, 1989, 86, Aug., 627–65*
43. J.P. Copsey *et al*. Singapore Mass Rapid Transit System: design. *Proc. Instn Civ. Engrs, Part 1, 1989, 86, Aug., 667–707*
44. Metro Monitoring and Development Study. *The Metro Report: The Impact of Metro and Public Transport Integration in Tyne and Wear* (1986)
45. Tyne and Wear Passenger Transport Executive. *Metro Power Supplies – Fact Sheet* (1989)
46. Greater Manchester Passenger Transport Executive. *Metrolink: Light Rail in Greater Manchester* (1989)
47. Greater Manchester Passenger Transport Executive. *Metrolink Information* (1989)
48. British Waterways. *Transport: The Severn Way* (1989)
49. *Hampshire Record Office Files 8M62/141c* and *d*. Specifications by John Rennie
50. Kennet and Avon Canal Restoration Consortium. *The Restoration of the Kennet and Avon Canal in Berkshire* (1987)
51. British Waterways. *Report and Accounts of the British Waterways Board 1988/89*
52. British Waterways. Opening the new tidal lock at Limehouse. *New Ways, July/Aug. 1989*
53. G. Haider. Reconstruction of Llangollen Canal. *Proc. Instn Civ. Engrs, Part 1, 1989, 86, Dec., 1047–66*
54. J.L. Simpson. The design and construction of Stanley Ferry Aqueduct. *The Structural Engineer, 62A.9, Sept., 1984, 267–74*
55. British Waterways. Blisworth Tunnel re-opened. *Supplement to Waterways News, 22 Aug. 1984*
56. G. Haider & L.R. Richards. Netherton Canal Tunnel: recent repairs of failed sections. *Proc. Instn Civ. Engrs, Part 1, 1987, 82, Feb., 35–58*
57. Eurotunnel. *The Channel Tunnel: A Technical Description* (1987)
58. D. Hayward. Back in the running. *UK Tunnelling. New Civ. Engr. Supplement, Sept. 1988*
59. S. Alford. Channel vulnerable to seabed explosion. *New Civ. Engr, 4 Feb. 1988*
60. Halcrow Airport Group. *Airports* (1988)
61. BAA British Airports Services. *Research and Planning for the 21st Century* (undated)
62. P.H. Wright & N.J. Ashford. *Transportation Engineering: Planning and Design, pp. 597–619.* Wiley (1989)
63. Property Services Agency, Civil Engineering Services. *A Guide to Airfield Pavement Design and Evaluation* (1989)
64. Department of the Environment. *Design and Evaluation of Aircraft Pavements* (1971)
65. International Civil Aviation Organisation. *Aerodrome Design Manual, Parts 1–3* (1983)
66. US Army Engineer Waterways Experiment Station. Procedures for development of CBR design curves. *Instruction Report S-77–1* (1977)
67. BAA. *Heathrow Terminal 4* (undated)
68. Heathrow Airport Ltd. *Heathrow Terminal 3: A New Terminal for the Old* (undated)
69. BAA. *1989 Report and Accounts*
70. BAA. *Heathrow Terminal 4: The Technical Profile* (undated)
71. BAA. *Gatwick, North Terminal* (undated)
72. D.J. Macleod & C.G. Harding. Track Transit System, Gatwick Airport. *Proc. Instn Civ. Engrs, Part 1, 1989, 86, Oct., 899–912*
73. BAA. *Stansted Airport Development: General Description of Terminal Building* (undated)
74. R.H. Maling & L.A. Kubik. Jumbo Hangar for Stansted Airport. *ICE, East Midlands Association, Year Book 1989, p.10*
75. BAA. *Stansted Airport Development: Environmental Aspects* (undated)
76. British Airports Services Ltd. *London Stansted Airport: Developments in the Treatment of Deicing Waste* (15 June 1988)
77. Underground to Stansted. *New Civ. Engr. 26 May 1988, 33–6*
78. B. Dumbleton. Stansted in Transit. *New Civ. Engr. 19 Jan. 1989, 24–6*
79. PWD, Singapore, Changi Airport Development Division. *Singapore Changi Airport: Data Book* (1982)
80. M. Suloway & J.M. Stevenson. O'Hare 2000: the development programme for Chicago – O'Hare International Airport. ICE. *Economics of Air Transportation, pp. 15–22.* Telford (1984)
81. PWD, Singapore, Airport Civil Engineering Branch. *Changi Airport: Masterplan Layout* (1986)
82. Chua Hua Meng. Changi Airport Passenger

Terminal: The Design and the Construction. *Proc. International Symposium on Airport Planning and Development, Singapore, 11–12 Jan., 1982*
83. *Journal of the Singapore Institute of Architects; Special Changi Airport Commemorative Issue, Nov/Dec. 1981, nr. 109, 14–16*
84. Lim Boon Liang. SIA's three-bay hangar. *Airport Forum 4/81, Aug. 1981, 48–9*
85. Laing-Mowlem-ARC Joint Venture/PSA. *Mount Pleasant Airport, Falkland Islands* (undated).

3

Highway and Traffic Engineering

This chapter is very wide ranging in its scope and it is therefore necessary to deal with some aspects less rigorously than others, but in these cases the reader will be referred to other sources for more detailed information. However, within the limitations of space available, the subject has been dealt with quite extensively and is supported by relevant case studies, which it is believed will of interest and value to the reader.

The chapter follows on very logically from the previous chapter on Transportation. The introductory section on national road problems and policies provides a useful backcloth to the study and illustrates some essential links with transportation in general, and the chapter then leads on to examine pavement construction methods and design techniques, road drainage, bridges, traffic control and management, car parking, road funding, road safety, road lighting, landscaping, services and maintenance.

National Road Problems and Policies

Road Congestion

This more detailed examination of a vitally important subject follows on the brief introduction in chapter 2. A survey undertaken by the Department of Transport in 1988 estimated that traffic jams were costing £3000m a year in the main conurbations of England, with delays on the 11 km stretch of the M1 between Luton and Hemel Hempstead alone costing £1m annually. At the same time, the British Road Federation forecast traffic growth at 13% per annum, far outstripping the highest forecasts of the Department of Transport, although it must be appreciated that long term forecasts are notoriously difficult to calculate with precision.

Nevertheless, even taking a modest assessment of traffic growth it was evident that substantial investment was required in UK roads to prevent impending chaos as the main national arteries become increasingly overloaded. This could result in the transfer of considerable numbers of vehicles to other routes which are far less suited for through traffic. The problems are accentuated by the piecemeal approach to tranportation, the use of average annual daily flows which are not sufficiently sensitive because of the significant hourly, daily and seasonal variations and the fact that many large schemes can take up to 15 years from conception to completion. In 1990 many motorways had flows exceeding their design capacities.

A very informative and authoritative report on *Congestion*, produced by the Institution of Civil Engineers in 1989,[1] emphasised the fragility of the situation with countless citizens facing delay, discomfort and even unreasonable hazards in road travel, while industry suffered constraints on development and increased costs. London and other major cities had become partially paralysed for many hours of each working day. Much of the problem stems from underfunding of the transport infrastructure from the late 1970s until 1990, accompanied by a rapid growth in car ownership.

The ICE Report[1] contained the following main recommendations for the alleviation of congestion, all of which deserve and some are receiving serious consideration:

1. Better co-ordination by setting up a transport co-ordinating group dealing with all modes of transport and reporting directly to the Secretary of State through the Department of Transport (DTp).
2. Modifying demand by more flexible work and school hours, establishing work centres in residential areas, encouraging out of hours

retail deliveries and raising the differential between peak and off-peak fares.

3. Making the most of existing roads in many different ways, including the wider use of traffic management techniques, greater enforcement of control of illegal parking and illegal loading, reducing the impact of road repairs and selective provision of additional road capacity.
4. Modifying road usage such as by transferring demand from private to public transport, considering road pricing, restricting central parking, implementing park and ride systems and further pedestrianisation of urban areas.
5. Motorways and trunk road congestion to be eased by introducing crawler lanes for heavy goods vehicles (HGVs), more lanes at junctions, better road signs, improved management of lane closures and strengthening of hard shoulders.
6. Public transport to be increased by greater use of buses and trains and by improving services in a variety of ways.
7. London congestion to be eased by provision of new infrastructure to relieve the M25, crossrail proposals in Central London Rail Study, additional high capacity rail links to Docklands and new links to south west and south east London, supplemented by government assistance with funding with support from developers and other benefitting parties.
8. Role of government included improving forecasting methods, quicker public inquiry procedures, improved compensation methods and a common basis for investment appraisal covering all modes of transport.
9. Financing with bulk of funds coming from government, supplemented by European Community (EC) grants, private sector and non-paying beneficiaries.

It is worth noting that serious traffic congestion and accompanying heavy pollution was also being experienced in other major cities. For example, Bangkok with a population of 5m was suffering from badly clogged roads at peak periods and traffic was fast grinding to a halt. Drastic measures were required to alleviate the problem. An underground railway had been ruled out because of the waterlogged ground and aerial railways were being considered in 1990, together with a ban on any further high rise buildings which apart from placing a great strain on public utilities were a major cause of worsening traffic congestion and pollution along one of the city's main traffic arteries.

At the same time Bangkok was also inviting proposals from private firms to invest in the construction of tollways over three canals to relieve traffic congestion in the city centre on the basis of a 30 year concession. Bids were to include engineering designs and environmental impact studies in addition to financial and technical proposals for the 19 km project. Another proposal was to increase tolls on existing expressways from 30 to 100%.

Milan also had serious traffic pollution problems and decided to ban driving in the entire metropolitan area, housing 3m people, on Sunday 21 January 1990 from 8 am to 8 pm if the high level of pollutants from heavy smog did not decrease before that date. Other measures to combat pollution will be the exclusion of large trucks from stopping in the city centre and smaller trucks will not be able to load and unload on Saturdays, as the pollution exceeded the first alarm level of 10 micrograms of CO_2/m^3 at nearly all smog control centres in the Milan area, at which level ill and elderly people are advised to be cautious about going out.

United Kingdom Road Proposals 1990–93

In February 1990, the Secretary of State for Transport announced plans to spend £5.7b on roads in England spread over the following three years as part of the rolling programme to invest at least £12.4b in the 1990s. The plans involved more than 500 schemes comprising more than 4025 km of existing or planned roads, including 175 km of new motorways. The spending on new roads was estimated at £4b which represented a 50% increase in real terms compared with the previous three years.

When the programme is completed it will result in nearly one third of the motorway network attaining dual four lane standard and most of the remainder will be dual three lane. The length of all purpose dual carriageway trunk roads will be doubled. The programme involved improvements to the trunk road network in all regions of the country, and included widening 215 km of the M1, over 130 km of the M6 and over 160 km of the M25.

The Transport Secretary considered that the programme of roadworks would not be hostile to the environment and that the worst pollutant was traffic jams which could be reduced by keeping traffic moving. In an attempt to placate the environment lobby he promised to plant more trees on verges, appoint consultants to advise on environmental matters and increase the grant for English Heritage's archaelogical works to £500 000.

It could, however, be argued that building roads on this scale may make it impossible for Britain to fulfil its international commitment to cut carbon dioxide emissions by 20% in the period 1990 to 2005, and that the proposed 'greening' of the new roads, desirable though it is, will not offset the harm done to the environment by the additional roadworks. The investment in the road building and improvement programme should also be viewed against the reduction in public spending on rail by 45% and other public transport by 20% over the period 1985–90. The government's counter argument is that road and rail for the most part serve different markets and for most journeys one mode cannot readily be substituted for the other. It is claimed that even a 50% increase in rail traffic would be equivalent to only 5% of 1990 road traffic or about one year's growth.

The Council for the Protection of Rural England felt that the Department of Transport (DTp) failed to recognise the incompatability of continued road construction with the protection of the environment, but it was welcomed by the British Road Federation who believed that it constituted a realistic recognition of the need to remove congestion, and the Freight Transport Association who considered it to be a welcome and urgent attack on industry's congestion blackspots.

London Road Proposals

In 1990, the Transport Secretary also announced a socially unpopular road programme for London estimated to cost about £3b, prepared by four separate consultants (Ove Arup, Halcrow, Travers Morgan and Mott Macdonald) for West London, the South Circular, South London, and East and North London. It was likely to involve the demolition of at least 2500 homes and 650 commercial properties in heavily built up areas. It constitutes possibly the last attempt to relieve urban congestion by a mass road building programme.

The programme emerged from the heavy congestion on London's road and rail networks, together with the forecasts of ever rising demand for road and rail travel in the 1990s and beyond. DTp forecast road traffic in London growing by between 27 and 47% by the year 2000 and by as much as 142% by year 2025.

There was, however, a growing belief that the study of London's transport problems was uncoordinated, too narrowly based and possibly misleading. For example, all the rail schemes incorporated in the transport studies were rejected by the government in 1989, while the Association of London Authorities raised doubts about the merits of the proposals, arguing that they were likely to worsen congestion, further damage the environment and that the costs were substantially underestimated, particularly the sections in tunnel.

It is worth noting that the Association of London Authorities (ALA) expounded a strategic transport policy for the capital, including moderate road pricing, public transport spending and traffic calming measures to control vehicles. It was claimed that the implementation of these measures would produce a projected 40% reduction in London traffic flows, less accidents and lower pollution. These measures were among the many recommendations contained in the ICE Congestion Report,[1] summarised earlier in the chapter.

Some Motorway Constraints, Characteristics and Weaknesses

This section examines some of the basic problems and constraints facing the designers of motorways and the resulting deficiencies, with particular reference to the M25 and the M40.

The *M25* orbital motorway around London was one of the most significant civil engineering projects undertaken in the United Kingdom since the war, costing some £940m. Yet it became overloaded as soon as it was opened, although it is normal practice to provide sufficient capacity for at least 15 years' growth and hence on this criterion the M25 was seriously underdesigned. Several different views have been expressed as to how this could have occurred, apart from the usual explanation of designing a road some 15 years ahead of completion must be based on probable future traffic flows which have proved difficult to forecast with any great precision. See also the House of Commons Public Accounts Committee's strong criticism of the DTp's forecasting and monitoring methods with regard to the M25 in chapter 2.

James, [2] for instance, believes that the decision to build dual three lane carriageways where four lanes were required owed as much to political response to the depressed economic outlook created by the oil crisis of the early 1970s as to underestimates of future traffic demands. Whereas Phillips[3] asserts that it resulted primarily because it was produced by joining together four entirely separate road schemes that were planned for different purposes, at different times, by different authorities, and was not coherently conceived from the outset as a ring road. Unfortunately, a similar criticism could probably be levelled at the major road networks for both Manchester and Birmingham, where there is a lack of co-ordinated transportation planning linked with major development proposals.

Another factor was the large amount of traffic using the motorway to travel from one suburban area to another as opposed to through traffic using the route to bypass London. In 1989, Rendel Palmer and Tritton, Consulting Engineers, and many other highway experts believed it necessary to implement access control at motorway junctions to reduce congestion, but the Department of Transport (DTp) did not proceed with this proposal. Possibly DTp's decision was influenced by political considerations as the restricted local traffic could include many potential Tory voters, and the Conservative government's popularity was declining at the time. The traffic control system would be designed to limit the number of vehicles on the M25 to an optimum level which would allow continuous traffic movement. Achieving this would involve stopping or limiting access at selected junctions of both the M25 and connecting motorways up to 15 km outside the M25.

Phillips[3] also considered that the M25 was poorly planned, designed, maintained and landscaped, and that these deficiencies also applied to most trunk road building in Britain. He asserts, with considerable justification, that one could have expected the experience of many years of road building to have resulted in improved standards of quality of road surfaces, junction design, signposting and landscaping, but this is not demonstrated in the M25. Contractors have been permitted to submit alternative carriageway designs at tender stage, resulting in constant changes of surface finishes and materials of varying quality to the serious disadvantage of drivers. Furthermore, the M25 incorporates sections with upstand kerbs, channels, thick gravel and combinations of all three. All of these can be dangerous as they exacerbate the loss of control of vehicles which inadvertently overstep the edge of the carriageway.

Phillips[3] also draws attention to the more common desirable practice on the mainland of Europe of providing smaller but more closely spaced service areas on motorways, which result in genuine price competition, more variety, more pleasant and easier managed establishments. He believes that our motorways would also benefit from the provision of some parking and picnic areas, to allow restful breaks from long journeys, which must contribute to safer driving.

As Halcrow[4] so rightly stated, given current concern about the environment and traffic congestion, the swift and sensitive design and construction of a motorway must be one of the most challenging tasks facing a civil engineer. It is vitally important to select a route which causes least disturbance to sensitive areas, such as sites of special scientific interest and areas of unspoiled countryside, and to incorporate landscaping features which reduce the impact of the highway and make special provision to safeguard the interests of local residents and wildlife. The provision of low embankments, noise mounds and tree planting, and taking roads through escarpments at an angle to avoid leaving a notch in the skyline, all help to reduce the visual impact of the motorway.

Examples of the kind of sensitive measures taken by Halcrow[4] selecting the final alignment of the M40 are now described. The chosen route skirted the edge of Shabbington Wood, a refuge for the rare Black Hairstreak Butterfly and home to a group of badgers, who have their own special tunnel to cross beneath the motorway, and care was taken to protect a colony of deer which commuted regularly between Shabbington and Borstall Woods, as well as the erection of special deer fences 2.1 m high along each side of the motorway. Two of the overbridges have soft verges and an underpass was modified by making its entrances wider and the tunnel section as short and light as possible to attract the deer, thus preventing them putting their lives and those of motorists at risk by attempting to cross the carriageways. Further measures included providing new natural habitats, such as a planted extension to Shabbington Wood and incorporating motorway drainage ponds into plans for new water features.

Unfortunately, not all motorways are aligned with such care and understanding with regard to sites of scientific interest and other sensitive areas or with adequate concern for the visual impact of the motorways on the surrounding countryside.

Bypasses

The bypassing of villages and small towns located beside trunk roads has become a common occurrence in the post-war years, to eliminate the noise and fumes emanating from heavy traffic and the resultant damage to buildings and injurious affects on residents related to convenience, quality of life, health and safety hazards.

However, a report by the Civic Trust[5] concluded that 'the present bypass programme is based more upon an uninformed faith in the environmental efficacy of bypasses than upon knowledge of the facts'. It is becoming increasingly apparent that as the size of a town increases the environmental benefits to be gained from a bypass decrease as they do not, of themselves, solve the internal traffic problems of larger towns. Consequently there is a strong argument to deploy more resources into solving the internal traffic problems of the larger urban areas and the conurbations.

Mackay[6] has rightly emphasised that it is important to recognise that the justification for bypasses should be based on the net benefits to a range of affected groups of people of whom the road user is only one. The assessment of the costs and benefits entails an analysis of complex issues ranging far beyond the criteria which govern optimum highway design. Engineers consequently need to examine in detail a variety of significant economic and environmental issues.

Mackay[6] has formulated a comprehensive methodology whereby emphasis is given by the assessors to objectives and to user groups. It enables assessors to review and reassess the process of ordinal analysis until they are satisfied that all aspects or facets have been accounted for. It also identifies any weaknesses in preferred schemes, even if these are for less important user groups or less important objectives. Ordinal analysis overcomes one of the main difficulties inherent in the implementation of cost benefit analysis (CBA) studies, by ranking options, weighting objectives and examining performance related to each user group.

Highway Construction Techniques

As this is such a comprehensive subject, it was decided to deal briefly with the main forms of highway construction and to refer the reader to more detailed sources of reference where appropriate. This introduction to construction techniques is followed by several selected case studies to illustrate the problems which can be encountered in practice and how they have been overcome in practice, displaying great skill and ingenuity on the part of the consulting engineers and contractors alike.

Useful sources of reference for highway construction methods are *The Civil Engineer's Reference Book*,[7] *Highway Engineering, Volume 2*,[8] *Highway Construction and Maintenance*,[9] and *Highway Design and Construction*[10]. In addition, reference will be made to various official publications in the text.

A highway pavement consists of superimposed layers of processed materials placed and consolidated on a subgrade, with the principal objective of supporting the applied traffic loads and distributing them over the underlying soil. The transmitted stresses must be sufficiently reduced in intensity so that they do not exceed the load bearing capacity of the subgrade, being the road formation. Pavements are normally classified into two categories, namely flexible pavements and rigid pavements.

Flexible Pavements O'Flaherty[8] describes how these maintain intimate contact with, and distribute loads to, the subgrade, and are dependent for their stability on such factors as aggregate interlock, particle friction and cohesion. The construction normally comprises a top surfacing, often made up of a wearing course and a base course, supported by a road base and a sub-base laid on the subgrade or formation. The sub-base is merely an extension of the road base and may or may not be present as a separate layer.

Hot rolled asphalt is the most commonly used material for wearing courses on roads with higher traffic loadings in the UK, whereas many other countries use asphaltic concrete. Alternative surfacings for more lightly trafficked pavements include dense bitumen macadam, dense tar surfacing, cold asphalt, open textured bitumen macadam, and open textured tarmacadam, and the desirable requirements for all these materials are fully specified in DTp *Specification for Highway Works*.[11]

A typical construction for a flexible pavement surfaced with rolled asphalt and carrying 100 to 3000 commercial vehicles per day would be 40 mm wearing course of rolled asphalt, 60 mm of rolled asphalt, dense bitumen macadam or dense tarmacadam base course, and a road base of one the materials listed for the base course making up the remainder of the thickness. The total thickness of surfacing plus road base varies with the design traffic loading, ranging from 185 mm for 100 commercial vehicles per day at opening in one direction to 440 mm for 10 000 vehicles. These figures are taken from the graph in DTp *Structural Design of New Road Pavements*.[12]

Rigid Pavements These are pavements which have sufficient strength to bridge over localised subgrade failures and areas of inadequate support without deflection, unlike flexible pavements. They consist of cement concrete pavements which are of three basic types, namely jointed and unreinforced, jointed and reinforced, and continuously reinforced. The concrete for surface slabs and road bases is specified in clause 1001 of *Specification for Highway Works*[11] as grade C40 with a minimum cement content of 320 kg/m^3. Paving machines for constructing concrete slabs are of two main types: fixed form pavers supported on flat bottom rails and slipform pavers mounted on caterpillar tracks. For concrete roads the slab design thickness related to the design traffic loading can be obtained from the graphs contained in *Structural Design of New Road Pavements*.[12] For example for jointed unreinforced concrete surface slabs there is a thickness range of 150 mm to 330 mm for traffic loadings of 200 to 10 000 commercial vehicles per day at opening in one direction; for rigid jointed reinforced concrete surface slabs the thickness range is 150 mm to 300 mm; and for continuously reinforced concrete surface slabs the thickness range is 200 to 260 mm. This shows little advantage to be gained from introducing reinforcement, as it gives only minimal additional structural strength and is mainly used to restrict the opening of cracks after they have formed, while the continuously reinforced slabs are very expensive.

The concrete slab is supported by a sub-base which may consist of granular material, stabilised soil or lean concrete. The range of granular materials includes naturally occurring gravel, crushed stone or concrete, industrial waste materials such as hard clinker, burnt colliery shale, spent oil shale and crushed slag. DTp *Structural Design of New Road Pavements*[12] gives the sub-base thickness for design purposes related to California Bearing Ratio (CBR) values. For example, on a weak subgrade of CBR less than 2%, the sub-base thickness will have to be increased from 150 mm to 280 mm.[13] A separation membrane is required between the concrete slab and the sub-base to prevent loss of water from the fresh concrete, and this usually consists of polythene beneath jointed unreinforced and jointed reinforced concrete slabs and a bituminous spray for continuously reinforced concrete.

Joints in concrete road slabs can take various forms as follows:

(1) Contraction joints to limit tensile stresses induced in the pavement resulting from contraction or shrinkage of the concrete and to prevent or control cracking and permit some subsequent contraction, with a sealed upper groove and possibly a bottom crack inducer.
(2) Warping joints are breaks in the continuity of the concrete in which any widening is restricted by tie bars, but which allow a small amount of angular movement between the slabs.
(3) Expansion joints allow expansion of concrete slabs when the temperature rises to prevent damaging compressive stresses developing or the buckling of slabs. They are provided transversely by embedding a vertical, non-extruding, preformed compressible filler between abutting slabs, with a wider space at the top filled with sealing compound to prevent the entry of water and grit. Any reinforcement must terminate about 60 mm from the centre of the joint and load-transfer devices called dowels are required at these joints with suitable provision for movement.
(4) Construction joints are those joints other than the deliberately designed joints previously described which arise when construction work is unexpectedly interrupted.

All these joints are very well described and illustrated in *Highway Construction Details*[14]. Faulty joints have been a major cause of premature failure on many large highway contracts and this was highlighted in a National Audit Office report in 1989.[15] Much of the criticism was levelled at poor workmanship and supervision.

Case Studies

It is now proposed to include three case studies covering projects with very different characteristics located in widely spaced locations, ranging from Wales to Hong Kong and Oman, to illustrate the types of problems encountered in practice and how they are overcome, supported by appropriate diagrams and plates.

A55 North Wales Coast Road

This particular project has been selected because of its large scale, complexity and diverse characteristics, involving the use of various new constructional techniques. With the continued growth of road traffic in the 1950s and increasing congestion on the existing A55 in town centres such as Colwyn Bay it became apparent that major road improvements were required.

In 1969 Travers Morgan and Partners were appointed to carry out a detailed route feasibility study extending about 45 km between St Asaph and Aber, where dual carriageways had already been constructed. A total of 45 different routes were investigated and the Welsh Office decided to proceed with the development of a coastal route, following the railway through Colwyn Bay, crossing the Conwy estuary on the south side of the existing causeway and remaining adjacent to the coast west of the estuary. The total cost of the complete project, which was subdivided into three phases, was £500m and the whole project was completed in 1992. The high cost of the project arose largely from the difficult geological conditions. The line of stages 1 and 2 of the new road is shown in Figure 3.1.[16]

The eastern section of the new A55 through Colwyn Bay from Llanddulas to Glan Conwy, 11 km in length, was constructed to urban cross sectional standards with dual 7.3 m carriageways and 1.8 m central reserve, with 2.75 m hard-shoulders over the most heavily trafficked section and 1 m hard strips elsewhere. The road was lighted by high pressure sodium lanterns on 10 m high steel columns at 30 m intervals in the central reserve.[17]

Springett and Stevenson[17] described how the *sea defences* consisted of a rock core embankment up to a level of 10 m OD. Mean high and low water spring levels were 3.8 m and −3.1 m OD respectively. The primary armour consisted of two layers of 5 t Dolos units, cast on site and laid to a density of 45 per 100 m^2; 55% were placed in the base layer and the remainder in the top. Secondary armour comprised 1–2 t rock lumps. At the outer face of the defences the rock armour was toed into the beach to a depth of about 2.5 m. The whole embankment was placed on a bedding layer 600 mm thick on a plastic filter membrane. The road embankment was constructed of suitable fill overlying a base rock fill layer to a level of 5.5 m OD as illustrated in Figure 3.2.

A *railway diversion* was undertaken at the western end of Colwyn Bay, moving the railway a distance of 20–30 m, to optimise the use of disused railway land. The original rail formation was about 20 m wide with four tracks, of which two had been abandoned. The design of the new road and railway was undertaken as a combined route corridor over one unified formation, but with the drainage designed separately. Travers Morgan were responsible for the design of the highway and the new railway formation up to

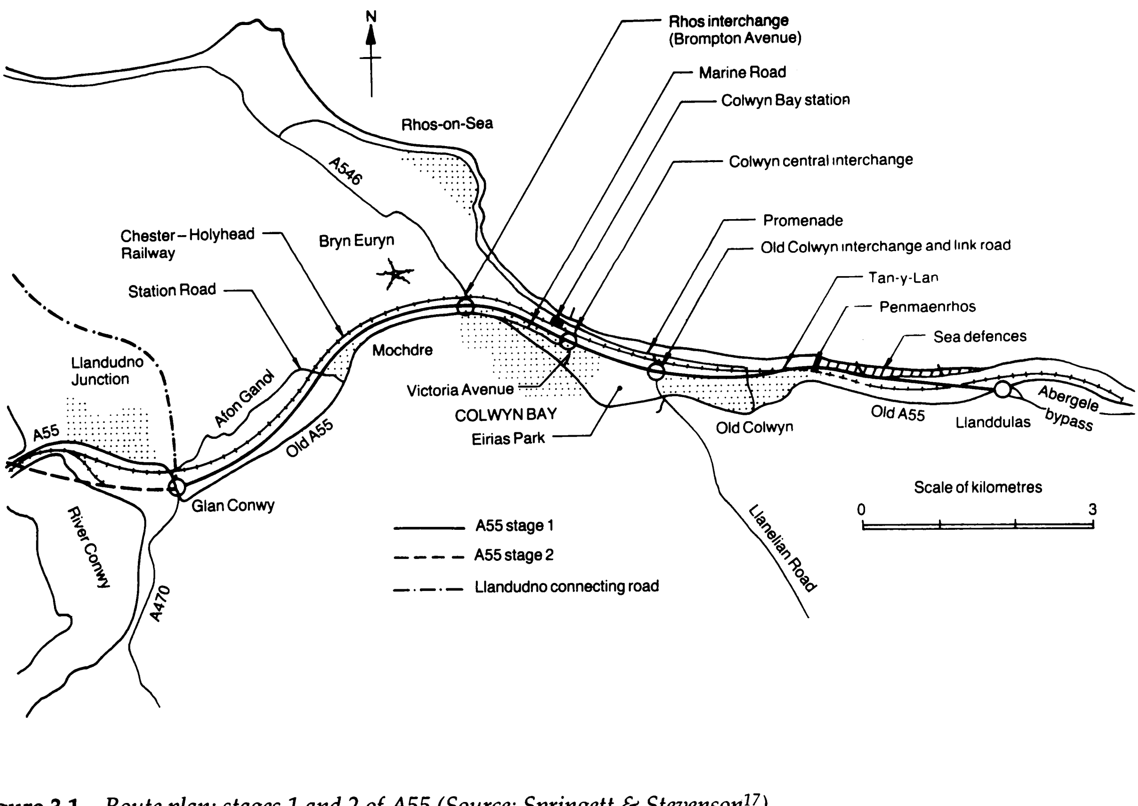


Figure 3.1 *Route plan: stages 1 and 2 of A55 (Source: Springett & Stevenson[17])*

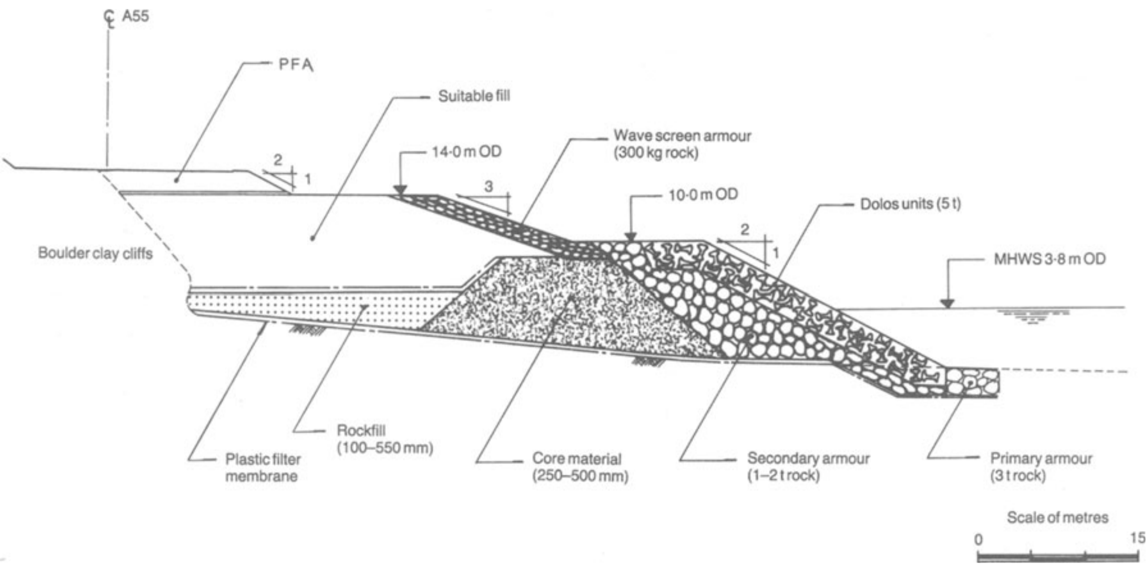


Figure 3.2 *Typical cross section through sea defence works to A55 (Source: Springett & Stevenson[17])*

and including bottom ballast, while the top ballast and track details were the responsibility of British Rail.[17]

At the Rhos Interchange, the rail formation was in cutting and the new road and railway is contained between retaining walls which were provided to reduce the amount of land taken, as illustrated in Plate 8. At Bryn Euryn it was necessary to cut into the hillside to a depth of 17 m exposing Silurian mudstone. The rock mass was weathered to a depth of 7 m. An open cut design was adopted with a slope of 1 to 1 and a 1.5 m bench at rockhead. The colluvium (mudstone gravel in a clay matrix) above the rock was retained by gabions up to 5 m high. West of Bryn Euryn to overcome the problems posed by the soft alluvium, piles were driven into the underlying gravel and clay strata to working loads of 50 t, to support the railway which was programmed for operation within two years of the start of the contract, without fear of long term settlement. The construction showing the piles and and PFA/OPC concrete raft under the railway and cantilevered retaining wall on a piled foundation adjoining the new highway is illustrated in Figure 3.3.[17]

In the *Afon Ganol valley*, the new A55 passed through an area subject to flooding, and contained soft alluvium up to 12 m thick and large quantities of peat. Hence much of the route was founded on a piled raft, comprising an unreinforced PFA/OPC concrete raft 800 mm thick supported by 16 000 concrete shell piles, 444 mm diameter with an average length of 13 m, and driven to a set designed to give a working load of 50 t. A PFA embankment was constructed on the raft to carry the road.

The *pavement* was of bituminous construction

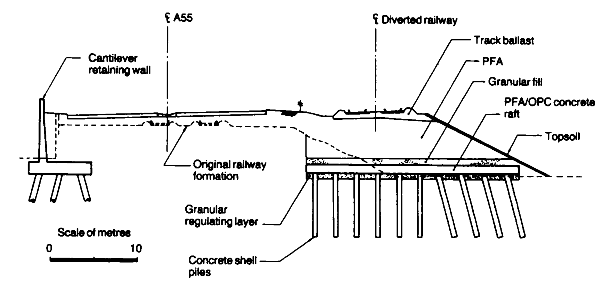


Figure 3.3 *Railway diversion on piled raft adjoining the A55 (Source: Springett & Stevenson[17])*

throughout the length of the Llanddulas embankment, in order to withstand long term differential settlement. The flexible construction comprised 100 mm of surfacing and 160 mm of roadbase both in hot rolled asphalt. Elsewhere contractors chose flexible construction incorporating a composite roadbase consisting of 60 mm of dense bitumen macadam and 210 mm of lean concrete. Provided throughout is a 190 mm type 1 granular sub-base and, generally, the subgrade has been improved by a granular capping layer 510 mm thick.[16]

There are 11 *bridges* on section one and these include a major bridge 150 m long crossing over the railway at Kneeshaw Lupton and consisting of a composite structure of seven spans, supported by 1.05 m bored piles up to 50 m deep. Three span reinforced concrete bridges carry the new A55 over existing side roads founded on bored piles 450 mm in diameter and there are three concrete pedestrian overbridges.

Retaining walls were constructed on most of the length through Colwyn Bay and between the Central and Rhos Interchanges. Most of the walls are in cast *in situ* concrete construction, but on selected lengths diaphragm walls were used to minimise construction impact and ground movements on adjoining properties. Three types of concrete finishes were applied to bridges and retaining walls.

The first was a random textured profile up to 50 mm deep and the other two consisted of vertical board marked profiles 15 mm and 5 mm deep. Coloured cladding panels were used on the face of diaphragm walls in the retained section through Colwyn Bay. *Noise barriers*, 2.5 km in length, were provided in both free standing and wall mounted forms, with heights varying up to 2.3 m. Free standing barriers were in timber while wall mounted barriers were of both timber and metallic manufacture.

The *Conwy Crossing* was a Costain-Tarmac joint venture costing £177m and comprised the largest single element of the A55 road improvement scheme. Its main feature is the UK's first ever immersed tube tunnel, 708 m long, approached at each end by cut and cover cast *in situ* sections 380 m long, incorporating many different and complex ground engineering techniques, and completed in 1990. Six twin bore immersed tube sections were built in a casting basin which was flooded, floated out and immersed in the Conway Estuary. Both cut and cover and immersed tube sections were constructed within bunded dewatered cofferdams. The bund cut-off wall used a thin vibrated grout diaphragm to a depth of 27 m and a total area of 35 000 m^2. This involved the injection of bentonite, cement and stone powder to produce a continuous but flexible diaphragm.[18]

Another daunting section of the project was the *Penmaenbach Tunnel*, 660 m long, accommodating a two-lane carriageway for west bound traffic to supplement the original road skirting the Penmaenbach headland taking east bound traffic, and which was completed in 1989. The tunnel passes through Ordovician rhyolite, an extremely hard rock some 500m years old. The first operation was to remove the accumulated scree down to the rock face, while three tiers of walling were constructed high up on the slopes above the west portal, to act as scree retainer, rock trap and water deflector.[19]

Travers Morgan[19] describe how prior to boring, the rock was secured by drilling in a ring of rock anchors consisting of long steel cables horizontally around the top of the porch to form a pretensioned arch. The only way of penetrating this exceptionally hard rock was by blasting. A Tamrock drilling machine with three universally mounted drills, bored charge-holes in predetermined patterns of 130 per session, each hole being 30 mm diameter and 4 m deep. A half circle or 'top heading' was blasted some 40 m ahead of the 'bottom bench' or ramp so that the Tamrock rig always had a working platform.

The explosive sequence started with two large charge holes around which the rock was literally atomised. A quarter of a second later, another ring of charges would be set off collapsing the rock into the new open space. Two wider rings of charges followed at 0.25 s intervals and completed the rock excavation. Finally, a series of chargers (lifters) blew back the masses of rock fragments so that they could be picked up more easily. The same process occurred at the bench face three or four seconds later.

Twenty minutes after the explosive reek cleared, mucking out began. The average 'pull' of 3.9 m yielded 650 t of high quality rock for use as aggregates and it was carried out in large bucket trucks to the crushing plant as shown in Plate 9. By the middle of the night or when there was sufficient working space available, some parts of the rock in the tunnel were sprayed with shotcrete to support the face. The Tamrock machine was also brought back to drill in rock bolts with quick setting resin to strengthen the roof.

The next stage of the main hard rock bore was for the bottom to be trimmed with the Tamrock machine to provide service ducts. Once the tunnel had assumed its final outline the shuttering was erected, consisting of a horseshoe-shaped shutter on rails which travelled down the tunnel leaving an annular gap. The gap was pumped full of concrete to provide the necessary support and the surface was painted to give the high degree of illumination required for a major trunk road.[19]

The east portal is protected by a temporary wall built against the exposed mountain face with further temporary supports on the tunnel side of the portal, where work is proceeding through soft ground and thence to the tunnel in hard rock, with boreholes projecting from the top heading beside the Tamrock drilling rig, with the steel shuttering beyond leading to the bench or ramp with numerous rock bolts drilled into position to strengthen the roof. Plate 9, also shows the working conditions in the tunnel looking back from the top heading beneath millions of tonnes of rock with a bucket truck removing loose rock in the foreground.

A Swiss made Profilometer with a revolving laser beam and on-board computer software was used to plot the outline of the tunnel. This enabled the resident engineer to calculate accurately the quantity of excavated material quickly and easily.[19]

Road traffic warnings and delay signs were posted up to 25 km away in order to lessen inconvenience to road users. An extensive vibration monitoring system was installed to ensure that no damage occurred to the British Rail unlined tunnel, built in the 1840s, and some 60 m away from the new tunnel.[19]

Tsuen Wan Bypass

The *Tsuen Wan bypass* was selected for the second case study as it involved construction across reclaimed land and over water. Tsuen Wan is one of the new towns in Hong Kong's New Territories with a planned population of 1m in 1991. In 1976 Scott Wilson Kirkpatrick and Partners were appointed by the New Territories Development Department, Government of Hong Kong, to study proposals for, and later to design and supervise construction of, a bypass to cater for the very large traffic growth resulting from the rapid expansion of Tsuen Wan itself and other new town development nearby. Tsuen Wan lies on a narrow coastal strip south of a steep rugged range of hills, as illustrated in Plate 10. Various options were considered for the bypass route but the one offering the greatest overall benefit involved the reclamation from the sea of 30 ha of land and the construction of the bypass above it on a continuous structure.

The bypass across Tsuen Wan Bay is about 2 km long. There is an intermediate interchange and one interchange at each end where the road continues as part of Route 2, the main trunk road in the New Territories. The bypass comprises dual three lane carriageways, except between ramps at interchanges and at the western end where the carriageways are reduced to two lanes. Narrow shoulders are provided on each side of the carriageways, and the bypass is provided with all normal services, including lighting, emergency telephones and hydrants for fire fighting. The interchange ramps are, depending on traffic demands, either one or two lanes wide. The alignment being mostly straight and level, is straightforward but the design speed of 60 kph was determined by the design speeds of the adjacent sections of road. The project was under construction from 1981 to 1987 at a cost of £40m (1981 prices).

Each carriageway of the bypass is carried on a 56-span structure over a total length of about 2 km. The two structures are divided into substructures ranging from 3 to 13 spans which are mainly 35 m and 45 m long. The decks of the parallel sided spans are post-tensioned *in situ* concrete single-cell box beams with side cantilevers. The two lane sections are 10.2 m wide overall (including the concrete parapets) and the three lane sections are 12.6 m wide. Where the carriageways vary in width, at the tapers to ramps, the decks are post-tensioned multi-cell box beams with side cantilevers. All main carriageway decks are 2 m deep and have the same curved exterior profile from soffit to cantilever, as illustrated in Figure 3.4.[20]

Each of the six ramps was designed as a single continuous structure with spans varying between 17.5 m and 25 m. The ramps with a single lane carriageway are 7.0 m wide overall and those with a two lane carriageway are 8.2 m wide. The ramp decks are 1.15 m deep and have the same external profile as the main bypass decks.

Because of the phasing of the reclamation, nine spans of the bridge were built over water, as shown in Plate 10. A mobile steel truss gantry, supported by steel frames on the pile caps, was used by the contractor for deck construction of these and other parallel sided spans.[20]

The majority of the foundations were located on reclaimed land formed between 6 and 18 months prior to foundation construction. Piling consisted of driven steel tubular and cast *in situ* bored vertical piles. In areas of original ground, and of long standing reclamation, 1.5 m hand-dug or machine-dug piles were used. The deck is supported mainly on single reinforced concrete columns with pot bearings, although columns are paired under the wider, tapering deck sections.[20]

A road system, comprising about 3 km of two and three lane carriageways connects the bypass to the existing road system. The main road linking the intermediate interchange with Tsuen Wan town centre, which is visible on Plate 10, is placed on a reinforced concrete deck, 600 m long and 35 m wide, placed over a main river.[20]

Mughsayl to Furious Highway

A good example of a most difficult highway project carried out under extremely exacting physical and climatic conditions in southern Oman, has been selected as the third case study.

In 1985, Balfour Beatty and Oman Building & Contracting were awarded a four year contract valued at £51m to link Mughsayl, a coastal

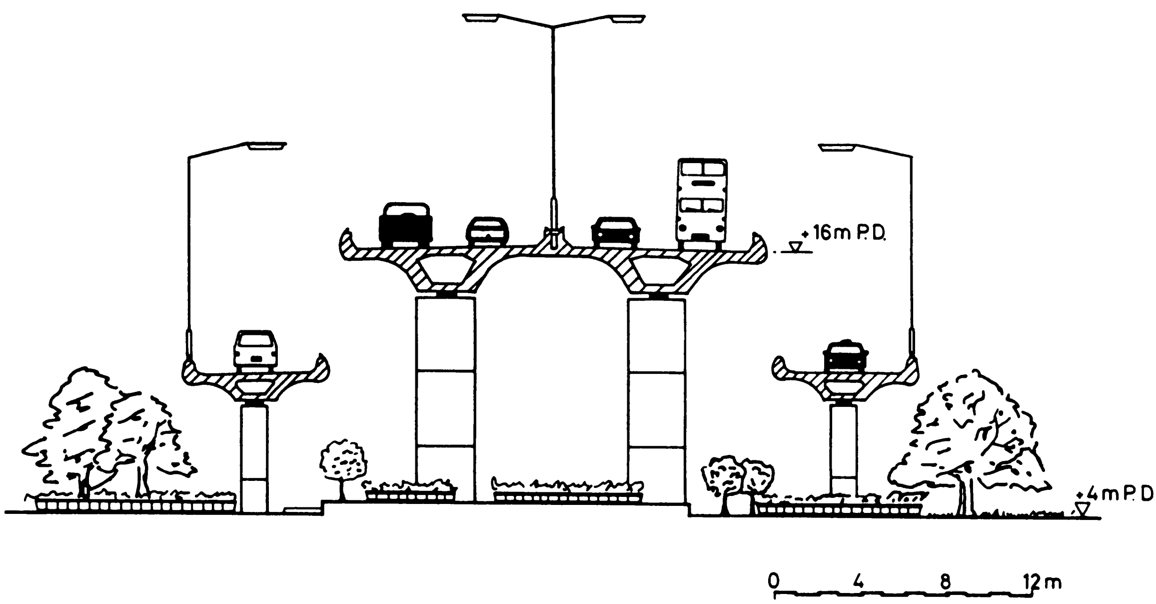


Figure 3.4 *Typical cross section of the bypass, Tsuen Wan, Hong Kong (Source: Scott Wilson Kirkpatrick[25])*

settlement near Salalah, and the isolated outpost of Furious, located 1100 m up in the Dhofar mountains, through exceptionally difficult terrain in an area without plant, labour or water and in weather ranging from extreme heat to thick mist which persists for several months. It provided the first metalled road between the main southern town of Salalah and the border with Yemen.

The project can be divided into three distinct sections: a 61 km length eastwards from Furious along the top of the escarpment, a 12 km drive west from Mughsayl through deep rock cuttings, and in between the 5 km multi-hairpin climb from the dry river bed or *wadi* at Afal. Balfour Beatty needed to move 7m m^3 of rock using 2500 t of explosives, stitching together the weathered, heavily fissured limestone above the road with around 13 000 anchors, bolts and dowels.[21]

Mobilisation entailed constructing a main camp at Mughsayl, a second base for the western end of the project at Arfit, reached by a 320 km detour across desert tracks, and a third 'fly' camp near the top of the Afal escarpment. Other arrangements included importing the necessary £13m of plant required for the construction work.[21]

Most of the materials were obtained on the site, with the excavated rock being more than enough to provide the fill and a *wadi* gravel pit supplying stone for concrete, asphalt and road base. However, the essential ingredient of water was lacking as the 910 m deep well sunk on site was barely capable of producing sufficient fresh water to compact the road base. To overcome the shortfall, Maunsell, the consultants for the project, approved the use of sea water to compact the earthworks, pumped through a 13 km long pipeline and four 'staging post' lagoons to the top of the escarpment. The pipeline was almost vertical in some sections between lagoons and powerful Lee Hawk pumps delivered up to 680 litres per minute into the storage reservoir at the top of the site.[21]

A third of the total rock excavation was on the wadi Afal mountainside, sloping at 75° and made up of a limestone which varied from soft and chalky to hard crystalline rock. The limestone contained large fissures and was often cavernous. Balfour Beatty drove access routes in two directions to reach the top and bottom of the escarpment as quickly as possible, and after a year and a half succeeded in linking the two with a track climbing as steep as 1 in 3, which could be negotiated by tracked vehicles.[21]

Construction was carried out on four fronts, with faces and benches often being presplit and blasted by drilling rigs suspended from wire ropes. In one section there were six lengths of road stacked one above the other on 4 m wide benches separated by 15 m high faces.[21]

Montague[21] described how a variety of rock stabilising methods were used. For example, large blocks in sound rock were supported by multistrand, high tension anchors up to 25 m long and grouted in position. Tensioned, high yield bolts between 2 m and 5 m long and grouted or glued into the rock face with resin supported medium sized blocks, while untensioned 2 m long dowels held small blocks mainly in shear. Elsewhere degraded and deteriorating faces were treated with shotcrete, with 70 000 m^2 applied throughout the project. Large overhangs were buttressed with mass concrete and fissures sealed with extensive grouting, as illustrated in Figure 3.5.

Multi span viaducts over the two largest *wadis*

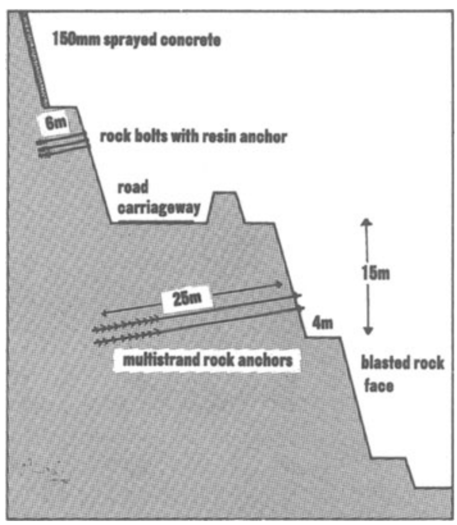


Figure 3.5 *Mughsayl to Furious highway, Oman: methods of stabilising rock surfaces (Source: Montague[21])*

were rejected in favour of 'Irish crossings' designed to be overtopped by the rare but ferocious floods. The larger one was some 800 m long, comprising a six cell box culvert in mid-stream, approached on each side by a road made up of a 7 m wide concrete deck supported by twin 2 m deep downstand beams. These are protected from erosion by banks of heavy riprap. In the few areas where it was impossible to cut the road into the mountainside, benches were formed behind 5 m high retaining walls consisting of rock filled gabion baskets.[21]

The 7 m wide carriageway is augmented by a 3 m wide climbing lane on steeper slopes and has a centreline radius of 14 m on the hairpins to allow for articulated lorries. Road construction consisted of a 30 mm thick asphalt wearing course (increased to 40 mm on climbing lanes) on a 50 mm thick base course (70 mm on climbing lanes) with a 200 mm thick granular road base.[21]

Highway Planning and Design

Classification of Road Networks

Most urban roads perform various functions besides providing passage for moving vehicles and pedestrians, and these may include environmental, access, local and through traffic. However, there is great merit in separating roads that perform different functions in a generally acceptable hierarchy, as mixed function roads rarely operate efficiently or satisfactorily.

The Surrey Design Guide[22] contains a useful hierarchical classification of road networks under the two main categories of primary and secondary road networks. The different types of road perform different functions and are designed to different standards. The different categories of road are now listed and briefly described.

Primary Road Network at National Level

National Strategic Roads – these form part of the national network of high quality routes linking major centres of population.

County Primary Roads – these are routes providing access to points of interchange on national strategic roads, routes for through traffic and links for centres of population.

Secondary Road Network in Urban Areas

Primary Distributors – these form the primary network for the town as a whole, and all longer distance traffic movements to, from and within the town are chanelled on to these roads.

District Distributors – these distribute traffic between the business, industrial and residential districts of a town and form the link between the primary network and the roads in residential areas.

Local Distributors – these distribute traffic within districts and form the link between district distributors and residential roads but do not normally give direct access to dwellings.

Residential Access Roads – these roads link dwellings and their associated parking areas and common open spaces to distributors.

There are also distributor roads and local roads in rural areas.

Road Width and Capacity

The width of a highway link between junctions must be adequate for its intended function in the road hierarchy previously described, and to achieve acceptable levels of safety and operating efficiency.[23] The Department of Transport's procedures for estimating carriageway width are contained in TD 20/85[24] and TA 46/85[25]. Typical design flows for different widths and types of carriageway are given in Table 3.1. James[2] identified the equality of flows on the M25 in each direction in the peak hour, which contained about 7.8% of the 24 hour total. This produced a two-way 24 hour limiting capacity of about 147 000 vehicles per day for dual three-lane carriageways and about 196 000 vehicles per day for dual four-lane carriageways. He also regarded a design life of 15 years to be a reasonable period for road construction.

The standard width for a single two-way, two lane carriageway in Great Britain is 7.3 m, divided by centre line markings into two 3.65 m lanes, one for each direction of flow. In rural areas it is customary to provide additional one metre edge

Table 3.1 *Design flows for two-way urban roads*

Road Type	2 lane carriageway					Undivided carriageway				Dual carriageway		
	Peak hourly flow veh/hour, both directions of flow+					Peak hourly flow veh/hour, one direction of flow				Peak hourly flow veh/hour, one direction of flow		
						4 lane			6 lane	Dual 2 lane		Dual 3 lane
	6.1 (m)	6.75 (m)	7.3 (m)	9 (m)	10 (m)	12.3 (m)	13.5 (m)	14.6 (m)	18 (m)	Dual 6.75 (m)	Dual 7.3 (m)	Dual 11 (m)
A Urban motorway											3600	5700
B All purpose road no frontage crossings, no standing vehicles, negligible cross traffic.			2000		3000	2550	2800	3050		*2950	*3200	*4800
C All purpose road frontage development, side roads, pedestrian crossings, bus stops, waiting restrictions throughout day, loading restrictions at peak hours.	1100	1400	1700	2200	2500	1700	1900	2100	2700			

+ 60/40 directional split can be assumed

* Includes division by line of refuges as well as central reservation: effective carriageway width excluding refuse width is used.

The recommended flows allow for a proportion of heavy vehicles equal to 15%. No allowance will need to be made for lower proportions of heavy vehicles; the peak hourly flows at the year under consideration should be reduced when the expected proportion exceeds 15% by:-

Heavy vehicle content	Total reduction in flow level (vehs/h)		
	Motorway and Dual carriageway all purpose road	10m wide and above Single carriageway road	Below 10m wide Single carriageway road
	per lane	per carriageway	per carriageway
15–20%	100	150	100
20–25%	150	225	150

Source TD 20/85 DTp (1985)

strips but these are usually replaced by kerbs in urban areas.[23]

Lanes on standard dual or multi-lane carriageways are normally multiples of 3.65 m, but local distributor roads often have a width of 6.7 m, reducing to 6.1 m for two-way roads where kerbside parking is restricted. Lanes of greater width than 3.65 m or additional strips at the edge of carriageways may be provided to accommodate cyclists or larger vehicles.[23]

Climbing lanes or crawler lanes are often provided on steep slopes for use by heavy commercial vehicles, and can be formed by either widening a carriageway or reallocating the existing width to provide an additional lane. Further details can be obtained from DTp, TD 9/81.[26]

Where traffic flow in opposing directions varies considerably at different times of the day, one solution is to incorporate an additional centre lane or lanes on which the direction of flow can be varied for fixed periods of time to suit the particular traffic conditions. These lanes must be suitably separated and signed normally using overhead gantries and different coloured road surfacing. The provision for tidal flow is particularly appropriate for major commuter routes and purpose-built radial roads and in locations where the carriageway cannot be widened to full capacity because of structural obstructions.[23]

Carriageways normally have a crossfall of 2.5% from the crown or central reservation outwards towards the side of the road. There are exceptions in the case of curves where superelevation, as described later in the chapter, or elimination of adverse crossfall or camber may be required. Excessive crossfall or camber can be a danger to both drivers and cyclists and should be avoided.[23]

Footways should ideally be physically separated or segregated from carriageways, but this is not always practicable in urban areas. A paved footway should desirably be at least 2.0 m wide and never less than 1.8 m, to permit the satisfactory passing of prams or wheelchairs. Wherever large pedestrian flows are anticipated or more space is available, wider paths can with advantage be provided. A maximum crossfall of 4% is recommended by DTp for footways and verges.[23]

Verges are used to separate footways from carriageways and are often 3.0 m wide, although they frequently have to be omitted in urban areas through lack of space. They have both functional and environmental functions, including accommodating public utility services. They may be grassed or of a hard surface of a different material to the adjoining surfaces and preferably finished with a rough texture, as with cobbles, to discourage use by pedestrians. Where structures such as retaining walls or bridge parapets adjoin the carriageway, they should be separated by a kerbed marginal strip at least 450 mm wide.[23]

Central reserves are provided to create dual carriageways and segregate opposing traffic flows, and are particularly appropriate on multilane roads where speed limits exceed 65 kph. They are also useful in accommodating street furniture such as lighting columns and traffic signs, provided there is adequate clearance. Vehicular crossing points across central reserves help in the provision of temporary diversions during maintenance works or other incidents, and are normally closed by removable barriers to prevent 'U' turns during normal road use.[23]

Road Alignment

Full Overtaking Sight Distance (FOSD) On single carriageway roads, overtaking vehicles have to use the opposing traffic lane for which adequate sight distances are vital. DTp Technical Standard TD9/81[26] contains a design methodology for the coordinated design of single carriageway roads, mainly for use in rural areas, that uses the concept of full overtaking sight distance (FOSD), climbing lanes and sections of four lane road (to facilitate overtaking) to achieve minimum prescribed overtaking values for a route. It also results in certain ranges of horizontal radii not being suitable for single carriageways. Furthermore, it is unlikely that the methodology can be applied to urban roads unless there is a significant length of grade separated or access free carriageway.[23]

Horizontal Curvature The geometrical parameters used in design are normally related to design speed, which is a little in excess of the relevant speed limit; typical ratios being 48:60, 64:70, 80:85 and 96:100 kph. In general terms, horizontal curves on rural motorways should have a minimum radius of 510 m and a desirable minimum of 960 m. Table 3.2 shows typical desirable and absolute minimum values for horizontal and vertical curvature and there is an additional lower level designated 'limiting radius' for horizontal curves.[23]

Superelevation. As a vehicle negotiates a curve it is subject to centrifugal force which can cause it to slide outwards or even overturn. Side friction between the wheels of the vehicle and the road surface will help to counteract this, and superelevation of the carriageway will reduce the overturning effect when V^2/R is greater than 7, where V is velocity and R is radius of curvature.

The percentage superelevation or crossfall, S, is obtained from the equation:

$$S = \frac{V^2}{2.828\,R}$$

where V is measured in kph and R in metres. On horizontal curves, DTp[23] recommend that adverse camber should be replaced by a favourable crossfall of 2.5% when the value of $V^2/\,R$ is greater than 5 and less than 7. However, for sharp curves in urban areas with at-grade junctions and side accesses, superelevation should be limited to 5%.

Transition Curves Transition curves are used to ease the change between a straight and a circular curve or two circular curves where the difference in radii is large. In general, transition curves are considered desirable on curves with a radius less than 3000 m, and essential where the radius is less than 1500 m. Superelevation, or removal of adverse camber, should be achieved progressively over the transition curve which introduces a horizontal curve.

Table 3.2 *Recommended geometric design standards*

Design Parameter / Design Speed (km/h)	120	100	85	70	60	50
A. *Stopping sight distance (m)*						
A1 Desirable Minimum	295	215	160	120	90	70
A2 Absolute Minimum	215	160	120	90	70	50
B. *Horizontal Radii (m)*						
B1 Minimum R *without elimination of Adverse Camber and Transitions	2880	2040	1440	1020	720	510
B2 Minimum R *with Superelevation of 2.5%	2040	1440	1020	720	510	360
B3 Minimum R *with Superelevation of 3.5%	1440	1020	720	510	360	255
B4 Desirable Minimum R *with Superelevation of 5%	1020	720	510	360	255	180
B5 Absolute Minimum R *with Superelevation of 7%	720	510	360	255	180	127
B6 Limiting Radius *with Superelevation of 7% at sites of special difficulty (Category B Design Speeds only)	510	360	255	180	127	90
C. *Vertical Curvature (m)*						
C1 FOSD Overtaking Crest K Value	*	400	285	200	142	100
C2 Desirable Minimum *Crest K Value	182	100	55	30	17	10
C3 Absolute Minimum *Crest K Value	100	55	30	17	10	6.5
C4 Absolute Minimum Sag K Value	37	26	20	20	13	9
D. *Overtaking Sight Distance (m)*						
D1 Full Overtaking Sight Distance FOSD	*	580	490	410	345	290

*Not recommended for use in the design of single carriageways. Source: TD 9/81 DTp (1981)[26]

The length of transition curve, L, can be derived from the equation:

$$L = \frac{V^3}{46.7\,qR}$$

where L = length of transition curve (m)
V = design speed (kph)
q = rate of increase of radial acceleration (m/s^3)
R = radius of curve (m).

Note: q is normally less than 0.3 m/s^3 for unrestricted design, although in urban areas it is often found necessary to increase it to 0.6 m/s^3 or even higher for sharp curves in tight locations.[23]

Vertical Gradients These slow all vehicles and heavy commercial vehicles significantly, increase running costs and the likelihood of accidents, as drivers attempt to overtake slower moving traffic. Steep gradients also present hazards in adverse weather conditions. For these reasons the following maximum gradients should desirably be applied:

> Urban motorways: 3%; all purpose dual carriageways: 4%; and all purpose single carriageways: 6%.[23]

DTp[23] admit that steeper gradients may be justified in hilly terrain but that they should be avoided if possible where traffic flows are high, and a maximum of 5% is suggested for primary distributors. A gradient greater than 0.5% should be provided wherever possible to facilitate drainage of the carriageway surface, while in flat areas it may prove necessary to provide greater falls in the kerbside channels.

Vertical Curves These are provided at all changes of gradient and the curvature has to be large enough to provide safe stopping sight distances. Hence it it is necessary to limit the severity of vertical curves on the brow of hills to provide adequate visibility. Suitable minimum vertical curve radii related to design speeds are given in Table 3.2.

Vertical curves should be parabolic in form to provide a constant rate of change of curvature. The length of a vertical sag or crest curve can be obtained from the following equation:

$$L = KA$$

where L = curve length (m)
K = design speed related coefficient (selected from Table 3.2)
A = algebraic difference in grades (%)

Co-ordination of Horizontal and Vertical Alignments DTp[23] recommend the co-ordination of horizontal and vertical alignments of a road to avoid optical illusions on the curvature of bends, by making all points where horizontal and vertical curvatures change coincident. Where this is not practicable and the curves cannot be separated in their entirety, it is recommended that the vertical curves should be either contained wholly within, or wholly outside the horizontal curves.

Case Studies

Three case studies have been selected covering projects with widely varying characteristics to illustrate different design approaches to meet local requirements. The projects are located in Singapore, Renfrew (Scotland) and Hong Kong.

Expressway Network, Singapore

The Singapore government adopted a middle of the road approach to road development as opposed to the extreme measures of planning for unrestrained traffic demand and that of not providing a major road network and relying on 'planned' congestion to discourage vehicle usage. Singapore's solution comprised a judicious mix of land use planning, road building, traffic restraints/management measures and great emphasis on public transportation to meet the needs of a nation possessing very limited land area.

A key component of the planned road system is an expressway network linking the new towns, airport, industrial zones and other areas such as the central business district (CBD) to one another, and designed to carry heavy volumes of traffic at relatively high speeds. The planned expressway network has a total length of about 141 km.

Construction of the expressways commenced in the early 1970s and by 1989 about 92 km had been completed and opened to use as tabulated in Table 3.3.

Table 3.3 *Singapore Expressways*

Expressway	Length (km)	Location and Function
Pan Island Expressway (PIE)	42	Main artery across middle of island (E-W) from Changi Airport to Jurong New Town
East Coast Parkway (ECP)	19	Changi Airport along East Coast to CBD
Central Expressway (CTE)	16	N-S expressway link through city
Bukit Timah Expressway (BKE)	11	N-S connecting PIE to Causeway to Malaysia
Ayer Rajah Expressway (AYE)	14	E-W connecting ECP to Clementi New Town and Jurong Industrial Area

(Source: Singapore Public Works Department)

Other expressways planned in 1989 were the Tampines, Seletar, Krangi and Kallang Expressways.

The expressways are mainly dual 3-lane carriageways, although there are some lengths of dual 4-lane on more heavily trafficked sections. Intersections with other roads are grade separated and the design speed is 80 kph. The expressways are generally at-grade and the 1989 cost of construction was about S$5m to S$8m per km of length, excluding interchange structures. Construction of interchanges, typically diamond, trumpet or hybrid, varied from about S$20m to S$30m each.

East Coast Parkway The East Coast Parkway (ECP) stretches from Changi Airport to the Keppel Viaduct near Shenton Way (CBD) and was completed in 1981 at the end of a four year construction period, on reclaimed land. It is 19 km in length and has eight interchanges. The impressive Benjamin Sheares Bridge, a high level bridge illustrated in Plate 11, carries the ECP over the Singapore and Kallang Rivers at the waterfront south of the city. It is constructed with a prestressed concrete box girder deck supported by prestressed concrete beams, 47 m long, on trestle frames. On this section traffic flows are at their highest and are typically about 6000 vehicles per hour in one direction during the peak hour.

To the south of the expressway are parklands, sports facilities and other recreational land uses, while to the north, the land use is more intensive, consisting of high rise office blocks, residential apartments and commercial development. Together with the Ayer Rajah Expressway (AYE), the ECP provides an attractive bypass route south of the city for east-west traffic in the southern part of Singapore.

Central Expressway The 5 km stretch through the city area is the most expensive section of the expressway as the highway is carried for substantial lengths in tunnels, comprising a 700 m long, dual 4-lane tunnel with on/off ramps and a 1800 m long, dual 4-lane tunnel with a major interchange linking to the city roads. It also involved crossing beneath the Singapore River and the construction cost of this section of expressway in 1991 was about S$400m.

Taking the expressway in tunnels resulted in improved environmental and aesthetic conditions, with less noise and air pollution, preservation of open spaces, elimination of visually obtrusive viaducts and the facility for future developments in some areas over the tunnels. To ensure the smooth and safe movement of traffic, the tunnels incorporated adequate ventilation, lighting, traffic surveillance and control, fire protection, drainage and emergency power supply systems. All these systems are monitored by a computerised control centre manned 24 hours a day, and there are emergency telephones and emergency exits provided in the tunnels.[27]

Renfrew Motorway Stage 1

Scott Wilson Kirkpatrick were appointed in 1971 to produce the final design and supervise the construction of this section of motorway as part of the Highway Plan for Glasgow. This section is a link in the east-west motorway route across the city, connecting the west flank of the Glasgow Inner Road to an existing rural motorway at the city boundary via stage 2 of the Renfrew Motorway. This section of the motorway was constructed in 1973–76 at a cost of £22m (1976 costs), and comprised four three-lane carriageways 1.9 km long, and two three/four-lane carriageways 1.4 km long. In addition there were 2.3 km of surface streets. Large traffic volumes at the junction with the Dumbreck Road Connection, constructed in 1981, led to a braided interchange design in which no weaving of traffic occurs, thereby providing a separate route to the east and the two motorways to the west, as illustrated in Figure 3.6.

To minimise the effect on the urban environment, the motorway route follows closely the Glasgow-Paisley railway along the western section and the edge of existing industrial development along the remainder, as shown in Figure 3.6. The relatively low profile of the motorway, together with the high water table, dictated the need for substantial sub-soil drainage work. Also as the route passed through a congested urban area, it was necessary to divert many existing services. A flexible pavement was adopted because of the ground conditions.

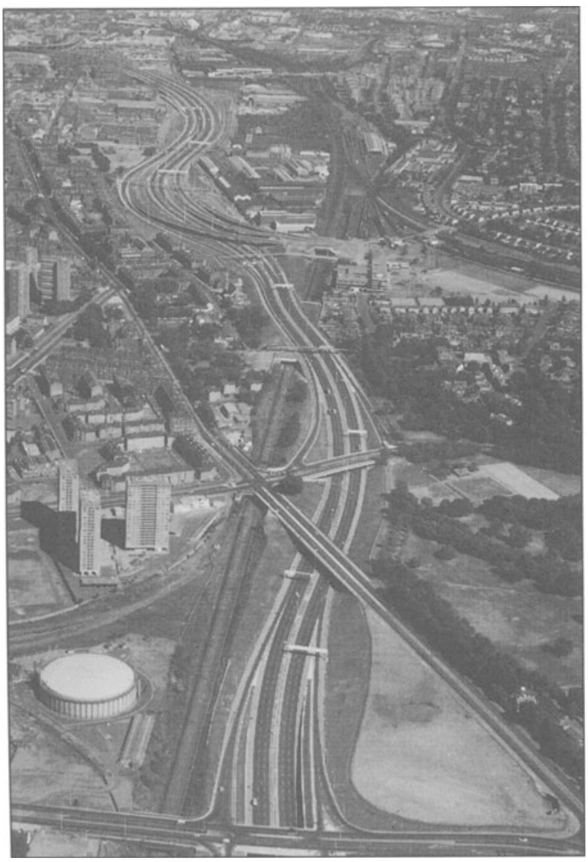


Figure 3.6 *Renfrew Motorway, Stage I (Source: Scott Wilson Kirkpatrick)*

Road bridges, railway bridges, footbridges and their associated structures accounted for a substantial proportion of the project cost. Four distinct types of structure were used, comprising post-tensioned concrete box girder bridges, pretensioned M-beam bridges, flat slab reinforced concrete bridges and prestressed concrete footbridges. The braided interchange section incorporated continuous post-tensioned box girder bridges, both curved and tapering in plan, with relatively long side cantilevers. Extensive reinforced concrete cantilever retaining walls were constructed and attention was paid to landscaping where it was practicable.[28]

Hong Kong Main Road Network

In recognition of the growing transportation needs, the main road network of Hong Kong was improved substantially in the 1980s, with the completion of the Island East Corridor, connecting the Central Business District (CBD) with the eastern part of the Island, the Cross Harbour Tunnel connecting the Island with Kowloon, and the Aberdeen Tunnel connecting the northern and southern sections of the Island. Further improvements were being implemented in 1989 including the Eastern Harbour Crossing, while further tunnels and bypass schemes were being planned, often involving considerable land reclamation because of the severe shortage of land suitable for development in the main urban areas.[29]

Figure 3.7 provides a striking aerial view of a section of the Island East Corridor near Quarry Bay, constructed partly over the harbour and partly on reclaimed land, with two graded interchanges to link the expressway with the adjoining road network. It shows clearly the immense and complex civil engineering works involved in implementing major highway improvements in Hong Kong.

Figure 3.7 *Island East Corridor, Quarry Bay, Hong Kong (Source: Hong Kong Territory Development Department)*

Traffic Appraisal and Modelling Techniques

Traffic Appraisal

Traffic studies provide vital information on the fundamental characteristics of traffic flow, the behaviour and desires of drivers, and the capacity of highway facilities. Traffic flow characteristics encompassing volume, classification, size, weight, speed, lateral placement and auto occupancy are evaluated and provide the necessary data for planning and programming. The information obtained from the comprehensive survey of an area provides the data needed for system selection, route location and design, cost benefit analysis (CBA), justification and priority assessment.[30]

Yu[30] describes how a volume count programme is important in supplying data for classification, study of demands, programming, economic studies, evaluation of service, design requirements, prediction of future traffic flows, and the extension of counts from a short period of time to average annual daily traffic. Traffic volumes are subject to hourly, daily and seasonal fluctuations and to annual trends, but they form a reasonably stable pattern in rural areas.

Origin and destination studies are carried out to provide information associated with motor vehicle trips and their lengths and purposes. Information is obtained by means of roadside interviews from as large a sample of traffic as is feasible.

Following the assembly and processing of information from traffic studies, traffic and flow maps can be produced. The traffic densities for each sector of road are recorded on the map. In order to facilitate interpretation, the volume of traffic is often shown on the traffic flow map by bands proportional in width to the volume of traffic passing through the various points at which traffic counts were taken. Traffic flow maps are useful in selecting routes for improvement and as a basis for comparison with future traffic volume studies.[30]

Ad hoc sample surveys produce useful data for specific problems but DTp[23] have described how their output may be difficult to integrate within a comprehensive time series data bank. However, regular monitoring surveys can provide the means of relating ad hoc surveys to a more comprehensive base, such as by using factors to convert average annual flows with an appreciation of the confidence levels of the estimates.

DTp's Traffic Appraisal Manual (TAM)[31] gives details of all the data sources provided from national surveys and of the appropriate methods for converting sample counts into equivalent traffic flow estimates for design purposes. These data are derived mainly from the core of 170 sites and rotating censuses of traffic carried out on the national road system, although few of the sites are located in urban areas.

Modelling Techniques

Application of Computers to Traffic Engineering
Williams[32] has described how analyses of the causes and effects of present and future traffic flows on main roads are based on the methodologies of quantitative procedures. The use of

mathematical models of road traffic have, as a major objective, the testing of alternative proposals for the development of parts of the main road network. The results assist with design work, cost benefit analyses (CBA), and the preparation of phased programmes for implementing plans and investing resources.

Analytical models of road traffic and transportation systems take various forms but most encompass a three phase process incorporating:

> generation (of traffic in relation to land use) distribution (of traffic between centres of activity) assignment (of traffic to specific routes and by various modes of transport).[32]

However, Williams[32] believes, with some justification, that the elegance of some theoretical treatments of these problems tend to be out of balance with the quality of the raw detail being input, and thus giving an unrealistic sense of precision. Hence there is a continuing need for refinement of the techniques.

The applications of the results of traffic computations to main road networks, in whole or in part, give emphasis to the critical importance of the interrelationships of land use development plans and transportation systems. Furthermore, the greater the compromise, in terms of geometric design, through less traffic lanes, less grade-separated interchanges and more at-grade junctions, the greater the need for traffic engineering techniques and police enforcement, often embracing traffic lane controls, signs, signals, markings, kerbside facilities and parking controls.[32]

Traffic Models DTp[23] have defined a 'traffic model' as a mechanism for estimating the way in which a transport network would be used by traffic given the distribution and characteristics of the area's population, employment and other land uses. The output could be the number of vehicles using each road or number of passengers using each public transport service, depending on the objectives of the study and the type of model being used. The term 'forecasting procedure' may also be encountered and refers to the process by which input information required for a future traffic model is produced.

A localised area traffic model may be sufficient to provide the required information and there are several models available, each with its own capabilities and limitations. In the UK models commonly in use include SATURN[33], CONTRAM [34], and TRAFFICQ[35] are all being used increasingly to test the effects of different situations on relatively small road networks.[23]

The Transport Studies Unit of Oxford University produced a computerised simulation model, called CLAMP, which enables the effects of a variety of policy changes to be assessed in terms of vehicle speeds, travel times, search times and generalised cost.[36]

DTp[23] have described how many transport studies use 24 hour average annual daily flows (AADF) but traffic congestion in urban areas usually occurs during relatively short peak periods (often 1 to 2 hours), and it is during these periods that most of the operational costs and benefits are incurred. Thus demand analysis in urban areas should concentrate on AM and PM peak periods together with a representative off peak period.

Congested Assignment Models One group of assignment models enables the user to describe selected road junctions in detail, so that delays which relate to specific turning movements can be modelled. Different types of junction, such as traffic signals, roundabouts or priority junctions, can be specified. Delays are calculated using time dependent queueing theory, specific traffic flow profiles and traffic volumes. They do however have limitations in use such as the inability to incorporate linked traffic signals and difficulties in taking account of 'queueing back'. Programmes of this type include HINET[37], JAM[38] and TRIPS.[39]

Another group of congested assignment models uses simulation techniques, rather than fixed equations to represent delays. These models examine traffic situations in more detail and are capable of representing time dependent effects, such as signal coordination and different route choice with varying conditions. Typical examples are SATURN[33] and CONTRAM,[34] each with their different approaches to traffic simulation.[23]

Traffic Simulation Models Simulation techniques have been used to model the progression of individual vehicles through small networks so that interactions with pedestrians, other vehicles and traffic control features can be represented more realistically. These differ from assignment models in that the precise route of each vehicle passing through the network forms part of the input data and changes in route choice caused by changing travel conditions are not included. A commonly used traffic simulation model in the UK is DTp's TRAFFICQ,[35] which represents the precise features of roads and junctions and a variety of traffic incidents in a dynamic way.

A useful traffic simulation model developed by West Yorkshire County Council, called TRANSIM, achieved simulation by progressing discrete vehicle units through a given network. A computer-generated graphical representation of the precise position of every vehicle at a given instant, together with the status of every traffic signal, is produced. A sequence of images is then recorded on cine film or video tape to give an animated display. It also permits the independent modelling of the movement of cars, buses and goods vehicles. The model caters for vehicle separation, speed, acceleration and behavioural characteristics. Gap acceptance criteria are specified for merging and overtaking situations, and various traffic signal cycle and co-ordination settings can be tested.[40]

Typical Applications of Draughting and Modelling Techniques

Chertsey Traffic Model

The traffic modelling work for the Chertsey study, undertaken by L.G. Mouchell and Partners, involved the building of a SATURN traffic assignment model upon which to test the impact of town centre traffic management schemes, pedestrianisation and a new relief road. The trip matrix was developed from roadside interview data supplied by Surrey County Council. The roadside interviews were carried out in September 1987 on seven sites forming a tight cordon around Chertsey town. All interviewing was conducted inbound to Chertsey but outbound trips were obtained by reversing the inbound trip matrices. To infill the wholly internal trips a matrix estimation technique using turning movement count data was employed. Finally, the trip matrix was growthed forward to 1989 using local factors derived from long term automatic traffic count data.

Figure 3.8 illustrates how a road can be designed on a computer. It shows a typical perspective view obtained by using MOSS (highway design system supplied by MOSS Systems Ltd) and GDS (general draughting system marketed by McDonnell Douglas). The figure also shows the site contours and the details of earthworks, highways and drainage work are all produced by computer aided design. GDS can also be used to generate accurate working and contract drawings.

Road Junctions

Choice of Road Junctions in Urban Areas

Road junctions are particularly important because of their constraining effect on traffic capacity, the possible creation of traffic hazards and their effect on route selection. DTp[23] have subdivided urban road junctions into three main categories.

(1) *Priority Junctions.* These establish the precedence of one road over another and can assist in emphasising the designated road hierarchy. Layout and road markings can be used to encourage or discourage particular turning movements. Staggering of cross roads or closure of a particular arm of a junction can reduce the attractiveness of a route for through movement as well as reducing accident risk by removing the number of conflict points.

(2) *Signalised Junctions.* Signal-controlled junctions can also be used to emphasise the road hierarchy by giving precedence to one route over another in terms of capacity and vehicular delay. They also provide the opportunity to assist pedestrians crossing at junctions, and are therefore used extensively in urban areas.

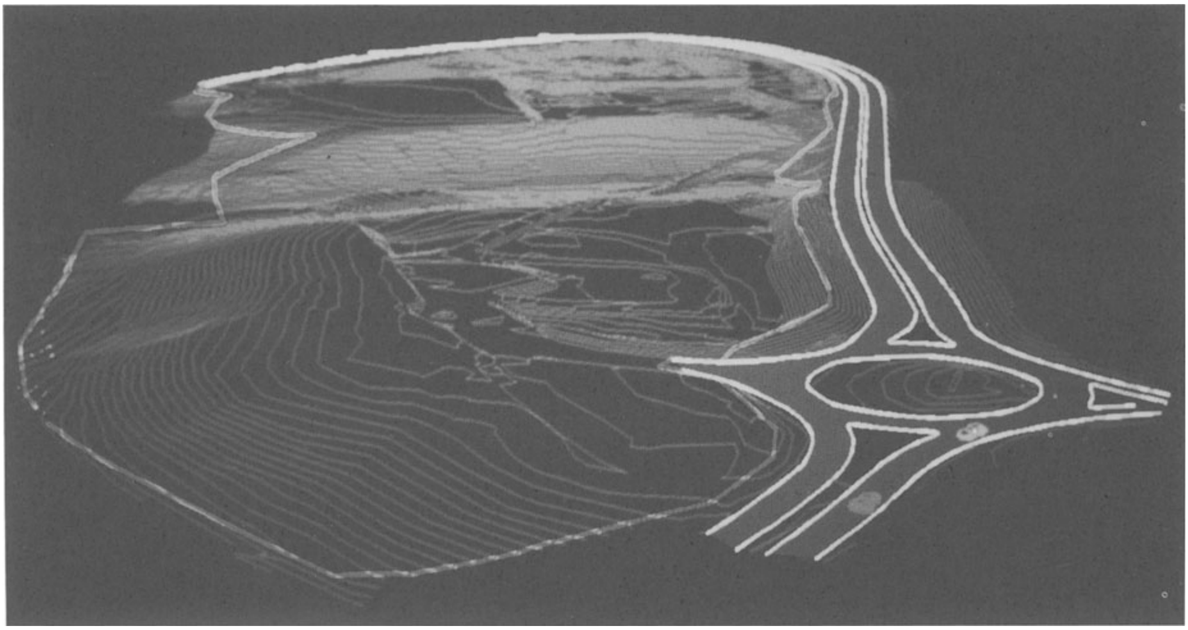


Figure 3.8 *Typical perspective view using MOSS and GDS systems (Source: Travers Morgan)*

(3) *Roundabouts and Gyratory Systems.* There are a number of different types of roundabouts and gyratory systems and their selection is influenced by the physical layout of the site, the nature of the approach roads and the traffic control objectives. The types available include traditional roundabouts with a kerbed central island more than 4 m in diameter; 'mini' roundabouts with a flush or slightly raised central marking; gyratory systems consisting of a series of one-way streets linked to provide a circulatory system; and 'ring' junctions where the arms of large existing roundabouts are treated individually to create a series of small junctions. Roundabouts provide good opportunities for vehicles to turn right and to create free flow conditions where capacity does not exceed demand.[23]

Advice on the size and layout of major/minor road junctions can be obtained from TA 23/81[41] and TA 20/84.[42]

Intersections with Grade Separation

On motorways all interchanges should be grade-separated as illustrated in Figures 2.1 and 3.6, whereas on all-purpose dual carriageways, junctions may be at-grade or grade-separated, while single carriageways are not normally grade-separated. It will be appreciated that at-grade junctions can give rise to vehicle conflicts, reduce vehicle speeds and increase operating costs.

The complexity and possible conflict between traffic movements at the intersection of two or more roads can be reduced significantly by providing for the separation of traffic on different levels, thus allowing the heaviest flows to pass unimpeded through the junction while lighter flows, including all turning movements, are accommodated at separate levels, either above, below or both. However, even where the topography is favourable grade-separation entails high capital cost and hence extensive economic, operational and environmental assessments are required prior to the detailed planning stage.[7]

Advice on the selection and design of all types of interchange is provided in TA 48/86[43] and TD 22/86.[44]

Turnbull[7] has subdivided grade-separated interchanges into two basic categories:

(1) those permitting free flow conditions; and
(2) those imposing the need for certain streams of traffic to give way to others.

Free flow interchanges are the most complex and expensive type of junction. They do, however, provide uninterrupted movement for vehicles moving between principal routes by the use of link roads with a succession of merging/diverging lanes and weaving sections. Whereas non-free flow include those between motorways where a roundabout is provided and those which involve two level intersections where the main road is connected by slip roads to the minor route at grade. These latter intersections include diamond and dumbell layouts and the use of roundabouts.[7]

O'Flaherty[45] has identified the simplest type of *four-way, two-level junction* with grade-separation as the *diamond*, which consists of a single bridge and four one-way slip roads, and can be accommodated within a relatively narrow strip of land. Its use is confined to intersections of major and minor roads and is adopted fairly extensively in urban areas because of its low land take up.

The *cloverleaf* is a four-way two-level single structure interchange with right turning traffic carried by loop slip roads. It offers relatively simple operation but requires a large area of land, particularly when used at the junction of two high speed, heavy volume roads. British practice is to adopt minimum radii of 75 m for loops that are connected to motorways and 50 and 30 m radii are used for loops connected to main all-purpose roads. O'Flaherty[45] identifies a number of other disadvantages associated with this type of junction.

The *turban*, *braided* and *all-directional* multi-level interchanges all accommodate direct right-turning and left-turning movements and are illustrated in *Traffic Planning and Engineering. Vol. 1.* [45] They fall into the category known as 'directional', free flow interchanges, whereas the *cloverleaf* could be categorised as 'semi-directional'. Directional interchanges are the most sophisticated type of interchange and are best suited for the intersections of motorways which carry high volumes of traffic.

Multiway junctions form another category of grade-separated junctions of which the most common type in the UK is the two-level bridge roundabout. It is particularly useful when the intersection has more than four approach arms. The main road underpasses or overpasses an at-grade roundabout intersection and vehicles enter and leave the main road on diagonal slip roads. A great advantage is that it can be adapted from an existing at-grade roundabout that is overloaded.[45]

Case Studies

This section of the chapter concludes with two case studies, one in the UK and the other in Australia, to show the practical implementation of the selection and provision of interchanges and grade-separations.

M25–M40 Interchange

This interchange was opened to traffic in 1985. At the preliminary design stage seven types of layout were studied and compared and this indicates the wide range of choices available and the main criteria to be considered. The alternative layouts comprised the following approaches.

1. Three-level roundabout of very large dimensions, approximately 1000 m × 750 m, and there were also substantial site constructional problems.
2. Three-level roundabout with direct links (south-west) involving steep gradients and extensive earthworks.
3. Free flow interchange with tight loops for north-west and south-east movements (loops and links).
4. Four-level free flow interchange which was unsuited to the site topography.
5. Free flow full cyclic interchange providing high standard links for all movements.

6. Three quarters cyclic with south-facing slip roads at the A412, showing some cost savings but causing delays at the A412 junction.
7. Half cyclic with north-facing slip roads at the A413, involving extensive site works.

Detailed comparison was concentrated on the loops and links (3), and the full, three quarters and half cyclical junctions (5–7). The full cyclical junction had the highest capital cost followed by the three quarters and half cyclics, while the loops and links had the lowest cost (74.5% of the full cyclic).

On balance it was decided that the loops and links scheme should be adopted, as it provided a high standard route for the main west-south movement, facilities for all other movements and had the lowest cost. It also made best advantage of the site; the skew of the crossing suited the loops and links concept for the traffic flows and only three major interchange bridges were required. The interchange contract layout incorporating the selected solution is illustrated in Figure 3.9.[46]

The Hume (Melbourne–Sydney) Freeway: Interchanges and Grade Separations

The Hume Highway is the major road link between Melbourne and Sydney in Australia. Following the National Roads Act 1974 it was declared a National Highway, and since then extensive Federal funding has assisted its progressive development to an ultimate freeway (motorway) standard, with a general design speed of 110 kph. In 1987 it was carrying up to 14 000 vehicles per day, of which approximately 30% were truck traffic.[47]

Along the Hume corridor the full diamond is

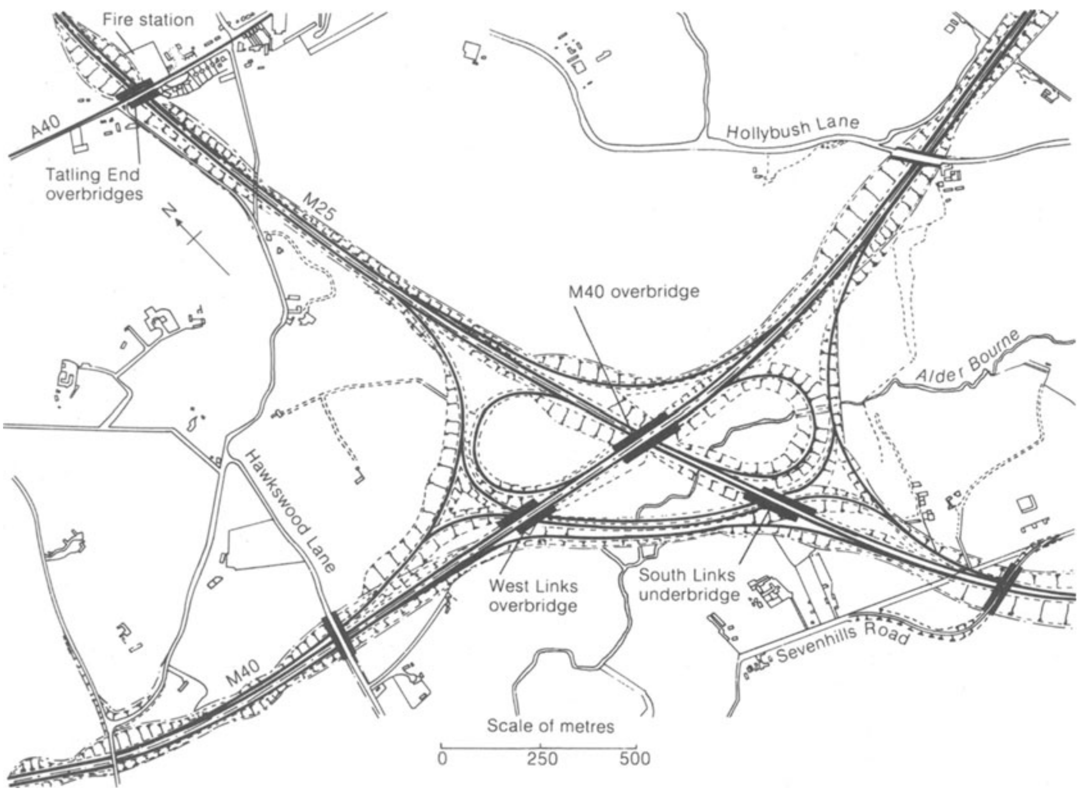


Figure 3.9 *M25-M40 interchange contract (Source: D. Langdon[46])*

the most common form of interchange, although there are examples of half diamonds and Y junctions. In a few cases, a semi-direct interchange has been adopted because of the relatively high volume of high speed traffic on the intersecting highway connections. Except where topography and/or grading dictate otherwise, the cross road has been taken over the freeway, and the ramps are spread to join the cross road at about ground level.[47]

Underwood[47] has described how in the location of interchanges and grade separations, the following factors were taken into account.

(1) the existing and possible future developments of the adjoining land
(2) the existing road pattern, and the need or otherwise to maintain reasonable continuity, and the restoration of local access
(3) the volume of traffic on the existing roads, and the requirement for access to and from the freeway
(4) provision for essential and emergency services
(5) topography
(6) costs
(7) spacing considerations
(8) type of interchange.

Interchange spacings vary from a minimum of 2 km to a maximum of 16 km, with an average of 5–6 km. On rural freeways, it was not considered necessary to build all interchanges and grade separations initially. Where local road volumes were low, at-grade intersections were provided initially and the interchange or grade separation constructed at a later date when conditions warranted it.[47]

Road Drainage

Approval of the Water Authority is required for all highway drainage schemes and surface water run-off from new roads is piped to surface water sewers, if available, or to natural water courses. All highway surfaces, including footpaths, verges and visibility areas, should, as far as practicable, drain towards a carriageway channel.

The Surrey Design Guide[48] describes how carriageways are generally either cambered or side-hung but that shared surfaces may be drained on the design centre line. Centre line drainage is particularly appropriate for housing courts or where a speed control island is provided. Crossfalls for mechanically surfaced and concrete roads should be between 3% (1:33) and 2% (1:50), and for hand laid bituminous materials or paviours, between 2.5% (1:40) and 3.5% (1:30). Drainage channels consisting of preformed units bedded on concrete should have a gradient of at least 0.67% (1:150), whereas those of reinforced concrete, bituminous materials or paviours bedded on sand should have a gradient of not less than 1% (1:100). Any shared surface with centre line drainage should have a minimum gradient of 2% (1:50) on the channel line.

Gullies are normally located under carriageway channels and are generally 450 mm diameter by 1050 mm deep, to take the run-off from not more than 200 m^2. Alternatively, 300 mm diameter by 750 mm deep pots may be used to receive the run-off from not more than 55 m^2. The maximum distance between gullies is usually 50 m, but where channel gradients exceed 4% the maximum spacing is reduced to avoid excessive velocity in channels, as shown in Table 3.4.

Table 3.4 *Maximum spacing of gullies*

Gradient	<4%	5%	6%	7%	8%	9%	>10%
Max spacing	50m	40m	33m	28.5m	25m	22m	20m

(Source: Surrey design guide.[48])

Rural motorways incorporate hard shoulders on the outer edges of dual carriageways and a central reservation. *French drains* are often provided in the central reservation and cut-off French drains at the outer edges of hard shoulders to lower the groundwater and remove surface water. French drains may consist of open jointed concrete or clay pipes or perforated pipes of concrete, pitch fibre or asbestos cement encased in filter material. The drain trenches are normally backfilled to a width equal to the outside diameter of the pipe plus 300 mm for trenches not exceeding 1.50 m deep, increasing to 450 mm for deeper trenches.[10]

Soakaways are occasionally used to remove surface water from roads but they are best avoided wherever possible as they entail expensive maintenance and can cause pollution of the aquifer.

Water Streams across Carriageways at Changes of Crossfall Direction Pratt[49] has identified the problem of flowing streams across carriageways which frequently occur at changes of crossfall direction. These present twin dangers to the motorist of aquaplaning and lack of visibility through spray suddenly thrown up by a preceding vehicle. Kerb inlet type gullies accentuate the problem, since bypass flows may range from 35–80% of the channel flow approaching the inlet, depending on the design flow width (0.5–1.0 m) and road gradient (1:200–1:15) at the inlet. Hence additional interception capacity should be incorporated at the terminal kerb inlet gully, prior to the crossfall change, to alleviate the problem.

The design of *surface water sewers* for the drainage of carriageways and associated surfaces will be examined in some detail in chapter 4.

Bridges

Bridge Types

The structural design and construction of bridges is often one of the most challenging and complex aspects of modern civil engineering work. The classification of bridges can take various forms and Fletcher and Lavan[50] have described how the traditional approach is to base them on the method of longitudinal support to the deck, namely girders, arch or suspension.

In a *girder or beam bridge*, the deck is supported by large girders of steel or concrete which span on to piers or abutments. Prefabricated beams of steel or precast concrete are economic for spans up to 40 m, and cantilever bridges can be formed by placing supports a distance in from the ends of beams.

Arch bridges are normally formed of brickwork or stonework, but are not in common use for modern bridges as they require substantial foundations and cannot provide a high clearance at mid span.

Suspension or cable stayed bridges are generally used for spans over 250 m. Suspension bridges can exceed spans of 1 km; the Humber bridge has a clear centre span of 1410 m. However, tentative calculations suggest that spans over 8 km are possible using carbon fibre composite cables. This type of bridge has two continuous cables anchored at their ends and carried over two towers. The towers are cellular in construction and can be built in reinforced concrete using a slip forming technique or in steel comprising stiffened welded steel plate. Another form of cable bridge is the elegant cable stayed bridge which has increased in popularity and is illustrated in later examples, whereby the deck is supported by tension cables which are supported from a tower or pylon. The cables normally either radiate from the top of the pylon as a fan or from points up the pylon in the form of a harp, although semi-harp and asymetric arrangements of stays are also available. They have advantages over suspension bridges in that the deck can either be reinforced concrete or steel, expensive anchorage blocks are not required and improved stiffness and aerodynamic stability is achieved, particularly with a concrete deck.[50]

Walther *et al.*[51] have described how cable stayed bridges consist of three main load bearing elements – cables, decks and pylons – each contributing to the structural behaviour of the whole. Hence it is possible to have a stiff deck, stiff pylons, or the stays themselves can be the stabilising element of the structure. There is therefore a wide range of possible load bearing systems and cable stayed bridges offer a great freedom of choice and expression.

Bridge decks can be of concrete, composite construction (concrete and steel) or steel. Reinforced concrete slabs are usually avoided to reduce self weight and are suitable for spans of about 20 to 25 m. Precast prestressed beams are used for longer spans. Composite decks normally consist of welded plate girders with a reinforced concrete deck, while steel decks are associated with suspension bridges often consisting of enclosed welded plate box sections.[50] Steel decks can be as little as one fifth of the weight of concrete decks but are likely to be two to four times as expensive.

Fowler[52] has identified the following limiting factors to maximum bridge spans apart from material strength:

(1) an innovation in bridge form would be needed to give say a 4 km long bridge aerodynamic stability
(2) the durability of bridges seems to be decreasing, as stone bridges have survived for many centuries, whereas some 50 year old suspension bridges are in serious states of decay
(3) the use of and loading on bridges can increase out of all recognition in as short a period as 20 years
(4) as vehicles are becoming lighter to conserve fuel, they are more sensitive to crosswinds and need to be protected from them.

Farraday and Charlton[53] have described very cogently how the design of a bridge over a river requires detailed consideration of route location, potential traffic flow, structural and foundation requirements and the river characteristics. This necessitates collecting information and understanding the factors that determine channel stability, water discharge and water levels, sediment discharge, scour and sediment deposition, and hydrodynamic forces, following which predictions need to be made about what is likely to happen in particular circumstances. Information may be collected by aerial, hydrographic and hydraulic surveys and future predictions may be based on calculations or numerical or physical model studies. The importance of this subject was highlighted in a Railway Inspectorate report in April 1990 relating to the collapse of the Glanrhyd bridge in October 1987 when a two car diesel multiple unit plunged into the River Tywi with the loss of four persons. The report established lack of understanding of river behaviour and the mechanics of scour by British Rail engineers as a key factor in the disaster.

Case Sudies of Bridge Design and Construction

A number of diverse and interesting case studies are now considered to show some of the principal approaches that have been adopted in practice.

The elegant *River Torridge Bridge* carries the A39 Bideford bypass over the Torridge estuary in North Devon. It is a high eight-span continuous structure made of variable-depth prestressed concrete, using the glued segmental balanced cantilever method, and carries a 7.3 m wide single carriageway and is 650 m long with 90 m river spans and 24 m headroom. The river foundations are formed of caissons sunk 16 m to the sandstone and mudstone bedrock, while other foundations consist of 2.1 m diameter bored piles and spread footings. The bridge won the Concrete Society Award 1988 and was shortlisted for the British Construction Industry award in the same year.[54]

The bridge was designed to carry HA and 45 units of HB loading in accordance with the DTp's technical memorandum BE1/77[55]. It was decided that in this area of great natural beauty, the most appropriate solution would be a bridge crossing the whole valley as a single entity with roughly equal spans as illustrated in Figure 3.10. Alterna-

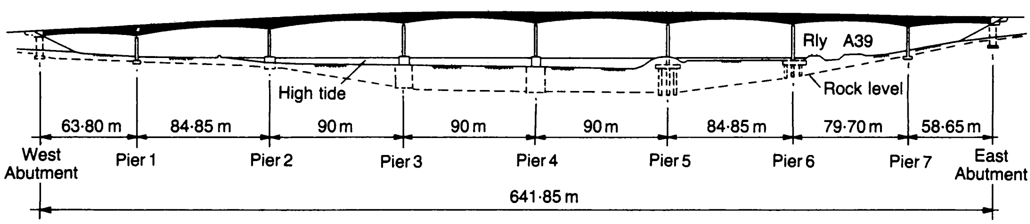


Figure 3.10 *Torridge Bridge: south elevation (Source: C.H. Pothecary & T.J.C. Christie[54])*

tive steel box girder designs were more expensive than the concrete design adopted. There were however special problems encountered in building a series of 90 m spans high above a tidal estuary that dried out at low tide and had to be kept open to commercial traffic at high tide. A balanced cantilever construction offered the best solution.[54]

Pothecary and Christie[54] described how the scheme was changed to single carriageway in 1980 and the loading became more onerous. The consultant (MRM Partnership, Barnstaple) requested the client (DTp) to reconsider the provision of a curved soffit bridge which would provide the greatest depth where the moments were greatest, light segments at the ends of cantilevers where the dead weight effect was most onerous and a more slender looking structure overall, and this was finally agreed. Because

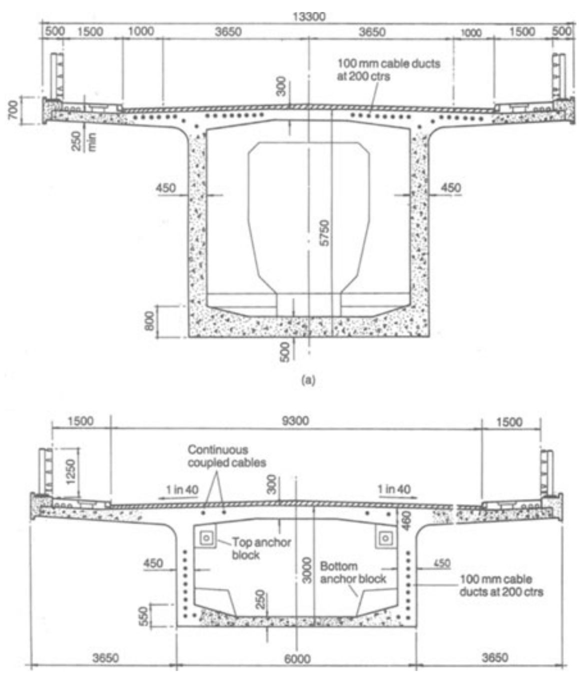


Figure 3.11 *Torridge Bridge: deck sections (a) near pier and (b) near mid-span (Source: C.H. Pothecary & T.J.C. Christie[54])*

multi-span variable-depth bridges sometimes produce a sense of visual restlessness, special care was taken with the deck proportions, especially the ratio of the haunch depths and mid-span depths, even though this resulted in different soffit radii for spans of different lengths, and computer-drawn perspective profiles from different angles were plotted to ensure there was no undesirable effects caused by foreshortening or oblique viewing.

The deck consisted of a single celled 6 m wide box with cantilever wings. The depth of the box varied from 5.75 m at the pier to 3 m in the middle of the span as detailed in Figure 3.11, which also shows the location of the prestressing cables. The soffit thickness varied from 500 mm at the pier to 250 mm near the quarter point. The concrete was of class 50/20.[54]

Pothecary and Christie[54] described how the superstructure is supported on seven single vertical columns or piers. These are roughly coffin shaped in plan tapering from 2.5 m wide on the centre line to 1.7 m wide at the edge as illustrated in Figure 3.12. This shape has aesthetic and structural advantages. The narrow leading edge gives the columns a slender appearance, and the inclined facets add interest by reflecting different intensities of light and shadow. There is a deep groove down the obtuse centre lines of the arrises so the shape of the column is apparent even in flat lighting. The grooves are also used to conceal the cables for the navigation lighting and as drainage channels for any water collecting on the surface of the pier/column. At the top of the columns the cross section is tapered down to a 1.7 × 6 m rectangle to avoid any visual conflict between the shape of the top of the column and the soffit of the pierhead unit which rests on it.

Pothecary and Brindle[56] have described how the caissons consisted of steel cutting shoes, reinforced concrete outer walls and internal stiffener walls sealed with steel bulkhead plates, suitably caulked to form the top of a large inverted waterproof box. The bulkheads were fitted with air cocks to allow air to be pumped into or out of the chamber. Steel tubbing was bolted to the outer walls of the caissons and

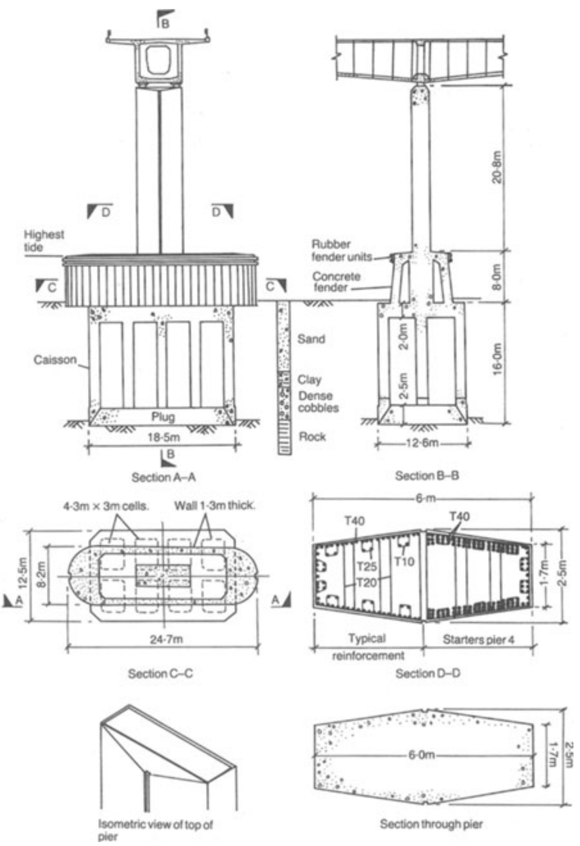


Figure 3.12 *Torridge Bridge: river piers/columns (Source: C. H. Pothecary & U. J. C. Christie*[54]*)*

sealed to give greater freeboard for floating them out to the bridge site. The tubbing was later used as formwork for the concrete pours, when completing the caisson construction at the bridge site. The complex caisson sinking procedures are illustrated in Figure 3.13.

A comprehensive description of the erection of the superstructure of the bridge is contained in ICE paper 9516.[57]

Another excellent example of a prestressed concrete balanced cantilever bridge is the *Tsing Yi North Bridge* in Hong Kong which was constructed between 1984 and 1987 with a main navigation span of 160 m. The bridge provides four traffic lanes connecting the island of Tsing Yi with the Hong Kong mainland, near to the new town of Tsuen Wan, and connects into the trunk road network in the region and forms part of the Tsuen Wan bypass described earlier in the chapter. The bridge crosses a channel 260 m wide and is connected at each end by prestressed concrete box girder structures giving a total length of crossing of 1015 m and is illustrated in Plate 10. The design is well described and illustrated in an ICE paper by Denton-Cox and Weir.[58]

Rendel Palmer and Tritton, consulting engineers, designed and supervised fifty bridges in the 15 km long Section II of the Heads of the Valleys Road which bypasses Merthyr Tydfil in South Wales. Three of the bridges including the *Nant Hir Bridge*, illustrated in Figure 3.14, comprised twin parabolic arches with a 13.2 m wide deck, supported on portal frame spandrels, all in reinforced concrete. The arch ribs were cast in successive sections cantilevering out from the abutments. Each section was tied back by steel cables to a temporary tower, which in turn was anchored to the arch springing block. This ingenious and innovative method of construction resulted in not only an economic proposition, but an extremely elegant bridge, blending well with the surrounding countryside. The excellence of the design was acknowledged by the granting of a Civic Trust Award for Design.[59]

A good example of a cable stayed bridge is provided in the *third Dartford crossing of the Thames* which was completed in 1991. The Dartford crossing stretches 2782 m between abutments with a 450 m long main span over the river Thames and three shorter anchor spans approached by 1 km of viaduct each side, linking the M25 motorway east of London. The bridge supplemented two tunnels which were grossly overloaded by flows of more than 80 000 vehicles per day. The bridge was privately financed, built and operated by Dartford River Crossing, formed by Trafalgar House, two banks and the Prudential, which also owns the tunnels. A consortium of TH subsidiaries, Cementation Construction and Cleveland Bridge and Engineering, undertook the £86m design and construct contract.

The bridge's two main towers stand 137 m

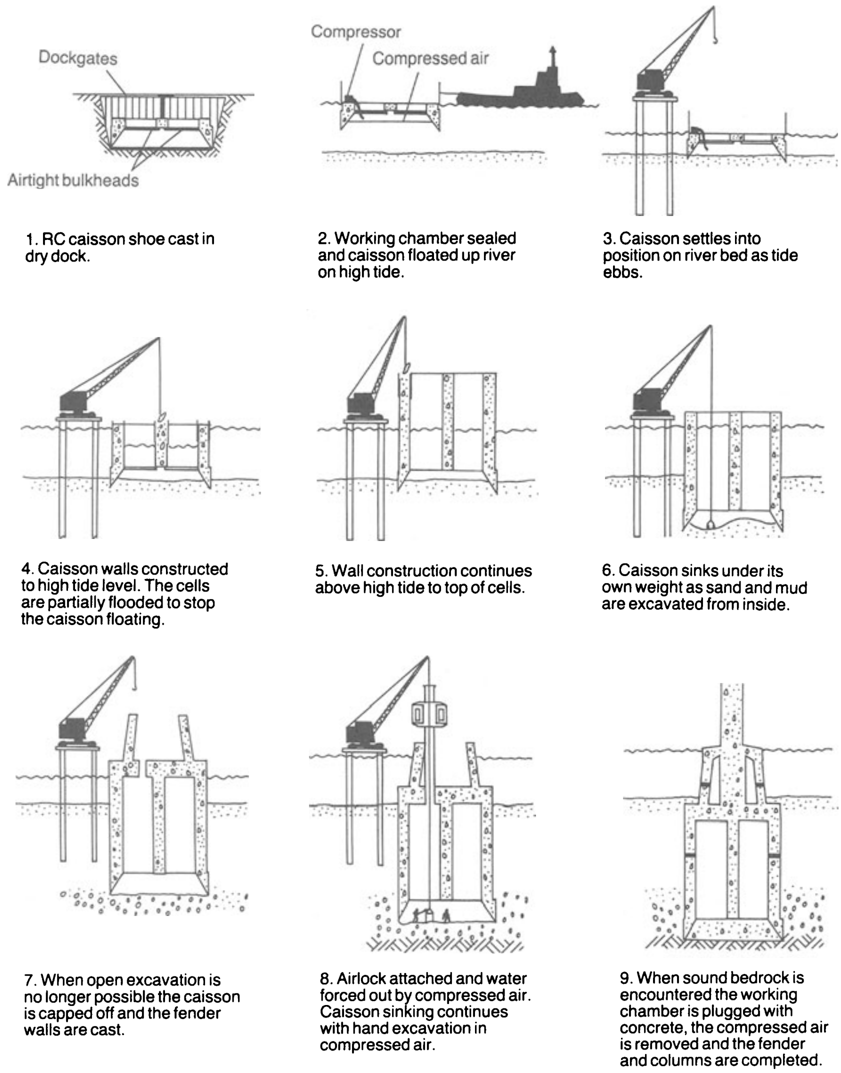


Figure 3.13 *Torridge Bridge: caisson sinking procedures (Source: C. H. Pothecary & L. Brindle[56])*

high, with twin arrays of cables off each tower connected to the outer edges of the deck, with caissons forming the bases of the main pylons. Outer girders are linked at 5 m intervals by cross girders and then inner longitudinal girders were built up in short lengths between the cross girders. A continuous steel plate forms the top chord of the orthotropic deck topped by a 120 mm thick concrete slab.

Central piers for the world's widest cable stayed bridge over Houston harbour in Texas are protected by artificial islands, but this option was not available at Dartford as the Thames is too narrow. It was therefore decided that only bulk in the piers could provide the necessary resistance to the rotational and sliding forces generated by a ship impact. The caissons are flat sided, closed base concrete with semi-cylindrical rounded ends, designed to offer the minimum profile to impact.

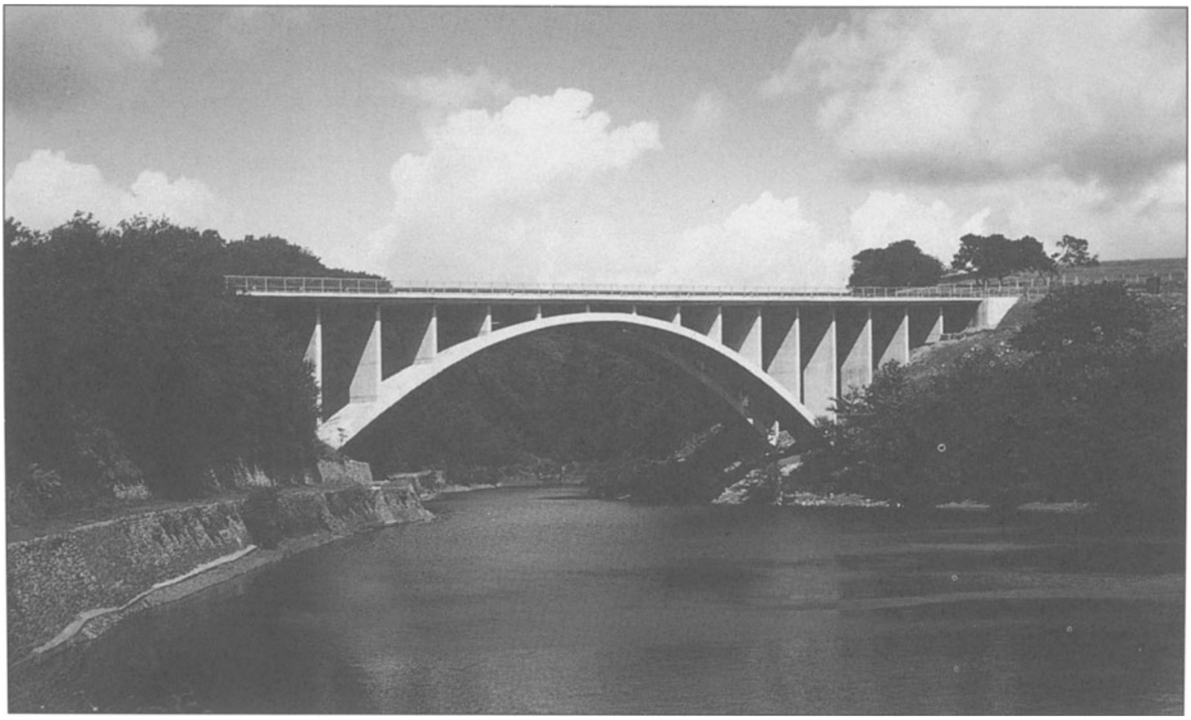


Figure 3.14 *Nant Hir Bridge on Heads of Valleys Road, South Wales (Source: Rendel Palmer & Tritton)*

The spectacular *Dolsan Bridge* is of cable stayed design and is located near the fishing port of Yoesu in South Korea. It was funded by the World Bank and designed by Rendel Palmer and Tritton. It has a main span of 280 m, with two 85 m side spans and an overall length of 450 m, connects the island of Dolsan with the mainland and is illustrated in Figure 3.15. The bridge is narrow being only two lanes wide but this made the design more difficult. Advanced design pneumatic caissons were employed in the excavation of the main piers, sunk to 25 m below sea bed.[59]

A 2000 tonne floating crane was used for erecting the towers and side spans. The tower base sections were the first units installed by the floating crane, and the fully assembled towers were each erected as single lifts. The construction period extended from 1981 to 1984.[59]

During the design stage special attention was paid to the aerodynamic performance of the bridge, involving wind tunnel tests and extensive use of the firm's Prime 400 computer system for carrying out complex analysis. The result shown in Figure 3.15 is an impressive, slender aerodynamic box girder, supported at its edges by cables radiating from the triangular shaped steel towers, straddling the two lane carriageway.

The Akashi Suspension Bridge, to be completed in 1998, will outstrip the Humber crossing as the longest span bridge in the world by more than 40%, with a 1990 m main span. Ferguson[60] describes how the site is in an earthquake zone with poor geology, treacherous currents and typhoon winds. The bridge will form part of the northernmost of three ambitious crossings between Japan's main island of Honshu and neighbouring Shikoku and spans between the city of Kobe on Honshua and the intermediate island of Awaji.

Many design aspects were still being determined in 1990. For example, the initial design showed towers rising to an unprecedented height of to 333 m above sea level, which would be

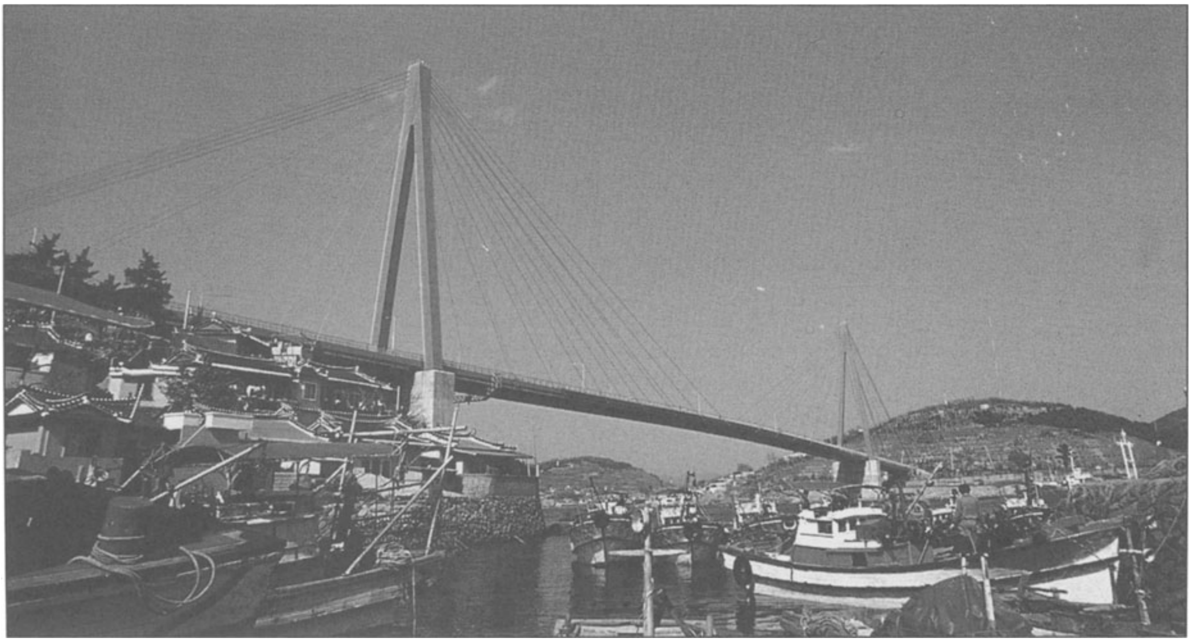


Figure 3.15 *Dolsan cable stayed bridge, South Korea (Source: Rendel Palmer & Tritton)*

subject to self induced oscillation at very low wind speed and have to withstand large lateral forces during storm winds leading to huge bending moments at the base. The designers were considering reducing the height of the towers to 297 m to alleviate these problems.

Another problem was the new phenomenon of 'ripple effect' which consists of a rigid oscillation of the towers occuring during construction when some of the cables are installed and possibly leading to fatigue failure of the steel. The very large total loading of 120 000 t led to the adoption in the initial design of four main cables, each 840 mm in diameter and arranged as two pairs of double cables. However, if the number of cables were reduced to two, this would make erection simpler and quicker and would also halve the number of hangers and deck connections. Such a change was dependent on developing a higher strength steel with a 1800 N/mm^2 breaking strength, which would permit the use of two 1090 mm diameter cables.

In the Akashi Straits, scour as deep as 15 m could occur with powerful tidal currents of 4 m/s. To counteract this, caissons were changed in shape from rectangular to circular, to reduce both drag and risk of scour. One will be 80 m in diameter and 70 m high and the other 78 m diameter and 57 m high. The bridge is designed to resist a Richter 8 earthquake 150 km offshore, producing an acceleration of 1.8 m/s^2 at the bearing layer. Rather surprisingly the only aspect of the design to be critically dependent on earthquake loading is the diameter of the tower foundations caissons, to prevent tilting. After the steel caissons are placed on the sea bed, an annular cylinder around the perimeter is filled with concrete.[60]

Sydney Harbour Suspension Bridge which was supplied by Dorman Long was commenced in 1926 and opened in 1932, is world renowned with its single arch of 503 m span. It carries eight traffic lanes, two railway tracks and lanes for pedestrians and cyclists, and has four attractive stone-faced pylons. In 1990 it carried more than 66m vehicles per year and was being supplemented by an adjoining tunnel. It contained about 6m rivets, 485 000 m^2 of steelwork to be painted

(30 000 l/coat) and annual maintenance costs in 1990 amounted to approximately A$3m.

Bridge Maintenance

Introduction Barnard[61] has described how the principal aims of bridge maintenance are to preserve or restore the intended load carrying capacity of a bridge and to ensure the continued safety of road users within the limits of available funds. Bridge maintenance includes strengthening even although this may be classified as capital works.

The 1981 OECD Report on bridge maintenance[62] showed that the bridge replacement rate in Britain was below that necessary to meet the commonly accepted design life of 120 years for modern structures. With the figure at about 0.4% p.a., the renewal and repair rate requires an average structure to last for twice its design life. Furthermore, the expenditure on bridge maintenance was estimated at 0.55% p.a. of replacement value, which, in the report, was stated to be only sufficient to cope with essential maintenance, but not adequate to prevent long term deterioration.

Inspections Bridge inspections are required to determine the current condition of a structure, to assess its load bearing capacity and to discover any faults, thus identifying the maintenance requirements and the cost implications. The Department of Transport, and numerous other authorities, follow the practice set out in Technical Memorandum TRMM 2/88,[63] comprising general inspections every two years and principal inspections every six years. However, some engineers vary the frequency of the inspections according to the type and condition of the bridge. Special inspections may also be necessary such as where traffic accidents have caused bridge damage or after floods. On these occasions, and at regular intervals, underwater inspections by divers with video cameras and other suitable equipment should be carried out to check on scour and erosion. A useful guide to current practice in contained in DTp's *Bridge inspection guide*,[64] and it is important to adopt adequate safety procedures. A variety of access hoists and lifting or underbridge platforms are used to enable all components of bridges to be closely inspected. The inspector may use high power arc lights, binoculars and cameras, including remote controlled devices, to assist in the work of inspection.[61]

Testing and Monitoring Most inspections start with a close visual examination of the surface of the structure, accompanied by appropriate probing and tapping to locate possible faults. If potential defects are suspected, non-destructive testing techniques are often used but in some cases samples are taken for laboratory testing. Table 3.5 shows some of the commonly used testing methods.

Monitoring the condition of a bridge can take various forms, ranging from tell-tales and crack width measuring instruments to the use of strain gauges, inclinometers and laser based methods. Non-destructive testing using ultrasonics and covermeters, or the taking of samples and exploratory holes and cores, all have an important part to play.[61]

Reports and Records Most engineers use standard report forms for the recording of inspection particulars, often supplemented by relevant sketches, measurements, photographs and test results. Records generally include drawings, basic dimensions and loadings, details of inspections and assessments, photographs and maintenance manuals. Much of the information is now held on computer databases for ease of storage, access and retrieval.

Bridge Defects

Foundations deterioration usually results from settlement and ground movement or from scour. Scour can be a serious problem in flood conditions, and prompt inspection is advisable followed by remedial works, which may comprise inverts, bagwork, sheet piling or tremie concrete.

Concrete can be subject to cracking and spalling and these together with inadequate cover to reinforcement, poor quality concrete or carbonation below the depth of the reinforcement, can

Table 3.5 *Schedule of tests for routine bridge inspection*

Property	Tests	Remarks
Concrete bridges		
Strength	Guide to assessment	BS 6089
	Cores	BS 1881 Pt 120 Minimum number required
	Surface properties	BS 1881 Pts 202 and 207
Durability	Carbonation	Phenolphthalein indicator
	ASR	ASTM C856-33 petrographic examination
	Chloride	BS 1881 Pt 124 or titration
	Sulphate	BS 1881 Pt 124
	Cement content	BS 1881 Pt 124 or BS 4551
Reinforcement location/cover	Covermeter	BS 1881 Pt 204
	Radiography	BS 1881 Pt 205 Safety precautions needed
Reinforcement corrosion	Half-cell potential	STM C876-80 Indication only
Cracks, voids and internal defects	Crack width gauges	
	Ultrasonics	BS 1881 Pt 203
	Endoscopes	Care needed for prestressing ducts
	Radiography	BS 1881 Pt 205 Safety precautions needed
	Sub-surface radar	
	Vibration methods	
Structural behaviour	Strain gauges	BS 1881 Pt 206
	Deflection gauges	Reponse to static loads
Dynamic response	Vibration methods	
Movements	Survey methods	Long term monitoring
	Laser techniques	
Steel bridges		
Material properties and thickness	Test samples	BS 5400 Pt 6 and
	Ultrasonics	BS 2600 Pts 1 and 2
Weld cracking and surface defects	Dye penetrant	
	Magnetic particle	BS 6072
	Ultrasonics	BS 3923 Pts 1 and 2
	Radiography	BS 2600 Pts 1 and 2
Internal flaws and laminations	Ultrasonics	BS 5996
	Radiography	BS 2600 Pts 1 and 2
Paintwork		
Surface condition	Microscopic examination	
	Mechanical tests, adhesion, cross-cut etc.	BS 3900 Group E
Paint thickness	Wet and dry film thickness gauges	BS 3900 Pt C5

(Source: C.P.J. Barnard[61])

result in corrosion of reinforcing bars. The increased use of deicing salts has resulted in severe cases of chloride attack, particularly on the underside of decks on overbridges and around leaking expansion joints. Alkali-silica reaction can occur when there is a combination of highly alkaline cement, reactive aggregate and water.[61]

A comprehensive survey and report for DTp by Maunsell and Partners in 1989[65] on the performance of concrete in 200 motorway and trunk road bridges found that 75% of the bridges surveyed were seriously damaged by road salting because of leaking deck joints and needed urgent repairs. The advent of heavier loads will result in the need for considerable strengthening work and one third of the bridges were showing signs of alkali silica reaction. The report contained recommendations for repairs and future maintenance as well as identifying areas for future research.

In an investigation carried out on 12 post-tensioned bridges built between 1958 and 1977,[66] voids were found in ten bridges and corrosion in one strand in a virtually empty duct. It was however considered that as post-tensioned bridges contained many longitudinal tendons, the risk of sudden collapse because of the corrosion of tendons was small. Nevertheless, in December 1985 the Ynys-y-Gwas bridge in West Glamorgan, made up of segmental I beams, collapsed,[67] mainly because of corrosion of tendons caused by salt water entering through the joints.

Steel structures are subject to corrosion unless adequately protected, usually by paint systems, which need regular inspections to assess the rate of deterioration and to determine the most suitable times for patch painting or a full repaint. For major structures in particular, DTp's Technical Memoranda BD 18/83 and BA 13/83[68] call for a survey by a specialist paint technologist where the breakdown of a coating is either premature or widespread. Corrosion in steelwork can lead to a significant loss of section in members and in bolted and riveted connections, and cracking in welds can also result in loss of strength in a structure. *Components* such as waterproofing, drainage, bearings, joints and parapets are all very vulnerable because of their high exposure.[61]

Traffic Management

Traffic Management Objectives and Techniques

In *Roads and Traffic in Urban Areas*[23] the term 'traffic management' is used to describe the process of adjusting or adapting the use of an existing road system to meet specified objectives without resorting to substantial new road construction. The process can also be subdivided into permanent and temporary traffic management. Permanent traffic management comprises permanent arrangements for controlling and aiding traffic movement, while temporary traffic management is introduced to assist the flow of traffic where roadworks are being undertaken and can embrace road signs and temporary traffic signals for minor works and extensive signs, bollards, contra flow systems and reduced speed limits on motorway widening, which are likely to be seen in abundance on the UK motorways and trunk roads throughout the 1990s.

The principal *objectives* are to reduce road accidents; improve the environment; improve access for people and goods; and improve traffic flows on primary and distributor roads. There are however often trade-offs between different objectives as there can be some conflicts between them.[23]

The *techniques* consist primarily of physical measures and traffic regulation, supported by statutory provisions and procedures.

Examples of physical measures include reallocation of existing highway space; alterations to road layout at junctions; opening or closing roads to particular classes of traffic in one or both directions; changes to surface level, texture or alignment to control the speed of traffic; coordinating the phasing of traffic signals; the provision of or alteration to traffic signs and road markings; providing crossing facilities for pedestrians and/or cyclists; providing stopping places for public service vehicles and shelters for passengers; providing taxi ranks; and alterations to landscaping and street furniture to improve the environment.[23] The choice of type of road junction can be an important component of traffic management and this aspect was examined earlier in the chapter.

Methods of traffic regulation include control by traffic signals; imposition of speed limits; introduction of one-way operation; restrictions on the directions of movement at junctions; restrictions on the use of parts of the carriageway by specified classes of vehicle; exclusion of vehicles by size or weight; limitations on parking and loading; and temporary regulations for special events.[23]

Aids to Traffic Movement

Aids to traffic movement are necessary for the guidance of drivers to ensure that they reach their destination in a safe and effective manner, with a minimum of inconvenience to other road users and the population generally. Drivers require a constant supply of information, such as the correct lanes to use, possible hazards ahead and nearby and more distant place names. Most of this information is supplied in the form of traffic signs located either beside the carriageway or above it. General guidance on traffic signs and their use is contained in *Traffic signs regulations and general directions*[69] and the Traffic signs manual.[70]

Traffic signs are divided in the traffic signs regulations[69] into four basic categories: warning, regulatory, directional informatory, and other informatory. The sizes of signs vary according to the type of road and the speed of traffic, and they may be illuminated or reflectorised.

Carriageway markings comprise white longitudinal lines, edge of carriageway lines, transverse lines and hatched markings, and yellow lines consisting of box junction markings, transverse bar markings, and school entrance and fire station markings. Roads studs are used in conjunction with lines and are generally reflective and may be white, red, amber or green.

Traffic Control Components

Any method or device that aims to limit conflicts and/or segregate vehicles and pedestrians is a form of traffic control. The four principal methods are:

(1) traffic signals at road junctions
(2) pelican and zebra crossings
(3) linked signals and urban traffic control (UTC) to minimise vehicle delays by using a central computer to coordinate a number of traffic signals over a wide area
(4) special applications of traffic signals ranging from peak hour control of roundabouts to assisting emergency traffic vehicles.

The use of traffic signals at road intersections allow vehicle movements to be controlled by allocating time intervals during which separate traffic demands make use of the available road space, and are frequently used at busy urban junctions. Their co-ordination over a section of a road network forms the basis of most urban traffic control (UTC) schemes, normally combined with a UTC operations centre.

Traffic signals in a UTC area are usually controlled by a central computer which sends electronic instructions by telephone type cables to each junction. Co-ordination can also be obtained by using 'cableless link' units which use timing devices to implement preset signal timings.[23]

The two basic types of UTC system in use in the UK are fixed time control systems and traffic responsive control systems. The most widely used technique for calculating fixed time signal settings is the TRANSYT 8 computer program developed by the TRRL.[71] SCOOT is a fully responsive control system is 'on-line' and monitors traffic flows continuously from on-street detectors, recalculates traffic model predictions every few seconds, makes systematic trial alterations to current signal settings and implements the alterations which the traffic model predicts will be beneficial.[72]

SCOOT and TRANSYT UTC systems can operate in adjoining parts of the same urban area. SCOOT is generally most useful in central areas where congestion is high and flow patterns are complex and variable, whereas fixed time TRANSYT UTC systems are best employed where congestion levels are lower and flow patterns reasonably consistent as on radial arterials.[23]

Surveillance Systems

Surveillance systems are used to control traffic flows on major motorways in urban areas and normally include the provision of closed circuit television, matrix signalling, emergency telephone upgrading and variable message signing. A typical control and surveillance centre is shown in Figure 3.16.

Road Safety

Extent of Road Accidents

In 1984 over 15 people were killed every day in road accidents in Great Britain and over 200 seriously injured and the total cost to the community was estimated at £2650m. Between 1958 and 1984, the number of personal injury road accidents remained relatively constant at about 250 000,[73] but rose to 317 000 in 1988, and 5050 people died. Over the same period the volume of traffic more than trebled, indicating a reduction in the accident rate of almost two thirds, as a result of the combined effect of legislation, improvements to highway layouts, vehicle design and safety education. Furthermore, road deaths per thousand of population were less than in any other European Community country, but there is still much to be done to reduce the level of accidents, as highlighted by Jones and Romanis.[74]

Figure 3.16 *Traffic surveillance centre (Source: L.G. Mouchel & Partners)*

Children and the elderly suffer higher pedestrian casualty rates than the rest of the population, and justify special attention. The effective costs of fatal accidents is staggering and a cost benefit analysis of an average fatal accident in 1987 was costed at just over £0.2m (£142 000 for lost output, £56 000 for pain, grief and suffering and £1100 for medical costs), although such costs are often difficult to assess precisely.

Factors Contributing to Accidents

The principal factors have been subdivided into two main categories (road users and road environment) by O'Flaherty[45] and these can be summarised as follows:

Road users

(1) perceptual errors, such as drivers or pedestrians looking but failing to see, distraction or lack of attention, or misjudgement of speed or distance
(2) lack of skill, resulting from inexperience, lack of judgement, wrong action or decision
(3) manner of execution, such as deficiency in actions (too fast, improper overtaking, failure to look, following too closely, wrong lane), or deficiency in behaviour (irresponsible or reckless, frustrated, aggressive)
(4) impairment, such as alcohol, fatigue, drugs, illness or emotional stress.

Road environment

(1) adverse road design, such as unsuitable layout and junction design, and poor visibility due to layout
(2) adverse environment, such as slippery road, flooded surface, lack of maintenance or bad weather conditions
(3) inadequate road furniture or markings, such as insufficient and/or unclear road

signs and road markings, or poor street lighting
(4) unexpected obstructions resulting from roadworks, parked vehicles or other objects.

General Characteristics of Road Accidents

DTp investigations have shown that about three quarters of road accidents occur on built-up roads.[73] The urban road environment is often complex and places a heavy strain on road users who must continually be on the alert. Junctions occur at frequent intervals, shops and advertisements compete with road signs for drivers' attention and parked vehicles can restrict manoeuvring space and hamper visibility. Probably worst of all, vehicles and pedestrians are brought into potentially dangerous proximity to one another.[23]

Accidents tend to be concentrated at particular locations, such as town centres or junctions on major roads, with two thirds of all accidents occurring at road junctions. These vulnerable areas justify close investigation and the implementation of alleviating measures such as improvements to lighting, signing or road layout. Pedestrians, cyclists and motorcyclists are more likely to become involved in accidents and their injuries are more likely to be serious or fatal.[23] In 1988 less than 3% of accidents occurred on motorways, while in built-up areas nearly 70% of accidents occurred at or near junctions.

Remedial Treatment

Sites are best selected for treatment on the basis of a screening process carried out against selected criteria, such as the total number of accidents which have occured at the site within the last three years. The definition of a blackspot can vary from one part of the country to another. For example, in a dense metropolitan area a site may be identified as a blackspot if it has twelve accidents in three years, whereas in an outer urban area four accidents in three years could be considered exceptional.[23]

Accident maps showing individual accidents plotted on a network overlay are a valuable aid to investigation work. The detailed analysis of individual sites requires a description of each accident, including details of the movement of each road user involved, together with road lighting and weather conditions prevailing at the time. Research should ideally be undertaken into the monitoring and evaluation of accidents and site conditions, likely effects of remedial measures, evaluation of probable benefits and a road safety audit.

Most local authority engineering departments have now established accident prevention units, supplied with accident data, computers and design manuals and having the expertise to identify blackspots where modest expenditure can yield large returns in terms of reduced accidents. A few thousand pounds spent on anti-skid treatment, improved sightlines, pedestrian guardrails, modified traffic islands or small roundabouts, introduced at carefully selected locations can produce a rate of return well in excess of any conventional road scheme.

Safety Information and Publicity

Roads and Traffic in Urban Areas[23] describes very aptly how education and training programmes mounted both nationally and locally can raise the level of understanding and skills of road users and assist in improving attitudes and behaviour. National campaigns are organised by the Department of Transport (DTp), while local authorities may undertake campaigns covering problems of general concern such as cycle awareness or to promote and reinforce specific local safety measures. Dissemination can be by television, radio, cinema, roadside posters, the press, leaflets and exhibitions. Guidance is given in an OECD manual.[75]

Comprehensive road safety education in schools should ideally be developed jointly by road safety officers, teachers and the police to provide a graduated process of instruction and learning, geared to the requirements, capabilities and ages of the children concerned.[23]

Parking

Parking Demand and Policy

Parking demand is generated by the land uses and it is necessary to formulate a parking policy to satisfy the identifiable needs and meet the following principal objectives.

(1) maintaining required traffic flows by taking appropriate measures for controlling on-street parking or loading
(2) regulating private parking space in building developments to ensure the provision of adequate operational space
(3) providing sufficient off-street parking space and
(4) taking adequate measures to ensure the efficient use of parking space.[76]

The parking policy should ideally be formulated after considering the following factors:

(1) The type of use for which parking provision is required, namely residential, operational (space required for vehicles regularly and necessarily involved in the operation of a business), and non-operational (space required for vehicles which do not have to park at the premises).
(2) The present use and predicted future demand for parking space derived from surveys and assessment of future demand.
(3) The existing parking space and areas where additional facilities can be provided.
(4) The financial targets and constraints.

On the basis of the data so obtained, the following decisions can be made:

(1) determining the amount, type and location of on-street and off-street parking
(2) deciding the method of providing the additional space
(3) determining the appropriate pricing structure, time limits and control methods.

Parking Provision in Urban Areas

In the central areas of towns and cities, the demands for car parking vary between long duration parking for commuters, short stay parking for shoppers, and short to medium term parking for people using the town for entertainment, business and other activities. Parking policies should aim to meet these needs and be structured to resolve conflicting demands. They are an important factor in the effective functioning and commercial well-being of a town.

On-street Parking This is the traditional and cheapest method of parking. It is however essential that it is controlled in busy areas to avoid traffic congestion and delay and to safeguard safety and amenity. On major city streets the permitted parking must be related to the capacity of the roads and the traffic flow.

Waiting may be prohibited at all times, during the working day or during certain periods only. It may be restricted to certain periods of time such as 30 minutes or two hours. The need to restrict periods for loading and unloading, to prevent all stopping by imposing clearway restrictions and to provide suitable areas for bus setting down or taxi waiting areas must also be considered. The issue of parking tickets by traffic wardens or the police is generally necessary to ensure the effectiveness of waiting restriction orders, but powers also exist under s99 of the Road Traffic Act 1984 for the removal of vehicles which are illegally or dangerously parked or parked in such a way as to cause obstruction.[76]

Parking Meters and Cards Parking meters are the most widely used method of imposing parking charges for vehicles parked on the highway. The main disadvantages are the reduced number of vehicles which can be parked because of the extra length of spaces, their poor appearance and the high initial equipment costs.[76]

O'Flaherty[45] has described how with the British disc system, the parking cards can be obtained free of charge from a number of sources, including police stations, garages and newsagents. The driver displays the cardboard card on the windscreen of the car, and a time-marked circular disc is rotated until the time of arrival is shown in an aperture at the front of the card. The maximum allowable time for parking is indicated on kerb signposts, and checking of the time parked is normally undertaken by a traffic warden. In other countries it is customary to make a charge for parking discs.

Residents' Parking Schemes In many older parts of urban areas where large numbers of houses were built without garages or parking spaces, car owning residents generally have no option but to park on the street. The Road Traffic Regulation Act 1984, sections 32–35, made provision for the making of parking place orders without charge for resident permit holders. Before implementing such a scheme detailed surveys are required to determine the extent of the problem, as described by Wadsworth.[77] Based on a 5 year payback period, annual permit costs in 1988 exceeded £20 each.

Lorry Parks In 1971 DOE recommended the setting up of a national network of secure lorry parks for long distance lorries. They need careful siting in relation to the major road network and industrial areas and with consideration to the effect on the local environment.

Off-street Parking Off-street parking is required for both operational and non-operational users. Operational users require good access to business premises, and shoppers need to park as near as possible to shopping areas, banks and associated facilities. The facilities may consist of surface level or multi-storey car parks. Parking areas for workers require separate provision.

In 1989, sixteen variable message signs were located strategically around Cambridge to direct drivers only to car parks with spaces available. At the time it was claimed to be one of the most advanced schemes of its kind. The concept of such signs was not new as they were already in use in Harrow, Torbay and Leicester.

Multi-Storey Car Parks

These are used extensively in the central areas of the larger towns and cities as the only way of satisfactorily accommodating large numbers of cars. Goldring[78] has listed their main essential features which are as follows:

(1) The building should be designed to avoid defects commonly encountered, such as inadequate falls for surface water, cracked and leaking decks, poor internal illumination, insufficient ventilation, difficult circulation, lack of security, difficult entrance and exit, and unsatisfactory geometry in general.
(2) Structure to be soundly constructed of durable materials entailing a minimum of future maintenance.
(3) Car park is completely functional and can be used by motorists with ease and safety.
(4) The building is environmentally acceptable inside and out.
(5) Adequate energy saving and security measures are incorporated.

Columns should be kept to a minimum consistent with being structurally sound to make the parking of cars easier and quicker, to improve visibility, security and illumination, and to make cleaning and maintenance easier.

The internal circulation should be so arranged as to provide drivers with a search pattern on entry so that they pass as many spaces as possible and have a short exit route. Double ramps are preferable to two single ones and the width between kerbs should never be less than 3.5 m and preferably much more. The usual recommended bay size is 5 m × 2.4 m with 6 m wide aisles. Where possible, slip roads should be provided to allow for queueing or tailbacks.

Readers requiring more detailed information on the design, construction and maintenance of multi-storey car parks are referred to Chrest *et al.*[79]

Road Lighting

Principal Objectives

The main objectives in providing road lighting can be summarised as follows:

(1) to supplement vehicle headlights, extending the visibility range beyond their limits both laterally and longitudinally, thereby increasing the safety of road users
(2) to improve the visibility of roadway features and objects on or near the road
(3) to clearly delineate the roadway ahead
(4) to improve the visibility of the environment, with minimum interference to amenities
(5) to reduce the apprehension of road users and
(6) to assist in the prevention of crime and acts of vandalism.

Road Lighting Principles and Categories

By illuminating the road surface uniformly, obstructions are seen as a dark outline against a light background (silhouette) for the whole width of the road. The driver is thus able to interpret the whole scene from a distance and this enables him to react to any obstruction in sufficient time. To achieve this, the pools of light from adjacent lamps should overlap so that dark patches on the road surface are kept to a minimum.[80] This objective can be nullified in practice by large overhanging roadside trees situated between the lights.

Wright[81] has aptly prescribed the criteria of quality for road lighting to ensure good visual conditions as follows:

(1) achievement of the appropriate level of road surface luminance
(2) uniformity of luminance distribution across and along the road
(3) adequacy of lighting to the immediate surroundings of the road
(4) correct limitation of glare from the lighting equipment.

Road lighting in the United Kingdom is broadly divided into two categories:

Group A lighting on main roads and traffic routes, which include motorways, trunk roads, principal county roads and other classified roads.
Group B lighting which is generally confined to residential and side roads but may include some classified distributor roads carrying relatively light traffic.[80]

Lighting Design

Group A Lighting
Columns generally have a mounting height of 10 m or 12 m which support lanterns (luminaires) containing electrical discharge lamps of 135–400 W with the rating dependent on the type of lamp and the mounting height.

Lamps These mainly comprise low pressure sodium lamps (SOX and SLI) and high pressure sodium lamps (SON). The older amber low pressure sodium (SOX) lamps were progressively being phased out in 1990 as, although they were efficient, produced a great deal of glare making driving more difficult and disturbed residents with bedroom windows close to street lamps. The improved high pressure sodium (SON) lamps are almost equally efficient, with improved colour, longer life and with cut-off luminaires the glare is much reduced.

Lanterns These are divided into two main types: cut-off and semi cut-off which differ in the amounts of light distribution.

The *cut-off lantern* is well suited for use on highways where there are open areas on both sides of the road, and reflection from adjoining buildings is minimal. It directs all light downwards, and the main beams are emitted at an angle of 65° to the downward vertical. Hence the columns are usually more closely spaced to secure maximum uniformity of lighting on the road surface. The central or opposite siting of street lights is best with cut-off lanterns.

The *semi cut-off lantern* is more widely used in urban areas where there is background luminance from adjacent buildings. The light distribution spreads to the surroundings of the highway. The main beams are directed at 75° to the downward vertical, and a certain amount of light is emitted above the horizontal plane.[80]

Column Siting Lighting columns can be sited in various ways depending on the road layout and design, and range from staggered and single sided arrangements on single carriageways to opposite and centrally sited columns on dual carriageways. The average spacing to height ratio is approximately three to one for cut-off lighting and four to one for semi cut-off lighting.[80]

Group B Lighting

The mounting height of lanterns may be 8 m, 6 m or 5 m, depending on the road width and use. The lamps range from 35 W to 150 W discharge lamps depending on the type and mounting height. The lanterns are usually of the semi cut-off type but provide more light above the horizontal plane to illuminate adjacent buildings for security purposes.

The lighting columns are normally sited in a staggered arrangement with particular emphasis on road junctions, and the actual position is influenced by the need to avoid entrances to properties, house windows and the like. The spacing of the columns is generally 5 to 6 times the mounting height for 5 m and 6 m columns and 3 to 4 times the mounting height for 8 m columns, depending on the road width.[80]

The Case for Major Road Lighting

An ICE publication[82] stated that at night there are three to four times as many fatalities per vehicle kilometre as during the day, often resulting from inadequate visibility. Car headlights have limitations – both in how much of the traffic environment they are able to light given the speed of the vehicle and reaction and braking time, and problems of glare from the car headlights of oncoming traffic. Most drivers believe that they are able to see better and observe faster than they actually do. In addition account must be taken of the driver's age, unfavourable weather, dirty windscreens, a complex traffic environment and hence the real conditions are more uncertain and the driving more exhausting than anticipated.

Good collaborative evidence comes from Hamburg, where between 1975 and 1977 the level of public lighting was reduced by half because of the economic requirements of the energy crisis. This proved to be false economy as a saving of DM2m (£0.65m) in electricity costs was far outweighed by £5.73m in accident costs. The Commission Internationale de l'Eclairage (CIE) in a draft white paper estimated reductions in night time road accident injuries and fatalities by road lighting as urban roads: 30%; rural roads: 45%; and motorways: at least 30%. This report embraced the results of over 30 studies covering 244 roads in cities and large conurbations. It concluded that as a result of installing road lighting, the number of pedestrian victims is reduced by between 45% and 57%, the number of road deaths is reduced by between 48% and 65% and the number of seriously injured by between 24% and 30%. The total number of road accidents is reduced by between 14% and 53%.[82]

Lighting accounts for less than 5% of total road building costs and just over 10% of maintenance. Good lighting is a sound investment and on the basis of these costs and the use of new energy effective lighting technology, all major motorways and urban roads in Europe should be lit. One approach to appraising lighting installations is to use cost benefit analysis which quantifies the benefits in monetary terms and compares these figures against the costs.[82]

In 1990, DTp confirmed that the contractors working on the M25 road widening programme had been requested to install new overhead lights on the remaining 55% of unlit motorway. DTp had initially intended to light the whole carriageway but changed the proposals under pressure from nearby residents who objected to lights shining all night near their homes. The scale of road accidents on what is one of Europe's busiest routes is believed to have played a major part in the change of policy. The DTp was installing special lights to reduce the environmental aspect and the lighting will be monitored by the Transport and Road Research Laboratory (TRRL) to provide guidance for the rest of the country. The Association of Chief Police Officers have been lobbying the Government for many years for fully lit motorways. To put it in perspective, the total cost of lighting 2100 km of UK unlit motorway could be as high as £156m (1990 prices).

Ripple Control of Street Lights

All 80 000 street lights in Singapore are operated by the ripple control system which allows the lamps to be automatically switched on and off according to the degree of brightness recorded by a sensor at the Public Utilities Board (PUB) control stations. The ripple system is an electrical remote control method, which sends signals to low voltage receivers fixed at PUB control boxes along the roads, with each box controlling about 60 lights. This system, which was completed in 1989, replaced the mechanical time switches which were first installed in the 1940s. The PUB 'eye' is a photo-electric cell at the heart of the S$21m (£6.6m) remote control system, which passes a signal to 10 sub-stations that in turn instruct the receivers to switch on or off the lamps in their vicinity.

Hence if it is dark and cloudy at 6.30 pm, the 'eye' will send a signal to the sub-stations and the public lights will be automatically switched on even although the normal switch-on time is 7 pm. On the other hand, if it is very bright at 6.30 am, the lights will be automatically switched off instead of at the usual 7 am. It was not however programmed to switch-on before 6.30 pm in the event of a dark thunderstorm occurring during the day. The system allows street lights to light up almost simultaneously and it provides savings in manpower which was previously needed to remedy faults in time switches.

Road Lighting Maintenance

The principal method of achieving efficient maintenance is to ensure that the original specification requires high quality equipment in both design and construction and that it is provided. For example, the sealing of lantern bowls should be of the highest standard to prevent the ingress of dirt. Steel lighting columns should have galvanised coatings to resist corrosion. Many authorities specify concrete columns in an attempt to minimise maintenance costs, although this requires careful long-term assessment.[80]

A typical maintenance procedure for street lighting in urban areas could take the following form:

(1) Every street lamp should be inspected for satisfactory operation at least once a week during the hours of darkness.
(2) Defective lamps should be replaced within five days.
(3) Once a year all lamps, refractors, reflectors and associated components should be cleaned, all component parts inspected and all moving parts operated and lubricated.
(4) Low pressure sodium lamps, mercury vapour discharge lamps and fluorescent tubes exceeding 40 W should be replaced after 8000 h use (two years) and fluorescent tubes up to 40 W every 4000 h (one year).

Thus the lamp changing cycles conveniently coincide with the annual cleaning and checking activities.[80]

Landscaping and Street Furniture

Landscaping

Trees and shrubs can advantageously be planted beside roads to serve a variety of functions. These functions include protection from strong winds, noise absorption, screening, prevention of soil erosion on steep slopes, formation of crash barriers, reduction of headlight glare, forming highway boundaries, reduction of monotony and providing interest and increased amenity.

Care must be taken to select suitable trees having regard to soil, climate, degree of exposure, space available and position of services. Large trees which have been used successfully on road planting schemes, where adequate space is available, include ash, beech, hornbeam, horse chestnut, lime, maple, Turkey oak, Scots pine and sycamore. Lombardy poplars can be very effective, but they do not flourish in clay soils and must be kept well away from buildings and drains. Suitable smaller trees of the flowering variety include almond, cherry, crab and mountain ash (rowan). Popular shrubs include berberis stenophylla, berberis darwinii, cotoneaster microphyllus and forsythia.

Street Furniture

Design of lighting columns, litterbins, bollards and railings in urban areas received increasing attention in the 1980s. Many local authorities set up working parties to rationalise the colours and materials of street furniture as part of an overall attempt to improve urban environments for visitors, workers and residents.

For example, in Bromley standardisation incorporated the provision of green steel columns with high pressure sodium lamps. Bollards were of cast iron standard design and painted either black or dark green, and litter receptacles were mid green. Street name plates were being replaced with plaques of mid green with white lettering. Different styles and standards have been applied to conservation areas and modern shopping streets. Paving breaks the pattern of green, using deep red paving blocks in the town centre and other popular shopping areas and small grey paving blocks elsewhere.

Leicester City Council was also promoting urban improvements and the city was in the top five British towns in the EEC's 1986 list of pleasant places in which to live. Centre bollards, lighting columns and seating are all of cast iron. More attention was being paid to good lighting and paving was narrowed down to a limited range of brick paviors. It was found that improved environments reduced the amount of vandalism.

Westminster City Council planned progressively to remove the clutter of features and provide a standard selection of street furniture and review landscaping possibilities and standards of conservation to smarten up Westminster for visitors and residents alike.

There is a wide range of seats, benches, litterbins and plant containers, often constructed of concrete with various types of exposed aggregate, with hardwood slats for seats and benches. Improved street furniture needs to be complemented by judicious tree, shrub and flower planting, possibly surrounded by cobbles or granite setts.

Subways should be well lit in order to provide a pleasant environment by day and by night, and also to deter muggings and vandalism. Luminaires must be of rugged construction, securely fixed to wall surfaces and made of UV stabilised polycarbonate. Whereas amenity lighting for mainly pedestrian areas often comprises the retention of the original lighting lanterns, or the provision of 'replica' replacements of the original oil or gas lanterns with electric light sources. When traditional lanterns are not considered essential and traffic is involved, a popular approach is to use painted steel columns, 60 to 100 mm diameter with a mounting height of 4 m to 8 m, and polycarbonate globes, 300 to 500 mm diameter which house the electrical gear as well as the luminaires[83].

Public Utility Services

Services to New Residential Developments

The layout, installation and future maintenance of public utility services must be considered as part of the initial planning stage. Developers should consult with the statutory undertakers at the relevant stages. In general, all mains and services shall be located in land which is reasonably accessible, communally owned and maintained whether or not adopted by the the appropriate local authority. If, however, the needs of statutory undertakers cannot be met in this way, then developers must provide service routes with secure easements across private properties by agreement with the undertakers concerned.[22]

In normal circumstances, the statutory undertakers prefer to provide their own mains (other than main sewers) beneath the highway verge.

Locations within landscaped amenity areas and beneath footpaths may also be acceptable subject to satisfactory access and routes. By this means, the installation and repair costs and general disruption associated with mains can be minimised. If, however, no other route is possible, then services may be sited in the carriageway with the agreement of the highway authority and the relevant statutory undertaker.[22]

Location and Records of Services

Major road junctions are often festooned with a large variety of services; these need to be recorded as accurately as possible to assist with future road and service work, as described in BRE Digest 348.[84]

Public Utilities Street Works Act 1950

This controversial piece of legislation was still in force forty years later and is believed by most highway engineers to have an overriding bias in favour of public utilities. There has been a lack of understanding by the public utilities of the impact of their operations on the highway structure and the safe movement of traffic, causing constant disturbance to the public and waste of public money. Where the undertaker undertook the reinstatement work, he was required to make good up to the orginal surface level, and if it subsided or deteriorated within six months, the highway authority must be paid the cost of any remedial works, subject to the statutory undertaker's right to prior examination. Highway authorities became liable for expenditure incurred where the alteration of a highway involved altering the undertaker's apparatus.

Public utilities often complained that local authority supervision costs were excessive, while highway authorities were particularly concerned about the poor performance of the public utilities and their contractors in respect of the excavation and support of trenches, the backfilling, compaction and reinstatement of trenches, the supervision of works, and the protection and signing of works, including the identification of the public utility undertaking the works.[85]

Horne Report

The Horne Report[86] in 1985 proposed that utilities should have full responsibility for reinstatement of their own roadworks, while highway authorities were offered a framework of legislation, regulations, specifications and guarantees which would greatly improve the organisation and quality of the reinstatement. Utilities would be required to pay the full cost of their works, including all damage to the road pavement and would no longer be confined to the perimeters of their trenches. Much of the cost of the work of utilities would be transferred from the public to the private sector, thus freeing more funds for road construction.

In 1986, the Government responded to the Horne Report, endorsing the central recommendations of the report, but by 1990 the recommendations had not been implemented.

Trials of Computerised Street Works Register and Main Records Systems

The Horne Report[86] referrred to various local trials relating to computerised street works registers, utilities damage, limitation trials and digitised mains record systems. These took place in the areas of Dudley Metropolitan Council and Lothian Regional Council, pending the possible introduction of a national computerised street works register.

Mason and Nitze[87] have described how both trials showed an ability and willingness by both the local authorities and the utilities to work together constructively. The Peat, Marwick, McLintock feasiblity study[88] confirmed that a central computerised street works register is feasible, but, in their present form, neither the Dudley nor the Lothian systems complied with the specified requirements. In the case of the Dudley system, the reliance on a full graphics base prevented its general application, and with the Lothian system, the register could not be interrogated directly by the utilities. However, the work by both authorities showed that electronic messaging and a central computerised street works register can provide both the road user and the customers of the utilities with a better service.

Road Space Rentals

In a government consultative paper issued in September 1989, contractors who dig up a road to repair a gas main or place a skip in the road while working on a house may be taxed for disturbing the flow of traffic. A road space rental charge would provide project promoters with the incentive to use less disruptive techniques. If these proved to be more costly, then the costs would be passed on to the consumers as a whole and would thus be spread equitably between all those who benefit from the service.

DTp estimated that 175 000 roads and footpaths are blocked every year by street works. The traffic congestion is estimated to cost the public some £55m a year in increased fuel and lost time. DTp planned a targeted charging system aimed to recover £15m a year from the 5% of utility sites where delays cost over £1000. The £15m is broken down based on figures in the Horne Report[86] on utilities' workloads. Water and sewerage would pay £7m, gas boards £5m, Telecom £2m and electricity £1m per annum. Non-utility excavators, and builders and developers which obstruct traffic for long periods with skips or scaffolding, would also be liable to charges.

Local authorities would be required to police and administer the collection of the charges. Money raised would return to central government, by deductions from rate support grant. The arbitrary nature of the charge is unsatisfactory as local authorities would have the discretion to decide which trenches, scaffolds, parked skips or whatever on roads should attract rental, and what daily charge should be levied, and this was seen as unfair and contentious and possibly open to abuse.

Highway authorities, in general, favoured lane rentals as opposed to charges for occupation of road space. Lane rental is a contractual device which has been used by highway authorities to accelerate the maintenance work on their highways, and hence minimise the disruption to use of these assets. The highway authority levies a charge on any organisation requiring temporary occupation of all or part of the carriageway. It was considered that a similar approach could be applied to utilities' work, which could charge the 'rent' to the contractor carrying out the work. The amount of the rent could be dependent on the sensitivity of the location to disruption.

It provides a much more refined mechanism than direct legislation like that adopted in Singapore, where digging up the roads is not permitted and the installation and repair of underground services must be carried out using trenchless methods. The road space rental proposal attempts to include some of the environmental costs so that a more comprehensive economic comparison can be made between conventional trenching methods and the newer trenchless technologies.

Road Maintenance

Maintenance Policy

Highway maintenance expenditure should be based on an assessment of needs rather than on historical precedent as has often happened in the past. Admittedly, surveying the condition of roads in sufficient detail and with sufficient frequency to provide adequate data for needs based management is a costly process, but all the evidence suggests that the investment will be repaid many times over in the more efficient use of road maintenance budgets.

In 1988, the National Audit Office[89] rightly advised that properly planned and managed maintenance programmes provide better conditions for road users, minimise disruption and delay and reduce the risk of accidents. Maintenance carried out at the right time also reduces costs, for example by preventing more serious deterioration of the road structure. A stable maintenance programme and a regular flow of orders are valuable in providing continuity of work for the road construction industry; and this encourages more economic, efficient and effective operation. The end result should be lower tender prices for both construction and maintenance contracts.

At the same time, an Audit Commission report stated that too little was being spent, too much of what was spent was being applied inefficiently, and as a result the standard of local roads was falling. Spending on motorways and trunk roads increased significantly during the period 1977–87, but the amount spent on local roads fell by 10%, despite a 20% increase in traffic. Data on highway condition and inventories was frequently inadequate, costs of maintenance were sometimes too high and agency arrangements between counties and districts caused many problems. Above all, maintenance of local roads was inadequately funded.

Code of Good Practice

Three local authority associations, the Associations of County Councils, Metropolitan Authorities and District Councils, jointly produced a code of good practice for highway maintenance in 1983.[90] The main objectives were to encourage highway authorities to use a systematic approach to decision making within a consistent framework, to provide a common basis for assessing the overall maintenance need, resource requirement and implications, to reduce the inconsistencies in highway maintenance standards, to assist in the more effective allocation of national and local resources, and to encourage the regular review of policies, standards and the effectiveness of maintenance programmes.

Highway maintenance was considered to have three specific purposes:

(1) to preserve the asset value represented by the highway (structural maintenance)
(2) to provide for the safe movement of traffic (safety)
(3) to preserve the amenity aspect of the highway (environmental).

Highway maintenance in England and Wales is the responsibility of 54 county highway authorities in addition to the Department of Transport (DTp), the Welsh Office and the London boroughs. The government departments are responsible for trunk roads but engage county councils as their agents to undertake the actual maintenance work. The county councils and London boroughs are responsible for all other roads and in many counties there are agency arrangements with district councils to undertake certain tasks.

The Code contained the important recommendation that all essential components of a highway system be properly recorded and kept up to date. The main benefits of an inventory were seen as:

(1) a more rational development of the maintenance budget
(2) the pre-planning and control of work
(3) the changing volume of demand to be identified and understood, for example adoption of roads and new street lighting
(4) the development of output measures, such as the cost per gully cleaned.

The need for standards and warning levels was duly emphasised. *Standards* are a yardstick against which a relative need can be assessed, priorities determined, funds allocated and performance measured. Some standards are readily recognised, such as empty gulleys twice a year or cut grass four times a year. Others will take the form of *warning levels*, for example, how far should conditions be allowed to deteriorate before active consideration is given to maintenance? Warning levels are often expressed more empirically, for example, 30% of road surface is crazed or 20% of kerbs have less than a 50 mm upstand. It does not automatically follow that action will be taken when a warning level has been reached. However, it is important that an engineering assessment is made and a maintenance policy formulated. There must be a common understanding of the standards and levels chosen and highway authorities must be prepared to identify the standards they wish to achieve.

The code made a strong case for the regular use of an assessment system to measure road conditions. Two major assessment techniques available in 1983 were MARCH (maintenance assessment rating and costing of highways) developed by the MARCH group of local authorities and CHART (computerised highway assessment of ratings and treatment) developed by the Transport and Road Research Laboratory (TRRL). The computerisation of the process enabled alternative policy options to be quickly formulated and evaluated.

Having determined where remedial work was required, the choice of maintenance treatment became crucial. The balance between short term measures had to be weighed carefully against the more expensive long term solutions.[91] A long term view must be taken of highway maintenance if value for money is to be achieved. The code recommends that all highway authorities should introduce a three year policy statement, forward programme and budget for highway maintenance.

In an effort to stem the deteriorating condition of local authority roads, the local authority associations issued a 1989 edition of the code, which was intended as a practical working document for highway engineers. It was produced not merely to update the 1983 edition but also to embrace new technology and to revive interest among highway authorities for common standards. It was believed that the partial adoption of the first edition stemmed primarily from lack of resources, coupled with problems experienced by some metropolitan authorities following the abolition of the metropolitan counties. Pressure from the EC for Britain to admit heavier lorries and the realisation that concrete bridges can collapse gave bridge maintenance greater urgency.

The new code stressed that as a basis for tender documents and contracts, a complete inventory was essential for calculating unit costs. It was also updated to include the latest system, PMS (pavement management system), which all local authorities were encouraged to implement. A number of authorities had their networks referenced in 1989, with Derbyshire and Devon County Councils being two of the more advanced.

New Technology

Margason[92] has described how the development of automatic equipment for surveying the condition of roads has made possible significant advances in producing maintenance plans matched more precisely to needs. For example, research and development on the *deflectograph* has led to its widespread and successful use, particularly for identifying priorities for strengthening motorways and trunk and principal roads and designing suitable strengthening treatments. The deflectograph is an automated interpretation of the Benkelman beam concept, which has been used to measure the deflexion of a road under a rolling wheel load as an indication of structural condition. Deflectograph surveys are carried out by DTp, preferably every three years, to provide early warning of strengthening needs and thus allow a longer period for planning.

Another valuable development was the introduction of the *high speed road monitor (HRM)* developed by TRRL with assistance from Cambridge Consultants Ltd. The machine measures road profile characteristics as it travels over the network, usually without any interference to other traffic. On-board computer facilities provide measurement control and instant data processing. The heart of the HRM is the laser height sensor as described by Margason.[92] By using the deflectograph and high speed road monitor the whole maintenance process may be optimised.

Road Repairs

There is no precise way of assessing the residual life of concrete carriageways, unlike blacktop surfaces where there are well established methods. Although concrete is nominally designed to last 40 years, this has unfortunately often not been achieved in practice. Poor design and construction or unexpectedly high increases in traffic loadings are frequently to blame, and highway authorities are incurring high maintenance costs because of the failure to accurately assess the optimum time for repairs. Some typical examples will help to illustrate the seriousness of the problem.

In 1989, TRRL[93] reported that poorly performing contraction joints caused by alkali silica reaction (ASR) in a 15 year old section of the concrete paved M40 motorway at Stokenchurch in Oxfordshire, where £4m was spent on repairs on a 13 km section over a 5 year period. Cracks developed in the concrete pavement near the joints because of a number of factors including thermal expansion, frost action, low concrete strength and inadequate performance and maintenance of the contraction joints. The cracks permitted water containing de-icing salt to enter and react with the cement paste to produce an alkaline solution which diffused into the white porous flint and reacted to form alkali silica gel. The gel absorbed water and expanded, causing internal pressure and eventual spalling. The hard shoulder was damaged as badly as the carriageway, suggesting that traffic density was not a factor. TRRL advised that ASR can be reduced by keeping joints properly maintained and sealed and that deicing salt should be kept to the minimum consistent with road safety. Risks can also be reduced by avoiding porous white flint and by using low alkali cement.

Another major concrete repair operation commenced in 1989 on the chloride damaged viaducts which link the M5 and M6 motorways in the West Midlands. The Department of Transport (DTp)[94] reported that parts of the Midland Links were in such poor condition that they required immediate replacement or refurbishment, ahead of the full scale repair trials. Irremovable chloride contamination resulted in most of the viaducts' substructures being subject to continuing deterioration. DTp reported that monitoring, repair and maintenance will be required for the remainder of their useful lives. Unfortunately, the operative design codes failed to give guidance on the assessment of corrosion damaged structures or the effects of structural repairs.

The variety and difficulty of repairs meant that a much greater research effort was needed if a long term, cost effective maintenance philosophy was to be developed. Sophisticated methods of detecting reinforcement corrosion, carrying out remedial work and monitoring the results were needed. Some £45m has been spent on the Midland Links since the decay caused by winter salting was first discovered in 1974. The eleven viaducts stretch over 21 km and carry up to 120 000 vehicles per day through the heart of the West Midlands. The substructures include 1200 cross beams and 3600 columns. The total cost of the project in 1972 was £28m, equivalent to £185m at 1989 prices. DTp estimated that demolition and replacement would amount to more than double the updated construction figure, quite apart from the major problems of ensuring traffic movement during the reconstruction period. Repair costs over the period 1990 to 2005 could exceed £120m, highlighting the enormity of the problem.

Excellent advice on the maintenance and repair of concrete roads has been provided by DTp[95] and is conveniently categorised into joint, surface and structural defects, trench openings and reinstatements and structural strengthening. It recommends that inspections be carried out in the winter months and very useful inspection record sheets are illustrated. Another useful guide to the assessment and repair of corrosion damaged concrete has been produced by CIRIA.[96]

With regard to blacktop construction, it has been estimated that for 80 to 90% of traditional *surface dressing* work, conventional materials and techniques are satisfactory[97]. Furthermore, surface dressing costs approximately 10% of that of stripping and asphalting. Road Note 39[98] provides guidelines for the surface dressing process which, when interpreted objectively, can result in successful road surfacing. Although there are serious doubts about the suitability of the process where the loading is in excess of 4000 commercial vehicles daily per lane. Also road surfaces where vehicles brake or turn sharply present additional problems because conventional binders lack the cohesive strength necessary to retain chippings under the extra stress imposed.

Peden[99] has identified the predominant method of failure in surface dressing as detachment of chippings from the surface, although loss of texture (abrasion), polishing and fatting up also occur. Chipping loss can be caused by a number of factors including:

(a) poor traffic control and after care
(b) poor application possibly arising from defective plant
(c) unsuitable weather conditions
(d) poor material specification
(e) low binder application
(f) unsatisfactory chippings, such as inappropriate size or surface condition.

Useful guidelines on other methods of repair of blacktop surfaces are well described by Watson[9] and these include resurfacing, slurry sealing, replacement of parts of the pavement, in *situ* stabilisation and off site stabilisation.

Winter Maintenance

Planning and Preparation

The object of winter maintenance was defined in *Highway maintenance: a code of good practice*[90] as 'to provide a winter maintenance service which, as far as reasonably possible, will permit the safe movement of vehicular traffic on the more important parts of the highway network while minimising delays and accidents directly attributable to the adverse weather conditions'. The code prescribed the following order of priorities.

First Priority Pre-salting Routes Motorways and certain primary routes as defined by DTp. Other primary routes, principal roads, roads leading to important industrial and military establishments, hospitals, ambulance stations, fire stations, bus garages, important bus routes, important commuter routes carrying at least 3000 vehicles per day, slip roads, approaches to interchanges, and known trouble spots.

Second Priority Known trouble and accident spots (not on the first priority routes), all other bus routes (including school buses), other commuter routes, main feeder routes and shopping centres.

Minor Roads When severe conditions are likely to persist, it will be necessary to give progressive support to those streets on which self-help cannot resolve the problems, particularly where the topography is difficult or where there is a concentration of the aged and infirm. Dealing with footpaths entails hard work and is expensive.

Planning

The ability to react speedily and efficiently is of major importance when dealing with adverse weather emergencies. To ensure that the necessary action will be forthcoming when required entails considerable preparation during the non-winter months when the following factors will normally require consideration:

(1) Establish a control centre or alternatively devolve control to divisional organisations.
(2) Replenish rock salt used during previous winter.
(3) All vehicles and equipment must be cleaned thoroughly and overhauled to prevent corrosion and seizure, new equipment and replacements ordered in sufficient time and tenders sought for supply of hired plant to be used on a contingency basis.
(4) The Meteorological Office provides a service to local authorities from 1 October to 31 May giving advance warning of snow or icy roads on a 24 hour basis. The forecast includes information on road surface temperatures, precipitation, anticipated timing and, in respect of snow, the depth of fall and wind direction.
(5) Reports from police can help considerably in receipt of information covering road conditions, and they must be provided with the appropriate highway authority contacts.
(6) Route lists for salting, snow ploughing and clearance of footpaths should be updated to take account of changes in traffic flow, new bus routes and other relevant factors, and must avoid covering the same roads twice. Liaison should take place with neighbouring authorities to prevent duplication of work.[100]

Implementation The principal material for pre-salting and treatment of ice and snow covered roads is rock salt to BS 3247, spread at the rate of 10 g/m^2 for ice and 40 g/m^2 for snow. Single size grit (6 mm) can be mixed with rock salt when roads, especially those with steep gradients, are covered with hard-packed snow. Salt lowers the freezing point and thus melts snow.

There are three basic types of gritter – bulk gritter, demountable gritter and trail gritter, all with a salt hopper of 3 to 9 m^3 capacity, with a conveyor belt or auger supplying the spinner with salt. Snow ploughs are available in a variety of sizes and specifications to suit a range of vehicles, from heavy duty ploughs bolted to vehicles to vee ploughs used in deep snow, and straight ploughs which are the most commonly used when the average snow depth exceeds 50 mm, and the angle of ploughing can be adjusted from straight ahead to 30° either side of the vehicle.

Snow blowers are used in situations which preclude the use of conventional ploughs, such as in deep snow or where lateral features such as fences and hedges or bridge parapets could be damaged. Agricultural tractors can be equipped with a snow plough and provide a valuable back-up service.

Highway Meteorology

In the late 1980s major advances were made in the harnessing of electronic equipment for weather forecasting and 'snow casting' for highway operations. Even by 1983, ice detection equipment reporting to microcomputers by way of public service telephone networks, thermal mapping and weather radar had all reached an adequate stage of development. Runacres *et al.*[101] have described how by the early 1990s ice detection systems were being used by county and regional authorities over half the area of Great Britain. They were mainly in 'Highland Britain' where topography increased the severity and variability of winter conditions, but many other authorities were investing in them. Systems were also widespread on the mainland of Europe, especially in Scandinavia, Switzerland, West Germany and France.

As highlighted by Runacres *et al.*,[101] weather radar is a powerful instrument for displaying precipitation patterns. Events can be tracked across the country and accurate timings can be obtained for all terrain types even in areas further than 75 km from a radar site. The timing of precipitation events is however difficult to forecast accurately given the complex weather patterns in the British Isles. Radar can give accurate information up to about 3 hours ahead of events and this allows time for maintenance operations to be implemented, postponed or cancelled. The necessity and timing of salting runs need to be calculated in advance and road danger warnings need to be issued early for preventive action to be taken. Heavy, moderate and light precipitation can be distinguished by the radar, which is useful when considering washing off salt or when a high snowfall is expected.

Road Widening

For full quality widening of motorways, three main options have been identified by Rendel Palmer and Tritton (RPT) in line with developing DTp practice, and these are likely to be used across the motorway network. The two traditional methods involve either building one extra lane on to the side of each existing carriageway by 'symmetrical widening', or adding two lanes on to the side of one carriageway by 'asymmetrical widening' and then moving the central reservation. Subsequently, a more radical solution was evolved known as 'parallel widening' in which a whole new carriageway is built alongside the existing road which is then reconstructed to give the correct number of lanes.[102]

Parallel widening involves a large land take which retards the planning process, while the scale of the new construction makes it the most expensive option. However, the motorist benefits from minimal contraflow requirements during the work and this makes it the safest method. The technique has been used several times in Britain to widen from two lanes to three. Widening from three to four lanes would entail the construction of large amounts of new carriageway for relatively little extra capacity. But the DTp believes the surplus space could be used either to build parallel collector-distributor roads alongside the motorway or for later widening to five lanes.

Symmetrical widening is the simplest, cheapest and quickest solution involving the straightforward addition of hard shoulders on to the outsides of the carriageways, while upgrading the original emergency lanes to full carriageway standard. With asymmetrical widening, structures have to be rebuilt but the system can still be attractive where new land is only available on one side of the motorway.

Another way of boosting capacity is to construct collector-distributor roads alongside existing motorways, and these would serve the extra function of reducing the volume of short distance traffic coming on and off the motorway at each junction. All these techniques are likely to be used by DTp with local conditions and requirements dictating the choice.[102]

Readers requiring more detailed information on road maintenance are referred to the *Highway Maintenance Handbook*.[103]

References

1. ICE, Infrastructure Policy Group. *Congestion.* Telford (1989)
2. J.A. James. M25 – the future? *Mun. Engr, 1988, 5, Oct., 257–64*
3. P. Phillips. M is for mess, muddle, M25. *Building Design, 25 Jan. 1987, 16–18*
4. Halcrow. M40; construction and conservation. *Halcrow Now, Jan/Feb. 1990, issue 15, 8–9*
5. Civic Trust. *Bypasses* (1983)
6. W.K. Mackay. The argument for bypasses. *Mun. Engr, 1984, Aug., 145–57*
7. L.S. Blake (Ed.). *Civil Engineer's Reference Book.* Butterworths (1989)
8. C.A. O'Flaherty. *Highway Engineering, Vol. 2.* Arnold (1988)
9. J. Watson. *Highway Construction and Maintenance.* Longman (1989)
10. R.J. Salter. *Highway Design and Construction.* Macmillan (1988)
11. DTp. *Specification for Highway Works.* HMSO (1986)
12. DTp. *Structural Design of New Road Pavements.* HMSO (1987)
13. DTp. *A Guide to Concrete Road Construction.* HMSO (1978)
14. DTp. *Highway Construction Details.* HMSO (1987) and DTp *Advice Note TA23/81*
15. National Audit Office. *Quality Control of Road and Bridge Construction* (1989)
16. Welsh Office. *A55: Stage One* (undated)
17. M. Springett & T.D. Stevenson. A55 Llanddulas to Glan Conwy – design. *Proc. Instn Civ. Engrs, Part 1, 1988, 84, Oct., 939–64*
18. L. Russell. Breaking new ground. *New Civ. Engr, Roads Supplement, Sept., 1989, 37–47*
19. Full blast. Penmaenbach Tunnel. *The Travers Morgan World, Issue 4, 4–5* (1987)
20. Scott Wilson Kirkpatrick. *Hong Kong: Tsuen Wan Bypass – Fact Sheet* (undated)
21. S. Montague. Furious Highway. *New Civ. Engr, Roads Supplement, Sept., 1989, 37–47*
22. Surrey County Council. *Roads and Footpaths: a design guide for Surrey* (1981)
23. Institution of Highways and Transportation and DTp. *Roads and Traffic in Urban Areas* (1987)
24. DTp. TD 20/85. *Traffic flows and carriageway width assessment* (1985)
25. DTp. TA 46/85. *Traffic flows and carriageway width assessment for rural roads* (1985)
26. DTp. TD 9/81. *Road layout and geometry: highway link design* and *Amendment nr 1* (1984)
27. Singapore PWD. *Central Expressway through the City* (1991)
28. Scott Wilson Kirkpatrick. *Renfrew Motorway Stage 1,* (undated)
29. Hong Kong Government, Land and Works Branch. *HK: The Development Challenge* (1989)
30. J.C. Yu. *Transportation Engineering: Introduction to planning, design and operations.* Elsevier (1982)
31. DTp. *Traffic Appraisal Manual (TAM)* (1985)
32. T.E.H. Williams. Assessment of urban roads. *Primary Route Network.* Telford. Proc. ICE Conference 4–5 March, 1986
33. D. Van Vliet. *SATURN: a user's guide.* Institute for Transport Studies, University of Leeds (1981)
34. DTp/TRRL. Supplementary Report SR 735. *Users guide to CONTRAM version 4* (1982)
35. Transpotich Ltd. *TRAFFICQ Manual.* MVA Systematica (1983)
36. J. Bates & M. Bradley. *The CLAMP parking policy analysis model.* TEC Vol. 27, nr 7/8 (July/Aug., 1986)
37. Transport Planning Associates. *HINET Manual* (1981)
38. Wootton Jeffreys & Partners. *JAM Users Guide* (1980)
39. MVA Systematica. *TRIPS Manual* (1982)
40. G.S.R. Hunter. The urban road – new technology points the way. *Mun. Engr, 1985, 2, Dec., 327–35*
41. DTp. *Determination of size of roundabouts and major/minor road junctions.* Departmental Advice Note TA 23/81. HMSO (1981)
42. DTp. *The layout of major/minor road junctions.* Departmental Advice Note 20/84. HMSO (1984)
43. DTp. *Layout of grade-separated junctions.* Departmental Advice Note TA 48/86. HMSO (1986)

44. DTp. *Layout of grade-separated junctions.* Departmental Advice Note TA 22/86. HMSO (1986)
45. C.A. O'Flaherty. *Traffic Planning and Engineering, Vol. 1.* Arnold (1986)
46. D. Langdon. Design and construction of the M25-M40 interchange. *Mun. Engr, 1986, 3, June, 125–37*
47. R.T. Underwood. The Hume (Melbourne–Sydney) Freeway in the State of Victoria, Australia. *Proc. Instn Civ. Engrs, Part 1, 1988, 84, Apr., 265–90*
48. Surrey County Council. *Roads and Footpaths: a design guide for Surrey.* 2 (1981)
49. C.J. Pratt. Traffic streams. *Public Service Local Government, May 1986, 66*
50. B.G. Fletcher & S.A. Lavan. *Civil Engineering Construction.* Heinemann (1987)
51. R. Walther, B. Houriet, W. Isler & P. Moia. *Cable Stayed Bridges.* Telford (1988)
52. D. Fowler. The shape of bridges to come. *New Civ. Engr, 30 June, 1988, 31–2*
53. R.V. Farraday & F.G. Charlton. *Hydraulic factors in bridge design.* Hydraulics Research Station (1983)
54. C.H. Pothecary & T.J.C. Christie. Torridge Bridge design. *Proc. Instn Civ. Engrs, Part 1, 1989, 88, Apr., 191–210*
55. DTp. Technical memo. BE1/77. *Standard highway loadings.* HMSO (1977)
56. C.H. Pothecary & L. Brindle. Torridge Bridge: construction of substructure and deck precasting work. *Proc. Instn Civ. Engrs, Part 1, 1990, 88, Apr., 211–31*
57. C.H. Pothecary & L. Brindle. Torridge Bridge: erection of superstructure. *Proc. Instn Civ. Engrs, Part 1, 1990, 88, Apr., 233–60*
58. R.A. Denton-Cox & K.L. Weir. Tsing Yi North Bridge: planning and design. *Proc. Instn Civ. Engrs, Part 1, 1989, 86, June, 471–89*
59. M.R. Lane. *The Rendel Connection: A Dynasty of Engineers* (1989)
60. H. Ferguson. Longest span in the world. *New Civ. Engr, 4 Aug. 1988, 18–21*
61. C.P.J. Barnard. Highway bridge maintenance. *Mun. Engr, 1990, 7, Apr., 97–107*
62. OECD Road Research Group. *Bridge Maintenance,* pp.27–32. Organisation for Economic Co-operation and Development, Paris, (1981)
63. DTp *Trunk road and motorway structures – records and inspection.* Trunk Road Management and Maintenance Notice TRMM 2/88. HMSO (1988)
64. DTp. *Bridge inspection guide.* HMSO (1983)
65. DTp. *The performance of concrete in bridges.* HMSO (1989)
66. R.J. Woodward. *Conditions within ducts in post-tensioned prestressed concrete bridges.* TRRL Laboratory Report 980. DTp (1981)
67. R.J. Woodward & F.W. Williams. The collapse of Ynys-y-Gwas Bridge, West Glamorgan. *Proc. Instn Civ. Engrs, Part 1, 1988, 84, Aug., 633–69*
68. DTp. *Maintenance painting of highway structures: procedural, contractual and technical requirements.* Advice Notes BD 18/83 and BA 13/83. HMSO (1983)
69. *Traffic Signs Regulations and General Directions,* 1981. S.I. 259 as amended by the Traffic Signs (Amendment) Regulations 1982, S.I. 1879 and Traffic Signs General (Amendment) Directions 1982, S.I. 1880
70. DTP. *Traffic signs manual.* HMSO (1982)
71. DOE/DTp/TRRL. Report LR 888. *User guide to TRANSYT version 8* (1975)
72. DOE/DTp/TRRL. Report LR 1014. *SCOOT: a traffic responsive method of co-ordinating signals* (1981)
73. DTp. *Road Accidents Statistics, Great Britain.* HMSO (1985)
74. V.E. Jones & J. Romanis. Road safety – do we care enough? *Mun. Engr, 1987, 4, Feb., 25–33*
75. OECD. *Manual on road safety campaigns* (1975)
76. AME. Parking. *Mun. Engr, 1984, 1, Dec., 311–25*
77. W.S.A. Wadsworth. Residents' parking. *Mun. Engr, 1988, 5, June, 149–60*
78. E.G. Goldring. Multi-storey car parks – design and construction problems and their avoidance. *Mun. Engr, 1988, 5, June, 137–48*
79. A.P. Chrest, M.S. Smith & S. Bhuyan. *Parking Structures: Planning, Design, Construction, Maintenance and Repair.* Van Nostrand Reinhold (1989)
80. AME State of the art report: Road lighting. *Mun. Engr, 1984, 1, Aug., 171–83*
81. P.D. Wright. Road lighting design. *Mun. Engr, 1988, 5, Feb., 25–34*
82. ICE. Emerging from the dark ages. *New Civ. Engr, Roads Supplement, Sept., 1989, 80–4*
83. GLC. *The Design of Urban Space.* Architectural Press (1980)
84. *BRE Digest 348.* Site investigation for low-rise building: the walk over survey (Dec., 1989)
85. R.F.V. Aylott. Review of PUSWA – a discussion paper. *Mun. Engr, 1984, 1, June, 11–18*
86. M.R. Horne. *Roads and the Utilities: Review of the Public Utilities Street Works Act 1950.* HMSO (1985)
87. P.J. Mason & R.T. Nitze. Local trials of computerised street works register and main record systems. *Proc. Instn Civ. Engrs, Part 1, 1990, 88, Apr., 283–94*

88. Peat, Marwick, McLintock. *Computerised street works register.* Feasibility study for DTp (1988) (unpublished)
89. National Audit Office. *Improving the Condition of Local Authority Roads: The National Picture.* HMSO (1988)
90. Local Authority Associations. *Highway Maintenance: A Code of Good Practice.* ACC, ADC and AMA (1983)
91. K.B. Madelin. The local authority associations' code of good practice for highway maintenance. *Mun. Engr, 1984, 1, June, 3–10*
92. G. Margason. New technology in highway maintenance. *Mun. Engr, 1986, 3, Feb., 27–34*
93. R.G. Sibbick & G. West. *Examination of concrete from the M40 motorway.* TRRL (1989)
94. DTp. *Repairs and maintenance of the Midland Links viaducts: working party report* (1989)
95. H.S. Mildenhall & G.D.S. Northcott. *A Manual for the Maintenance and Repair of Concrete Roads.* DTp. HMSO (1986)
96. P. Pullar-Strecker. *Corrosion Damaged Concrete: Assessment and Repair.* CIRIA/Butterworths (1987)
97. M.F.W. Heslop *et al.* Recent developments in surface dressing. *Highway Engr, 1982, 29, July, 6*
98. DOE. *Recommendations for road surface dressing.* Road Note 39. HMSO (1981)
99. R.A. Peden. Modern surface dressing – an appraisal. *Mun. Engr, 1988, 5, Apr., 107–14*
100. AME. State of the art report: Winter maintenance. *Mun. Engr, 1984, 1, June, 65–80*
101. A.M.E. Runacres, A.H. Colville-Symons & L.J. Symons. Highway meteorology and winter maintenance operations. *Mun. Engr, 1989, 6, June, 171–84*
102. H. Jones. Giving it width. *New Civ. Engr, Roads Supplement, Sept., 1989*
103. K. Atkinson (Ed.). *Highway Maintenance Handbook.* Telford (1990)

4

Wastewater Engineering

This chapter is concerned with the design and construction of sewers to convey both foul and surface water to disposal points, the main characteristics of pumping stations, maintenance and restoration of sewers, and the design and maintenance of sewage treatment works.

Historical Background and Third World Needs

Historical Background to Sanitation

Civil engineers, particularly those specialising in municipal and public health engineering, can be justifiably proud of the improvements in sanitation that have taken place throughout the Western world since the latter part of the 19th century, even although much still remains to be done. In the early part of the same century the larger British cities, including London, comprised mainly alleys and courts which were malodorous and poorly drained. Human excreta were piled in heaps or in ash pits which were cleared infrequently, while night soil men visited the homes of those who were fortunate enough to have latrines of their own.[1]

By the end of the Victorian era most towns had some form of sewerage system. Coverage of urban areas by sewerage systems gradually increased during the years up to the Second World War. Separate sewers became common on new housing estates and many small towns and villages had their own sewage works. However, in the 1930s there were still many sewage farms and night soil collection from bucket latrines was still quite common in many parts of Britain. In rural areas the pit latrine or privy was the usual method of disposing of excreta, especially in the United States, as portrayed in such a fascinating way by Sale[2].

Since the Second World War there has been a substantial extension of sewerage facilities and a significant improvement in the standard of sewage treatment in all industrialised countries. In the absence of public sewerage systems, wastewater is mainly dealt with in septic tanks. The quality of discharges from sewage treatment works to rivers and streams is generally of a satisfactory standard, but in 1990 there were still many discharges of untreated sewage into coastal waters.

Sanitation in the Third World

In some Third World cities, sewers were laid only a few years later than in some European cities. For example, Bombay, Calcutta, New Delhi, Madras and other Indian cities had comprehensive sewerage systems by the time of independence in 1947. Similarly the commercial centres of most large towns in East Africa had sewers in 1947. By contrast there were virtually no sewers in the capitals of Ghana, Nigeria and Sierra Leone in the 1940s. Even in 1990 Bangkok, the capital of Thailand, had no general foul sewerage system, although a number of comprehensive schemes had been prepared over the years. A United Nations ten year development programme in 1981[3] set the ambitious goal of providing safe drinking water and sanitation for all the world's people, more than two thirds of whom live in rural areas.

Pickford and Speed[1] have described how during recent decades, apart from some notable exceptions, there has been a serious decline in the standard of sanitation in almost all Third World towns, stemming mainly from the factors that follow. Probably the most significant factor is the unprecedented rate of urbanisation, encouraged by the lure of better prospects of employment, education and health care in the towns and the rural poverty and inability of agriculture to provide jobs for more people, exacerbated in some countries by an influx of refugees. For example, Jakarta (Indonesia) has 5000 additional people every week, while Nairobi (Kenya) has a weekly intake of 2000. Many urban immigrants take over a piece of vacant land and construct a shelter which generally becomes a permanent settlement. The demolition of squatters' shelters almost invariably results in them being built again elsewhere. Thus the second major factor in the decline in urban sanitation is the presence of so many squatters in most urban areas throughout the Third World. In the early 1980s, 90% of the population of Addis Ababa were squatters and it has been estimated that about one half of the inhabitants of the cities and large towns in the Third World fall into this category.

Resources A severe shortage of resources of all kinds is a salient characteristic of poor countries. Generally the greatest shortage is foreign exchange, and frequently special authority is required to import even the smallest and cheapest items, because there is so little currency available and so many competing demands for it. Invariably sanitation has low priority so that it may take several months of processing before an official order for a spare part for a sewage pump can be placed.

Appropriate Technology A growing minority of engineers have advocated low cost technology as the only possible solution to the problem of providing adequate sanitation for hundreds of millions of people with totally inadequate resources. Subsequently the World Bank supported their arguments and published research into appropriate technology and health, economic and sociological factors.[4] On grounds of economy and simplicity of operation, the bucket system and pit latrines have proved popular despite their inherent deficiencies. In some towns, such as Dar es Salaam (Tanzania), pit latrines were still used by the majority of the population in 1990. Improvements, including suggestions by the World Bank, have been introduced over the years. Where water is used for anal cleaning, offset pits with water seals under latrine bowls are good practice. Deep pits will have a long life in stable soil, and double pits should be used where high level rock or water table is encountered. The pits are used alternately and mature stabilised solids removed by hand or machine. Ventilation, lining of pits and smooth, easily cleaned latrine floors or squatting slabs assist in obtaining satisfactory latrines.

Between pit latrines and conventional sewerage, measured in terms of technology or cost, are vacuum trucks and small bore sewers. The vault-truck system, although widely used in the Far East, requires a reliable collection organisation which is difficult to provide in most developing countries. Small bore sewerage systems with mini septic tanks have considerable potential but there was little practical experience of their use in 1990.[1]

Non-technological Factors The technology of low cost sytems is simple, but their implementation on the scale necessary to serve the 2400m people requiring adequate sanitation by the end of the UNDP decade (1990) was not feasible. They are essentially household on-site systems and thus require the co-operation of householders. To be successful, engineers need to be aware of the sociological, cultural and behavioural factors and to make allowance for local variations. Large scale projects with which British civil engineering consultants and municipal engineers are most familiar are unlikely to be successful. A different approach is needed – one which is community-oriented and one in which the community participates from the initial survey onwards. Sanitation in these situations must be in such a form that people will use it and must be so devised that operation and maintenance are within the capability of the local community.[1]

Pickford and Speed[1] rightly emphasise that the overriding need in developing sanitation, as well as water supply, in the Third World is for simplicity. Where spares are unobtainable, chemicals and power unavailable, and fuel supplies at best intermittent, robust simple engineering is a necessity. Community involvement, education and training are equally as important as survey and design if the finished scheme is to succeed and be satisfactorily maintained.

Sewer Design

Types of Sewerage System

The function of a sewerage system is to convey domestic and industrial wastewaters, and run-off from precipitation, safely and economically to a point of disposal. The term 'sewage' relates to the contents of the sewers. There are three main types of sewerage system, namely combined, separate, and partially separate, and each is now considered.

Combined System In a combined system there is one sewer only which receives all types of sewage (foul and surface water). This method is commonly used in village schemes where the maximum flow is relatively small. The use of this system simplifies and cheapens the house drainage system, as a single drain takes the discharges from foul appliances, wastes and rainwater pipes. It ensures that the drains will be well flushed during times of storm and eliminates the possibility of connecting a house drain to the wrong sewer.

With regard to the sewerage system itself, there is a possibility of silting in a larger pipe unless self-cleansing velocities are obtainable with peak foul flows. Storm overflows may be needed to remove surplus water in the event of heavy rainstorms and these may cause pollution of watercourses. The pumping of large quantities of surface water can prove costly and excessive flows at the sewage treatment plant can also create difficulties.

Separate System In a separate system there are two pipes, one to receive foul sewage and the other to take surface water. The domestic and industrial wastewaters are dealt with at the sewage treatment works, whereas the surface water is usually discharged into watercourses. This system involves two separate runs of drains to properties and thus results in additional expense in both provision and maintenance. There is also the risk of a drain being connected to the wrong sewer and foul drains are not flushed with surface water.

No storm overflows are required, but foul sewers may need periodic flushing where flows are small or the pipes are laid to flat gradients. Pumping costs are, however, reduced to a minimum and it simplifies the operation of the sewage treatment works.

Partially Separate System This is a compromise between the first two methods whereby there are two sewers, one taking foul sewage together with some surface water, often from paved areas and roof slopes at the rear of properties, while the other sewer takes the surface water from highways and front roof slopes. This system simplifies and cheapens the house drainage arrangements and enables the foul drain to be flushed in times of storm. The sewerage system has most of the advantages and disadvantages of the combined system but to a lesser extent.

When selecting the type of sewerage system to be adopted, all the circumstances must be considered including the economics of each method.

Foul Sewerage

Foul sewerage entails the conveyance of foul sewage or the waterborne wastes of a community from water closets, urinals, bidets, baths, showers, wash basins, sinks and washing machines in homes, educational buildings, hospitals, offices, shops, industrial and other buildings. Industrial effluent is the waterborne waste of industry which will be considered in more detail later. In addition infiltration into foul sewers can occur where pipes are laid below groundwater level and contain leaking joints.

In order to design foul sewers it is necessary to determine the population to be served and to decide on a discharge figure per head of population. In determining the design population, it is advisable to allow for possible future increases in population throughout the catchment area over a specific period, such as twenty years, when consultation with the staff of the local planning authority will be of considerable assistance. Existing population figures can be obtained from a number of sources, such as statistics prepared by the Medical Officer of Health or collated by the local planning authority, or from the census published by the Registrar General. Another alternative is to survey the properties on the ground and check them against the Ordnance Survey (OS) sheets. When using the number of dwellings as a basis it is necessary to decide upon an average occupancy rate, and this can vary from district to district depending on the type and class of property. A typical figure is 3.5 persons per dwelling.

The volume of foul sewage is closely related to water consumption and the water authority can supply details of water consumption per person per day for domestic use and also the figure for industrial use, which is separately metered. In most cases in the United Kingdom the water authority also controls the sewers and sewage treatment works. Any industrial or other premises which have their own sources of water supply will need to be included. It would be prudent to allow for possible future changes in water consumption arising from an increased provision and use of sanitary appliances and hot water supply systems, the changing character and residential densities of districts resulting from redevelopment schemes and industrial expansion.

The term *dry weather flow* (DWF) is used to describe the rate of flow of sewage, including infiltration if any, in a sewer in dry weather, which has been defined as a period of five successive days and nights without measurable rain. DWF values can vary in summer and winter resulting from changes in infiltration caused by changes in groundwater level, domestic holidays or changes in the pattern of industrial activities. Hence the DWF consists of domestic and industrial flows and infiltration.[5]

Watson Hawksley[5] have quoted typical domestic flows in the United Kingdom as 185 litres per head per day. This could be reduced to 75 to 100 litres in developing countries and be as high as 400 to 500 litres daily in areas such as North America, where there is extensive air conditioning, lawn watering and automated car washes. Infiltration values can be determined from sewer gauging at night, when domestic flow is virtually nil and industrial discharges are at a minimum. Typical values could be about 15 000 litres per day per kilometre of sewer and house connections for average conditions but there are bound to be wide variations in practice.

Taking a domestic occupancy rate of 3.5 persons per dwelling and a domestic flow of 185 litres per head per day discharging over a 12 hour period, a flow of about 650 litres per dwelling per 12 hour day is obtained. Discharges per hectare for varying house densities would then be as follows:

20 dwellings per hectare: flow of 0.30 l/s per ha
30 dwellings per hectare: flow of 0.45 l/s per ha
40 dwellings per hectare: flow of 0.60 l/s per ha

It is however generally accepted that pipes should be capable of carrying a minimum of four times the average flow. Furthermore, these figures illustrate the relatively small flows of domestic sewage, in the absence of any surface water, and the limited capacity needed to cope with them. For example, a 150 mm pipe sewer at a gradient of 1/80 can carry 13.30 l/s.

Industrial Effluents

Industrial effluents are liquid discharges from industrial premises and they vary tremendously in amount, character and chemical content. In the absence of pre-treatment, some industrial effluents can cause deterioration of sewers, manholes and pumping machinery. The worst effluents are acidic wastes, liquids at high temperatures and discharges containing inorganic sulphates or sulphides, or ammonium or metallic salts. In some cases suspended matter in industrial effluents can cause blockages in sewers, and in other cases may give rise to dangerous conditions for operatives working in sewers or adversely affect the operation of sewage treatment works. For these reasons it is essential that strict control is exercised over the discharge of industrial effluents into public sewers by means of industrial effluent agreements, and that suitable pre-treatment shall be carried out by the industrialist as necessary.

The first essential is for the engineer to determine the temperature, chemical contents, probable maximum daily discharge and highest rate of discharge. In the event of any uncertainty, the engineer should obtain the services of an analytical chemist to assist in determining the probable effect on the operation of sewers and sewage treatment works and the nature and extent of pretreatment operations.

Prior to the discharge of any industrial effluent into a public sewer, an industrial effluent agreement should be drawn up with the industrialist covering all or any of the following matters:

(1) The installation of plant at the factory, at the industrialist's expense, to partially purify, remove harmful contents or cool hot effluents to a prescribed temperature.
(2) Payments to be made to the authority responsible for the treatment of the sewage, normally the appropriate water authority, to cover the additional cost of treatment of the industrial effluent, which is usually metered. The charge is often assessed on the pollution load, based on the volume and strength of effluent.
(3) Provision for members of the engineer's staff to make periodic inspections of the industrialist's plant, to satisfy themselves that the effluent is being properly treated.
(4) The authority is permitted to take an agreed number of samples per year for independent analysis, and the cost of the analysis is often paid direct by the industrialist.
(5) On signing the agreement, the authority normally receives a payment to cover the cost of the fees of consultants and/or analytical chemists and any other preliminary expenditure.

Some of the worst types of industrial effluents are those discharged from tanneries, town gasworks, dairies, sugar factories and chemical works. Sometimes the industrialist has insufficient spare land on which to treat the industrial effluent, and it may be necessary to dilute the effluent to a prescribed ratio and for the authority to carry out the whole of the treatment. Consideration must also be given to the ratio of industrial effluent to domestic sewage – a large tannery in a small country town can cause serious problems.

Farm Wastes

In rural areas the discharge of farm wastes can cause authorities responsible for sewage treatment considerable concern when, for example, the drainage from extensive cowsheds enters the sewerage system serving a small village. It is often possible for a farmer to install his own purification plant and, in any event, he should be required to provide some pre-treatment plant. Farm wastes, because of their volume and content, can create serious problems and considerable additional expense in the construction and operation of the authority's sewage treatment works. For instance, the cost of the sewage treatment works serving a small village with a population of about 140 was doubled in order to cope with the discharge from fifty cows.

Storm Sewage

With combined and partially separate sewers, it is both unnecessary and uneconomical to treat the full peak flow carried by them. Provided the sewage treatment works has adequate capacity to treat fully the maximum rate of flow of foul sewage, without bypassing in dry weather, it is customary to separate the remainder of the combined or partially separate flow by means of a storm sewage overflow. However, the uncontrolled discharge of excess storm flow to the nearest watercourse is likely to cause pollution.[5]

For small overflows (0.15 to 0.85 m^3/s), storage-type overflows controlled by a throttle pipe and overflow weir and with manual screening are generally considered suitable. For larger overflows, storage capacity is limited and the design must concentrate on preventing overflow of the first storm flush. Control may be exercised by throttle pipe, orifice or flow regulator and mechanically raked screens provided.[5]

Watson Hawksley[5] have described how the volume of foul sewage flowing in the sewer, downstream of the last stormwater overflow, will be approximately 6 DWF. However, not all of this can be fully treated, if the rainfall continues for a long period. It is generally recommended that 3 DWF is fully treated and the remainder bypassed to stormwater tanks for gravity settlement. Furthermore, it is customary, after the rain has ceased, to pump the contents of the stormwater tanks back to the sewage treatment works inlet for full treatment.

An alternative method is demonstrated by Severn Trent's scheme of purification lakes on the River Tame running through Birmingham, which protect the river from large amounts of polluted water running off streets and houses during storms. Water entering the lakes takes the solids – about 1.25m tonnes per year – and these settle to the bottom, leaving only the cleaner water to flow downstream.

Surface Water Sewerage

Basic Approach and Terminology

Road Note 35[6] contains recommended guidelines for the design of surface water or storm sewerage systems for relatively small urban areas where the largest sewer is unlikely to exceed 600 mm diameter, using the TRRL hydrograph method. Fletcher and Lavan[7] have defined the principal terms used in surface water calculations and these follow with some adaptions and additions.

Catchment Area The total area from which run-off of surface water will flow by gravity to a sewer.

Time of Concentration The time taken for the surface water to reach the point under consideration after falling on the most distant part of the catchment area. It comprises the sum of the time taken to flow across the surface and enter the sewer (time of entry) and the time taken to flow along the longest route of sewer assuming full bore velocity, and is equivalent to the duration of a storm which gives the peak rate of flow in the sewer.

Time of Entry A time of entry of two minutes is normally adopted for typical urban areas increasing to 4 minutes for areas with large paved surfaces and flat gradients. However, a Department of the Environment and National Water Council Manual of Practice[8] gives times of entry varying from 3 to 10 minutes, according to the size and slope of the catchment area and the severity of the storm. The smaller values apply to subcatchments of less than 200 m^2 and slopes greater than 1/30, while the larger values are for subcatchments greater than 400 m^2 with slopes less than 1/50.

Time of Flow The time of flow can be calculated or is more likely to be obtained from design tables produced by Hydraulics Research.[9] For the design of new systems, trial calculations are necessary to determine the approximate size and gradient of pipe or channel, generally at the natural slope of the catchment area.[5]

Intensity of Rainfall This depends on storm duration and frequency of storm and it is customary to use a mean rate of rainfall during a storm. The duration of the storm is often taken as being equal to the time of concentration of the drainage area, to the point for which the calculation is being made. Designs are frequently based on a frequency of storms of one year, particularly where surface flooding during storms of greater severity is acceptable. However, where inhabited basements are at risk, storm return periods of once in 50 years or even 100 years should be considered.[6]

Watson Hawksley[5] suggest that as a first approximation for a one and five year storm return period, the rainfall intensities in Table 4.1 could be used. Average rainfall intensities for a specific location in Britain can be obtained from the Meteorological Office, Bracknell, or alternatively may be derived from a straightforward manual calculation contained in the appendix to Volume IV of the Practice Manual.[8]

Table 4.1 *Rainfall intensities*

Time of concentration (min.)	Rainfall intensity (mm/h)	
	1-year	5-year
10	35–40	60–65
20	23–25	40–42
30	18–20	33–35

(Source: Watson Hawksley.[5])

In the absence of precise local data relating to rainfall intensity, the Ministry of Health formula may be used for most urban sewerage systems:

$$R = \frac{750}{t + 10} \text{ mm/h for storms of 5–20 mins duration}$$

$$= \frac{1000}{t + 20} \text{ mm/h for storms over 20 mins duration}$$

where t is the time of concentration.

Design Approach

Road Note 35[6] recommends that the following approach is adopted when using the Rational (Lloyd Davies) formula for the design of surface water sewers up to 600 mm diameter.

(1) A key plan of the proposed sewer system is first prepared as illustrated in Figure 4.1, using a decimal classification, which facilitates the addition of further branches.

(2) A sewer design sheet is formulated as illustrated in table 4.2 to simplify the calculations.

(3) The basic design data is entered in columns 1, 2, 3, 4, 9, 10 and 11. The total in column 11 is the area of surface directly connected into each length and is derived from the sum of columns 9 and 10. Column 12 is then completed by adding in the discharges from the relevant branches to give the cumulative flow.

(4) An assumed pipe size is entered in column 14, the pipe-full velocity of flow in column 5 is obtained from hydraulic design tables[9] and the time of flow in column 6 calculated from the figures in columns 3 and 5. The time of concentration in column 7 is the total time of flow up to and including the length under consideration plus the time of entry.

(5) The rate of rainfall in column 8, corresponding to the time of concentration, is found from tables published by the Meteorological Office or an approximation can be obtained from the Ministry of Health formula as previously described.

(6) The expected peak rate of flow in the pipe is then obtained using the rational (Lloyd Davies) formula:

$$Q = 2.78\,Ap \times i$$

or alternatively:

$$\frac{Ap \times i}{0.360}$$

where Q = peak discharge in litres per second
Ap = impermeable catchment area in hectares
i = average rainfall intensity during time of concentration in mm/h using the figures entered in columns 8 and 12.

The assumed pipe size is then checked to ensure that it can carry the expected flows, if not a larger pipe is selected, and the steps from (4) are repeated until a pipe of suitable size is obtained.[7]

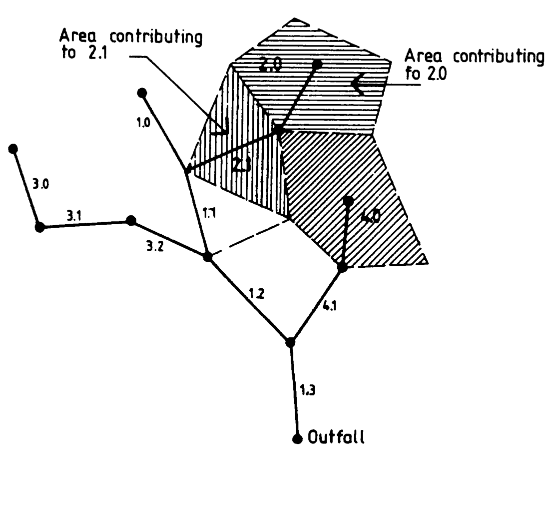


Figure 4.1 *Sewer system key plan with decimal classification (Source: Road Note 35[6])*

Table 4.2 *Sewer design sheet with worked example*

Example of pile length 1.1

Crimp and Bruges value (   )

Rational formula design sheet
Storm frequency one in 1 year
Time of entry 2 min/roughness coefficient 0.6 mm

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
								Impermeable area (ha)						
Pipe length (number)	Diff. in level (m)	Length (m)	Gradi-ent (1 in)	Vel-ocity (m/s)	Time of flow (min)	Time of concen-tration	Rate of rainfall (mm/h)	Roads	Blds. yards etc	Total (9+10)	Cumu-lative	Rate of flow (l/s)	Pipe dia. (mm)	Remarks
1.0	1.10	63.1	57	(1.25) 1.33	0.79	2.79	67.9	0.089	0.053	0.142	0.142	(22.8) 26.8	150	
1.1	1.12	66.1	59	(1.61) 1.70	0.65	3.44	62.5	0.077	0.109	0.186	0.328	(66.2) 56.9	225	
1.2	0.73	84.7	116	(1.40) 1.46	0.97	4.41	57.4	0.081	0	0.081	0.409	( )		

Length number 1.1 Assume pipe size 150 mm dia	Column 1
Length 66.1 – Difference in level 1.12 m	Columns 2 and 3
Gradient L ÷ F 66.1 ÷ 1.12 = 1 in 59	Column 4
Velocity of flow from tables 1.70 (1.61 Crimp & Bruges)	Column 5
Time of flow 66.1 ÷ 1.70 ÷ 60 = 0.65	Column 6
Add time of entry = 2.00	
Add time of flow of 1.0 = 0.79	Column 6
Total time of concentration so far = 3.44 min	Column 7

$$Q = \frac{Ap \times i}{0.360} = \text{litres/sec}$$

$$Q = \frac{0.328 \times 62.5}{0.360} = 56.94\ \text{l/s}$$

Source: Road Note 35[6].

The Wallingford Procedure

A manual of practice[8] for the design and analysis of urban storm drainage systems was published in 1981 and is generally termed the 'Wallingford procedure', and the five volumes describe the general procedure and choice of method of analysis and design, and also include maps of Britain with meteorological and soil data, and computer programs. One volume is devoted to the modified rational method of sewer design which incorporates a combined coefficient relating to volumetric runoff and a dimensionless routing coefficient. This method is particularly suited for small systems (not exceeding 100 to 150 ha in area or where pipe sizes are not larger than 600 to 1000 mm diameter).[5]

The fourth edition of the Wallingford tables[9] was published in 1983 for use with circular and egg shaped conduits expressed in metric sizes. The latest edition took account of the considerable developments in new pipe materials, manufacturing processes and jointing procedures. The tables also incorporate the revised roughness data based on Hydraulics Research Station (HRS) tests and cover a wider range of pipe diameters. The tables have become increasingly popular with civil engineers engaged in the design of urban drainage systems and water supply schemes.

The use of the tables is well illustrated in the following example:

A circular concrete sewer pipe of 500 mm diameter is to be laid to a slope of 0.006. Determine (a) the full bore discharge, and (b) the velocity of flow when the depth is 225 mm.

Table 38 indicates a roughness value k of 0.15 mm for this type of pipe, and hence the flow data given in table 16 is appropriate.

(a) Reading from table 16 the full bore discharge is 0.379 m^3/s.

(b) Table 16 gives a full bore velocity of 1.931 m/s and a coefficient for part full pipes of 350. At a depth of 225 mm the proportional depth is 225/500 = 0.45. Table 35(a) gives a proportional velocity of 0.956 (interpolating between adjacent columns). Hence the velocity of flow when the depth is 225 mm is 0.956 x 1.931 = 1.846 m/s.[9]

Another useful aid produced by HRS is the Wallingford design charts[10] which provide a direct solution to almost any problem of fluid resistance, utilising the best available equation for friction loss. There is also an excellent range of Wallingford software, including MicroRAT where the package is a spreadsheet to implement the modified rational method in the design of surface water drainage channels, combined sewers, foul sewers and storage ponds used for draining areas up to 150 ha. Other relevant software packages include WALLRUS – advanced sewer design and analysis in the UK and overseas, and CHAT – hydraulic analysis of treatment works.

Preparation of Sewer Plans and Sections

It is advisable to adopt a logical sequence and the following approach, devised in the office of John Dossor, Consulting Engineer, York, is an admirable one:

(1) Determine discharge factors, persons per hectare, impermeability factors and other relevant matters as described earlier in the chapter.

(2) Prepare a 1/2500 plan showing previously taken ground levels and invert levels of existing sewers. Lay down possible lines for proposed sewers and plot sections showing existing sewers (common scales are 1/2500 horizontal and 1/200 vertical). Manhole positions are fixed provisionally and indicated on both plan and section. Manholes are generally required at humps and hollows, changes of direction or gradient and at intervals not exceeding 100 m. It is advisable to avoid positions in roads near channels and in fields away from hedge lines.

(3) Prepare a drainage area plan of the type shown in Figure 4.1 showing the area to be drained with existing surface uses indicated thereon where relevant. The drainage area is then subdivided having regard to the way in which the run off will reach the sewers. A division will normally cross the sewer at each manhole, except at the heads

of sewers where the first area will extend to the second manhole. Each area is assumed to drain to the upper manhole as pipe sizes cannot be varied between manholes. Where a branch sewer has to be partially outside the original drainage area, the area is best extended to include the additional area that can conveniently be drained into the branch. Consideration should also be given to the deletion of areas which can be drained only at excessively high cost.

(4) On the sections show at least once on each sewer run between manholes, the minimum depth at which connections can reach the sewer. To arrive at this depth, allow 800 mm below the level of the furthest property and a gradient of 1/50 (1 in 50) from the property to the sewer. Allowance must also be made for passing under existing sewers/drains or services (gas and water) – the latter may usually be taken as about 900 mm deep. Any significant levels which control sewer depths should be shown on the sections. Approximate invert levels are now drawn at the minimum depths, keeping the crowns of the pipes level at manholes and connections. The manholes at the heads of sewers normally have a depth of about 1.05 m.

The sewers are then designed in detail, probably using a design schedule of the type illustrated in Table 4.2, taking the branch sewers first and ensuring self-cleansing velocities throughout.

Sewer and Manhole Construction

Sewer Materials

Watson Hawksley[5] have described how the selection of the most appropriate sewer material is usually a compromise between first cost and service life. The costs of relaying and consequent disturbance are often so great that the first cost of the material is unlikely to be the main choice criterion. The material selected must be capable of resisting aggression by the liquid conveyed, matters in suspension and by-products of biological degradation, such as sulphides, and external agents, and be strong enough to withstand internal and external loads. The principal materials in common use are as follows.

(1) *Clayware*

Clay pipes are suitable for non pressure situations but are not generally available in diameters in excess of 1 m. They withstand satisfactorily aggressive chemical wastes and sewage at high temperatures, but they are relatively brittle. Various types of flexible joint are available which offer superior self-alignment properties.

(2) *Concrete*

Concrete pipes are generally robust, reliable and relatively economical. However, unless a protective lining is provided they may suffer from attacks by sulphates in groundwater, acids in industrial wastes or bacterial action in septic sewage, although modern concrete pipes offer substantial resistance to these corrosive agencies.

Unreinforced concrete pipes are available up to 1.4 m diameter but their use is restricted to gravity flow. Reinforced concrete pipes are widely used for gravity sewers in temperate climates in diameters up to 3 m and can also be used for pressure pipelines up to about 4 bar. Prestressed concrete pipes have been used up to 7 m diameter and are particularly suitable for pressure pipes. While glass and steel fibres have been used to reinforce concrete pipes, and polyvinylchloride liners have been introduced to protect inner surfaces from septic sewage.

There are three strength classes of concrete pipes prescribed in BS 5911, namely light, medium and high strength (L, M and H). In addition, specially high strength H+ or H++ can be produced for special situations and often offer an economic alternative to high strength beddings. Concrete pipes are interconnected by spigot and socket or in-wall joints; those for sewage and for pipe jacking are flexible incorporating an elastomeric (rubber) ring, and those for surface water and land drainage being generally of the ogee or rebated design.

(3) *Ferrous*
Ductile iron is used widely for sewage pumping mains up to 1.6 m diameter, while steel pipes are less widely used but are available in larger diameters. Steel pipes with welded joints are particularly suitable for long sea outfalls and river crossings. Corrugated steel pipes have been used in the United States for storm and surface water culverts.

(4) *Plastics*
There is a substantial difference between thermoplastics, whose strength generally reduces significantly with temperature, and thermosetting resins (normally glass fibre reinforced), whose strength falls much less with temperature. Both groups have good chemical resistance, provided the pipes are not subjected to stresses or strains.

Of thermoplastic pipes, polyethylene (PE) is the most widely used for sewerage and is available in diameters up to 1.6 m and suitable for pressures up to at least 12 bar at 20°C. Helically welded polyethylene pipes are available up to 3 m diameter for gravity sewers. Additionally, polypropylene (PP) is available up to 1.2 m diameter and for pressures to 15 bar (20°C), while polybutylene (PB) is made up to 600 mm diameter and 17 bar pressure (20°C). PB is probably the best of all the thermoplastic pipe materials, with good high temperature strength, environmental stress cracking resistance, abrasion resistance and low creep. All these pipes can be welded by thermal fusion, making them suitable for the pulling of outfalls and river crossings and for sliplining of old pipelines. Of the vinyl type thermoplastics PVC, in its unplasticized form, is the most commonly used as a gravity sewer material.[5]

Reinforced thermosetting resin pipes, classified as GRP, FRP, RTRP and RPMP, are available in a large range of sizes up to at least 4 m and for pressures up to at least 25 bar. Pipes containing essentially resin and glass fibre are known as GRP in Britain and FRP in the United States.[5]

Loads on Buried Pipelines

The principal specification requirement for any pipe of rigid material is its crushing strength. The load on the buried pipeline derives from the depth of soil and surcharge, together with live loading from road, rail or construction traffic. Design tables are available either from HMSO,[11] TRRL[12] or from pipe manufacturers to enable the designer to select the most suitable type and class of pipe for a particular situation.

Traffic loads are normally subdivided into three categories:

1. Main roads: static wheel load of 86.5 kN and contact pressure of 1100 kN/m^2.
2. Light roads: static wheel load of 70 kN and contact pressure of 700 kN/m^2.
3. Fields: static wheel load of 30 kN and contact pressure of 400 kN/m^2.

Backfill loads are based on an equivalent soil weight of 19.6 kN/m^3.

Minimum cover over pipes It is advisable that pipes laid under roads should have cover over the pipe of not less than 1.2 m. Where pipes have to be laid with less than 1.2 m cover, special consideration is needed to reduce the risk of damage. For pipes laid in fields a minimum cover of 0.6 m should be provided, as at shallower depths there is risk of damage from agricultural operations.[13]

Various types of pipe support are used ranging from granular beds, concrete beds and soil cement beds to granular beds and surrounds and concrete beds and surrounds. Readers requiring more detailed information on loads on buried pipelines and bedding procedures are referred to Watson and Hawksley[5] and the Concrete Pipe Association.[13]

Constructing Sewers in Tunnel

Norgrove *et al.*[14] investigated the comparative costs of constructing new sewers in either open cut or tunnel in built-up areas, analysing data from 16 tenders and 11 final accounts, and including the cost of traffic delays caused by sewer trench construction, for the Northumbrian Water Authority. Their main findings were confirmed by investigations undertaken in other parts of the UK.

The research showed that with the improvement in tunnelling and micro-tunnelling technology, the break-even depth of smaller diameter sewers is becoming progressively shallower. It is in the best interest of sewer promoters that engineers designing sewerage schemes should allow tendering contractors as much flexibility as possible, so that the benefits of cheaper constructional methods can be maximised and innovation encouraged and rewarded. It is only by testing the full range of options available that engineers can be sure of obtaining the best value for their employers or clients.[14]

Fillingham[15] has described how the replacement of a 1.5 km length of the St Helens main intercepting sewer constructed in variable, difficult and potentially hazardous ground conditions took the form of a 2.40 m internal diameter pipejack. Boreholes were taken along the proposed route and from the geological report it was concluded that only in limited locations was an open-cut pipeline suitable because of the proximity of a brook, the existence of extensive lengths of very soft material, the high cost of removing large volumes of hazardous chemical wastes and the need for driven sheet piling to support the trench line and manhole excavations which would have resulted in vibration and environmental problems.

It was therefore decided that construction of the total length of the sewer in tunnel was the most suitable method. Because of the health hazards arising from working in chemical wastes accompanied by dangerous gases, pipe jacking was preferred to bolted segmental lined tunnel, as there would be fewer joints and these could all be circumferential and relatively easy to seal with O rings.[15]

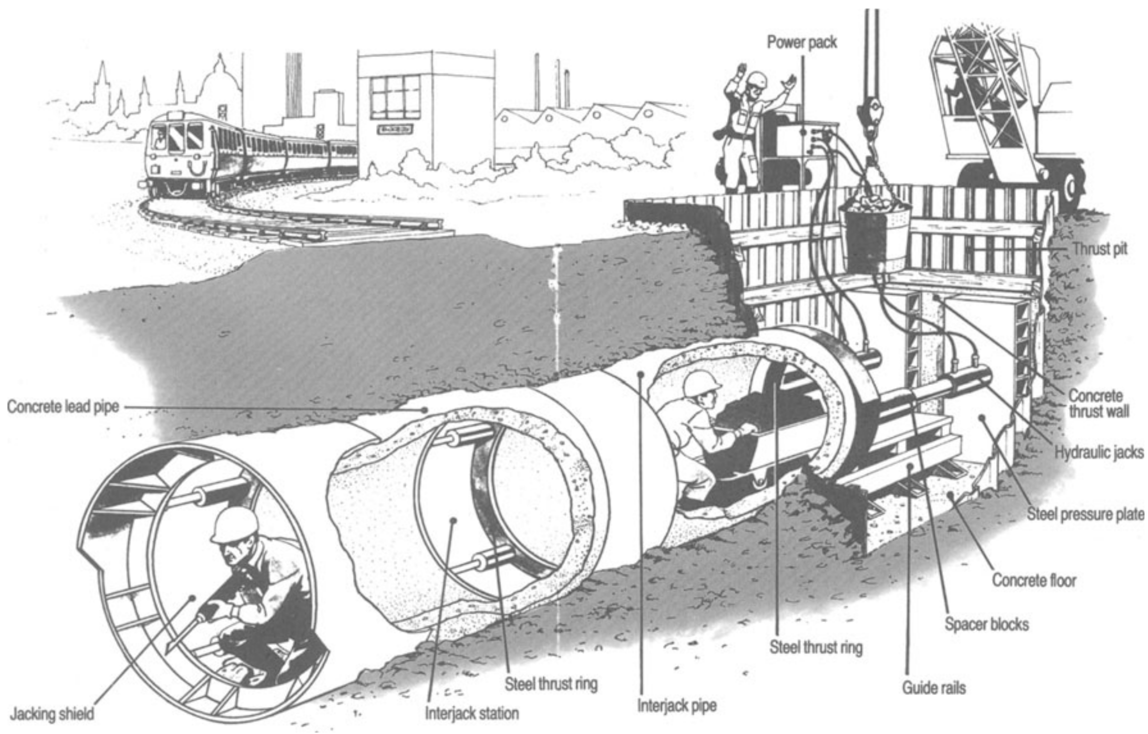


Figure 4.2 *Pipe jacking equipment (Source: Concrete Pipe Association)*

Concrete jacking pipes are manufactured in accordance with Part 4 of BS 5911 with a thicker wall and are designed to withstand the considerable axial loads occurring during the jacking process. Three types of pipe are involved, namely: (1) lead (or shield) pipe with rebated front over which the trailing edge of the shield is fitted; (2) line pipe for the main length of pipeline; and (3) intermediate jacking pipes (lead and tail), jointed pipes used each side of the intermediate jacking station. All jacking pipes are required to be flexibly jointed with a rubber sealing ring, either with an in-wall or a steel collar joint.[16] Figure 4.2 illustrates the jacking process using concrete pipes.

Manholes

Manholes can be constructed of brickwork, *in situ* concrete, precast concrete or cast iron, each of which will now be considered.

Brickwork Brick manholes supported on concrete bases are useful for shallow manholes or for deep manholes on large sewers. For manholes up to 3 m in depth 215 mm walls are normally adequate, but beyond this depth some thickening of the walls will probably be necessary. Brick relieving arches or precast concrete lintels are usually built over sewer pipes where they pass through manhole walls. The reduction in size from the chamber to the access shaft is normally formed with a reinforced concrete slab.

In situ Concrete This form of construction is well suited for irregular-shaped manholes or where there is considerable repetition so that the same formwork can be used a reasonable number of times.

Precast Concrete These are formed of tubes and step irons can be cast in at the supplier's works. The chamber rings are made in diameters from 900 to 3000 mm and taper pieces are used to reduce the diameter to 675 or 900 mm at the access shaft. The manhole cover is bedded on a precast concrete cover slab and the base may be formed of *in situ* concrete or be specially cast. Precast concrete manholes are quick to construct and are particularly well suited for use in difficult ground conditions.

Cast Iron Manholes can be constructed of cast iron segments bolted together, but this is a costly procedure and is only used in exceptional circumstances.

Composite manholes using a combination of materials are also used on occasions.

Manhole covers vary in design with the loads to be carried and a common heavy duty cover is of cast iron coated in black bitumen, watertight and airtight, with a single or double seal, solid or double triangular (three point suspension non-rocking), with locking bolts if required, and a clear opening of 600 × 600 mm or 600 mm diameter. The main advantages of cast iron covers are strength, durability and resistance to corrosion.

Benching to manholes normally has a fall of about 1 in 12 towards the invert and should be at least as high as the soffit of the outgoing sewer to avoid fouling and to provide a suitable working space for operatives. In the shallower manholes, *step irons* of galvanised malleable cast iron are normally built into the manhole walls at 300 mm vertical intervals and staggered 150 mm each side of the centre line of one of the shaft walls. Where the depth of a manhole exceeds 5 m, it is preferable to use a galvanised wrought iron ladder.

Where the manhole exceeds 8 m in depth, rest chambers should be provided at about 6.5 m intervals with a grated landing platform incorporating a hinged trap door. Manholes on sewers of 900 mm diameter and over should be provided with safety chains, for fixing across the mouth of the downstream sewer when operatives are working in the manhole, and with 38 mm diameter galvanised pipe handrails along the edges of benchings and platforms.

Back-drop Manholes Where it is required to connect one sewer with another, 1.8 m or more below the level of the first, it is advisable to construct a back-drop or tumbling bay manhole, incorporating a vertical drop pipe. The drop pipe is usually constructed outside the manhole and encased in concrete, with an easy curved junction pipe at its upper end and a cast iron duckfoot bend at the lower end. The higher level sewer should pass through the manhole wall beyond the junction for rodding and inspection purposes, terminating with a half blank flange. Where the drop pipe exceeds 225 mm diameter, the pipe should be formed of cast iron and some form of water cushion should be provided at the base in the form of a radial junction or stilling pool, to lessen the impact of the falling sewage.

With sewers exceeding 450 mm diameter, it is customary to overcome the drop in level by a ramp or cascade. Similarly, where the difference in level between the sewers is less than 1.5 m, it is usual to form a ramp of about 45° with a rodding eye.

Wastewater Case Studies

Two major wastewater schemes are examined to highlight their enormous scale and to highlight some of the main problems encountered in the execution of the works. The Greater Cairo wastewater project comprises one of the largest civil engineering projects in the world and was vitally needed to overcome serious public health problems and to improve the sanitary conditions of millions of people in a very large densely crowded city. The second case study relates to the vast Shanghai wastewater scheme in the People's Republic of China.

Greater Cairo Wastewater Scheme

Binnie and Partners, in association with John Taylor and Sons, prepared a master plan for the wastewater collection and disposal for the city of Cairo to the year 2000. Following acceptance of the report and subsequent international financing arrangements, by means of grants from the UK and USA governments, they were appointed in 1978 as members of an Anglo-American consortium (AMBRIC) to design and supervise the top priority works for Cairo's wastewater system.[17]

Cairo's first main sewerage system was built in 1915 to serve a million people and it was successively extended or duplicated haphazardly but was outstripped by the large population increase. By the 1970s it was grossly overloaded and unable to cope with the increased discharges. Research indicated that one in five children born in Cairo died before the age of five, 70% of them from gastro-enteritis carried by flies from raw sewage. Before 1983 there were about 120 places in Cairo where the sewers overflowed regularly.[18]

The initial AMBRIC work was to investigate, qualify and quantify the condition and performance of the existing system to identify where corrective action could most rapidly lead to improvement. This led to a rehabilitation project under which 57 km of existing sewers were cleared of substantial quantities of grit, 38 pneumatic ejector stations, 65 conventional pumping stations and a 330 Mld secondary treatment plant were rehabilitated, and 6 new pumping stations and 46 km of sewers and force mains were constructed by 1986, which relieved the flooding problems.[17]

The first major contracts were let in 1984 for completion between 1987 and 1990. British and Egyptian contractors worked along the east bank of the Nile, building tunnels, culverts and pumping stations to carry away foul water to the north of the city, while American firms were installing a maze of culverts and collectors among 1.5m people living on the west bank. These works formed the first phase in an overall £2500m scheme, which is intended to satisfy Cairo's wastewater demands at least until the end of the 20th century, when the 1986 population of 10.5m is expected to rise to 17m. Immense challenges arise from bureaucracy and cash shortages, and the new sewers have to be built along crowded streets where disruption on the surface causes traffic chaos while underground, waterlogged sands test the contractors' technical skills to the utmost. In the tunnel work, full face slurry shields from West Germany and Japan were in use, in sewer tunnels ranging from 1.8 m to 5.0 m in diameter. The vast size of the accompanying shafts are evident from Figure 4.3.

The majority of the tunnels are constructed in saturated alluvium but there will be one 4.5 km section constructed in rock. The system has been designed to transport high silt loads and special corrosion protection measures have also been incorporated into the design. Associated with the

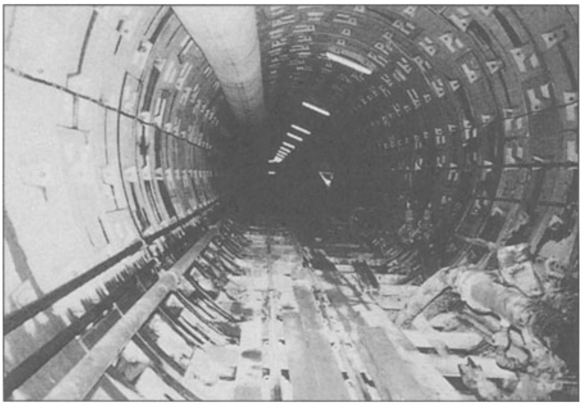


Figure 4.3 *Cairo wastewater system, typical shaft (Source: Binnie & Partners)*

system were numerous major appurtenances to deliver individual flows up to 6 m^3/s into the tunnels which themselves carry flows up to 35 m^3/s. Extensive hydraulic modelling was undertaken for some of the structures.[17]

To monitor the progress of the contracts, a computer critical path analysis program called 'Management and Project Systems' (MAPPS) was used. A critical path network for the projects was built up from networks modelling individual contracts. The networks were updated monthly to provide senior management with progress reports together with an up to date critical path. The results from the monthly update of contract networks were combined with the build up for the monthly payment certificates to produce cashflow analyses. These were used by AMBRIC in advising the funding agencies of their future funding requirements.[17]

In the old city of Cairo, on the east bank of the Nile, development is very dense and it is impracticable to construct large sewers in open cut through the city. Thus it was necessary to construct the principal interceptors by tunnelling through the alluvium under the city. The east bank portion of the GCWW project comprises principally:

16 km of 4–5 m diameter spine tunnel from Maladi to Ameria under the centre of the old city.

30 km of 1.2–2.5 m diameter branch tunnels.

A pumping station complex at Ameria lifting 2.2 million m^3/day of sewage from the tunnel interceptor into the outfall culverts.

A 14 km rectangular concrete culvert of duplicate 3 m × 4 m barrels from Ameria pumping station to Gabal el Asfar wastewater treatment works.

Three archimedian screw pumping stations of 0.57 million, 1.5 million, and 1.9 million m^3/day capacity.

The Gabal el Asfar wastewater treatment works, of which the first stage will treat a flow of 1 million m^3/day.[19]

Much of the initial development at Cairo took place on the west bank where the city now extends 16 km from the Giza pyramids in the south to Embaba in the north. Development is less dense than on the east bank and the sewers are laid in open cut. The works comprise:

37 km of sewers up to 2.75 m diameter.

21 km of concrete culverts mainly of twin box construction, with each box about 3 m wide and 2 m deep.

Seven pumping stations with a capacity ranging from 240 000 to 1.7 million m^3/day.

The Abu Rawash wastewater treatment works of which the first stage will treat 400 000 m^3/day.[19]

Tunnelling on a key part of the scheme, the Ameria connector tunnel, suffered 9 months delay in 1989–90, when despite prior freezing of the surrounding ground, water breached the bulkhead. The 17 m manual drive, 32 m below ground level and 24 m below the water table, through frozen ground, was needed to connect two giant caissons for the Ameria pumping station, as shown in Figure 4.4. The construction of caissons had already caused immense difficulty, resulting in the contract running about three years behind the original programme. In 1990, numerous vertical freeze tubes were installed to re-ice the disturbed ground. Installation was made more difficult because lumps of concrete and other surface debris had been dragged into the ground collapse. The caissons were

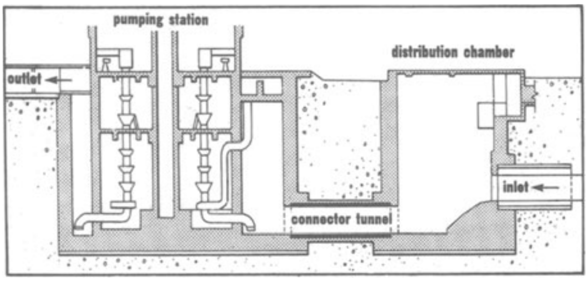


Figure 4.4 *Ameria connector tunnel, Cairo wastewater scheme (Source: ICE[20])*

pumped out and the connector tunnel completed in late 1990.[20]

Shanghai Wastewater Scheme, People's Republic of China

The Australian Development Assistance Bureau commissioned Binnie and Partners, as part of a group of Australian consultants, to assist the Shanghai Municipality in developing a programme of urban upgrading. Shanghai is one of the world's largest cities, with an estimated population of eleven million, and its rapid development has put severe strains on the urban infrastructure and services. Binnie and Partners Pty Ltd were responsible for the largest sector of the work, the liquid waste management issues.[21]

The principal objective of the liquid waste management sector was to define a scheme and a management system to improve the quality of Suzhou Creek and the Huangpu River which were seriously polluted by industrial and domestic wastes. Estimated total liquid waste generated in the city proper amounted to 3.4 million m^3/day, of which 2.4 million m^3 came from industrial sources. The Huangpu River is the source of the city's drinking water and the improvement of the water quality was considered to be of major importance by the Shanghai authorities.

The first stage of the wastewater project concentrated on cleaning up the Suzhou Creek catchment. Effluent discharging into the creek and its tributaries will be intercepted at 52 existing pumping stations and redirected through a system of link sewers to a major interceptor conduit and discharged through an outfall and diffuser system into the main flow of the Chang Jiang (Yangtze River), for completion by 1993/94.[21]

The US$450 million project involved:

interceptor facilities at existing pumping stations;
35 km of link sewers ranging in diameter from 600 to 2200 mm;
35 km long main interceptor comprising:
   10 km of gravity sewers ranging in diameter from 1800 to 4000 mm, 24 km of twin low pressure culverts 3.5 m deep × 4.25 m wide, and twin 1 km long 4000 mm diameter siphons beneath the Huangpu River;
Peng Yue Pu pumping station, with 8 pumps to discharge 40 m^3/s through 22 m head;
pretreatment works to screen the effluent;
outfall pumping station, with 10 pumps to discharge 45 m^3/s through 13 m head;
twin tunnelled outfalls, 1.3 km long, 3500 mm diameter.

The World Bank funded the foreign currency component of the project.[21]

Long Sea Outfalls

Purpose and Requirements of Outfalls

Coats[22] has described how long sea outfalls have been used primarily for safe sewage disposal and have been designed to comply with the European Economic Community Directive 76/160/EEC which became operative in 1985, to safeguard the quality of bathing water and protection of shell fish, etc. Extensive research has been undertaken by the Water Research Council and other organisations to maintain and improve the effectiveness of such outfalls. Their planning and construction require skills in many disciplines, including oceanography, hydrographic surveys, environmental considerations, geology relating to tunnelling, site investigation, hydraulics, in addition to the complex aspects of design and construction which will be considered later in the chapter. Correctly sited and designed sea outfalls allow the discharge of effluent with no detectable harm to the environment. Furthermore, in 1989 the House of Commons Environment Committee was told at the Water Research Centre that long sea outfalls are not a waste of money as they will be needed even if all sewage is treated before disposal. The same committee in 1990 stressed the failure to keep pace with scientific progress and the need for more research & monitoring.

In 1990 a European Commission (EC) report indicated that in 1988 about 145 British beaches failed to meet the EC pollution standards and they included Brighton, Worthing, Hastings, Folkestone and Blackpool. The government contended that the information was out of date and that, for example, Brighton, Worthing and Hastings passed EC tests in 1989. The Commission stated that Brussels was doing its best to speed up the release of its annual reports on sea bathing waters, required under 1975 legislation, so that figures were more up to date, but the main problem was that some member states were slow in reporting their findings, with only six states submitting 1989 details in time for the 1990 report. The report showed substantial differences in the extent of testing by member states. For example, in Greece there were only 658 testing points compared with more than 3500 in Italy.

In 1990 the British Government was taken to the European Court of Justice for prosecution by the European Commission for failing to clear up the north west coastline at Southport, Formby and Blackpool. A representative of North West Water stated that cleaning up its worst polluted beaches could cost £100m to satisfy the EC standards which came into force in 1985. A representative of the Department of the Environment (DOE) reported that almost £3b had been allocated to alleviating sea pollution in 1989 and about 75% of Britain's beaches passed the bathing water guidelines in 1990 with the number increasing each year, so that by 1995 most British beaches would satisfy EC standards.

A European Commission Municipal Wastewater Treatment Directive published in 1989 with a two year consultative period aims at stopping all European states discharging raw sewage into the sea. The directive aims to secure the biological treatment of sewage before being discharged into the sea, thereby considerably reducing the amount of marine breakdown required. In 1990 Britain had long term plans costing £100m per annum to replace the 1000 sea outfalls, which often discharge raw sewage just below the low tide mark, with much longer pipes taking the sewage up to 1.6 km out to sea. Britain maintains that discharging sewage into the sea is the best environmental option, but West Germany and other North Sea states are concerned about the possible long term effects.

The directive will require all sewage to be macerated to ease digestion by marine microorganisms followed by secondary treatment to assist in neutralising the sewage before it enters the sea. Countries have five years to implement directives. Estimates of the cost of implementing the directive vary between £5b and £14b. There are 1000 sea outfalls in Britain serving 15.5m people living in coastal areas. In 1987 the ICE estimated it would entail an expenditure of £300m per annum for ten years to bring the outfalls up to the 1985 EC standard. The directive would bear particularly heavily on Mediterranean countries such as Greece, Italy and Spain whose outfalls have caused severe pollution.

Preliminary Procedures

Prior to designing a sea outfall, it is necessary to obtain a variety of approvals and to carry out a feasibility study. The type of approvals that may be required are as follows:

(1) consent under the Control of Pollution Act 1974
(2) planning approval under the Town and Country Planning Act 1971
(3) consent under the Coast Protection Act 1949
(4) licence under the Food and Environment Protection Act 1985

(5) consent of the coast protection or sea defence authority
(6) consent of a dock or harbour authority or of the Ministry of Defence
(7) consent of the Nature Conservancy Council under the Wildlife and Countryside Act 1981
(8) purchase of land and easements from landowners
(9) easement from the Crown Estates Commissioners.[23]

Brown[23] has provided a useful case study relating to Margate which gives excellent guidance as to the possible form of a feasibility study. Margate is situated in the Isle of Thanet, a popular holiday area in East Kent, with a total summer population of about 180 000 in the four seaside towns of Margate, Ramsgate, Broadstairs and Birchington. Sewage was discharged to the sea through a number of short sea outfalls and EC requirements for bathing waters were not met over much of the coastline. It was decided that the feasibilty study should embrace the whole area and a range of options considered.

The early part of the study was devoted to collecting the background information relating to existing facilities, flows, population, sewage characteristics and projections, and identifying possible treatment works and outfall sites prior to early discussions with water quality officers regarding design standards. Extensive marine surveys were undertaken in the summer of 1982 and included hydrographic, float tracking and dye and bacteriological tracer surveys. These surveys showed that the North East Kent coastline was generally favourable for sea disposal, with fast tidal currents providing good dilution and dispersion, with a general residual movement of water away from the coastline. At the conclusion of the study in December 1983, the chosen strategy for Thanet was a separate outfall at Margate, for Margate and Birchington combined, an outfall at Broadstairs and a treatment works serving Ramsgate. This was followed by public consultation and formal application for approvals.[23]

Another useful study was that undertaken by Watson Hawksley for the South Hampshire Plan Advisory Committee in 1970–72 at a cost of US$200 000.[24] At that time the Government's development plan for South East England included a new city of 600 000 population sited between Southampton and Portsmouth, although in the event declining population projections made the project unnecessary. Watson Hawksley was instructed to study the feasibility of marine disposal of liquid wastes from the new Solent City, including examination of the acceptability of marine disposal of partially treated sewage effluent and of sewage sludge. The most suitable locations and methods of discharge were to be identified, and engineering studies undertaken to provide estimated costs for the submarine outfall and preliminary treatment works for comparison with full treatment. The study area included the stretch of water between the mainland and the Isle of Wight known as the Solent, which has an international reputation as a yachting centre, and is the main shipping channel to the Port of Southampton.

Mass water movements were investigated and a mathematical model developed to determine possible outfall performance. Dispersion performance was checked using dye tracing methods and the float and dye checking chart is illustrated in Figure 4.5. Ecological studies included investigations of phyto plankton and bottom fauna and extensive chemical and biochemical studies relating to water quality were undertaken. Hydrographic surveys included sea bed movement studies, seismic and borehole investigations. The information from these was evaluated in conjunction with specialist contractors to establish construction details for the proposed outfalls. The final report was submitted in 1972 and concluded that, although all reasonable health and amenity standards could be met by partial treatment and discharge through a 5.75 km long outfall, the cost estimated at US$40m would be high and the decision was taken to adopt full treatment of sewage from the proposed new city.[24]

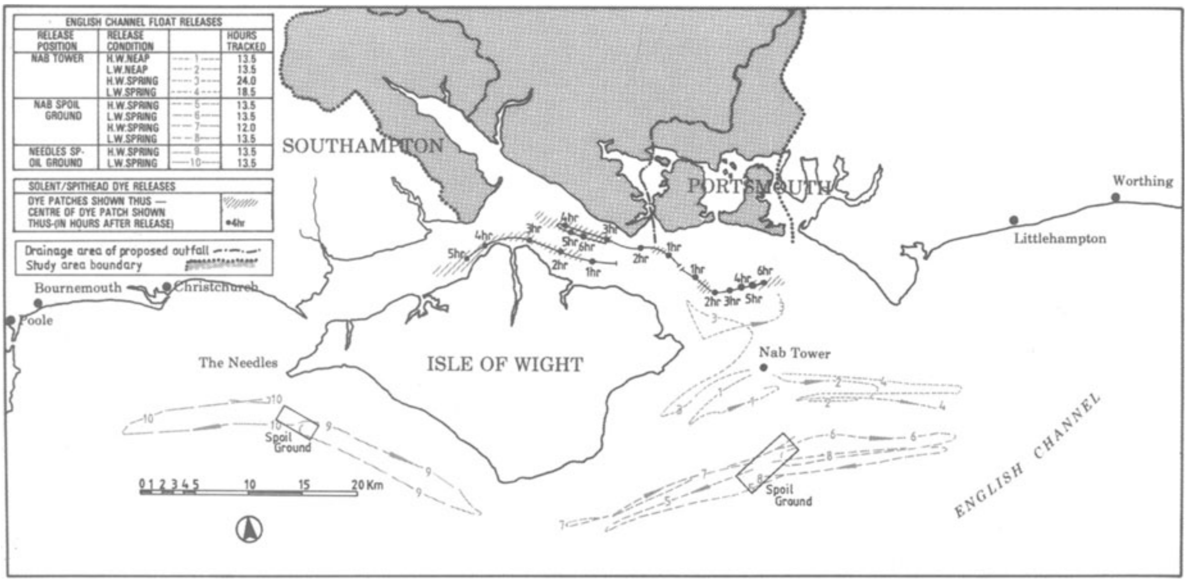


Figure 4.5 *Marine survey, Southern England (Source: Watson Hawksley[24])*

Design of Outfalls

Willis[25] has described how the results of hydrographic field studies, site investigations and computer modelling provide the designer with the basic tools for designing an outfall to achieve ease of construction and economic and satisfactory operational use. The results of water movements studies preferably using bacterial tracer and computer modelling of dispersion and die off, together with environmental base line surveys, determine the general area within which an outfall discharge can be located and the achievable treatment standard. Side scan and solar information and borehole results determine the sea bed contours, depth and type of sediments and geological strata below the sea bed. Wind, tide and current data together with the nature of the sea bed will assist in the assessment of the constructional difficulty and the selection of the most suitable plant.

A construction site is essential for a 'pulled outfall' and preferably one which allows the pipe strings to be assembled in the direction of pull. If no construction site is available or a suitable platform cannot be fabricated over the foreshore then the construction options for large diameter sea outfalls are limited to tunnelling; float and drop; pipe by pipe construction; construction from a large barge; or directional drilling.[25]

The treatment performance and the costs of an outfall increase with the water depth at the point of discharge. Willis[25] described how economic construction is achieved by the use of conventional dredging equipment which becomes restricted for water depths in excess of 25 to 30 m. However, it is unlikely to require a water depth in excess of 25 m to achieve EC water bathing quality on UK coastlines. Strong currents ensure rapid dilution and dispersion of the effluent but also necessitate good anchorage systems for dredgers and pulling barges.

Most modern sea outfalls incorporate pumping to control the rates of flow either by pumping direct through the outfall as at Yarmouth or by pumping to a tower from which a gravity discharge occurs to the sea as at Minehead. Risers and diffusers are usually provided to maintain self cleansing velocities resulting in intermittent discharges. Sea outfalls discharge just above sea bed level and where discharges are pumped direct, part of the pipeline will empty if air enters when no pumping occurs. When pumping is resumed the air is expelled through air valves, a chamber at the head of the outfall or diffusers.[25]

Figure 4.6 shows an air valve chamber constructed under the promenade at Great Yarmouth with adequate odour and noise control facilities. Diffuser assemblies vary with the location and sea bed conditions prevailing at each outfall and the following examples illustrate some of the different designs that have been adopted in practice. Figure 4.7 shows the assembly at Weymouth in a deep water location with stable sea bed conditions and contains six port diffusers, while Figure 4.8 illustrates another deep water location at Yarmouth but with prohibited anchorage and unstable sea bed conditions and has a two port diffuser. Figure 4.9 shows a shallow water location at Minehead with stable sea bed conditions with a four port diffuser, while Figure 4.10 shows a diffuser concrete protection dome to the plastic riser pipe at East Cowes, where it is important that the weight of the dome is not transferred to the riser or pipeline. The shape of the diffusers should be designed to prevent as far as possible snagging of fishing nets and anchors.[25]

Willis[25] has described how a long sea outfall is costly to construct and is normally designed for a 60 to 100 year operational life. To achieve this, it must be protected from scour action, sea bed

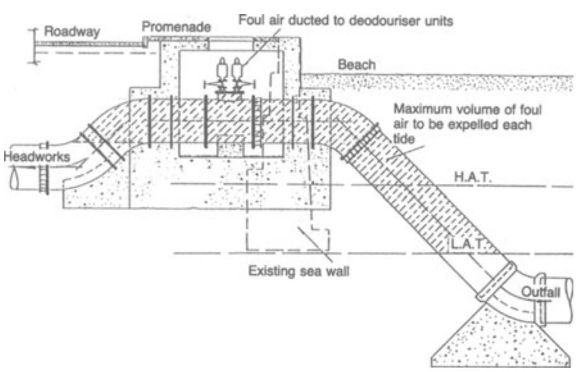


Figure 4.6 *Air valve chamber constructed under the promenade at Great Yarmouth (Source: R.R. Willis[25])*

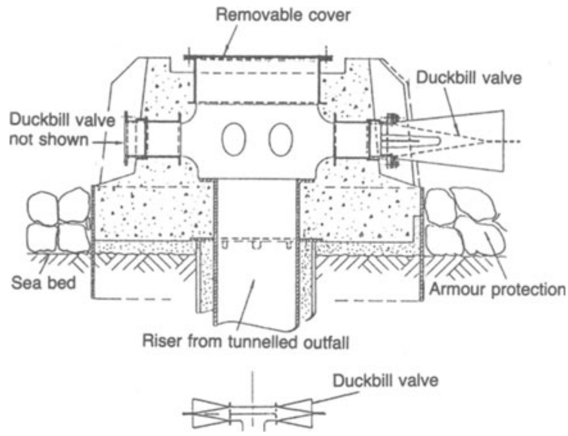


Figure 4.7 *Weymouth six port diffusers, deep water location (Source: R.R. Willis[25])*

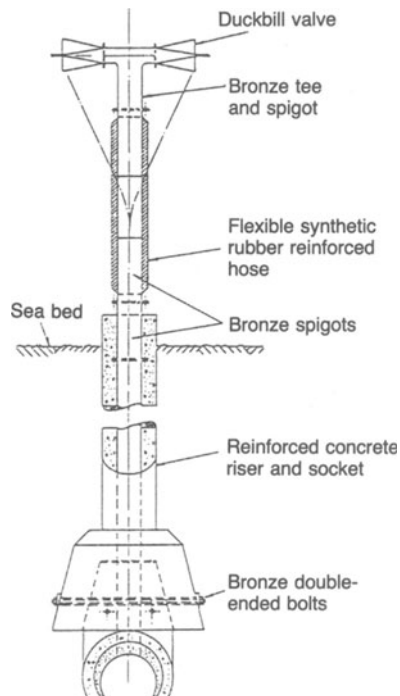


Figure 4.8 *Yarmouth two port diffuser, deep water location (Source: R. R. Willis[25])*

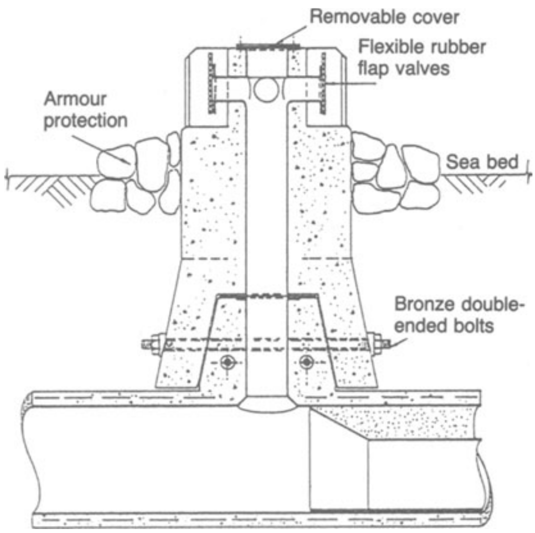


Figure 4.9 *Minehead four port diffuser, shallow water location (Source: R. R. Willis[25])*

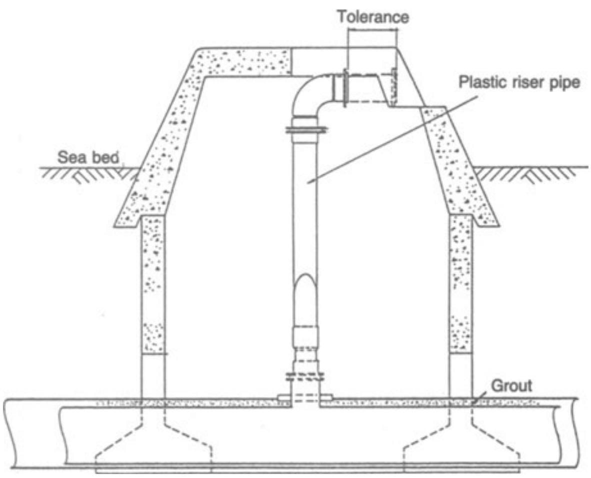


Figure 4.10 *Diffuser concrete protection dome, East Cowes (Source: R. R. Willis[25])*

movement and possible anchor drag from ships. With a pulled pipeline constructed in a preformed trench, the depth to invert and the consequent amount of backfill over the completed pipeline should be so designed that changes in the sea bed level do not affect the stability of the outfall. For an outfall constructed on a sea bed of rock the armouring will have to be adequate to prevent movement and damage by ships dragging their anchors. Diffusers above sea bed must be designed to minimise scour and be well protected by rock armour.

When effluent is discharged from a submerged marine outfall it rises to the surface because of buoyancy and is diluted with sea water as it rises. Reasonably accurate methods of predicting dilution in still water are available and a number of methods have been proposed for estimating dilution of jets discharging into moving water. A technical note produced by Sharp and Moore[26] compared the predictions of three mathematical models developed by the United States Environmental Protection Agency with field data collected at outfalls in England. The comparison shows a tendency to overpredict dilution and the conclusion is that a conservative approach should be taken to the design of outfalls affected by currents.

Sea Outfall Headworks

Hendry and Perfect[27] have described two headworks at Kirkcaldy and Scarborough which utilise similar plant in conjunction with long sea outfalls to meet the requirements of EEC Bathing Waters Directive 76/160. Pre-treatment works for domestic sewage sea outfall schemes comprise full preliminary treatment. Grit is removed to prevent it settling in the outfall and sewage solids are removed by fine mesh screens, and in some cases macerated to a very small size, returned to flow and passed through the fine mesh of the screens, for discharge to the outfall. Alternatively, the screenings are removed, dewatered and disposed to a tip. In the future it is likely that the discharge of macerated screenings will be unacceptable and they will have to be disposed of on land sites.

The Fife Regional Council at Kirkcaldy planned a rolling programme of expenditure imposed by financial restraints, installing the sea outfall in 1986 and the interceptor sewer pumping station in 1990, while the Yorkshire Water Authority decided on a programme of concurrent works at Scarborough to be fully operational in 1991.

Kirkcaldy on the north shore of the Firth of Forth had a population of about 56 000, and the Fife Regional Council constructed a sewage disposal scheme valued at £9.5m which collected several existing short sea outfalls into a new headworks and a new long sea outfall as shown in Figure 4.11. The maximum flow to the works will be 1600 l/s, which represented six times DWF, thus serving an equivalent population of 96 000.

A general layout and flow diagram of the Kirkcaldy headworks is illustrated in Figure 4.12. An alternative design for a headworks as implemented at Scarborough, Yorkshire is shown in Figure 4.13 to serve a peak summer population of 100 000; the total cost of the sewerage scheme being £26m in 1990. The control of both headworks is fully automated.

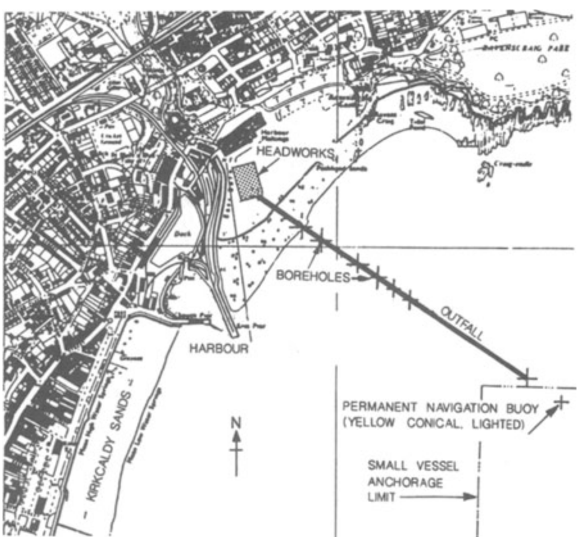


Figure 4.11 *Layout of Kirkcaldy sea outfall (Source: Henry & Perfect[27])*

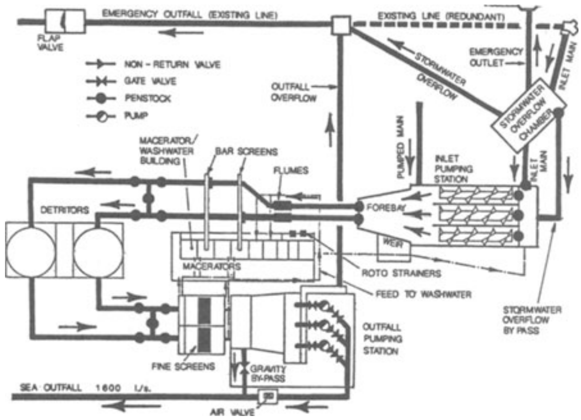


Figure 4.12 *Schematic layout of Kirkcaldy headworks (Source: Henry & Perfect[27])*

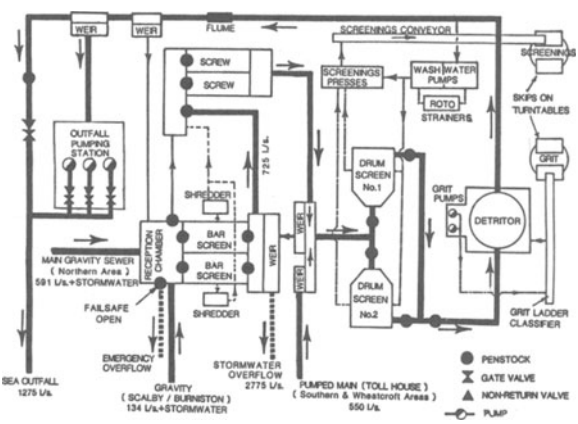


Figure 4.13 *Schematic layout of Scarborough headworks (Source: Henry & Perfect[27])*

The fine mesh drum scheme has proved very effective in removing particulate matter from sewage. Where screenings are to be macerated and returned to the flow, experience shows that macerated particles can pass through a 5 mm mesh into the sea outfall. Macerators are used at Kirkcaldy to chop up the screenings so that they will pass through the drum screens to the outfall, whereas shredders are used at Scarborough to ensure that screenings removed by the drum screen can be easily and efficiently pressed.[27]

Should it become mandatory in the future to keep out screenings once they are removed, the Kirkcaldy process can easily be modified to comply. Shredders or macerators have the valuable side effect of breaking down much of the organic matter thereby producing cleaner screened material.[27]

Construction of Pipeline Outfalls

Smy[28] has classified the principal materials used for outfall pipelines as:

(1) ductile iron pipes
(2) welded steel pipes
(3) high density or medium density polyethylene (HDPE or MDPE)
(4) glass reinforced polyester pipes (GRP)
(5) concrete pipes
(6) flexible armoured pipe

and the main construction methods are:

(a) bottom or off bottom pull
(b) float and sink
(c) pipelaying from a lay barge
(d) pipelaying from a reel barge
(e) pipelaying by divers
(f) directional drilled outfalls.

A combination of either materials or methods can be used to suit the particular requirements of the outfall, such as a lined pipe part bottom pull and part float and sink.

Mild steel pipes are the most commonly used for long sea outfalls as they can be welded into a continuous steel pipeline of known strength and flexibility which allows them to be bottom pulled in long lengths. Construction by the bottom or off bottom pull method has proved to be the most popular, safest in exposed areas and most cost effective. A working area is prepared adjoining and in line with the proposed outfall and storage beams and pipe support rollers installed. The individual steel pipes are then welded into strings to suit the space available, the number being dependent on the length of the outfall.

Concurrently with this, it is customary to carry out the dredging of the trench ready to receive the pipeline. When these operations are complete and checked by survey and other appropriate tests, the first string is pulled along the rollers into the trench until the landward end is opposite the seaward end of the second string. Pulling then ceases and the second string aligned with the first string to which it is welded. Pulling is then resumed until the third string can be added and welded and the operation repeated with subsequent strings until the full length of the outfall pipeline has been pulled into position.[28]

With the float and sink method of installation, where there is no space available for welding the pipes adjacent to the proposed outfall, it may be necessary to establish a fabrication yard on a site some distance away and to tow the pipeline to the proposed outfall site. There it is carefully secured over the predredged trench and then lowered by controlled methods into the final position. This method is illustrated in Figure 4.14 showing an outfall pipe at Southend being floated prior to sinking.

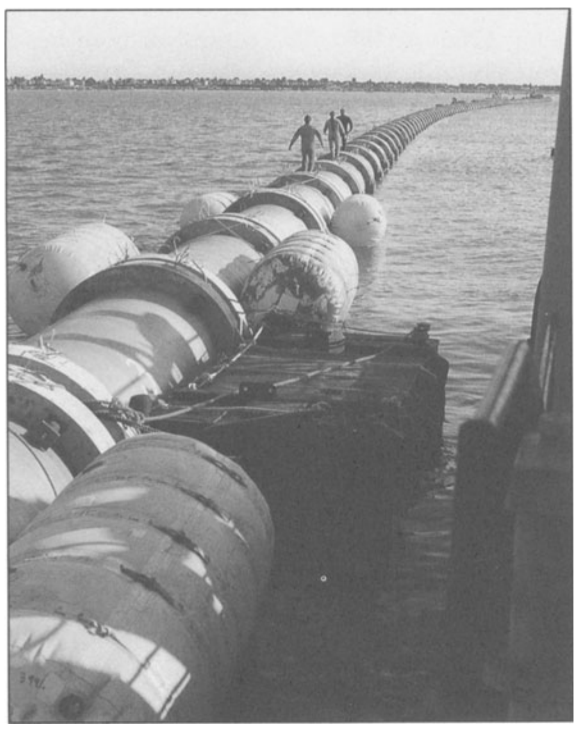


Figure 4.14 *Southend outfall pipe before sinking (Source: Watson Hawksley)*

Osorio[29] has described how there is no real difficulty in laying a continuous welded steel pipe by the bottom pull method on the softest possible sediments; the problems are to steer the leading end of the pipe along the chosen vertical profile and to support any armour needed to prevent damage by a ship's anchor to the pipe by direct hit, dragging on the surface or dragging at depth, and assessing the load factors to be applied in these cases. For example, the Manila outfall, which is 2 km long and 1.8 m diameter, is in an area where vessels of up to about 30 000 dwt drag their anchors in typhoons and the pipe was designed to resist an 8 t standard anchor, with a sand shoulder to prevent the pipe dragging sideways through the soft mud. There was no anti-corrosion coating between the steel and concrete so that the steel tube and the reinforced concrete casement could be designed to act together to resist the twin point loads from the anchor.

The Tolo Channel pipeline in Hong Kong was first planned on similar lines, but plans to build a liquified petroleum gas terminal close to the pipeline necessitated careful consideration of the much larger anchors carried by LPG carriers. The use of concrete alone to prevent corrosion of the steel tube was also rejected and it was decided to lay the pipe on alluvium and protect it with armour at substantially increased cost. Pipe strings 91 m long and weighing 500 t were handled successfully. However, larger diameter pipe would be heavier and would require flatter bonding radii which would affect the dredging profile and costs. Pipes up to 3 m diameter have been reported laid by bottom pull.[30] The upper limit for bottom pull would be a function of cost and would vary according to circumstances, available plant and preference. Tenderers should desirably be permitted to price alternatives.[29]

Osorio[29] has highlighted another problem which can have a dramatic effect on the design of large diameter submarine pipes and this is the risk that the outer reinforcing bar can corrode before the end of the design life. Expert opinion on this aspect is changing and in Manila, for instance, the corrosion engineer was content with 40 mm cover of good quality concrete made with type V ASTMS cement. At Tolo, Hong Kong, type V (and SRC its nearest British equivalent) was rejected because of poor resistance to penetration by chloride ions. Another outfall in Hong Kong constructed in 1990 had a concrete encasement similar to that used at Tolo but with the addition of epoxy coating to the outer re-bar cage.

The range of stiffness and submerged weight will cause wide variations to the vertical force required to ensure that the pipe has the correct alignment, and it is therefore necessary to monitor the level of the leading end of the pipe continually and to adjust the force as required. The survey methods used on submarine pipelines in Hong Kong embraced levelling inside the pipe, diving on the lead end of the pipe with a sensitive pressure gauge, a trench profiler on a survey boat stationary over the line and a narrow beam echo sounder on a boat drifting slowly over the line. Osorio[29] believes the simplest method to be the narrow beam echo sounder with the boat's position determined from a laser beam on the line, but he considers the other methods are useful and should be available.

This section of the chapter concludes with a case study of the construction of a modern UK long sea outfall. In 1991, Southern Water diverted the flow of Portsmouth's sewage from its old headworks into a new system incorporating Britain's longest sea outfall at that time, being 5.7 km long. Southern Water claimed that the environmental damage from discharging the sewage 17 m below the low tide level in the Solent, a deep water channel between Portsmouth and the Isle of Wight, will be neglible. A mathematical computer model of the tidal movements in the Solent was used to determine the location of the outfall, and tests using floats and tracers were carried out to ensure maximum dispersion.[31]

The outfall consisted of a steel pipeline weighing 2900 t with a 5000 t concrete surround, and the bottom tow used a very large winch barge. The 1.4 m diameter pipes arrived on site in 12 m segments and these were followed by 166 mm concrete weight surrounds placed around the pipes using steel moulds, and each 350 m long string was assembled on rollers in line with the launch positions. As each segment was added, the string was pulled back until the operation was complete. Each string was then moved parallel to the launch line.

Both the internal sand and cement lining and the external concrete coating stopped just short of the end of each string to allow sufficient space for a Reynolds joint. The diffuser section was the first to be conveyed out to sea with the launch pad profiled at 2500 m radius to lead the pipeline down to the sea bed. It passed through a gap in the temporary cofferdam at the high water mark on the beach which was sufficiently large to allow the free movement of the line but did not permit surges to damage the works as water rushed through in storms.[31]

Once the end of the first string was in line with the start of the launch pad, the second one was rolled over and joined on. The bottom tow continued until the string had been pulled through its full 350 m length, and the joining operation repeated. The operation was completed in less than two weeks. The 100 m long diffuser section was partly assembled off site and had nine 300 to 400 mm outlets. Each outlet was covered by a precast concrete chamber, as were the inspection hatches.[31]

One of the most interesting features of the headworks was the contiguous bored pile retaining wall built around the whole of the screening works, as sheet piling in the hard clay would have resulted in too much noise and vibration. Contingency plans were also made to deal with stormwater flows at the outfall site. An existing 60 000 m^3 storage tank in which sewage was previously stored before discharge two hours after high water, will be used to store excess flow until the stormwater throughput has reduced sufficiently.[31]

Failure of Sea Outfalls

Cowie and Low[32] have described how the many operational difficulties experienced with sewage sea outfalls around the British coastline dispels any lasting theory that an outfall is merely a pipe laid into the sea bed which can be forgotten once installed. Furthermore, it is only through careful identification and evaluation of these difficulties that designers, contractors and operators of sea outfalls can be expected to improve on their approach. The following case study which highlights some of the possible problems relates to an outfall located at Peterhead in the Grampian Region of Scotland, which suffered extensive structural failure within five years of installation in 1974.

The consulting engineers for the outfall obtained information from a brief marine survey and decided that a bottom pull method should be deployed because of the prevailing storm and sea bed conditions, using steel pipes of 1016 mm outer diameter with a 9.5 mm thick wall and coated with 125 mm of reinforced concrete, pulled into a trench which was to be excavated partly in rock, to a depth which would leave the top of the pipeline at or below sea bed. The pipeline was to be anchored to the bottom of the trench by up to 82 concrete anchor blocks incorporating steel bands bolted into the rock. The total length of the outfall from the onshore treatment works to and including the diffuser section (comprising 18 risers 150 mm in diameter) was established by design at 740 m to cater for a maximum flow of 1120 l/s.[32]

The steel pipes were supplied by the client and good progress was made both onshore with the preparation and weight-coating of the pipe strings and offshore with the blasting and excavation of the pipe trench. The pulling operation lasted ten days in September 1974. In December 1974 the consulting engineers produced a record drawing showing the outfall buried minimally with its crown flush with the sea bed but no anchor blocks. The consulting engineers subsequently explained that the severe sand movements that had been anticipated did not occur and so the anchor blocks were not required.

A 1975 post-laying diving report, together with underwater photographs and a drawing showing longitudinal and cross sections of the outfall, indicated a number of faults. In November 1979 a small sewage slick was observed over the pipeline close inshore to the sewage treatment works, and the plume of sewage increased in size over the winter months. An inspection was carried out by a commercial diving firm and their survey reported the complete failure of the outfall.[32]

In 1981, Grampian Regional Council engaged Binnie and Partners, in selective competition, to assess the likely cause of failure and to design the restoration of the outfall. There appeared to be five possible reasons for the failure of the outfall: a mine explosion; sabotage; ship strike; anchor drag; or storm waves. Acoustic surveys were used to collect evidence, together with a diving survey of the outfall and adjacent sea bed carried out by divers and surveyors. Sonar contacts were made and the outfall positioned and accurately levelled. The movement of sea bed sediments were monitored and diving inspections on the outfall were made to measure accurately the extent of the damage to the outfall. Debris searches were made with metal detectors and a report produced by an ex-naval mine disposal expert on the effect of underwater explosions on structures. Figure 4.15 shows the main findings and the damage was not considered consistent with the mine detonation in 1979.

It was found that storms from the north contributed to wave action and winds from the section 0–135° were important in generating waves. Two methods of calculating lift and drag forces were used, the first based on data published by the Hydraulics Research Station (HRS)[33] and the second following the procedure suggested by Grace[34]. The HRS method was used to identify which section of the outfall would be subjected to the highest forces, and both methods of calculation were used to devise forces on the pipeline at the point where the break apparently occurred for a range of wave conditions between 3 and 7 m.[32]

In normal operation, with the pipe full of sewage, the submerged weight with concrete surround would have been 8.2 kN/m. It was evident that vertical movement of the pipeline would occur where exposed. The wave analysis showed that during winds of force 8 and above the average of the highest 10% of waves would have been 7 m with a period of 8–12 s. The resulting lift forces were about 7 kN/m and 14 kN/m (depending on whether HRS or Grace procedure was used) and these were comparable to or larger than the submerged weight of 8.2 kN/m.[32]

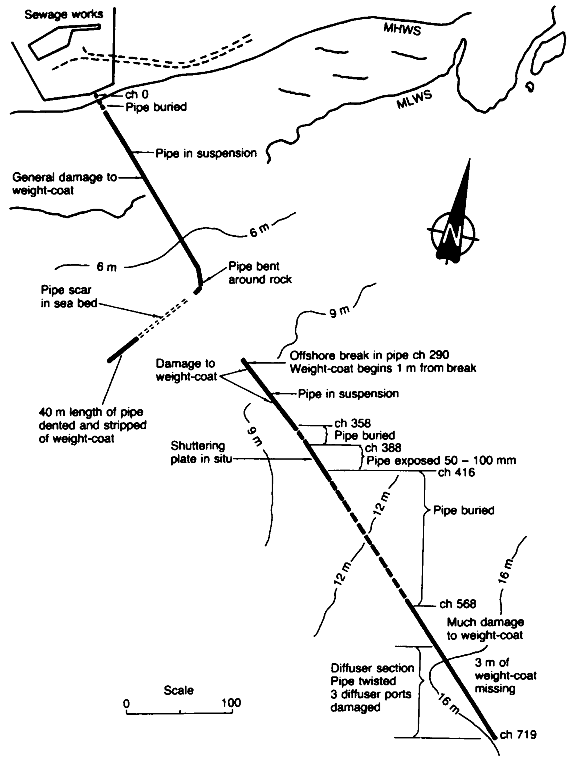


Figure 4.15 *Condition of Peterhead sea outfall in July 1981 (Source: Cowie & Low[32])*

The outfall lost much of its sand cover from wave-induced currents, and lay exposed on a sea bed consisting mainly of bedrock and boulders. Lift forces in this area probably exceeded the submerged weight of the pipeline, resulting in vertical movement of the outfall. Binnie and Partners reported in 1981 that forces resulting from storm waves were probably the cause of the failure.[32]

The four major lessons arising from this failure were as follows:

(1) In order to design a sea outfall or submarine pipeline which is likely to stay secure in the sea bed, it is essential to collect sufficient information on the sea state and sea bed

conditions. In particular, it is essential to know the behaviour of superficial sediments on the sea bed and the maximum height of wave that can be generated above the outfall or pipeline.

(2) There are a large number of design methods for wave force prediction which produce substantially variable results despite the considerable research which has been undertaken.

(3) Another area of design uncertainty which requires further research is the prediction of rock armour size for pipeline protection in the surf zone.

(4) Sea outfalls represent a large capital investment by Britain's water authorities. Even the best designed outfall or submarine pipeline can be affected by the forces of the sea or man's activities. There were few sea outfalls which received regular structural and performance monitoring in 1989, and regular monitoring would lessen the probability of severe damage or failure.[32]

Sewage Pumping Stations

General Characteristics

In flat and low-lying areas it is often necessary to install pumping stations, from which the sewage is pumped through a pumping main to a sewer at a higher level or a sewage treatment works. Pumping entails high installation, operating and maintenance costs and hence the number of pumping stations should be kept to a minimum. When siting pumping stations special attention should be paid to ground conditions, to restricting the length of pumping main to prevent the possibility of sewage becoming septic, and of locating stations as far as possible from residential properties.

Standby pumps should be provided of sufficient capacity to deal with the flow when a pump is out of service. With electrically driven pumps it is advisable to have standby plant using some other form of power, particularly where serious flooding would otherwise result from electric power failure.

The wet well or sump, in which the sewage is collected, should be of sufficient capacity to prevent a pump continually cutting in and out, but conversely it should not be excessively large or the sewage may become septic. The design head for a pump consists of static head (including suction lift) and friction head (including losses caused by bends and other features). The pump selected must be reliable, robust and easily accessible.

For small flows in isolated locations, pneumatic ejectors may be installed and they are particularly suitable for discharges below 8 l/s. They are very reliable and easy to maintain. They usually consist of an automatic self-starting compressor, air storage and the ejectors. A minimum of two ejectors should always be provided to allow for repairs and it may be advisable to provide a second air compressor.

Sewage pumps are usually centrifugal or mixed flow although submersible pumps may be used on occasions as illustrated later in the chapter. The latter pumps have a close-coupled, fully submersible electric motor fitted to the pump and are designed to be lowered into the sewage.

Pumping generally needs to be able to operate continually under all conditions. Hence it must be possible for all routine maintenance, including major overhauls, to be performed with the station operating. The normal pumping equipment comprises electrically driven automatic pumps, operated from level-measuring devices or switches in the receiving sump, enabling them to operate without full time attendants.[5]

The sump should be designed to allow easy flow to the pump suctions, and with sufficient benching to prevent excessive settlement of solids.[35] In major installations, it is customary to provide two interconnecting sumps to enable either of them to be drained for cleaning or maintenance, without closing down the installation. Some intakes to sumps are fitted with screens, when it is necessary to dispose of the screenings periodically to avoid blocking of or damage to the pumps.[5]

Watson Hawksley[5] consider that the following features are generally regarded as essential in the design of pumping stations:

(1) Pump casings are below the invert of the incoming sewer, thus avoiding the need for any priming equipment.
(2) Non-return valves and entries to the rising main are both horizontal, thereby avoiding the deposition of solids when pumps are not running.
(3) Electrical equipment is positioned at a sufficiently high level to prevent damage occurring in the event of the pump well becoming flooded, and automatic cellar-drainage pumps are also usually installed in the well.
(4) Sufficient access and cranage is provided for ease of maintenance.

Case Studies

Three case studies are included of very different schemes, each with their own particular characteristics and problems, to give an indication of the range of pumping stations that are used in practice.

Portland Pumping Station

The Weymouth and Portland main drainage scheme was approved in principle by the Wessex Water Authority and their agents, Weymouth and Portland Borough Council, and a scheme was designed which allowed all sewage from both Weymouth and Portland, Dorset, to discharge to a major collector pumping station and thence to sea by long outfall, after primary treatment at the headworks at Wyke Regis.[36] The nature and size of the scheme at an estimated cost of £35m at 1989 figures led to considerable phasing, with the improvement of Weymouth Bay beach to the EEC's directive on bathing beach standards in 1976[37] as a first priority.[38]

Hunt and Lynes[38] described how five possible sites for the pumping station were evaluated. Three were discounted by the Ministry of Defence on security grounds, the fourth because of possible sea flood damage and the fifth site was approved. The location was a redundant gasworks site a reasonable distance fron Chesil Beach, Portland, although problems with a nearby major electricity substation had to be overcome. Furthermore, it was necessary to restrict the building height to not more than 1 m above surrounding buildings to satisfy air station flight path restrictions, and flooding considerations were met by raising the ground floor levels above the worst recorded flood levels. Chemical analyses of the ground dictated the use of sulphate- resisting concrete in conjunction with additional external protection instead of external tanking for the substructure, typical sulphate levels being 125 ppm in the groundwater.

At an early stage in the design, three alternative sump types were considered, namely: diaphragm wall; cofferdam and conventional construction; and secant wall. A full investigation of the possible artesian ground conditions led to the choice of a conventional pumping station layout using a raft base and multiway spanning wall panel design, and the construction took place from 1985 to 1987. All ancillary bases to the main building were designed as propped cantilevers to the main substructure and piled. Minimum dewatering durations were enforced to limit long term settlement and short term flotation problems during the construction of the sub-base and the walls. The permissible depth range of the temporary piling was strictly controlled so that the artesian beach layer had minimal effect on base heave, boiling or flotation. The restricted site meant that sump storage could only be achieved by extra depth of construction.[38]

Hunt and Lyness[38] described how the following special features were incorporated. The wet well was subdivided into a small dry weather sump and a larger storm overflow sump as shown in Figure 4.16, to avoid deposition of grit (grit removal is carried out at the long sea outfall headworks in combination with some of the Weymouth gravity flows). Mechanical raked screens and macerators were incorporated in the station as shown in Figures 4.16 and 4.17.

The storm sump was deepened to give spare sump capacity to avoid as far as possible small

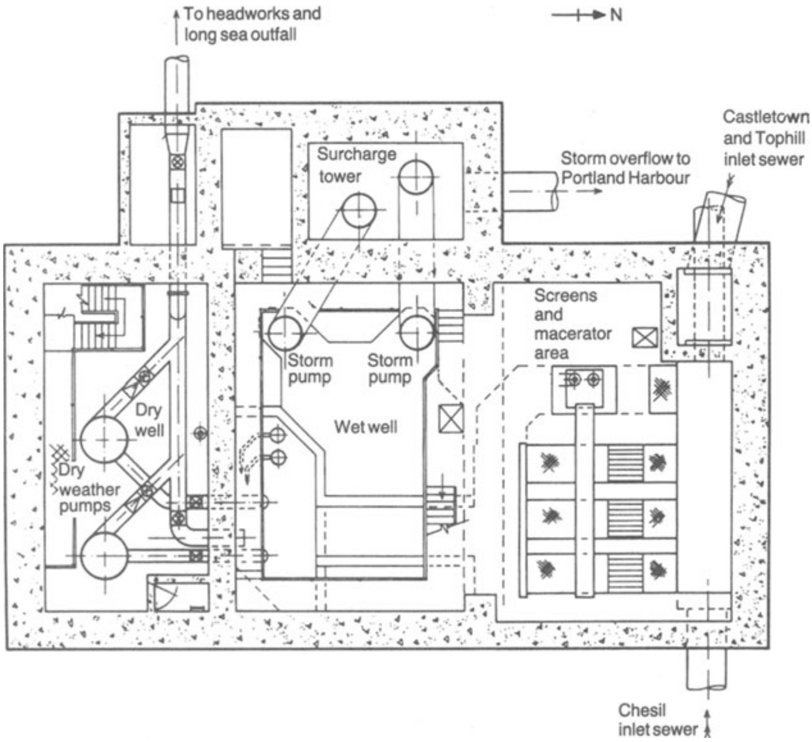


Figure 4.16 *Portland pumping station, substructure plan (Source: Hunt & Lyness[38])*

storm flows being pumped to Portland Harbour. A submersible cellar pump was installed in the storm sump to return residual storm flows to the dry weather wet well. The extra corresponding dry weather depth also prevented the drowning of incoming sewers and screens. The storm pumps discharged to a gravity surcharge tower, thereby limiting the pump head to an acceptable operating range for mixed flow. All other alternatives would have required pump operation in both the axial and mixed flow ranges. The storm pumps had variable pumping rates to match storm overflows as closely as possible.[38]

Hunt and Lyness[38] described how because of the close proximity to several Ministry of Defence establishments, the pumping station roof was erected of lightweight sandwich construction that could be blown off in the event of terrorist attack. By contrast, the walls were built of diaphragm block construction to resist much larger internal blasts, as shown in Figure 4.18. The pumping station was provided with a negative pressure ventilation system which was interlinked with fixed gas monitors. Low concentrations of the heavy (hydrogen sulphide) and light (methane) gases trigger the ventilation system to clear the station automatically, and all fan motors are explosion proof. The ventilation system consists of PVC ducting stiffened with a glass fibre reinforced polymer liner, the fans at the inlet and outlet ducts are centrifugal and smells are eradicated by an in-line activated filter

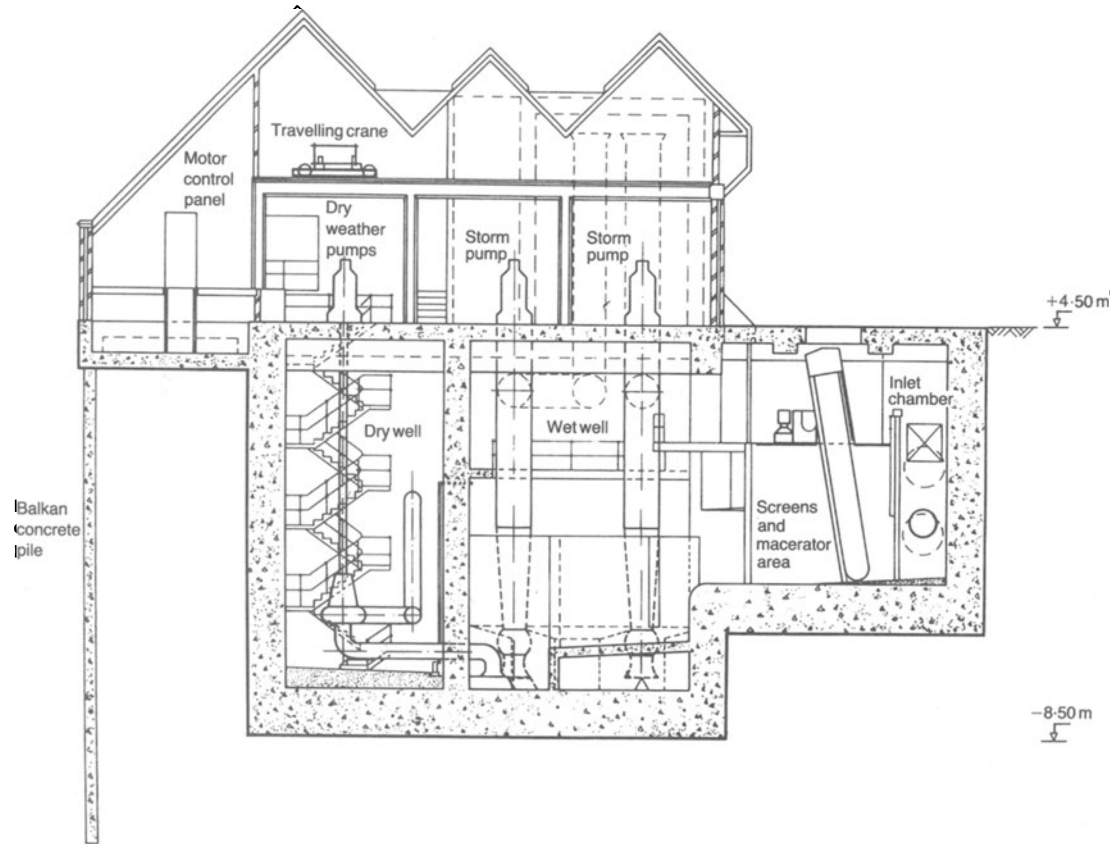


Figure 4.17 *Portland pumping station, typical cross section (Source: Hunt & Lyness[38])*

system. These provisions satisfied the latest requirements following the Abbeystead disaster, which was described in chapter 1.

All major plant in the station is monitored by a dual-alarm back-up system, using a telemetry outstation together with an exclusive British Telecom rented line linked directly with a monitoring microcomputer at the main Weymouth pumping station, which was compatible with the other main drainage telemetry installations. It is possible to obtain all current plant states and also review analogue signals of pump flow. A remote portable modem and printer were provided whereby the central computer can be interrogated from anywhere within the borough, including the other 14 water authority pumping stations and the two main control centres at Bristol and Poole.

Since all inflows are below sea level and require pumping, and since the island's electricity is exceptionally vulnerable, complete electrical standby is provided by a generator set. As the construction work incorporated substantial mechanical and electrical subcontracts, an all-inclusive contract was adopted.

Royal Docks Pumping Stations

Halcrow were appointed in 1984 as main drainage consultants to London Docklands Development Corporation (LDDC) for the massive £2b Royal Docks redevelopment in an Enterprise Zone in East London. The Royal Docks site is a

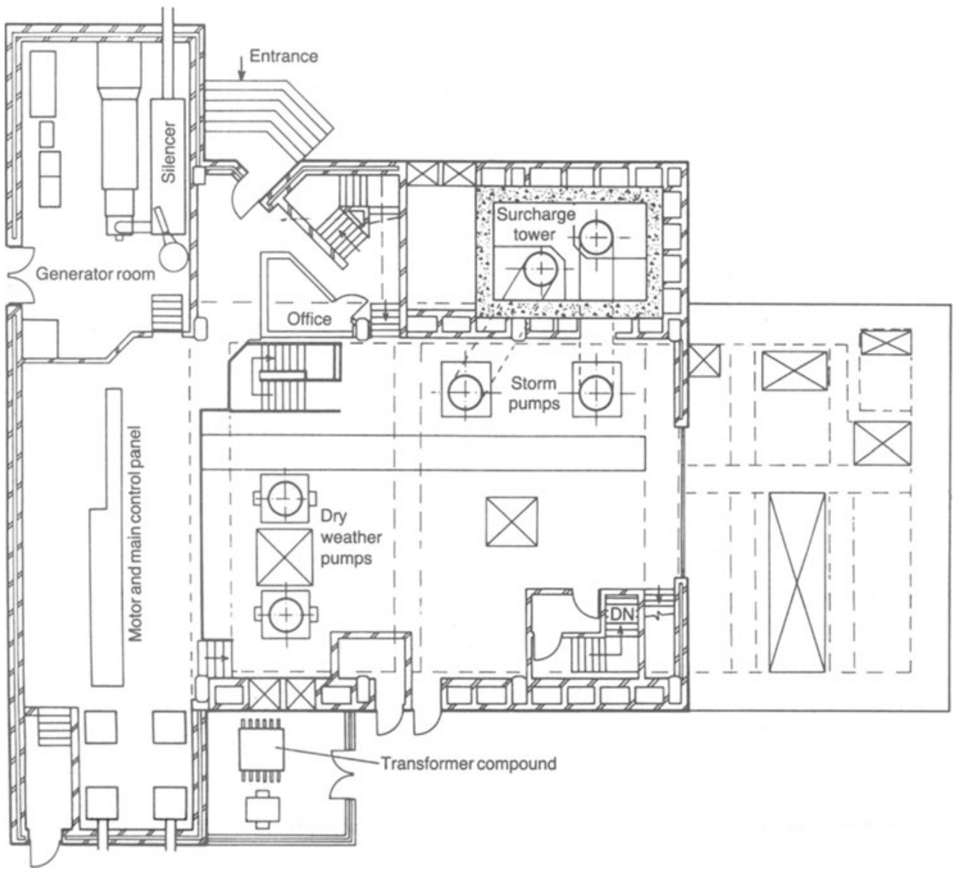


Figure 4.18 *Portland pumping station, ground floor plan (Source: Hunt & Lyness[38])*

low lying area of some 270 ha surrounding the Victoria, Albert and King George V Docks. The estimated capital value of the drainage works was approximately £40m, and included 8.5 km of tunnels with the largest pipe jacking contract in the United Kingdom in the late 1980s. The work also comprised two of the largest submersible pumping stations in the UK, one at the Isle of Dogs which was completed in 1988 at a cost of about £4m and the other at the Tidal Basin, beside the Royal Victoria Docks, which was completed in 1989 at a cost of £5.2m.

Both pumping stations pump very large stormwater flows from most of London Docklands' extensive redevelopment schemes to the River Thames and, although similar in concept, they differ significantly in construction. The rectangular diaphragm walled sump design of the Isle of Dogs station was to be repeated in the Tidal Basin station, but poor ground conditions encouraged an alternative design bid from the successful contractor. The cylindrical concrete caisson sunk to form the well was claimed to be the first of its kind in the UK and the work under construction is illustrated in Figure 4.19.

In the wake of the Abbeystead tragedy, all electrical fittings were designed to be spark free and both stations contain zone one and zone two rated hazard areas to BS 5345 and BS 4683, with the two zones separated by double sets of airtight doors. Each area has a very sophisticated ventilation system which will operate automatically to

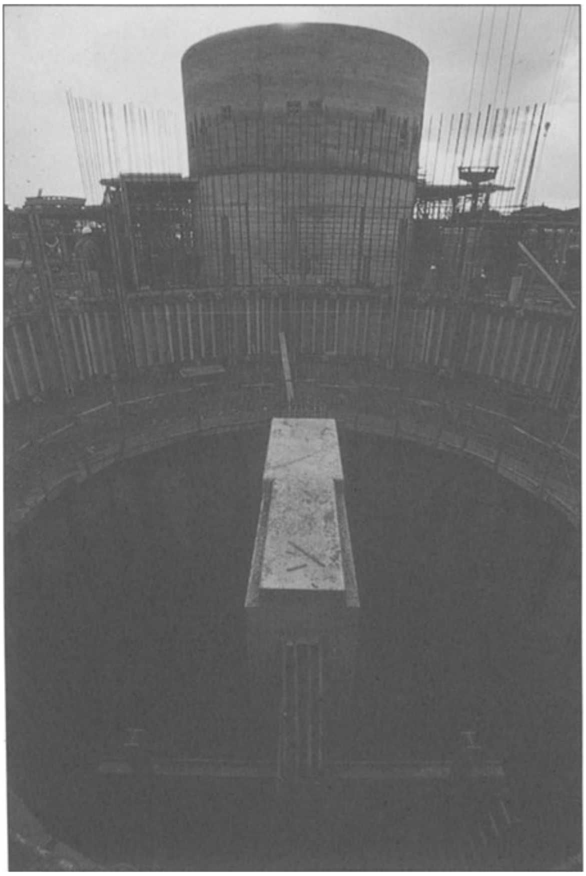


Figure 4.19 *Construction of deep shaft by caisson sinking at Tidal Basin (Royal Victoria Dock) Pumping Station (Source: Sir W. Halcrow & Partners)*

expel any potentially lethal gases when the front door is opened. Fans in the ventilation plant area will draw air in through louvred openings and intakes concealed under the roof eaves. From these fans, ducting will convey air to all parts of the building. Extraction from the roof of each pump hall required two more 3 m diameter fans mounted in the gables. Extraction from other areas was by duct mounted axial flow fans.[39]

In the Isle of Dogs station, situated close to West India and Millwall Docks, after screening, the flow passes into a 15 m deep, 26 m long diaphragm walled pumpwell, which contains 10 Flygt CP3500 main and two CP3300 sump submersible pumps. Each main pump has a discharge capacity of 1000 l/s with the sump pumps rated at 150 l/s. The main pumps deliver through 600 mm diameter epoxy coated welded steel siphon discharge pipes to a high level surge chamber from which the water flows by gravity to the river. The station is unattended but continuously monitored by water level sensors and a telemetry link to Thames Water Authority's Abbey Mills area control centre. The superstructure of the station has a pagoda type appearance with a tiled roof supported by steel portal frames and it has non load bearing brick and precast concrete walls.[39]

The pumping station at Tidal Basin, near the Royal Victoria Dock, was sunk as a cylindrical caisson, the main substructure is 25 m deep and 24 m diameter, with an adjoining 13 m diameter screening chamber, 22 m deep. The contractor (Edmund Nuttall) submitted the design and a fabricated steel cutting edge was provided to support the *in situ* concrete caisson. Inside the pumpwell is a central concrete core which forms the inlet chamber, and this was constructed using slipforming which proved to be difficult.

The flow enters the station through mechanically raked screens into the central circular sump. From there it disperses radially through slots in the outer sump wall and through individual siphons into a discharge chamber over the central sump. The station is equipped with 16 Flygt CP3311 submersible pumps to raise surface water from incoming tunnelled sewers through a 21 m static head lift. It is fully automatic and discharges at a rate of 8 m^3/s through twin 1400 mm diameter outfall sewers into the river. The total height of the structure from the base of the sump to the top of the discharge chamber is 36 m. The superstructure is designed in the style of a Norman keep with many unusual brightly coloured features.[39]

Ameria Pumping Station, Cairo

The Greater Cairo Sewerage Scheme, described earlier in the chapter, incorporated three massive pumping stations, of which Ameria is a centrifugal lift pumping station and the other two are screw lift stations. Ameria has eight pumps each rated at 3.6 m^3/s against a head of 23 m, housed in a circular structure 45 m in diameter and 32 m deep. The two screw lift pumping stations are of similar design containing twelve and ten 3 m diameter screw pumps respectively. Each pump has an output of 2.2 m^3/s against a head of 7.5 m. Associated with the pumping stations are administration buildings, workshop and stores, standby generators, substations and other smaller pumping stations. Figure 4.20 shows a section through the Ameria Pumping Station.[17]

Montague [18] described how the Ameria pumping station contract was probably the most fascinating of all the Cairo wastewater projects, and included the sinking of an enormous 45 m diameter caisson by marine style dredging. Ameria is on the site of four old pumping stations which pick up three major collectors and deliver sewage through force mains and a canal to the Gabal el Asfar sewage treatment works on the outskirts of the city. The contractor (Christiani & Nielsen/Misr Concrete) had to install civil works for a single replacement pumping station for the collectors and a new deep centrifugal station to lift flows from the main tunnel into culverts leading towards Gabal el Asfar.

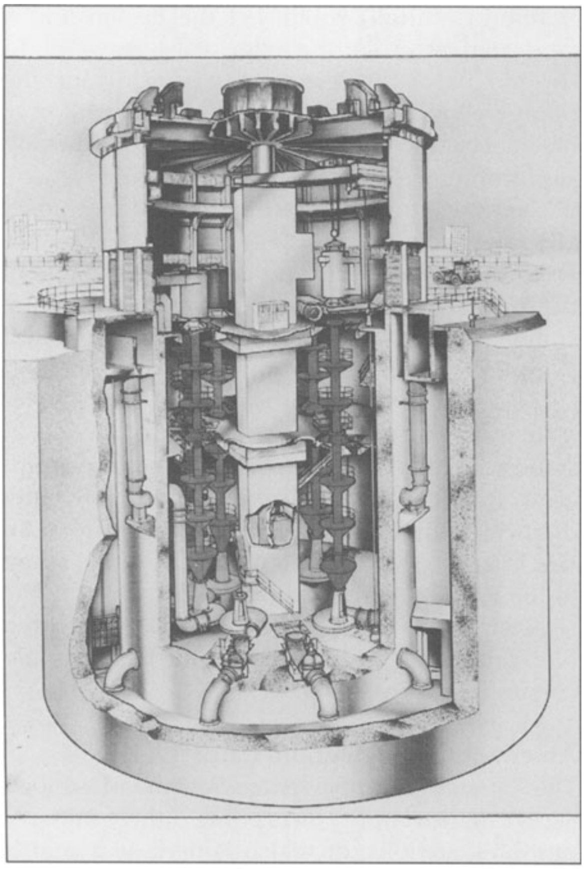


Figure 4.20 *Ameria tunnel pumping station, Cairo (Source: Binnie & Partners)*

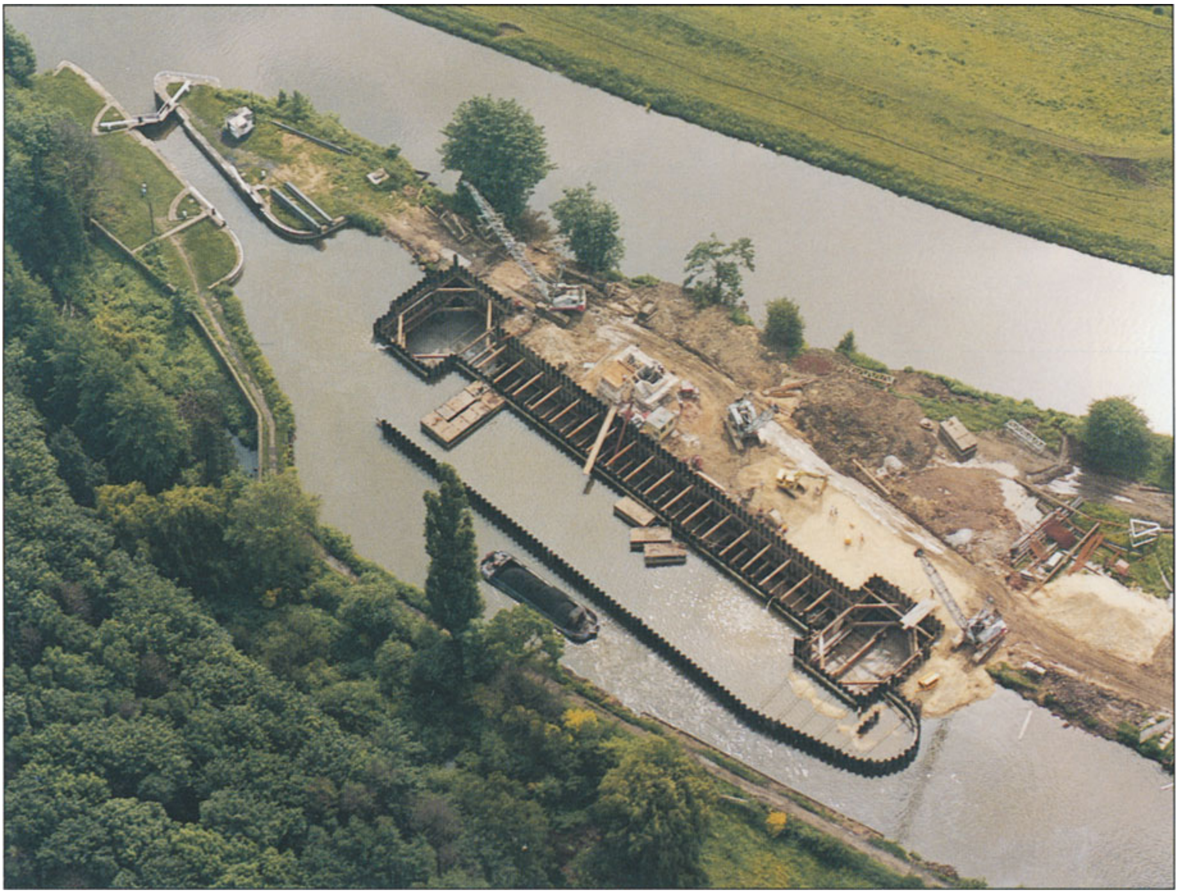
A 22 m diameter distribution chamber picks up the main tunnel and feeds a controlled flow of sewage into the new centrifugal station, consisting of two large diameter vertical tubes or rings. The outer acts as a wet well while the inner tube forms an enclosed dry well. The sewage in the irregular annulus is raised by eight pumps located within the dry well. Both the distribution chamber and the pumping station had to be sunk 32 m below the surface through clay lenses and water bearing sands in which disturbance to the natural water table had to be kept to a minimum to avoid damage to nearby houses or, worse still, to the heavily loaded force mains across the site.

Three suggestions for building the structures included excavation under compressed air, ground freezing or a combination of diaphragm wall and base plug freezing. The contractor (CM joint venture) considered that ground freezing would have taken far too long and could have affected surrounding structures through ground heave. For the depth and size of structure diaphragm walling would have approached the limit of its technology, and compressed air would have required massive temporary air decks across the caisson with the water table no more than 6 m below the surface, resulting in pressures of around 250 kN/m^2.

Because of these difficulties, the contractor used Toyo submersible dredging pumps to suck out the sand within a concrete caisson which ultimately formed the outer shell of the structure. The water table remained very largely at its natural level. For the smaller distribution chamber the contractor opted for a full 360° bentonite annulus to assist the passage of the reinforced concrete caisson through the ground. Sinking proceeded steadily at rates of up to 1.5 m/week, and finally a concrete plug was cast under water to form the floor of the chamber.[18]

1 London Docklands Light Railway (Source: W. S. Atkins, Consultants Ltd)

2 Singapore Mass Rapid Transit Train and Ang Mo Kio Station (Source: Sir W. Halcrow & Partners Ltd)



3 Sprotbrough Lock, South Yorkshire Canal, under construction (Source: W. A. Dawson Ltd)

4 Sprotbrough Lock, South Yorkshire Canal, after completion (Source: W. A. Dawson Ltd)

5 Channel Tunnel, night working below Shakespeare Cliff, near Dover
(Source: Sir W. Halcrow & Partners Ltd)

6 Heathrow Airport, aerial view of airport
(Source: British Airports Authority, Heathrow Airports Ltd)

7 Changi Airport, Singapore, aerial view of airport
(Source: Singapore PWD Airport Development Division)

8 A55: Rhos Interchange
(Source: Travers Morgan)

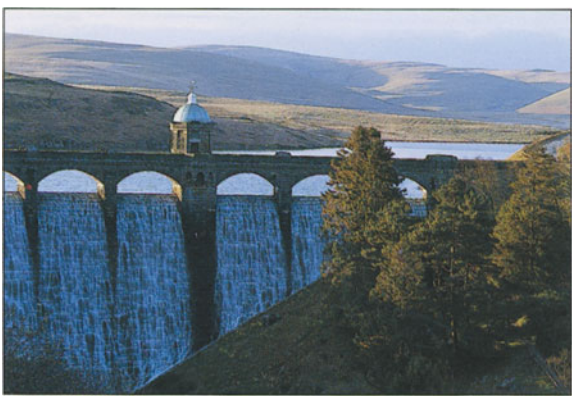
9 A55: Penmaenbach Tunnel
(Source: Travers Morgan)

10 Tsuen Wan Bypass, Hong Kong
(Source: Scott Wilson Kirkpatrick)

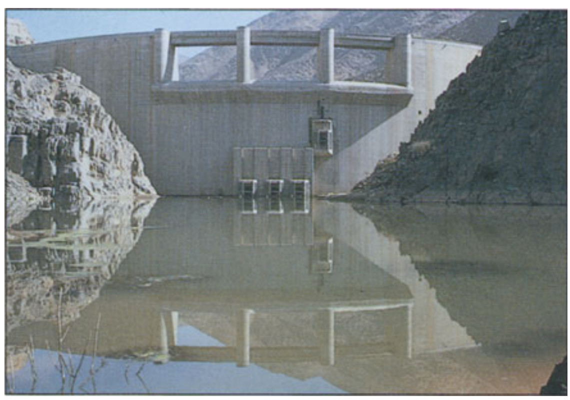
11 East Coast Parkway, Singapore
(Source: Singapore PWD)

12 Broadholme sewage treatment works extension, Wellingborough, aerial view of work under construction
(Source: W. A. Dawson Ltd)

13 Sha Tin sewage treatment works, Hong Kong (Source: Watson Hawksley)



14 Elan Valley (Craig Goch) Reservoir (Source: Severn Trent Water)



15 Mudhiq Dam, Saudi Arabia, in operation (Source: Binnie & Partners)

16 Syracuse water treatment works, Sicily (Source: Watson Hawksley)

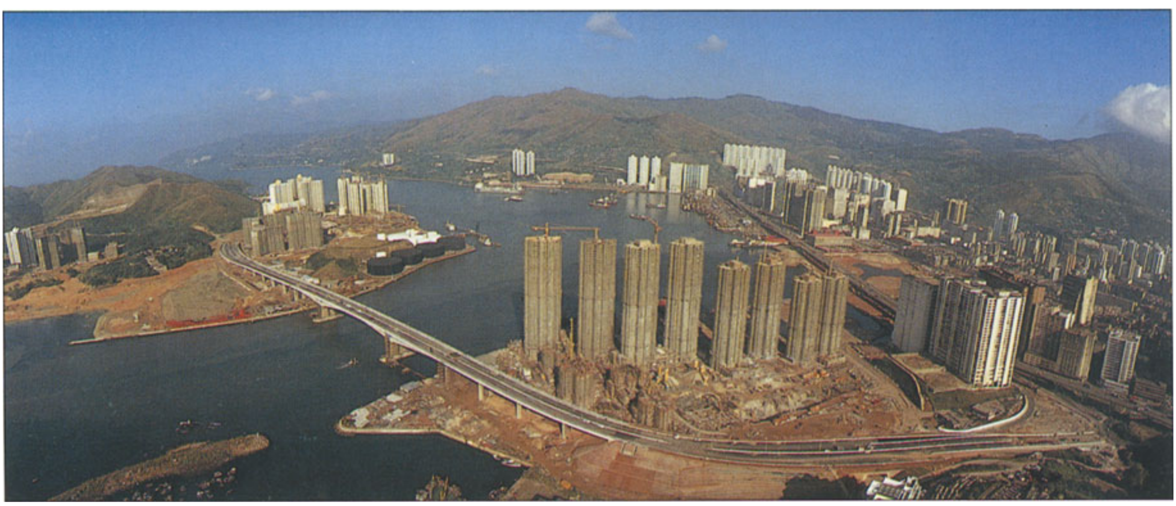
17 High Island Dam and Reservoir, Hong Kong (Source: Binnie & Partners)

18 Dubai water tower, Jumeirah, United Arab Emirates (Source: Watson Hawksley)

19 Public housing, Junk Bay New Town, Hong Kong (Source: Territory Development Department, Hong Kong)

20 Borrow area developments, Sha Tin New Town, Hong Kong (Source: Territory Development Department, Hong Kong)

21 Developments from Tsuen Wan to Tsing Yi Island, Hong Kong (Source: Territory Development Department, Hong Kong)



22 Housing development, Bishan West New Town, Singapore (Source: HDB, Singapore)

23 Ridings Shopping Centre, Wakefield (Source: Shepherd Construction Ltd)

24 Watchmoor Business Park, Camberley, landscaped buildings (Source: London & Metropolitan)

25 Albert Dock, Liverpool, before restoration (Source: Merseyside Development Corporation)

26 Albert Dock and Wapping Warehouse, Liverpool, after renovation (Source: Merseyside Development Corporation)

27 Tanjong Pagar Conservation Area, Singapore, Chinese shophouses before restoration (Source: Author)

28 Tanjong Pagar Conservation Area, Singapore, Chinese shophouses after restoration (Source: Author)

29 Canary Wharf development, London Docklands, under construction in 1990 (Source: Olympia and York, Canary Wharf Ltd)

30 Sha Tin New Town, Hong Kong, town park (Source: Territory Development Department, Hong Kong)

31 Bishan New Town, Singapore, town park (Source: HDB, Singapore)

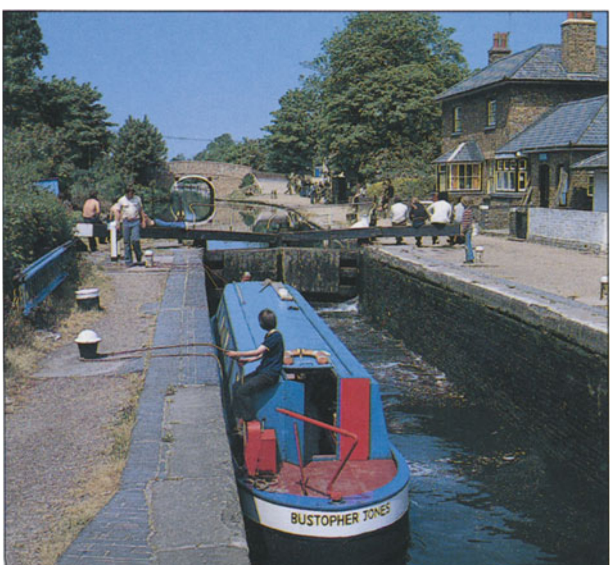
32 Tidal Surge Barrier, River Hull
(Source: W. A. Dawson Ltd)

34 Kwai Chung Container Port, Tsuen Wan, Hong Kong
(Source: Territory Development Department, Hong Kong)

33 Blacksness Harbour, Scalloway, Shetland Islands, under construction
(Source: W. A. Dawson Ltd)

35 Sea reclamation for Ma On Shan extension, Sha Tin New Town , Hong Kong (Source: Territory Development Department, Hong Kong)

36 Brighton Marina: breakwaters, part of inner harbour and housing, 1989 (Source: Brent Walker Group)



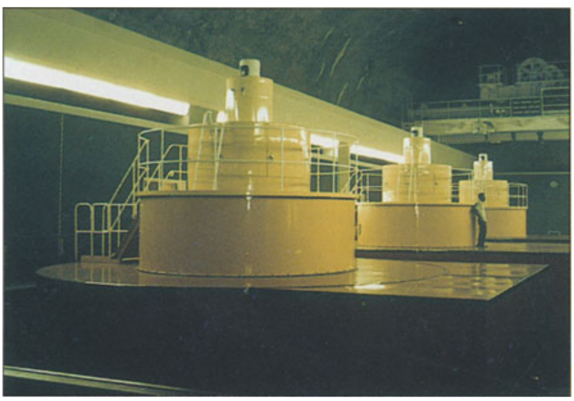
37 Grand Union Canal at Cowley Lock, Uxbridge (Source: British Waterways)

38 Aerial view of Holme Pierrepont Water Sports Centre, Nottingham (Source: National Water Sports Centre)

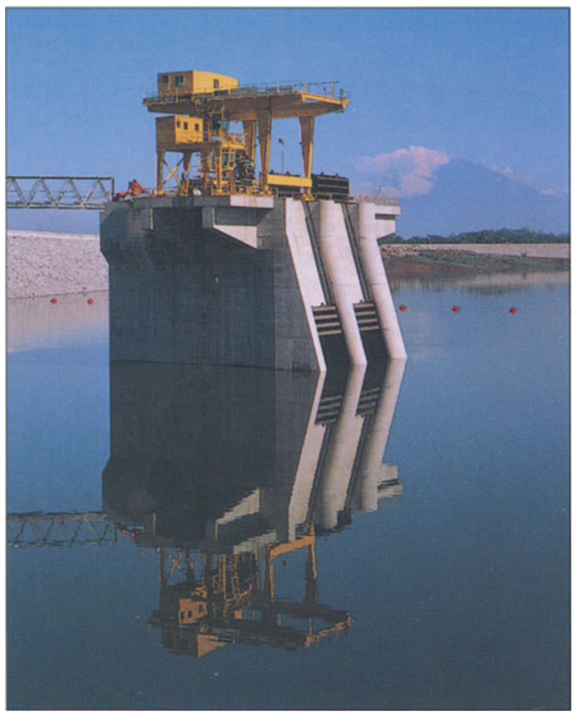
39 Waves Leisure Pool, Blackburn (Source: Shepherd Construction Ltd)

40 Aerial view of Sentosa Ferry Terminal, Singapore (Source: Sentosa Development Corporation)

41 Gale Common, ash disposal from power stations
(Source: Rendel Palmer & Tritton)



42 Underground power station, Batang Padang Hydroelectric Scheme, Malaysia
(Source: Binnie & Partners)



43 Mrica Hydroelectric Scheme, Java: intake tower under construction
(Source: Sir W. Halcrow & Partners)

These case studies show the wide variations in the design and construction of pumping stations, the large range of sizes and the complex problems that can arise with the underground structures and the ways in which they have been overcome.

Sewer Maintenance, Renewal and Restoration

General Background

The Water Authorities in the UK reported in 1989 that about 20% of critical sewers in some parts of the country were in danger of collapse. Furthermore, about 7% of the sewerage system had already collapsed and many authorities did not know the precise location of their sewers even though many needed urgent repairs. There is no doubt that in older areas sewer replacement is becoming an urgent priority and the costs involved are exceedingly high. However, new techniques of relining and identifying suspect lengths, as described later in the chapter, are helping to ensure that resources are spent effectively and with less disruption to the community.

A CIRIA Report[40] contained the results of a survey in which almost 80% of the participating authorities reported that they had sewers containing sediment, and one third of the areas surveyed had more than 25% of the sewers in their systems containing sediment. The systems most prone to sediment deposits were those draining flat or mildly sloping catchments and those with a large proportion of combined sewers located in old core areas which were subject to surcharging even under normal flow conditions. Over 45% of the systems were regularly surcharged during non-storm periods and over 90% during storm conditions.

In the late 1980ş, annual capital expenditure on sewerage in the UK was approximately £250m, of which £200m was spent on rehabilitation work. The Water Research Centre (WRc) considered that the latter figure could be further divided on a 1:2 basis between structural and hydraulic improvements. The hydraulic improvements include eliminating flooding and rationalising and upgrading storm sewage overflows to avoid pollution of receiving streams. Work may also be done to reduce the frequency of surcharge in structurally suspect sewer lengths. Sewer cleaning accounted for a sum in excess of £10m per annum. It appeared likely that expenditure was well below that actually required.

Reed[41] has described how the UK sewerage system spans some 160 years but age, important as it is, is not the only criterion by which to judge condition, and there are numerous factors which contribute to the poor state of sewerage systems. These include depth, geology, height of water table, pipe specification, character of sewage, quality of wormanship, adjoining services and traffic loading. These factors sometimes individually, although more often in combination, manifest themselves in a range of faults which include cracks, fractures, collapses, blockages, deformation, displaced joints, erosion. corrosion, infiltration, exfiltration, tree root intrusion, rat infestation and open joints.

Deterioration of cement and lime mortar in brick sewers not only causes structural weakening, but also permits infiltration of groundwater which may cause further deterioration. Similar problems exist with pipe sewers resulting in pipe settlement and joint displacement. Aggressive industrial effluents, both acidic and alkaline, can corrode the materials used in sewerage systems, and the formation of hydrogen sulphide can result fom slack gradients or occur in pumping mains and this is particularly aggressive to cementitious materials. Concrete and cast iron pipes appear to be more susceptible to corrosion than clay pipes.[41]

In 1978 the Water Research Centre (WRc) started a study of sewer failures, and expressed the collapse rates as incidents per 100 000 population served per annum. Their research showed that each water authority had a collapse rate of at least 5 incidents per year per 100 000 population served, and that about 60% of collapsed sewers were beneath main roads. It was further pointed out that the contractor's invoice for repairing a sewer was only part of the cost, the remainder being borne by the community, which included

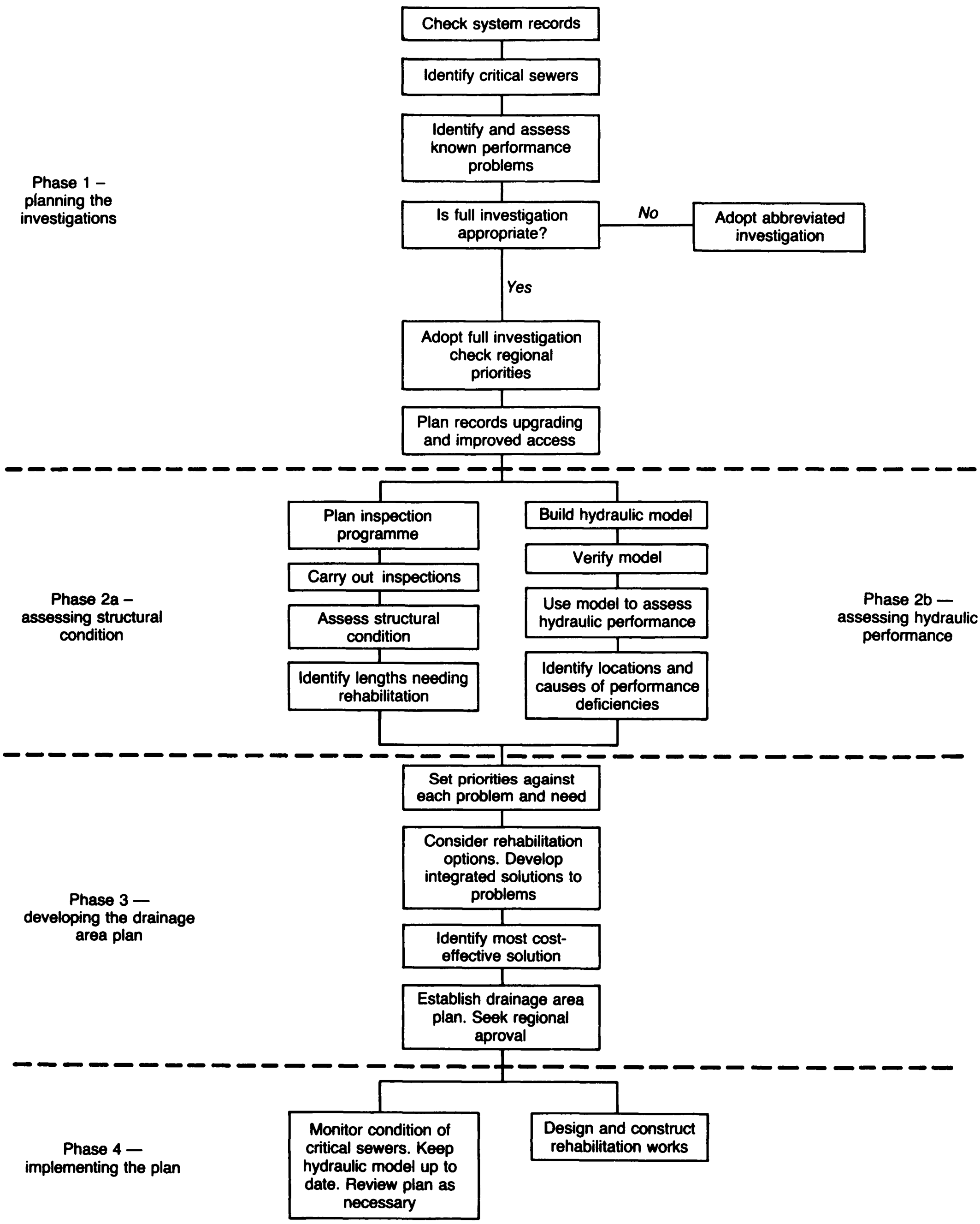


Figure 4.21 *Sewer rehabilitation – primary flow diagram – full investigations (Source: Water Research Centre)*

disruption and social costs, and preliminary investigations suggested that their sum was comparable to the direct costs. Blockage rates were found to be much higher than collapse rates, but they varied considerably from one area to another.[42]

Sewer Rehabilitation – Planning Procedure

In 1984 the Water Research Centre (WRc) published excellent guidelines for carrying out sewer rehabilitation work and these were updated in 1986 in the *Sewer rehabilitation manual*[43]. In the manual, which is now widely adopted by water authorities, the planning of a sewerage rehabilitation project is divided into four phases as illustrated in Figure 4.21.

The principal purpose of phase 1 is to identify the critical sewers and assess the extent of known problems. Critical sewers, where the consequences of failure would be severe, typically show some of the following characteristics: they are in deep or bad ground, built of brick or masonry, are of large diameter, under busy roads, in town centres or under buildings. To provide an objective basis for assessment, the potential consequences of failure in terms of the cost of repair or replacement must be identified, and the social consequences, primarily in traffic delays, considered. Finally, the strategic importance of the sewer is considered to ensure that no key sewers have been omitted.[44]

The second major action required in phase 1 is an assessment of known problems. These may include previous collapses, flooding incidents attributable to lack of sewer capacity, and pollution complaints. Large scale future developments which will drain to the existing system should also be considered.

Phase 2 entails two parallel investigations of the overall performance of the critical sewers: phase 2a covering structural condition and phase 2b embracing hydraulic performance. The main objective in phase 2a is to inspect the critical sewers to identify any points where the collapse risk justifies rehabilitation. Where work is justified, renovation will frequently offer the most cost effective solution. It is normally substantially cheaper than renewal and causes much less surface disruption, which is an important factor as many sewers are under busy roads and in town centres.[44]

The prime objective of phase 2b is to assess the hydraulic performance of the critical sewers in their present form and to identify the causes of substandard performance, usually by the use of a hydraulic model of the system on a computer, such as the WASSP-SIM model of the Wallingford procedure.[45] Once a model has been verified by actual flow and rainfall measurement, it can be used to assess the performance of each critical sewer and to identify the direct cause of any performance problems. For example, flooding at one point in a system may be caused by backing up from an inadequate length downstream. With the completion of phase 2b, the investigations will have yielded a list of identified structural and hydraulic problems and guides as to their likely solution.[44]

The main objective of phase 3 is to develop an outline set of rehabilitation proposals which deal with all identified problems, provide economical construction, minimise disruption during construction and divide the work into logical stages. At the end of phase 3 an outline plan will have evolved encompassing all the works needed to improve the condition and performance of the critical sewers in the system to acceptable standards.

The prime purpose of phase 4 is to implement the plan. This involves the detailed design and construction of the rehabilitation works, and the reinspection of the critical sewers, particularly those showing signs of deterioration, and the monitoring of hydraulic performance. A prime objective is to check that the drainage area plan remains appropriate. Changes can entail additional works, deferral of planned works or changes in priorities.[44]

The practical application of the WRc approach at Herne Bay, Kent, is fully described by Gooch and Warne[46] and identifies the critical sewers and simulated flooding areas for a 50 year storm. They emphasised the need for good quality sewer records, and showed how the pilot study achieved savings of around 28% compared with a traditional solution, gave a greater understanding of how the drainage system operated and more confidence in the preferred solution, obtained greater flexibility in design through the use of the computer model, and permitted the ready assessment of future development proposals using the drainage area plan (DAP).

Data Collection

Data are collected on site where inspection may be remote using closed-circuit television or direct where personnel enter the sewers. The choice of method used is mainly governed by sewer size, although cost and safety are important constraints as shown in Table 4.3. For remote inspections the range is limited to closed-circuit television and/or in-sewer photography together with a report coded in accordance with the *Manual of sewer condition classification*[47]. The STC25 computerised sewer records system offered by Contract Data Research Ltd provides a useful approach to collecting, processing and checking manhole survey data, creating sewer network overlay drawings and maintaining a complete record of sewer systems, which has been used extensively by a number of UK water authorities. The best visual medium for assessing the condition of a sewer is a coloured photograph taken

Table 4.3 *Choice of sewer inspection systems*

Sewer size and height	Systems available	System preferred	Notes
Up to 500 mm	CCTV†	CCTV	No real alternatives
500–900 mm*	CCTV	CCTV	In larger sizes may need specialist lighting and mountings to give satisfactory performance
	Manual crawl through	Manual inspection only where necessary to assess minor defects found by previous CCTV inspection	Difficult to ensure safe working conditions. Data logging is difficult and time-consuming in these small sewers
900–1500 mm	CCTV	CCTV only for initial screening to reduce costs or where safety precludes manual inspections	CCTV systems limited by lighting and camera lens angles
	Manual walk through	Manual	The cost of manual inspection makes preliminary CCTV inspection attractive in some cases
Greater than 1500 mm	Manual Walk through	Manual	Beyond limits of normal CCTV equipment

* The lower limit of 500 mm for man access to sewers reflects some current practice but must be subject to local working practices and safety procedures.
† In the context of the manual,[43] CCTV is deemed to include a facility for taking in-sewer colour photographs.
Source: J. MacPHEE. Sewerage rehabilitation.[44]

within the sewer. The inspection of critical sewers will generate large quantities of videos, photographs and coded reports and these require careful collation and management.

Renovation Techniques

Renovation is defined in the WRc manual[43] as 'methods by which the performance of a length of sewer is improved by incorporating the original sewer fabric, but excluding maintenance operations such as isolated local repairs and root or silt removal'. WRc has classified renovation techniques under the three broad categories of stabilisation, linings and coatings, each of which are now described in outline:

(1) Stabilisation involves the pointing and chemical grouting of joints.
(2) Linings are of three types: essentially, type I uses the structural capacity of the existing sewer and requires a bond between the lining and the grout, and the grout and the existing structure; type II is designed as a flexible pipe requiring no bond between the lining and the grout or the existing structure, and no long term strength is assigned to the existing sewer; and type III provides permanent formwork for the grout, and the lining cannot be assumed to contribute to the long term strength of the sewer.
(3) *In situ* gunite is the only established structural coating.[44]

Table 4.4 summarises the advantages and disadvantages of established techniques.

When considering the renovation option, the five most significant issues are economics, hydraulic capacity, materials considerations, strength and installation aspects. WRc has also given advice on determining the overall hydraulic effect of renovation on the sewer network resulting from changes in cross sectional area and roughness coefficients. With the exception of sliplining in pipe sewers, lining techniques in general do not have a detrimental effect on hydraulic capacity, and many techniques can improve the capacity of brick sewers. Furthermore, for the leading lining materials sufficient durability data have been accumulated to justify design life predictions of 50 years. In most renovation systems annulus grouting is necessary to ensure satisfactory performance. However, grout pressure can cause buckling, excessive deformation or overstressing of sewer linings, and various methods of offsetting these problems, such as filling the lining with water or internal strutting are described by MacPHEE.[44]

Renovation Costs

Unit cost equations are provided in the WRc manual[43] for use in preliminary assessments to give an early guide to total scheme costs (excluding design and supervision). Detailed budget quotations are best obtained from appropriate manufacturers and/or contractors. The data has also been analysed to show the spread of unit costs, and confidence multipliers have been derived.

The major influences on unit costs are highlighted to provide an indication of when high or low costs can be expected. Some of the more important factors are manholes, connections, overpumping, sewer preparation, location, contractual arrangements and specification standard. In general renovation can be undertaken for less than 75% of renewal cost.

Australian Experiences

Jeffries[48] has described some of the main sewerage problems encountered in Australia and some of the more interesting ones have been extracted to provide an overseas dimension to the study.

In Sydney, for 300 mm diameter and larger pipes, where it is impracticable to provide slime control gradients, the designer must incorporate protective measures. For concrete pipes, these may include internal coatings or lining, or the use of chemical addition or forced ventilation. These measures are necessary because of the rate of attack on an unprotected ordinary Portland

Table 4.4 *Established sewer renovation techniques – advantages and disadvantages*

		Techniques	Accessibility	Advantages	Disadvantages
Segmental linings		Glass reinforced cement (GRC): design type I	ME, MA	Variety of cross-sections available. Easily cut to form connections.	Labour-intensive jointing Strutting often required
Segmental linings	Glass reinforced plastic	Single piece lining (single longitudinal joint): design type III	ME, MA	Deforms to suit variety of cross-sections High strength: weight ratio	Requires temporary support during grouting Acts only as permanent corrosion resistent formwork Care needed to prevent damage to barrier layer, or excessive strain Not suitable below water-table
Segmental linings	Glass reinforced plastic	Two-piece linings: design type I or III	ME, MA	Variety of cross-sections available High strength:weight ratio	Care needed to prevent damage to barrier layer, or excessive strain May require temporary support during grouting Labour-intensive jointing
Segmental linings		Resin concrete (PRC): design type I	ME	Variety of cross-sections available Units very stiff Strutting not required during grouting	Heavy Monopoly supplier Labour-intensive jointing Not suitable below 900 mm x 600 mm
Segmental linings		Precast gunite: design type I	ME	Variety of cross-sections available No strutting required Variation of cross-section accommodated	Heavy Labour-intensive jointing Not suitable below 1070 mm x 760 mm
Coatings		*In situ* gunite	ME	Connections easily accommodated Access via existing manholes Variation of cross-section readily accommodated	Dusty and difficult to supervise Dependent on operator skill Control of infiltration required Not suitable below 1800 mm dia
Stabilisation		Hand pointing and pressure pointing	ME	Minimal disruption Materials and equipment inexpensive Possible improvement to hydraulic capacity Existing access normally suitable	Existing sewer must be pointing structually sound Quality control difficult Flows diverted when working in invert Control of infiltration required

		Techniques	Accessibility	Advantages	Disadvantages
Stabilisation		Chemical grouting	ME, MA, NME	Minimal disruption Access via existing manholes Low flows tolerated Infiltration reduced therefore possible extra capacity	Monopoly on non-man entry system Difficult to seal packers where surface is irregular
Pipe linings		Glass reinforced plastic (GRP): design type I, II or III	ME, MA	High strength:weight ratio Variety of cross-sections available	May require temporary support during grouting Care to prevent barrier layer damage or excesive strain Must work away from lined sewer
Pipe linings	Polyolefins	Butt fusion welded (HDPE or MDPE) – conventional slip-lining: design type II	ME, MA, NME	Quick insertion Large radius bends accommodated	Circular cross-section only Lead in trench disruptive Relatively high loss of cross-section Flotation during grouting Less cost-effective where deep
Pipe linings	Polyolefins	Screw joints (PP): design type II	NME	Access via existing manholes Cost-effective for short and deep lengths Quick insertion Large radius bends accommodated	Circular cross-section only Relatively high loss of cross-section Flotation during grouting Large number of joints
Pipe linings		*In situ* form: design type II (< 6 mm type III)	ME, MA, NME	Rapid installation No excavation required Bends/minor deformation accommodated Capacity maximised Grouting not normally required	Full overpumping required during insertion Monopoly Site set up high proportion of costs on small schemes

*ME man entry, MA man accessible, NME non-man entry.
Source: J MacPHEE. Sewerage rehabilitation [44]

cement *in situ* concrete sewer has varied from between 2.6 mm and 6.5 mm per annum.

The New South Wales PWD recognises the problem of septicity and states that sewage in a rising main may become septic with retention times of less than one hour, and that methods to control the formation of hydrogen sulphide should be used. The consequences of septicity are corrosion of the sewer fabric, malodour and toxicity. The severity of the septicity problem is due, in part, where the sewage temperatures are between 18° C and 30° C all the year round, and the long retention times in the sewerage system.

In Melbourne, mechanical ventilation has been adopted to prevent corrosion of the sewerage network. The authority has a sewer failure problem and has adopted a rehabilitation programme which consists of replacement and lining.

Tree root infestation causes considerable blockage and breakage problems. Brisbane City Council was spending A$500 000 (£320 000) in the late 1980s to remove roots from its sewers.

Wastewater Treatment Processes

General Background

Sewage treatment works perform a vital function in dealing effectively with the disposal of domestic and industrial sewage and preventing the pollution of watercourses, rivers and coasts. Unfortunately, extensive pollution was still being caused by sewage effluents in the United Kingdom in the early 1990s. Many old sewage works were overloaded and/or ineffective and required urgent modernisation or replacement.

New sewage treatment requirements stemming from EC directives were outlined earlier in the chapter. The provision of new treatment works will present major physical problems in coastal towns where existing headworks are often located near the sea front. Folkestone was typical of the problem that can arise, with headworks at the end of the east promenade next to the cliffs, necessitating a tunnel through the cliffs to a new sewage treatment works. In addition, the decision to stop sewage sludge dumping at sea by 1998 presented water authorities with a tight timetable for building incineration plants in the face of likely local opposition. For example, in 1990 4.5m t of sludge was produced annually in London and was dumped into the Thames Estuary. It is likely that two incineration plants will be required, sited near London's main sewage treatment works on opposite banks of the Thames at Beckton and Crossness, at an estimated cost of £100m.

In 1990, the UK Environment Secretary estimated the cost of providing primary treatment for coastal discharges and secondary treatment for estuarial discharges at £1500m, but the Water Services Association calculated an estimated cost of £2500m. This policy was in accordance with the relevant EC draft directive in 1990 banning the discharge of untreated effluent into the sea. Subsequently, the government in a White Paper 'This Common Inheritance' issued in 1990, stated that drinking and bathing water will be brought up to standard by the mid-1990s with an investment of £28b to be met by consumers. Primary treatment embraces passing the sewage through settlement tanks to allow suspended solids to separate and be retained. It could be advantageous to explore more compact methods of treatment, such as those using wet oxidation, fluidised beds or membrane processes. Furthermore, there will almost inevitably be major planning battles over the location of new coastal treatment sites and, in some cases, the covering of new works or their construction underground may be the only acceptable solution.

The ten UK water authorities established in 1989 together operated some 290 000 km of sewers, over 6400 sewage treatment works and some 15 200 sewage pumping stations, and they dealt with over 16 000m litres of sewage daily. These statistics give an indication of the large scale of the wastewater operations being undertaken.

Wastewater Characteristics

There are many compounds and micro-organisms in wastewater which can cause pollution. The components can be classified into three broad categories, namely organic, inorganic and microbial, and each component requires a specialised form of treatment to render it harmless.

Horan[49] has described how organic components consist of carbonaceous compounds, which can be oxidised both chemically and biologically to produce carbon dioxide. If biological oxidation is used, the test is termed biochemical oxygen demand (BOD), whereas for chemical oxidation, the terms chemical oxygen demand (COD), permanganate value (PV) or the total oxygen demand (TOD) apply, depending on the chemical oxidising agent used and the nature of the oxidising conditions. The BOD test is both simple and popular but has a long incubation period and its use can be inhibited by industrial wastes.

There is no simple testing procedure for inorganic components, but fortunately very few of them cause serious pollution problems. Nitrogen and phosphorus are often found in watercourses and may originate from artificial fertilisers applied to farmland, farm animal waste, many manufacturing processes and effluents from sewage treatment works. Together these two elements are known as nutrients and their removal as nutrient stripping.[49]

A wide variety of micro-organisms or microbial components are found in wastewaters including viruses, bacteria, fungi, protozoa and nematodes, and these organisms occur in very large numbers. From the engineer's viewpoint, the main aim in the biological examination of water is to detect the presence of pathogenic microrganisms which can constitute a danger to human health through contact with contaminated water.[49]

Treatment Processes

Horan[49] has described how engineers designing wastewater treatment plants are faced with a large choice of individual treatment options. A sound selection of options will ensure the discharge of an effluent which has no ecological impact on a receiving watercourse. However, many countries have severe financial constraints and the engineer is then often faced with satisfying rigid environmental requirements but also has to keep within strict financial limits, and needs to ensure that the money expended gives the greatest cost benefit. Developing countries frequently pose additional problems arising from the lack of skilled personnel, no dependable source of power and non- availability of facilities for plant operation and maintenance. All wastewater treatment plants are required to reduce the level of suspended solids and organic material in the inflowing sewage and, in addition, are often expected to remove nutrients and provide a high level of removal of pathogenic micro-organisms, and this requires a combination of processes.

A typical sewage treatment process comprises preliminary treatment in the form of screening and grit removal, primary treatment (primary settlement), secondary treatment (biological filtration and final settlement in humus tanks), tertiary treatment by sand filtration, coupled with primary and secondary digestion and disposal of sludge. Each of these operations will now be considered in some detail.

Screening

Raw sewage delivered by sewers to a treatment works contains significant quanitities of debris, such as wood, rags, paper, suspended solids and faecal matter, which unless removed could damage equipment and block pipes. The preliminary removal process normally takes the form of screens or strainers. Mechanically raked bar screens are usually preferred for removing large solids from the flow and a common bar spacing is 20 mm. The screenings pass to a suitable container and are generally disposed of by landfill or incineration.

Comminutors may be installed in place of bar screens and they consist of a rotating drum with attached cutting teeth which macerates the larger solids. Although relatively clean and innoffensive, problems do occur as the material has a tendency to reform and agglomerate in later treatment stages, an additional burden is placed on primary settlement tanks and there is a greater loss of head than occurs with screens.[49]

Grit Removal

Efficient grit removal is needed in all sewage treatment works to prevent abrasion and wear of mechanical equipment, deposition in pipes or channels and accumulation in aerators and anaerobic digestors. Grit chambers are normally parabolic, trapezoidal or V-shaped in cross section often with a constant velocity of 0.3 m/s, controlled by a flume at the outlet end, and should remove about 95% of particles with a diameter > 0.2 mm. In larger works, grit removal may take place in detritors, spiral flow aerated channels or vortex type chambers as described by Watson Hawksley.[5] The deposited grit is removed from channels either by suction pumps or by bucket dredgers mounted on moving bridges.

Primary Treatment

Primary sewage treatment follows the preliminary treatment previously described and generally encompasses sedimentation for the removal of readily settleable solids (SS), usually in the size range 0.05–10 mm, and associated BOD. Sedimentation or settlement tanks may be circular (radial flow), rectangular (horizontal flow) or pyramidal (upward flow) and normally remove 60 to 70% of SS and 30 to 40% of associated BOD. The rectangular tanks usually have a length/breadth ratio of up to 4 to 1, and the pyramidal tanks have side slopes of not less than 60° to the horizontal. The tanks generally operate on a continuous flow basis and contain hoppers or troughs for the collection of sludge and, in the case of rectangular and circular tanks, power driven scrapers move the sludge across the tank floor to the outlet. Facilities are also provided for collecting and removing surface scum and other floating material for subsequent treatment and/or disposal with the settled sludge.[5] Horan[49] observed that circular tanks appear to be more efficient in removing solids and BOD and thus provide the best choice where site layout permits.

Wastewater is usually delivered to the tanks by pipes, manifolds or open channel troughs, and desirably discharging equal amounts of solid and liquid. Velocities should be kept below 15 mm/s in order to achieve solids removal> 50%. Watson Hawksley[5] recommend maximum surface loadings of 1.5 to 2 m^3/m^2 h and minimum retentions of 1.5 to 2.0 h. A sufficient number of tanks must be provided, so that a tank can be out of service without adversely affecting the sedimentation process. Thus even with small works the tanks must be in duplicate.

Secondary Treatment

The primary aim of secondary treatment is to reduce the oxygen demand of an influent wastewater to an acceptable level of purification. Horan[49] has categorised biological treatment into fixed film (bed) and dispersed growth processes. In the former the micro-organisms are immobilised or attached to an inert support which is kept in contact with the inflowing sewage, while in the latter the micro-organisms and wastewater remain in close contact by mixing.

(A) Fixed Bed Processes

Land application of sewage is the oldest form of wastewater treatment using a fixed bed or film system, whereby the micro-organisms become attached to soil particles as the wastewater percolates down through the soil, undergoing purification on the way. Land application gave way to percolating or trickling filters in the UK in the nineteenth century, and these are used extensively world-wide because of their relatively simple and reliable means of operation. Since 1960, a modification of the process, known as rotating biological contactor (RBC), has become increasingly popular, particularly in Japan and the United States.[49]

Percolating Filters These consist of permeable media over which the sewage is evenly distributed mechanically, and through which air passes freely, as the source of the essential oxygen. Traditionally, the media has been crushed rock or blast furnace slag of 25 to 100 mm diameter in filters up to 3 m deep. More recently lightweight plastic media has been used and this has permitted lighter containing structures up to 12 m deep. A microbial film or slime layer forms over the surface of the media, on which bacteria breed, and this removes the BOD during the passage of the sewage through the bed. The bacteria feed on the organic material in the sewage, converting it into carbon dioxide, water and nitrogen compounds.

The media is supported by brick or concrete containing walls and may be rectangular or circular in plan. Settled sewage may be applied to the filter beds by fixed sprays or moving sprinklers. Many filters are of circular shape, and their rotating sprinklers are often driven by the reaction of the sewage itself, involving intermittent application controlled by a siphon dosing chamber. On a rectangular filter the distributor is driven backwards and forwards with the liquid siphoned from a channel running the length of the bed. The sewage percolates down the filter to collect in an underdrain system at the base. The distribution of air in a filter is usually assisted by draught tubes located in the sides of the filter. Loading rates for filters depend on the effluent quality required, the media used and the type of wastewater being treated, with the rates varying between 1 and 40 m^3/m^2 d.

There is usually a continual cycle of film growth followed by its death and detachment from the media. The process is termed 'sloughing off' and the resultant sludge is carried away with the filter effluent. Hence humus tanks are required to settle out and remove the solids from filter effluents, in the form of humus sludge.[49]

The main advantages of percolating filters are their relatively simple operation and low running costs, and their ability to withstand shock and toxic loads because of the short contact time of the wastewater with the slime layer. They do, however, also have some disadvantages with high land requirements, limited treatment efficiency and the production of odours and fly nuisance in hot countries.[49] Watson Hawksley[5] have described how performance may be improved by recirculating treated and settled effluent and by using filters in series, with the order of filtration being alternated.

Rotating Biological Contactors RBCs provide an alternative secondary biological treatment system, and comprise a rotating bed of attached bacteria which is immersed in a tank of wastewater. Horan[49] describes how the bed consists of a number of closely spaced circular discs mounted on a rotating drive shaft. A microbial film up to 3 mm thick soon forms on the discs and this removes the BOD. The discs can be of wood, metal or polystyrene and be of flat, corrugated or honeycombed profile. The discs may be up to 4 m in diameter and mounted on 7 m shafts, rotating at speeds between 1 and 2 rpm, and the rotating action produces aeration, mixes the tank contents and assists in generating the shear forces for 'sloughing off'.

Horan[49] has identified the main advantages of RBCs as ease of operation and low land requirements, making it suitable for developing countries, and they have been used in rural areas of northern Europe and the United States. The main disadvantages arise from disc and shaft failures and lack of operational control. They are generally enclosed to protect them from rain and wind, and if the enclosing structure is poorly designed, it may hinder access for inspection, maintenance and repair of the discs.

(B) Dispersed Growth Processes

The Activated Sludge Process This is a suspended growth system consisting of a mass of micro-organisms constantly supplied with organic matter and oxygen. The micro-organisms grow in flocs which convert the organic material into new bacteria, carbon dioxide and water. The flocs are continually being washed out of the reactor to the secondary sedimentation tank by the flow of incoming sewage, where they flocculate and settle under quiescent conditions. A small part of the settled sludge is recycled back to the aeration tank in order to generate sufficient biomass to secure efficient BOD removal.[49]

Horan[49] has identified the following three main variations on the conventional activated sludge process, namely method of oxygen supply; loading rate; and aeration tank configuration, each of which are now briefly described.

The two methods of oxygen supply consist of mechanical surface aeration and diffused air aeration. In *mechanical surface aeration* the devices transfer oxygen from the atmosphere to the mixed liquor by agitating the surface of the liquid. Mechanical aerators can be mounted either vertically or horizontally, with the vertical mounting being the most common, with the reactor divided into a series of pockets, with an aerator at the centre of each pocket. The horizontal type normally comprises oval channel tanks formimg a continuous loop and termed oxidation ditches.

Diffused air aerators are mounted on the floor of a reactor and they release air into the mixed liquor as a stream of bubbles. Oxygen transfer occurs at the interface of the air bubbles and the water as it rises to the surface, and the circulation currents thus generated keep the mixed liquor solids in suspension. Air distribution systems comprise porous tiles made of ceramic or more recently reticulated foam, which produce bubbles of up to 2 mm diameter.

Horan[49] lists four basic parameters for describing the rate at which settled sewage is applied to an activated sludge reactor, which is termed the *'loading rate'*. They consist of: (1) volumetric loading, which determines the amount of time the sewage will undergo aeration in the reactor; (2) organic loading, which measures the amount of BOD applied per unit volume of aeration tank capacity; (3) food:micro-organism ratio (F/M) or sludge loading rate is considered the most useful of the loading parameters; and (4) floc loading, which gives an indication of the *BOD* concentration available to the sludge micro-organisms at a given time. These are all well described in *Biological Wastewater Treatment Systems*.[49]

Process Configurations Activated sludge reactors require provision for the introduction of settled sewage and its removal, together with the mixing of returned sewage. The precise tank configuration has a significant effect on many aspects of plant performance and economy. The major forms of plant configuration are described by Horan[49] as follows:

(1) Batch reactors originally operated on the fill and draw process and were rather time-consuming. These have largely been replaced by the sequencing batch reactor (SBR) which allows several processes, such as carbonaceous oxidation, nitrification, denitrification and phosphate removal, to be performed in the same reactor.

(2) Complete mix reactors wherein the settled sewage and return activated sludge are quickly distributed throughout the tank such that a sample, taken from any point in the reactor, should give identical values for mixed liquor suspended solids (MLSS), BOD and oxygen concentration.

(3) Plug-flow reactors are normally tanks with a high length to breadth ratio, with settled sewage and return activated sludge introduced at one end and removed at the other. A plug-flow reactor consists of a number of tanks or pockets in series, each equipped with its own aerator and operating as a complete mix reactor.

(4) Step feeding is an alternative method to step aeration with the aim of distributing the load more evenly and preventing oxygen deficiency at the inlet. All return sludge is recycled to the reactor inlet and the flow of the incoming settled sewage is split and fed to a number of pockets.

Modifications can be made to the conventional activated sludge process, based on differing reactor configurations and modes of aeration, but still providing sludge recycle, with the main objective of reducing construction and operating costs. Horan[49] has described the principal processes as contact stabilisation; oxidation ditches; absorption-bio-oxidation (A/B) process; deep shaft process; and the VITOX process. Readers requiring more detailed information on these processes are referred to *Biological Wastewater Treatment Systems*.[49]

Severn Trent[50] have produced an excellent summing up of the activated sludge process which is well worth repeating. 'Activated sludge is often used as an alternative to biological filtration, usually on larger works or where less space is available. As with filtration, naturally occurring bacteria are used. But instead of taking the oxygen they need from the air which circulates around the media on filter beds, the bacteria are provided in aerated water. The air is provided by agitating the surface of the tank, using rotating paddles or bubbling up air from fine porous domes on the floor of the tank. The settled sewage is mixed with the activated sludge containing the bacteria in the aeration tanks and the bacteria feed on it for four to ten hours, after which the organic material in the sewage is oxidised, with the time varying according to the type of sewage treatment works and the strength of the sewage. The remaining liquid – the final effluent – is separated from the activated sludge in final settling tanks. Some of this activated sludge is then returned to the inlet of the aeration plant to mix with more incoming settled sewage and so the process continues'.

The final effluent remaining after biological filtration or the activated sludge process should be a clear liquid that can be discharged safely into a river or stream. However, some streams are too small to dilute the effluent that they receive, and where the river or stream is to be used for public water supply further downstream, the effluent needs to be treated even more thoroughly. The 'polishing' or tertiary treatment processes are described in a later section of this chapter.

Final Sedimentation

Watson Hawksley[5] have described how about half of the BOD in the biological treatment stage is converted to new micro-organisms and must be removed to ensure a high quality effluent. Final settlement is therefore required in addition to separating the activated sludge solids for return to the aeration tank. The solids to be settled in final tanks are lighter than those removed in primary settlement and the design upflow velocity is therefore commonly limited to 1.5 m/h at peak flow. With extended aeration the velocity may be reduced to 1 m/h.

Water Stabilisation Ponds

In many parts of the world it is not possible to provide either the energy or the maintenance requirements for the conventional processes previously described. In these circumstances a wastewater treatment, known as waste stabilisation or oxidation ponds, provide a cheap alternative. They are shallow excavations, often in the form of lagoons up to 4 ha in area and often about 1.0 to 2.5 m deep, which receive a continuous flow of wastewater and are frequently arranged in series, such that successive ponds receive their flow from the previous pond. The ponds require only simple maintenance and rely on sunlight for energy, which is readily available in hot countries, but treatment is slow and land requirements are great.[49]

In many arid and semi-arid countries. large scale reuse of sewage effluents is necessary because of water shortages resulting from increasing populations and agricultural needs. Horan[49] has indicated that a series of five ponds, each with a retention time of five days, producing an effluent with a low BOD and nutrient concentration is suitable for unrestricted irrigation. The main irrigation processes are described in chapter 8.

Tertiary Treatment

It is sometimes considered necessary to produce a final effluent quality significantly better than the 30 mg/l SS, 20 mg/l BOD, which can normally be obtained with biological treatment methods. The additional treatment generally known as tertiary treatment or 'polishing', normally involves reduction of residual suspended solids and associated BOD. Processes that have been employed include sand filtration, upward flow clarifiers, microstrainers, lagoons, irrigation over grassland and disinfection, and these have been described in detail by Watson Hawksley[5] and condensed descriptions of each follow.

Sand Filtration The effluent is passed upwards or downwards through beds of sand which filter it and the beds are washed regularly to remove particles filtered out of the effluent. The filters may be slow sand, rapid downflow or upward flow. Slow sand filters are little used on modern works since they occupy large areas of land and involve high maintenance costs. In rapid downflow filters the sewage passes downwards through a bed of graded sand up to 1.5 m deep by gravity or pressure and can deal with loadings up to 50 times that of slow sand filters. The gravity type, with 3 to 4 m head and loadings of up to 10 m^3/m^2 h, is generally used in preference to fully enclosed pressure filters. Backwashing with treated effluent, 1 to 3 times daily and around 10 l/m^2 s prevents clogging of the filter media, with backwash flows being returned to the head of the treatment works for further treatment. Air scour is often used to assist the backwashing process. Removal of 80% SS and 70% associated BOD can be obtained with rapid downflow filters, but rather higher loading rates are achievable with upward flow sand filters (up to 17 m^3/m^2 h) for similar pollution removal levels.[5]

Upward Flow Clarifiers These may be used for effluent polishing at small treatment works. The secondary effluent passes through a shallow bed of pea gravel on a perforated base, a mesh screen or other suitable medium, which removes suspended solids by flocculation and settlement. Any remaining particles combine together on the surface of the gravel, from whence they can be removed by backwashing. Maximum hydraulic loadings are usually in the range of 1.3 to 1.8 m^3/m^2 h.[5]

Microstrainers Watson Hawksley[5] have described how with microstrainers or microscreens effluent is passed through a stainless steel fabric, stretched around the periphery of a rotating drum, which is partially immersed in the liquid. The effluent enters the drum through a single open end and flows radially out through the steel mesh. Solids collected on the inside of the drum are then removed by a continuous filtrate spray entering the drum at the highest point, with washings being collected in a trough and returned to the inlet of the works. Suspended solids removals of 30 to 80% and 25 to 70% associated BOD can be obtained depending on the mesh size and hydraulic loading.

Lagoons The provision of lagoons as a final treatment stage permits further flocculation and settlement of suspended solids and removal of associated BOD.

Some further oxidation, reoxygenation and removal of bacteria also take place. In order to minimise the growth of algae, retention times should not generally exceed two days, suitably split between several lagoons in series. Lagoons often support fishes and attract wildlife and can have significant amenity value. In general, the availabilty and cost of land will decide whether they are to be preferred to other tertiary treatment processes. A number of lagoons will improve performance and provide flexibility.[5]

Irrigation over Grassland This process is used at many small and some medium sized treatment works in the UK. The effluent runs from a series of channels on to grass plots, flows over the surface and is collected in a second series of channels. Where suitable land is available, this is a cheap and effective method of improving the effluent quality. The plots are rested in turn, the grass being cut and the accumulated solids removed. Loadings are normally in the range of 2000 to 5000 m^3/ha d, depending on the climate and soil structure. Removals of 60 to 80% SS and 50 to 75% BOD can be obtained, together with some removal of bacteria, nitrogen and phosphorus and some increase in dissolved oxygen.

Disinfection Watson Hawksley[5] have described how the disinfection of sewage effluents by chlorination or ozonation is undertaken in many countries, particularly where waterborne diseases or parasites are prevalent, and where effluent reuse for irrigation or other purposes is required, as described in chapter 8. It is not, however, used extensively in the UK.

Advanced Treatment

The main objective of advanced treatment is to remove the pollutants which remain following conventional secondary treatment, in order to render the effluent suitable for reuse. Such pollutants include suspended, colloidal or dissolved, organic and inorganic compounds, as well as bacteria and viruses. Many processes exist for advanced treatment and some of these are outlined by Watson Hawksley.[5] They include chemical coagulation and flocculation; ammonia stripping; recarbonation; use of granular activated carbon; membrane processes, such as reverse osmosis, ultrafiltration and electrolysis; and ion exchange.

Sludge Treatment and Disposal

Character and Amount of Sludge Watson Hawksley[5] have described how the volume of liquid sludge produced at a sewage treatment works usually amounts to about 1 to 2% of the total sewage flow. Nevertheless, its treatment and disposal comprise major operations accounting for as much as 50 % of the operating costs of the works. The purpose of sludge treatment is to render the sludge more amenable to disposal and to minimise the disposal costs.

Primary sedimentation is carried out at most treatment works and this results in the removal of about about 60 to 70% of the suspended solids and 30 to 40% of the associated biochemical oxygen demand (BOD). The sludge normally contains an average of about 5 to 6% dry solids although the constituents at any given works will vary according to the frequency of the sludging operation. This usually takes place between once and three times daily, but where primary sludge is subsequently thickened in continuous flow tanks, sludging could be as frequent as every hour producing thinner sludges containing about 2% dry solids.

Sludge Thickening Thickening of sludge is often carried out to reduce the volume of liquid sludge requiring subsequent treatment and/or disposal. The resultant liquors are normally returned to the main sewage flow for further treatment. The most common method of thickening is by gravity, but centrifuging, gas flotation or belt thickening may be adopted, as described in some detail by Watson Hawksley.[5]

Anaerobic Sludge Digestion Watson Hawksley[5] have described how anaerobic digestion of raw primary or mixed primary/secondary sludges, is performed in the absence of oxygen, and results in conversion of organic matter into soluble and gaseous products. The process changes a maldorous sludge into one which is relatively inoffensive, destroying grease and reducing the numbers of certain pathogenic organisms. The process developed from cold digestion in open tanks to the current mesophilic system using covered tanks operated at 30° to 35° C, and utilising the gas for heating or power generation. The sludge gas normally consists of about 65 to 70% methane, with the remainder being mainly carbon dioxide, and gross calorific values generally range between 24 000 and 26 000 kJ/m^3. With a 20 day retention at 30 to 35° C the organic content of the sludge is reduced by 40 to 45%, equivalent to a reduction of 30 to 40% total solids, and about 1 m^3 sludge gas per kilogram volatile matter-day is produced. Cold digestion, although considerably less efficient, is still used in many small treatment works.

Heat exchange units can be incorporated in the sludge mixing system or as a separate circuit. Heat is generated by a boiler in which the methane gas or an alternative fuel is burnt. The gasholding capacity may be provided by means of floating covers on the digestors or separate floating roof gasholders. Sludge gas, surplus to that needed for heating the digestor contents, is often used for incinerating screenings, sludge drying or for vehicle propulsion in an emergency. Subsequent to heated digestion, the digested sludge is normally passed to storage tanks or lagoons (secondary digestors) prior to dewatering and/or off-site disposal.[5]

Aerobic Sludge Digestion An alternative to anaerobic sludge digestion is the partial oxidation of sludges using aerobic micro-organisms supported by aeration. It stabilises the sludge to minimise odour nuisance and to reduce the solids content. However, the process has limited use within the UK.[5]

Sludge Dewatering This process produces an easily handleable cake normally containing between 15 and 40% dry solids, depending on the type of sludge and method of dewatering. In the early part of the twentieth century, drying beds, comprising a sand and gravel bed overlying tile underdrainage, were used extensively for dewatering sludge, and can still be found on many small works. In the UK, changing disposal strategies and the development of a range of mechanical dewatering equipment has rendered land-intensive drying beds less attractive. Mechanical dewatering processes include filter plate and filter belt pressing, centrifuging and vacuum filtration, all of which are well described by Watson Hawksley.[5]

Sludge Disposal Watson Hawksley[5] have described how following treatment, sludge residues normally require disposal off-site. The selected method of disposal usually depends upon the outlets available and the characteristics of the sludge, particularly its toxic metal content. It is customary for the ultimate method of disposal to influence the type of treatment adopted prior to disposal. Both sludge treatment and disposal are costly processes and the prime objective is to obtain the optimum balance between treatment and disposal, to discharge the sludge to the environment safely and at an acceptable cost.

The principal methods of sludge disposal are as follows:

(1) as liquid to agricultural land after digestion
(2) as a liquid at sea, often after digestion
(3) as a cake to agricultural land or to tip
(4) as cake to incineration, the ashes produced being dumped to tip.

Sludge has some manurial value and assists in breaking up heavy soil. It is essential that sludge deposited on agricultural land has been adequately treated to render it sufficiently odourless and free from metals.

The dumping of sludge at sea has been practised in the UK according to two international conventions as embodied in the Disposal at Sea Act 1974, and all sludge dumping activities are controlled by licence. As described earlier in the chapter, the process will have to cease by 1998, when incineration will become the normal method of sludge disposal.

The dumping of sludge by tipping on sacrificial land has been subject to normal waste disposal legislation in Britain, under which tipping sites are licensed and controlled by Waste Disposal Authorities, and the restrictions are likely to be increased in the 1990s. Controls on incineration relate to the dumping of ash as a solid waste and the discharge of gaseous emissions to the atmosphere.[5]

Case Studies of Treatment Works

Six case studies of wastewater treatment works have been selected in the UK and overseas to illustrate some of the main problems encountered and processes used in a variety of situations.

Boston Sewage Treatment Works (UK)

The first case study covers a sewage treatment works for the medium sized town of Boston in Lincolnshire, with a population of about 35 000, situated on the tidal reach of the River Witham 5 km from its outfall to the Wash. For many years sewage, which contained effluent from several major industries, had been discharged, screened but otherwise untreated, directly to the river. Binnie and Partners were commissioned by Boston Borough Council to prepare a scheme for the interception and treatment of these sewage flows (14 Mld design flow), and the works were commissioned in 1979 and are illustrated in Figure 4.22.

The works was designed to treat sewage to a 50:30 standard for discharge to the tidal River

Figure 4.22 *Boston sewage treatment works, Lincolnshire (Source: Binnie & Partners)*

Haven and consisted of two hydraulically operated screens, Dorr detritor, four circular upward flow sedimentation tanks of 20 m diameter with half bridge scrapers, sixteen circular filter beds of 30 m diameter and eight circular upward flow humus tanks of 15 m diameter with half bridge scrapers. Biological treatment is provided by filters containing slag media incorporating arrangements for alternate double filtration.[51]

Sludge thickening tanks, sludge consolidation tanks and press house containing four 40 plate Johnson Progress filter presses were designed and constructed and the dewatered sludge is used on the land as a soil conditioner. Pumping stations for final effluent, washwater, drainage and sludge were provided together with an administration building.[51]

The sewage treatment works is sited on reclaimed land, which was formerly part of the tidal river, and investigations showed that the subsoil had limited bearing capacity. Dynamic consolidation was used to improve the bearing capacity of the four hectares under the filter beds and humus tanks, with 600 piles driven to support the other main treatment units.[51]

Broadholme Sewage Treatment Works Extension (UK)

W.A. Dawson Ltd undertook the extension of Broadholme sewage treatment works at Wellingborough, Northamptonshire for Anglian Water Authority in 1987–88 at a cost of £0.81m. The works under construction are illustrated in Plate 12 and Figure 4.23, show four commonly used reinforced concrete circular/conical final settlement tanks 24 m in diameter constructed in water bearing gravels to a depth of 9 m, alongside part

Figure 4.23 *Broadholme sewage treatment works extension, pouring concrete into conical settlement tank (Source: W.A. Dawson Ltd)*

of the existing works. The work entailed 5600 m^3 of excavation, 5000 m^3 of filling, 1660 m^3 of concrete, 3380 m^2 of formwork, 70 t of reinforcement, 840 m^2 of paving and 1160 m of pipework.

Bury Sludge Digestion Plant (UK)

This case study embraces a modern UK sludge digestion plant at Bury in Lancashire for the North West Water Authority, which was completed in 1986. A policy was developed whereby sludges from towns in the Mersey catchment were pumped through a pipeline to a new terminal at Liverpool, and the works at Bury was one of the first to be connected to the pipeline. Binnie and Partners were appointed to design and supervise the construction of a sludge digestion plant at the Bury works.

The plant was designed to treat 750 m^3/d of sludge with a solids concentration of 5%. It consists of three 5000 m^3 digestion tanks with a height/diameter ratio of 1.5, gasometer, sludge pumping station, boiler house and compressor room. The digestors are of the 'completely mixed' type and the total reactor volume provides 20 days detention for future sludge quantities. Digestion is carried out in the mesophilic range at a temperature of 35° C and the plant is automatic in operation.[52]

The instrumentation includes automatic controls for the pumps, dual-fuel boilers, heat exchangers, and gas handling plant. Sludge gas produced in the digestors is recirculated to mix the digestor contents and as the main fuel for the heating boilers. Provision is made to switch automatically to firing by fuel oil in the event of insufficient gas being available at any time.[52]

Design of the mixing system incorporated the latest knowledge on hydraulic behaviour of sludge flow developed by Binnie and Partners during the design of a nearby long sludge pipeline. The pipeline conveys sludge at the rate of 360 m^3/h over a distance of almost 35 km. Normal working pressures in the pipeline are in the range 12 to 20 bar.[52]

Jubail Wastewater Treatment (Saudi Arabia)

During 1978–82, Binnie and Partners designed and supervised the construction of two treatment plants for the Royal Commission for Jubail and Yanbu Jubail, Saudi Arabia, and these comprised unusual arrangements, with separate and sophisticated plant for sewage treatment and industrial wastewater treatment. The works were designed as part of the comprehensive design of water and waste systems for an industrial complex covering an area of 65 km^2. Sewage and industrial wastewater is treated at separate works and the effluent used for irrigation purposes. The industrial wastewater contained quantities of oily materials. [53]

The sewage treatment plant was designed to treat domestic sewage with a BOD of 210 mg/l and a suspended solids concentration of 350 mg/l and to be built in stages; stage I utilising a pond system to enable it to be built quickly. The first stage of the works was designed to treat 15 Mld of sewage by the use of aerated lagoons of 150 000 m^3 capacity. These lagoons were designed for use as effluent storage ponds in stage II. The design provided screening for the incoming sewage followed by pH correction before discharge to the lagoons. Effluent from the lagoons was routed through pressure filters prior to chlorination and discharge for irrigation on landscaped areas of the industrial complex. The design provided for sludge treatment in aerobic digestion ponds with a total capacity of 17 700 m^3.[53]

The second stage of the works was designed to treat 72 mld of sewage using the activated sludge process following preliminary screening and grit removal and primary settlement. An aeration capacity of 35 200 m^3 was provided to permit online denitrification should this be required in the future. Effluent was routed through secondary sedimentation, pressure filtration and finally chlorination prior to discharge to lagoons and use for irrigation. Sludge in this second stage was to be thickened, mesophysically digested and dewatered prior to landfill disposal.[53] A layout plan of the sewage treatment plant is shown in Figure 4.24.

The industrial wastewater treatment plant was designed to be built in stages, in a similar manner to the sewage treatment plant, and stage I was to consist of a pond system. Stage I consisted of inlet

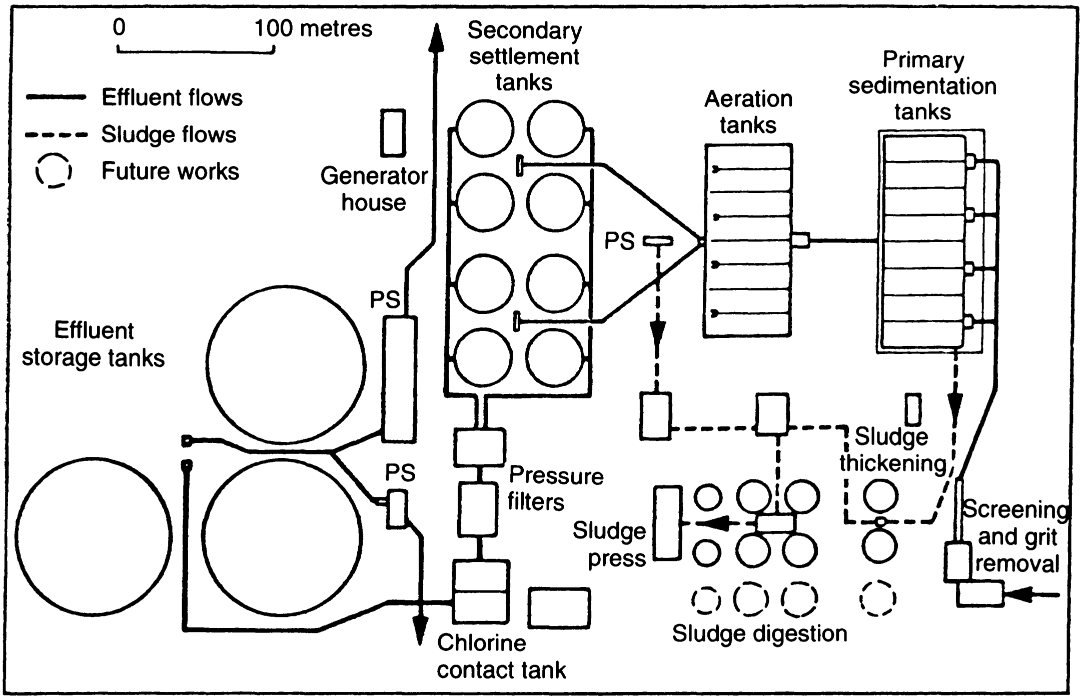


Figure 4.24 *Sewage treatment plant layout, Jubail, Saudi Arabia (Source: Binnie & Partners)*

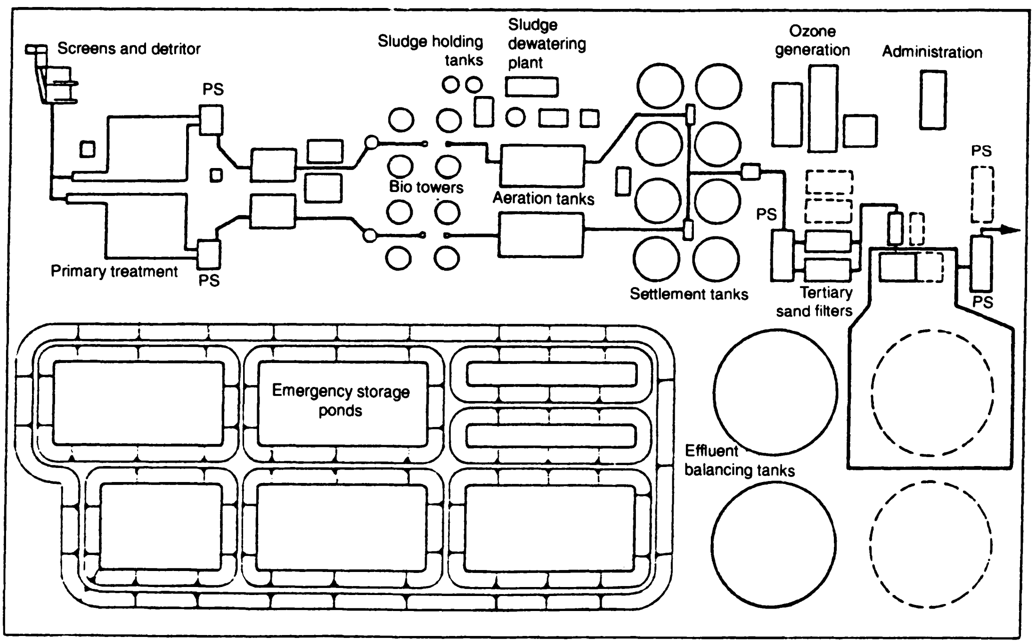


Figure 4.25 *Industrial wastewater treatment plant layout, Jubail, Saudi Arabia (Source: Binnie & Partners)*

works incorporating floating oil skimmer aerated lagoons of 142 000 m^3 capacity to provide biological treatment and sedimentation, pressure filter and ozone disinfection system. Sludge was to be removed from the aerated lagoons and stored for later treatment on completion of the stage II works.

The stage II works were designed to provide treatment for 62.5 Mld of wastewater in four streams capable of extension to double this capacity. Because of the possibility of oil spillage into the system the inlet works incorporated, in addition to screens and detritors, an overflow arrangement which would enable oily wastewater to be diverted to the first stage aeration lagoons.[53] A layout plan of the industrial wastewater treatment plant is shown in Figure 4.25.

MAM Sewage Treatment Plant (Sultanate of Oman)

W.S. Atkins were appointed initially to investigate and subsequently to redesign the wastewater treatment plant at the Mam Military Camp, north west of Muscat in the Sultanate of Oman. Problems arose because the original camp facilities were inadequate to accommodate the present and future growth of the camp complex. Much of the original sewerage system required replacing and the sewage pumping station remodelling. In addition, a gas scrubbing plant was installed for the removal of obnoxious odours from the raw sewage.

The capacity of the sewage treatment plant had to be increased 2.5 times so as to handle 5200 m^3 of sewage per day. Various alternatives were investigated, including extension to the existing works, oxidation lagoons and a complete replacement of the works. The factors which decided the final choice were capital cost, running cost, ease of operation and maintenance, and the requirement to produce a very high quality effluent to comply with local standards. The final scheme involved modifying the existing works and adding a complete new plant to accommodate the increased flows. Both the existing and new plants were designed to operate on the extended aeration process. Liquor from both the old and new aeration tanks passing through clarifiers and then through new rapid gravity sand filters and a chlorination tank. The final effluent is stored in lagoons and used for land irrigation, which is a common arrangement in this type of hot arid climate[54]. The plant is illustrated in Figure 4.26.

In other countries, such as Singapore, the recycling of sewage for use as water for industrial purposes has been used to augment the water supply, which in this case is obtained from Malaysia. For example, sewage effluent from the Ulu Pandan sewage treatment works is treated at the Jurong industrial water works as a supplementary supply of water to industries on the Jurong industrial estate.

Sha Tin Sewage Treatment Works (Hong Kong)

The final case study covers the Sha Tin works in Hong Kong in which special provision has been made for a number of unusual features. The population of Hong Kong increased from 600 000 in 1945 to over 5 million in 1979 and much of the new development took place on the mainland in the New Territories. The Hong government commissioned J.D. & D.M. Watson (later to become Watson Hawksley) to prepare a master plan for sewerage and sewage disposal in the new development areas. The proposals included the construction of a treatment works for the projected new town of Sha Tin, for which detailed design followed and construction commenced in 1978 at a cost of US$44m at 1977 prices. The works were designed for a population of 650 000 and provided full treatment by diffused activated sludge before discharge to the tidal inlet at Tolo Harbour.[55]

Sewage from the new town is delivered to the works by a pumping station, housing four centrifugal pumps each capable of delivering 4770 l/s against 31 m head. Power is taken from the public supply but can also be provided in an emergency from the independently generated supply at the treatment works.

The treatment works incorporated a system for reducing nitrogen in anoxic zones in the aeration plant; a method pioneered by the UK Water Research Centre. Space was allocated for further treatment to reduce phosphates, or by rapid sand filtration, in case the effluent is needed for use as a non potable supply. Sludge from the works is

Figure 4.26 *MAM sewage plant, Oman (Source: W.S. Atkins)*

digested anaerobically and partially dewatered in centrifuges for use in a compost plant. Gas from the digestion tanks is used in two MW dual-fuel engine generation units which will supply all the power used in the works.[55] An illustration of the works is shown in Plate 13, which indicates the large extent of the works.

The works were built on land reclaimed by the Hong Kong government from the sea and all units were constructed on piles through the fill. The fill material was placed over marine mud of very low strength and to avoid problems arising from excavating through the fill crust and the near liquid mud, the works were raised 3 m above the originally intended level. Particular care was taken in designing the works to provide safeguards against the typhoons which are experienced periodically.[55]

References

1. J.A. Pickford & H.D. Speed. Low technology water supply and sanitation in developing countries. *Mun. Engr, 1985, 2, Apr., 69–76*
2. C. Sale. *The Specialist.* Putman (1930)
3. United Nations Development Programme. *Decade Dossier, the International Drinking Water Supply and Sanitation Decade 1980–91* (1981)
4. J.M. Kalbermatten *et al. Appropriate technology for water supply and sanitation.* (several volumes). World Bank, Washington DC (1980 onwards)
5. L.S. Blake (Ed.). *Civil Engineer's Reference Book.* Sewerage and sewage disposal. Watson Hawksley, 29/1–29/26. Butterworths (1989)
6. TRRL. Road Note 35. *A Guide for Engineers to the Design of Storm Sewer Systems.* HMSO (1976)
7. B.G. Fletcher & S.A. Lavan. *Civil Engineering Construction.* Heinemann (1987)
8. Department of the Environment and National Water Council. *Design and analysis of urban water*

storm drainage, Vols. 1–5 (1981)
9. Hydraulics Research, Wallingford. *Tables for the hydraulic design of pipes and sewers, 4th edition* (1983)
10. Hydraulics Research, Wallingford. *Charts for the hydraulic design of channels and pipes, 5th edition* (1983)
11. O.C. Young & J.H. Smith. *Simplified tables of external loads on buried pipes.* HMSO (1970)
12. O. C. Young & M.P. O'Reilly. *A guide to design loadings for buried rigid pipes.* TRRL (1983)
13. Concrete Pipe Association of Great Britain. Technical Bulletin 2. *Loads on buried pipelines, Part 1. Tables of total design loads in trench* (1983)
14. W.B. Norgrove, M.P. O'Reilly & G. Stansfield. Cost comparisons of constructing sewers in trench or tunnel in urban areas. *Mun. Engr, 1989, 6, Aug., 219–30*
15. K.C. Fillingham. The planning and design of a pipe jacked tunnel through hazardous ground conditions at St Helens. *Mun. Engr, 1989, 6, Dec., 319–27*
16. Concrete Pipe Association. *Concrete pipes for drainage and sewerage* (undated)
17. Binnie & Partners. *Cairo sewerage, Egypt.* EXP6/S&SDOs/18/10/86 & 26/1/88
18. S. Montague. British battle on wastewater front. *New Civ. Engr, 30 Oct. 1986, 24–43*
19. N.J. Dawes. The Greater Cairo Wastewater Project. *Project Management 6.2, May 1988.* Butterworths
20. ICE. Cairo wastewater work restarts. *New Civ. Engr, 12 July 1990, 13*
21. Binnie & Partners. *Shanghai Wastewater, People's Republic of China.* EXP6/S&SDO/26/1/89
22. D.J. Coats. *Long Sea Outfalls, p. 1.* ICE (1989)
23. M.J. Brown. Planning and promotion of long sea outfalls. *Long Sea Outfalls, pp. 3–16.* ICE (1989)
24. Watson Hawksley. *Marine disposal of liquid wastes, South Hampshire.* ST/10/82/1
25. R.R. Willis. Design for construction. *Long Sea Outfalls, pp. 103–115.* ICE (1989)
26. J.J. Sharp & E. Moore. Marine outfall design – computer models for initial dilution in a current. *Proc. Instn Civ. Engrs, Part 1, 1989, 86, Oct., 953–61*
27. K.I.M. Henry & H.G. Perfect. Sea outfall works. *Long Sea Outfalls, pp. 27–40.* ICE (1989)
28. E.D.A. Smy. Construction of pipeline outfalls. *Long Sea Outfalls, pp. 117–30.* ICE (1989)
29. M.J. Little & J.A. Duxbury. Tolo Channel submarine pipelines, Hong Kong. *Proc. Instn Civ. Engrs, Part 1, 1989, 86,* Dec., 1213–16
30. J.M. Reynolds & D.A. Willis. Design and construction techniques for the future. *Marine treatment of sewage and sludge, pp. 258–81.* Telford (1987)
31. B. Grant. End of the line. *New Civ. Engr, 31 Aug. 1989, 18–20*
32. D. Cowie & G. Low. Peterhead sea outfall – investigation of failure. *Mun. Engr, 1989, 6, June, 127–36*
33. Hydraulics Research Station. Wave forces on submarine pipelines. *Offshore Focus, 1980, 18, Apr.*
34. R.A. Grace. *Marine Outfall Systems.* Prentice-Hall (1978)
35. M.J. Prosser. *The hydraulic design of pumps, sumps and intakes.* British Hydromechanics Research Association and Construction Industry Research and Information Association (1977)
36. D.G.M. Roberts *et al.* Weymouth and Portland marine treatment scheme; tunnel and marine treatment works. *Proc. Instn Civ. Engrs, Part 1, 1984, 76, Feb., 138–41*
37. Council of the European Communities. Directive concerning the quality of bathing water. *Off. J. Eur. Commun., 1976, No. L31*
38. N.B. Hunt & N.M. Lyness. The Portland connection of the Weymouth and Portland main drainage scheme. *Mun. Engr, 1987, 4, Dec., 335–54*
39. B. Dumbleton. Safety rules on storm flow stations. *New Civ. Engr, 10 March 1988, 36–7*
40. CIRIA Project report 1. *Sediment movement in combined sewerage and stormwater drainage systems* (1987)
41. E.C. Reed. The assessment of the problem in the UK. *Restoration of Sewerage Systems.* ICE (1982)
42. N. Cullen. The sewer dereliction problem – evidence from collapse studies. *Restoration of Sewerage Systems.* ICE (1982)
43. Water Authorities Association and Water Research Centre. *Sewerage Rehabilitation Manual.* WRc (1986)
44. J. MacPHEE. Sewerage rehabilitation. *Mun. Engr, 1986, 3, Apr., 67–78*
45. National Water Council and Department of the Environment Standing Technical Committee. *Design and analysis of urban storm drainage: the Wallingford procedure.* NWc Report 28 (1981)
46. M.N. Gooch & E.A. Warne. Sewerage improvements – the first pilot study goes underground. *Mun. Engr, 1990, 7, Apr., 69–85*
47. National Water Council & Department of the Environment Standing Technical Committee. *Manual of sewer condition classification.* Report 24 NWc (1980)
48. C. Jeffries. Australian sewerage problems and their solutions. *Mun. Engr, 1987, 4, Apr., 87–94*
49. N.J. Horan. *Biological Wastewater Treatment Systems: theory and operation.* Wiley (1990)
50. Severn Trent, Information Services. *Sewage treatment and disposal* (1989)
51. Binnie & Partners. *Boston sewage treatment works.* EXP5/STW/2–3/10/88
52. Binnie & Partners. *Bury sludge digestion plant.* EXP5/STW/10–11/10/88
53. Binnie & Partners. *Jubail wastewater treatment (Saudi Arabia).* EXP5/STW/7–8/10/88
54. W.S. Atkins. *Mam sewage treatment plant (Sultanate of Oman).* 80103.8
55. Watson Hawksley. *Sha Tin sewage treatment works, Hong Kong.* ST/5/80/1–2

5

Solid Waste Management

Introduction to Municipal Solid Waste Management

Khan *et al.*[1] have described how solid waste management planning is the development, comparison and monitoring of various alternative approaches to the solving of municipal solid waste problems. Solid waste management is one of the major environmental problems facing most of the developed and developing countries. Higher rates of waste generation, relevant manpower shortages, limited land resources, and increasing costs of collection and disposal are among the major factors to be considered in solid waste management planning.

Solid waste management consists of a number of individual activities, which can be conveniently grouped into six functional elements, namely waste generation, on-site storage, collection, transfer and transport, recovery, and disposal. Figure 5.1 shows the interrelationship of these functional elements. In addition to these functional elements, solid waste management also includes environmental, economic, social and political factors. Furthermore, the dynamic nature of these factors and their interrelationships makes collection and analysis of data very difficult and imposes a number of constraints on solid waste management.[1]

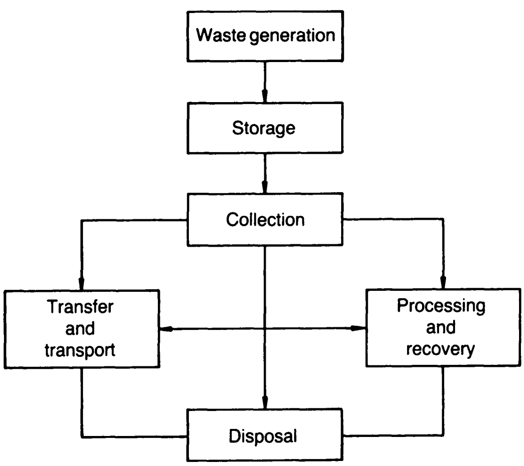


Figure 5.1 *Interrelationship of functional elements of solid waste management (Source: R. Khan et al*[1]*)*

In addition to disposing of domestic waste, it is necessary to establish efficient and safe methods of dealing with industrial and hazardous wastes. The latter aspect has given rise to acute public concern in the UK and will be examined in some detail later in the chapter.

Waste collection in the UK, subject to competition, is now being better managed than before. Furthermore, waste disposal is being considered over a wide sphere encompassing recycling, the use of waste as energy, its close relationship with collection and illict dumping, and research into making methods other than land fill cheaper and more efficient.

Domestic Waste Composition

Field[2] has emphasised that although analyses of the composition of household waste are available on a national basis, their use is limited to establishing trends and making specific estimates, such as the amount of glass available for recycling. If the waste disposal authority requires design criteria for treatment plants or transfer stations then an analysis of the composition of the waste must be carried out locally and for that specific purpose.[3] The composition of waste will vary from year to year, from region to region, and even from one neighbourhood to another, influenced by such factors as social groupings, season and the method of collection. It is in this

Table 5.1 Typical composition of domestic waste in the United Kingdom

Type of waste	*Percentage by weight*
Fine dust and cinders	*13*
Vegetables and putrescibles	*26*
Paper	*29*
Metals	*8*
Textiles	*3*
Glass	*10*
Plastic	*7*
Unclassified	*4*

context that the average national figures for the UK shown in Table 5.1 should be viewed.[4]

Many factors cause changes in the content of solid waste. For example, fewer coal fires result in less waste burnt on fires and less ash to be collected. More light packaging and less ash leads to greater bulk and lower densities. Further variations arise from the use of wheeled bins with their greater capacity and frequent inclusion of garden refuse. Hence despite the development of efficient compaction equipment, the modern refuse vehicle requires a larger volume than its predecessors to perform the same functions.

By way of comparison, Khan *et al.*[1] have produced comparable figures for some Middle East countries, with their very hot climates, and these are listed in Table 5.2. These figures show considerable variations between different Middle East locations and with domestic waste in the UK, particularly with regard to organic and vegetable matter, paper and metals.

Quantities of waste are invariably lower in developing countries, because of the lower standard of living and consumption, as well as extensive scavenging and salvage by beggars and the very poor. Densities of waste are much higher because of the virtual absence of paper, plastic, glass and packing materials and hence a much greater concentration of putrescible matter.[5]

Rainer[6] has provided the following typical breakdown of the composition of wastes in heavily urbanised areas in the United States:

Household wastes	48%
Commercial	31%
Construction	5%
Other	16%

Waste Collection

General Background

In the 1960s side loaders represented about 30% of the collection vehicles in use,[7] but by the 1990s they were little used in the UK and most municipal fleets mainly comprised compression rear loaders, as described later in the chapter. In

Table 5.2 *Domestic waste composition in Middle East countries*

Waste	Percentage by weight						
	Kuwait	North Yemen	United Arabic Emerate		Saudi Arabia		
	Safwa	Sanaa	Dubai	Al-Ain	Dammam	Khobar	Jeddah
Fine dust and cinders under 10 mm	–	18	2.1	4	–	–	–
Organic and vegetable	30	56	40.6	10	9.07	2.72	–
Paper, board and wood	40	6	41.2	50	38.34	40.34	36.25
Metals	5	7.5	7.5	15	23.11	31.77	16.00
Textiles	2	1.5	3.5	3	–	–	2.25
Glass	2	2	3.3	5	10.92	9.89	6.55
Plastic	6	0.4	1.8	5	13.25	12.40	10.50
Unclassified	15	8.6	–	8	3.32	4.88	–

Source: Khan et al[1]

the early 1960s kerbside collection was used at about 15% of premises, with rural districts accounting for about 39%. In 1964, a working party on refuse collection stated that both the Rural District Council Surveyors and the Institute of Public Cleansing advocated that it should be abolished except perhaps in city centres, mainly on grounds of hygiene.[7]

However, in 1984 the Audit Commission[8] indicated that a typical distict authority moving from back door collection to kerbside collection might save about £200 000 per annum and a typical metropolitan district as much as £500 000. The Commission then posed the question 'Is the extra service inherent in back door collection worth the additional costs – given all the other local uses to which the savings could be applied?' Since that time the widespread introduction of the wheeled bin has radically altered the situation.

By 1990 the volume of waste generated had risen to over 40 000 t per annum and was still rising, giving an indication of the large scale of the on-site storage, collection and disposal activities. In England the provision of waste collection is the responsibility of district councils using either direct labour or private contractors, while waste disposal is controlled by county councils. Different arrangements operate in Wales and Scotland.

Since the early 1980s considerable interest has been shown in the development of computer based planning aids for use in the reorganisation and restructuring of waste collection systems. The Local Government Operational Research Unit (LGORU) can give valuable advice on their availability and use in a particular situation.

In a service which visits every household every week, quality of service is an important factor. Even a small percentage of poorly carried out work results in a significant number of dissatisfied householders. Hence local authorities are increasingly seeking to monitor and improve the quality of service provided. Various changes to methods of storage and collection have been introduced to meet the changing needs of waste producers, the need to improve the efficiency, quality and economy of the service, to make use of modern and improved equipment, and to improve the working conditions and safety of operatives. Waste collection is predominantly labour and transport intensive and collection vehicles are becoming increasingly sophisticated and expensive.[9]

Problems can arise with the collection of waste in many ways, including the depositing by the householder of valuable articles not intended for waste collection in the vicinity of the dustbin, inability of operatives to gain access to premises and the decision as to whether certain waste can be classified as business or trade waste and an additional charge imposed for its removal.

Refuse collectors have been measured, timed, reorganised and rescheduled probably more times than any other group of municipal operatives. Incentive bonus schemes, valuable as they may be in improving productivity, do present problems in operation, as they require substantial supervision and the possible enforcement of penalties for unsatisfactory work, and above all they must be seen by the operative to be fair and readily understood.

Categorisation of Collection Methods

The Chartered Institute of Public Finance and Accountancy (CIPFA)[10] has categorised the waste collection methods used by local authorities under four main headings, namely back door collect and return; kerbside; other collect and return methods; and skep and other methods. Each of these methods is now examined, together with the use of plastic or paper sacks and wheeled bins:

(1) The back door collect and return system involves the operative collecting a bin or sack from within the curtilage of the property, but excluding the front of the dwelling. This method is still employed by many authorities but is deceasing both in use and popularity. Problems can sometimes occur when lids are removed before the bins are carried to the street, as litter can then be blown or fall from the bins while being carried or awaiting collection. Furthermore,

metal bin lids can be noisy in use, hence rubber lids have been used extensively.

(2) With kerbside collection, the householder takes the bin to the boundary of the property nearest to the street or on the street itself, thereby reducing operational costs but placing a greater burden on the householder. The aged and infirm experience difficulties in moving a full bin from the rear of the property to the street and problems can arise where the bins are placed on the street long before the time for collection, as they can cause obstruction of the footpath and be a source of litter. In addition, the waste collection authority needs the approval of the highway authority to the temporary depositing of waste on the highway.

(3) Other collect and return systems include requiring the operative to collect from the front or rear of the dwelling and to return the bin some lesser distance within the curtilage of the property. These systems are less costly than back door collect and return and eliminate most of the disadvantages of kerbside collection.

(4) In the skep system the operative empties the contents of one or more bins into a skep or larger bin which is carried between the property and the vehicle. This system was criticised by the Working Party on Refuse Collection,[7] mainly because it is a dirty process, produces litter and could lead to long term health problems for the operatives.[2]

In the late 1980s plastic and paper sacks and wheeled bins were replacing the traditional dustbin to a significant extent. In the financial year 1986–87, 6120m plastic sacks and 1.25m paper sacks were used in England and Wales.[10] Sacks can be collected at the property or the kerbside. Their use leads to a reduction in litter, but if left on the street for significant periods they are liable to damage by scavenging cats, dogs and foxes. In addition, paper sacks lose strength as they become wet, and plastic sacks are readily punctured by sharp objects. Indeed many operatives have been injured by broken glass, knives and hypodermic needles in domestic or commercial waste.[2]

The wheeled bin has been increasing substantially in popularity in the UK since the mid-1980s. In 1988, 93 authorities in England and Wales had adopted the system to a greater or lesser extent – 90% of these after a period of free trials. The traditional dustbin has a capacity of 100 litres whereas the wheeled bin commonly used for domestic waste collection has a capacity of 240 litres. This gives the householder the opportunity to vary the type, bulk and weight of material disposed of in the normal collection, usually including garden refuse. Chrichton[11] reported that in Bury, following the introduction of wheeled bins, domestic waste collected per week rose from approximately 8.5–9.0 kg per household to 11.0–11.5 kg per household. They are normally incorporated into a kerbside collection system with the bins normally positioned at the nearest point within the property curtilage to the street, where they will show a net saving when changing from back door collect and return. Otherwise the change will need to be made based on the presumption of a reduction in litter and better working conditions for the operatives, with much less physical effort, set against increased costs. However, many householders interviewed by the author assert that much of the work of the operatives has been transferred to them when it replaces a back door collect and return service, and they experience difficulties in pushing fully loaded wheeled bins from dwellings well back from the street and sometimes having to negotiate steep slopes and many steps. Many authorities provide smaller capacity wheeled bins for elderly people living on their own and may also arrange for the operatives to collect and return them to the dwelling.

Waste Collection in Developing Countries

Holmes[5] has emphasised that waste management methods in developing countries must take account of the dissimilar patterns of living compared with those operating in the more advanced countries. Apart from differences in composition and quantities of waste, a major factor in urban waste management is that only part of the service can be in the form of direct house to house collections. The use of side and rear end loading vehicles and tippers is only feasible in city centres and the middle and upper income suburbs where good access and western housing standards permit their efficient use. For the remainder, the usual solution is a communal collection system, with centrally located skips and bulk containers or occasionally purpose built concrete bays where manual labour or mechanical loading shovels load the waste from the ground into tippers or container vehicles. The communal points can be served by teams of collection labourers using wheeled trolleys to bring waste from households or illicit dumps. Occasionally refuse vehicles act as static compactors, occupying several set positions daily and served by teams of labourers collecting waste from inaccessible areas. In other cases the populace may be persuaded to bring their waste to the communal points.

Religious and social custom also has to be considered in Muslim countries, where the seclusion of women and the privacy of the domestic courtyard prevent waste collectors entering the home. With markets, central collection systems must be able to cope with large quantities of organic and animal waste often mixed with equal amounts of western packaging material. Collections must be more frequent than in western temperate countries, because the high temperatures and humidity cause the waste to decay and decompose very quickly with consequent dangers to health and hygiene. Flies and rodents are a continual problem and must be removed quickly from the home environment.[5] In 1990, it was estimated that the municipal administration in a typical Third World city managed to collect only about half of the rubbish generated by its residents, and that even this poor performance could cost one-third of the municipal budget, apart from the cost in poor health and environmental degradation resulting from rotting waste.

Vehicle Design

By 1990 compression type rear loaders formed the bulk of municipal waste collection fleets, with each manufacturer developing his own compression mechanism. They may, for instance, incorporate an intermittent compactor, which completes one cycle before stopping. Other mechanisms provide a continuous loading cycle or may be used intermittently or continuously. Waste may be loaded manually over the tailgate or by a hydraulic bin lift. Universal bin lift mechanisms are available which can empty 120, 240, 360, 600 and 1100 litre containers, permitting vehicles to be used in mixed household and commercial waste rounds and this also simplifies back-up in the event of vehicle breakdown.[2]

Field[2] has described how the whole of the tailgate of the rear compaction vehicle is raised during tipping. When waste is being loaded it is compacted against an ejection plate which moves into the body of the vehicle in response to the pressure imposed by the compacted waste. When the tailgate is raised, the ejection plate under hydraulic pressure pushes the waste out of the body.

The prospective purchaser of a vehicle has the choice of body, compression equipment and chassis. When using vehicles with bin lifts the payload has to be reduced to compensate for the weight of the equipment. Large waste collection authorities may use a 24 t, three axle vehicle, which when fitted with a Zoller bin lift has an average payload of about 11 200 kg. However, the larger vehicles generate higher capital and operating costs, heavy tyre wear and have restricted manoeuvrability. A choice should be made only after a detailed economic analysis of the available alternatives.[12]

Moir and Winterton[9] have described how the design of modern commercial compexes need to take account of the way in which the waste will be handled, starting with compaction of the waste on the commercial premises and making the best use of modern equipment and adequate manoeuvring area for large collection vehicles. Larger vehicles are ill suited for use in old narrow streets and some residential estates.

Household Waste Reception

In England the district councils operate the regular waste collection service, usually on a weekly basis, and also offer a special bulky waste collection service on demand for householders. This latter service is a very necessary one as it enables elderly and infirm residents or those without their own transport to dispose of awkward items of waste. County councils were given the responsibility of providing reception areas for similar waste, for use by residents with suitable transport, under the provisions of the Refuse Disposal (Amenity) Act 1978, with the aim of reducing roadside dumping.

Steels[13] has described how Cheshire County Council inherited 52 waste reception tips under local government reorganisation in 1974, including skips in town centre car parks and on every village green. The County Council decided on a policy of rationalisation with fewer centralised, controlled sites replacing the numerous large unmanned containers. Under the Health and Safety at Work Act 1974, local authorities have a duty to protect members of the public using household waste sites, and hence it was necessary to man all sites during all reasonable times which were adequately publicised. This resulted in the provision of a network of secure, manned sites to which few people have to travel more than 8 km and most less than 5 km. Wherever possible the salvaging of marketable materials, such as heavy metals (iron and copper alloys), light metals (aluminium alloys) and engine oil, with newsprint and glass bottles added subsequently at selected sites, which offset the attendant's costs. The main requirements in site design were the provision of adequately sized containers which could be readily positioned, filled and removed, ready access for the public and the layout should lend itself to the reclamation of wastes.

Transfer and Transportation Systems

General Arrangements

Kermode and Wells[3] have aptly described how landfill sites for waste disposal in reasonable proximity to densely populated areas are becoming scarce and significantly more expensive to operate as higher environmental standards are being required. This is compelling both waste disposal authorities and private operators to seek larger and more distant sites, which necessitate both the transfer and transportation of the waste and increase the overall waste disposal costs.

The three transfer and transportation systems adopted in the UK use road, rail and water, the choice depending on local conditions and existing transportation facilities. The main objective of a modern waste transfer station is to provide an efficient back-up for the collection service which cuts down the turn-around times, increases the payload and reduces the number of vehicles travelling to the landfill sites. These systems invariably use ISO type enclosed containers with consequent environmental benefits.[3]

Transfer stations can also be designed to perform various methods of waste treatment prior to disposal and can be adapted as reclamation centres, thus reducing both transport and landfill costs. Typical operations include compaction and baling, shredding and pulverisation, incineration, conversion into an energy source, composting and recycling, of which compaction is the most common method as described in the case studies that follow later in the chapter.

Compaction, possibly combined with baling, ensures economic use of landfill void space and reduces transport costs to the disposal site. Most transfer stations have a hydraulic ram compaction system which compresses the waste into purpose-built ISO enclosed containers. Each container normally accommodates the loads of 3 to 4 waste (refuse) collection vehicles, and the compaction systems are computer controlled to ensure that maximum legal payloads are achieved. This initial compaction is usually followed by *in situ* compaction on the landfill site, which enables densities of more than 1 t/m^3 to be obtained, thereby substantially extending the life of the site. In addition, the waste may be compacted into bales which are stacked on landfill sites with a covering of inert material to improve density and reduce voids. The baling may be carried out by the high pressure method (self-sustaining) or medium pressure (wire-tied).[3]

By 1984, West Yorkshire County Council had constructed five purpose-built transfer loading stations and provided two conversions from old plants, indicating the increasing use of these facilities. Two basically different designs have been used, both of which pack economic payloads into Rolonof containers, which are then road hauled to any part of the county or beyond.[14]

Case Studies

Four case studies have been selected located in Blackpool and various parts of London, using different systems of transportation to suit the local circumstances.

Blackpool Waste Transfer Station

The Blackpool Waste Transfer Station formed a major component in Lancashire County Council's long term strategy for the disposal of the community's waste in the Fylde coast area, and was commissioned in 1984. The two original landfill sites were almost exhausted and there was a lack of suitable replacement sites in the area. The County Council therefore decided to provide a transfer station from which wastes collected by the Blackpool and Fylde Borough Councils and from commercial and industrial sources within the area would be transported to the nearest available landfill site located at Clifton Marsh, Freckleton, situated on the estuary of the River Ribble, with a disposal capacity of up to 25 years. The transfer station serves a population of approximately 200 000 and enables waste to be transferred from relatively small collection vehicles and be compacted into bulk units, thereby achieving maximum payloads. The station was designed to handle up to 400 tonnes per day and the complete operation of unloading the collection vehicles, handling of waste and compaction into containers, is carried out in a single building to cause minimal impact on the environment.[15]

Vehicles entering and leaving the site pass over weighbridges to a traffic light control point for entry into the reception hall, which has a storage capacity of 400 tonnes. Inside the reception hall are facilities for fire detection, automatic ventilation and a wash down ring main. Loading shovels move the deposited waste on to one of two identical flow lines leading through the plant, as illustrated in Figure 5.2. On each flow line, a steel plate conveyor elevates the waste from the reception hall through to the treatment hall and on to a horizontal reversing conveyor, from which the waste is delivered to the charge boxes of compactors, with the direction and rate of flow automatically linked to the operation of each compactor through sensors in the charge boxes. All the components are provided with ample dust extraction plant.

The control room is in a central elevated position overlooking the treatment hall and contains a panel accommodating all the controls needed for the plant operation and an illuminated display shows the operating sequence. TV monitors provide views of the external road system, reception hall, waste within the conveyor and compactor enclosures, and there is radio communication between all key personnel.[15]

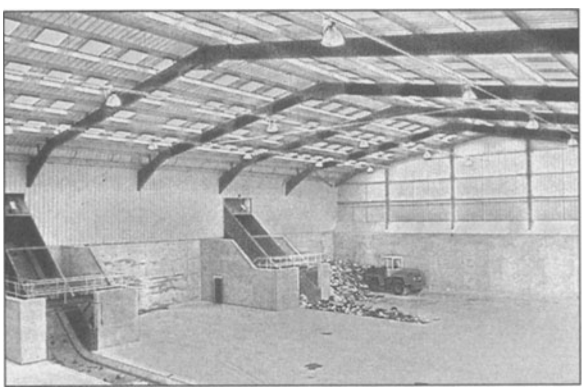


Figure 5.2 *Blackpool waste transfer station, waste reception hall (Source: W.S. Atkins)*

The two compactors are reciprocating, hydraulically driven, and compress the waste into large enclosed containers. The compacted waste is discharged into containers mounted on tri-axle road trailers, their weight is automatically recorded, and the trailers are then moved by slave vehicles to the vehicle park. The loaded trailers are hauled by tractor units to the Clifton Marsh landfill site where, in a purpose-built compound, the containers are transferred to a rough terrain vehicle and the waste is ejected horizontally by means of a ram.[15]

The total cost of the project was £3.27m (1984 prices), and the construction was carried out by Tollemache under the direction of the County Surveyor to Lancashire County Council.

Newham Road Transfer Station, London

Approximately 80% of London's waste is delivered to one or other of over twenty transfer stations, strategically sited throughout the Greater London area, where it is loaded into road vehicles, barges or containers for transport to landfill sites. Suitable sites, arising mainly from mineral extraction, may be as far as 80 km from the transfer station. Road, rail and river communications are used for moving solid waste to landfill sites, the choice depending on the location of the transfer station and the landfill site.

A typical example of a London Road Transfer Station is the one at Newham, serving the London Boroughs of Newham, Barking and part of Redbridge, with the compacted waste buried at a landfill site at Aveley in Essex within 24 hours. The station was commissioned in 1976 by the former Greater London Council at a cost of £2.9m and can handle 700 tonnes per day. In addition to the solid waste received from the Boroughs, it also accepts waste from commercial sources and there is a civic amenity site within the perimeter to receive bulky and other household refuse from the public.[16]

The operation of the plant has many similarities with the one previously described at Blackpool. The delivery vehicles are weighed, pass through an assembly area with three queuing lanes and signal control system, up a ramp into the tipping hall and to one of five tipping bays, with the help of an illuminated display board and safety barriers. Dust control and fume extraction equipment is provided at each discharge bay. After discharge, vehicles leave the station by an exit lane and out across the second weighbridge.

Waste material is discharged through hoppers into the charge boxes of compactors, and is then ready for transfer and compaction into 34 m^3 containers clamped on to the charge boxes. The containers are mounted on semi-trailers to permit fast movement by detachable road tractor units for road haulage after automatic vehicle washing to the landfill site, where the full containers are lifted off and replaced by empty ones. The full containers are carried by special terrain vehicles with large wheels and several driven axles, which carry a power-pack and ram for the horizontal discharge of the containers, the front ends of which are moving barriers.[16]

Western Riverside Transfer Station, Wandsworth, London

The Western Riverside Transfer Station alongside the River Thames in Wandsworth was commissioned in 1985 by the former Greater London Council and represents one of the more recent London river transfer stations. It receives household wastes from the London Boroughs of Wandsworth, Hammersmith and Fulham and the Royal Borough of Kensington and Chelsea. Separated recyclable wastes are handled by the adjoining Wandsworth Recycling Centre which also accepts commercial and civic amenity wastes. The station was designed to handle up to 4000 tonnes per week of solid waste, with a peak daily flow of 1200 tonnes and a peak hourly flow of 300 tonnes.

It comprises a weighbridge, tipping ramp with traffic signals and twelve loading bays discharging into a reception hopper. Wastes from the reception hoppers are compressed by one of ten compactors into a container with a ram boost force of 60 tonnes. Each container is of standard ISO pattern, allowing easy transferability between barge, road and rail haulage, and the use of any standard container handling equipment. Each container has a capacity of 28 m^3 with a stable door design, allowing loading through the upper door, but requiring both doors to be opened for unloading, to eliminate spillage. On average, a container will take the contents of four household waste collection vehicles. The station has 440 sealed containers and 15 open top containers with lids for non-compressible wastes.[17]

Each full sealed container is then lifted by one of the two available 25 tonne capacity overhead travelling cranes. Each container is weighed on one of two quayside container weighbridges and is then loaded directly into a barge or placed in a container storage area. The crane driver uses data on container weights to ensure the correct trim for the barge. Each container carries 30 containers, in two layers of 15, with a total weight of 400 tonnes. There are berths for six barges. The barges are towed by tug downstream to a landfill site at Mucking in Essex, where waste land is being reclaimed and restored. At the Mucking jetty, one of two overhead cranes unloads each container onto a site terrain vehicle to be driven a short distance inland on to the landfill site. The movements of the barges are timed to take advantage of the tides, to give considerable savings in tug fuel.[17]

In the event of fog or other disruption to river traffic, the containers can be loaded by the quayside cranes directly onto flatbed container lorries and removed from the site by road. This inbuilt flexibility will allow the station to continue operating without interruption. A mobile container handling unit, capable of stacking containers three high, is provided for container movement outside the working area of the overhead travelling cranes.

Hendon Solid Wastes Rail Transfer Station, London

This was the second London station after Brentford to use an integrated rail transfer system for waste disposal and was unique in that it was a joint venture between private industry (London Brick Landfill Ltd) and a local authority (the former Greater London Council). It receives waste from the London Boroughs of Barnet, Camden and Brent and was commissioned in 1978, at a cost approaching £600 000. The waste is used to restore London Brick clay pits at Stewartby in Bedfordshire to agricultural cultivation. The GLC provided the access road and weighbridge reception area and the Company constructed and operate the transfer station and transport the containerised waste by rail to Stewartby.[18]

The station processes a daily minimum of 800 tonnes transported by about 300 vehicles, and this can rise to 1200 tonnes in post Bank Holiday periods. The building is of concrete, brick and steel construction, and incorporates a concrete ramp which gives access to a partially elevated, totally enclosed, tipping hall containing 12 tipping bays, with compaction equipment located beneath 10 of the bays, with feed hoppers to compress the wastes into $6.1 \times 2.4 \times 2.4$ m ISO containers of 28 m^3 capacity, of which 230 are available. The two tipping bays without compaction equipment are for the reception of bulky non-putrescible wastes which are discharged directly into open top ISO containers, of which there are 10 available. Two electrically powered travelling cranes, each of 20 t capacity, move each container overhead to a stock line or directly to a waiting train.[18] A layout plan of the station is shown in Figure 5.3.

Two trains leave the station each day in the morning and afternoon, hauling either 30 or 45 loaded containers to Stewartby. The morning train returns with empty containers during the afternoon of the same day, while the afternoon train returns early in the morning of the following day. Transportation by rail or river helps to reduce road congestion by relieving the road network of many large vehicles.

Waste Disposal Methods

Introduction

Kermode and Wells[3] have rightly emphasised that no single disposal method is appropriate for every type of waste disposal project; the selection will depend on many factors including the nature of the waste, where it arises, availability of disposal options, planning conditions including environmental assessment in some cases and the costs involved.

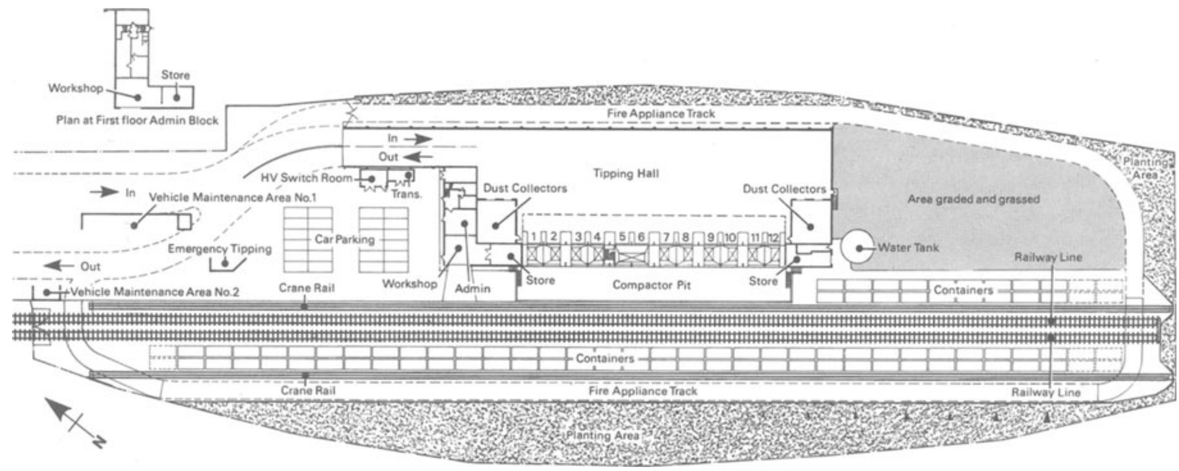


Figure 5.3 *Layout of transfer station, Hendon (Source: Greater London Council[18])*

Controlled waste is defined in section 30.1 of the Control of Pollution Act 1974 as household, industrial or commercial waste, the disposal of which is subject to the waste disposal licensing regulations. In England and Wales the county councils are the licensing authorities, except in Greater London where responsibility rests with the London Waste Regulation Authority (LWRA). The principal methods of dealing with controlled waste are landfill, incineration, production of energy, composting and recycling.[3]

Landfill

General Background Landfill is currently the most widely used method and accounts for 95% of all waste in England and Wales and in excess of 90% in the United States. When properly executed and adequately funded, as in the Coney Hill site described later in the chapter, it enables derelict, unusable or low grade land to be improved for a variety of productive uses. Good examples are at Appleford in Oxfordshire and Harefield, Middlesex, where crops are growing and cattle grazing on former landfill sites since restored to farming. Thus controlled tipping plays an essential role in waste disposal and will continue to do so in the future. For some wastes it is the only viable disposal option, and even when waste is processed, as by incineration, there is still a residue to be disposed of by landfill.

Because of the environmental impact of landfill sites, great importance is now attached to a scientific approach which embraces ecology, geology and hydrogeology. The EEC *Directive on environmental assessment*,[19] implemented in 1988, stresses the importance of this approach. Kermode and Wells[3] have aptly described how landfill sites must be properly designed and all necessary protective measures taken against leachate (polluted water), landfill gas, infestation by vermin, litter, dust, noise and odour. The main problems are caused by the production of leachate and methane gas: neither can be prevented but both can be reduced by good design and operational techniques.

The serious danger of methane gas is now fully recognised in the UK and the Inspectorate of Pollution wrote to all waste disposal authorities in 1987 concerning licensing and control of landfills emitting gas. This was further strengthened by the publication of *Waste management paper 27*[20] which provided guidelines for the control of landfill gas. On sites producing large quantities of gas, active systems can be developed on a commercial basis thereby providing an income to offset the high costs of gas control equipment. The scale of the problem was highlighted in 1989 when the Pollution Inspectorate reported that waste authorities had identified 1390 operational and closed sites which were a potential risk.[3]

Site Preparation Crawford and Smith[21] have identified and described in detail the principal measures entailed in the site preparation of landfill sites. The first operation is the clearance of vegetation, which can include mature trees, saplings, grass and moss. Diversion of springs and streams may also be required and in some cases it is possible to 'plug' springs using clays or concrete, but careful consideration is needed of the possible consequences. The lining of the site is described in more detail later and there is also the construction of both permanent and temporary roads, fencing of the site for security purposes and/or litter control, and the provision of services. It is advisable to install wheel cleaners at site entrances, often consisting of a series of metal bars over a collecting chamber to receive the mud. Bund formation can constitute another important site preparation activity at the boundaries of the site or intermediate divisions, often formed of a core of waste surrounded by clay. Leachate disposal may be provided in the form of open jointed, porous or perforated pipes discharging into a collecting sump, with a vertical access shaft from the top of the landfill to the sump. Where the leachate is to be treated, storage lagoons or sumps are usually provided. If methane is to be abstracted from the landfill, a gas collection system will be installed progressively as the site is developed.

The Landfill Operation A case study of the Coney Hill landfill site in Surrey developed by the former GLC[22] has been adopted as a good example of a sound approach to this method of waste disposal. The waste is deposited at depths of approximately 2 m, each progressive layer being covered with a minimum of 0.25 m of soil on all faces at the end of each working day. Heavy machines known as mobile compactors crush and compact the waste into the landfill producing an initial density before covering of around 1 t/m^3. Decomposition of the waste occurs through chemical and bacteriological reactions. As the waste degrades certain by-products are released either in the form of gas and/or contaminated water known as leachate, and substantial pollution control measures are required to render these pollutants ineffective, and these will be described in more detail later.

The Surrey County Council issued a licence for the use of the site for the disposal of domestic and commercial solid waste. The licence detailed the type of waste to be deposited and the conditions under which the landfill operation was to be undertaken, and included the following matters:

a) Construction of proper access and site roads including gates and fencing and the installation of offices, staff amenity facilities, plant storage garage and other associated works.
b) Type and daily amount of wastes to be deposited.
c) Traffic movements to and from the site including routing.
d) Hours site may be operated.
e) Conditions under which the waste is deposited.
f) Procedures for preventing pollution including the application of an impervious membrane, and the regular monitoring and sampling of gas and leachate and surrounding groundwater.
g) Installation of a vehicle wheelwasher to prevent mud from being conveyed to the carriageway.
h) Control of insects by spraying with suitable chemicals.
i) Control of dust and litter.[22]

A detailed investigation of the site was undertaken by the former Greater London Council, the East Surrey Water Company, Water Research Centre (WRc) and Surrey County Council to determine the geological and hydrogeological details of the area. Because of the groundwater level and the need to safeguard against pollution, the general level of the site was raised with sand to 1 metre above the water table level and an impermeable membrane was laid over the base of the site. These details are shown in Figure 5.4.

Clay was used to maintain the seal up the sides of the site and this was placed prior to raising the

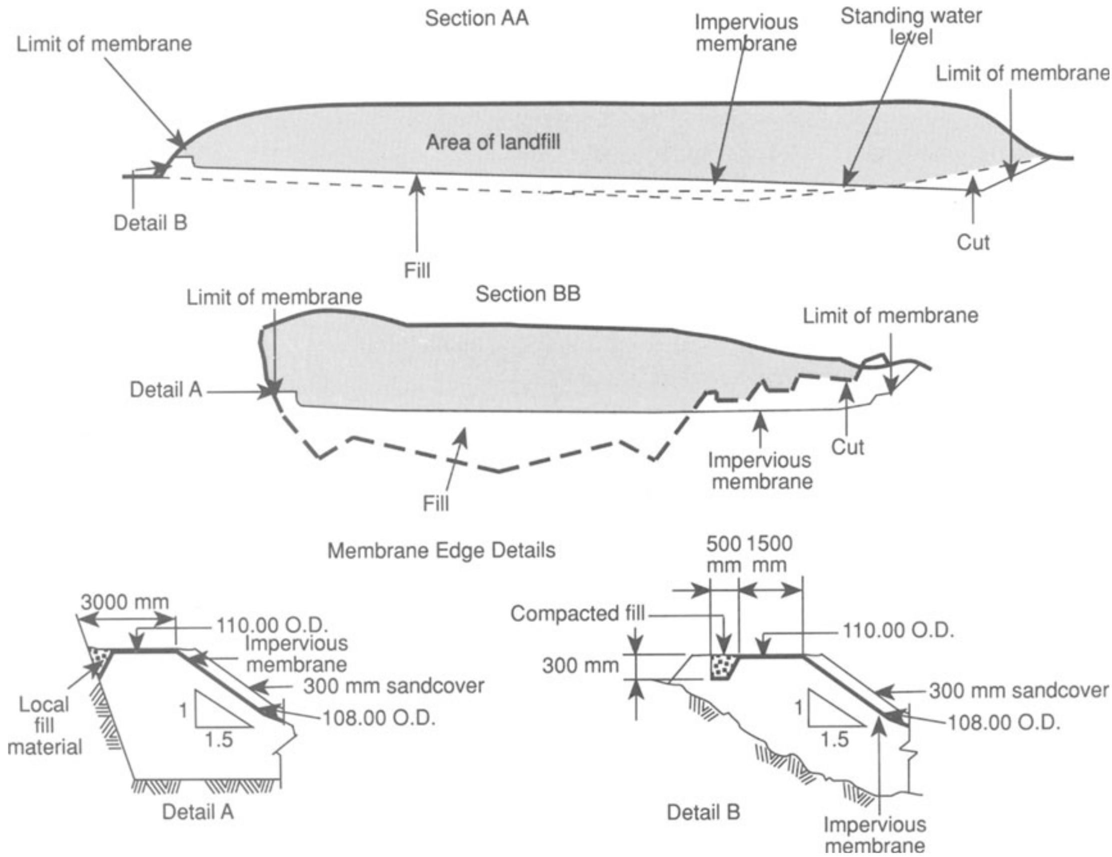


Figure 5.4 *Sections through landfill area, Coney Hill (Source: GLC[22])*

respective layers of landfill. Membranes can be formed from natural soils such as clay, bentonite and puddled chalk or by using man made materials such as polyethylenes and PVC. Because of inadequate long term information, tests were carried out at Harwell Hazardous Research Laboratories to simulate the long term effects of exposure of these man made materials to pollutants from decomposing household wastes. Following these tests a number of materials were considered suitable and it was decided to line the site with 1.2 mm high density polyethylene. As a buffer' between the membrane and the wastes a 0.3 m layer of sand was placed above the liner.[22]

Landfill gas, consisting mainly of carbon dioxide and methane, is safely vented through the surface of the landfill by means of specially constructed wells. As an alternative at a large 28 ha site in Aveley, Essex, gas recovery equipment was installed to extract the gas from the decomposing wastes. At Aveley, the gas is dried, cooled and piped to industrial premises as a medium grade boiler fuel. Landfill gas from the Coney Hill site is used to produce electricity for the local generating board. The London Waste Regulation Authority (LWRA)[23] believes that gas could continue to emerge from closed landfill sites up to twenty years or perhaps longer after the deposit of waste has finished. The Department of Energy (ETSU) identified 18 commercial landfill gas exploitation schemes in operation in the UK in 1987.

To minimise the formation of *leachate* (contaminated water) at Coney Hill, the working area is sectionalised into a number of self-contained clay bunded cells. During landfilling each cell is filled in sequence according to a predetermined plan and as much waste as possible is placed into one cell before moving to the next. Surface run-off of rainwater from the cells is achieved by ensuring satisfactory surface gradients. By these means leachate production is considerably reduced. Rainwater falling on unworked parts of the site is pumped into the surface drainage system. An on-site treatment plant reduces the level of contaminants and after treatment liquid is discharged to a sewer for subsequent treatment at a local sewage treatment works.[22]

On completion of filling, a minimum of 1 m of soil is placed over the wastes and seeded and the land returned to agricultural use. Tree and shrub planting will also be included in the final restoration scheme, details of which are agreed with the local planning authority and the owner of the site.[22]

Sanitary Landfill in Developing Countries

Holmes[5] has aptly described how controlled sanitary landfill is rarely practised in third world countries and one of the major tasks of a waste management contractor is to bring some semblance of order and hygiene to what can only be described as apalling dumps of decomposing material. A combination of lack of technical knowledge and finance exacerbate the problem, but simple standards of responsible sanitary landfill can produce substantial improvements to disposal standards. Very high rainfall can cause problems of drainage and leachate and require special care in planning. At the poorest end of the scale the World Health Organisation (WHO) has described sanitary landfill sites almost totally operated by manpower with the minimum use of mechanical plant. Health and hygiene can still be achieved and these do not always need to be accompanied by high technology.

Incineration

General Background

In 1990 there were 524 incineration plants operating in Europe, the majority of which were built before 1980. In the UK about 45 modern incineration plants were constructed between 1968 and 1976, of which 40 were still operational in 1990 and incinerated approximately 5% of the country's municipal waste. The majority of these are simple mass burning systems without energy recovery, and Kermode and Wells[3] consider it very unlikely that any new plants will be built of this type. Five plants were provided with energy recovery facilities, two of which include power generation. The Edmonton plant was the first large scale power generation plant to be constructed in the UK and this is described in considerable detail later in the chapter. However, other European countries built 144 incinerators between 1980 and 1990, although the majority of these were French low capacity units, but Germany constructed 12 large units with greatly improved operating standards.

In the UK the operation of incineration plants is controlled by the Clean Air Acts and the Public Health Act. In general, the controls relate to chimney heights and grit and dust emissions. Adequate chimney heights are needed to ensure the safe dispersal of fumes, while the control of grit and dust can be overcome by the installation of efficient electrostatic precipitators. In 1990, the DOE Air Quality Division was reviewing air pollution control in Great Britain and a consultation paper[24] was issued in December 1988. This paper proposed that all waste incinerators should be included in a new two part schedule of processes subject to a system of prior approval, and be required to use the 'best practicable means' to minimise atmospheric emissions and to render those that cannot be prevented harmless and inoffensive. It was further proposed that control of the procedures should be a joint activity encompassing a National Pollution Inspectorate and local authorities, and these proposals were awaiting legislative approval in 1990.[3]

In addition, the harmonisation of standards through the EEC was being processed in readiness for 1992. In June 1988 the following two relevant EEC directives were issued:

(1) 89/369[25] on the prevention of air pollution from new municipal waste incineration plants sets out emission standards for a variety of pollutants, a monitoring procedure and combustion conditions to minimise the risk of micropollutants.
(2) 89/429[26] on the reduction of air pollution from existing municipal waste incineration plants. Within ten years all the conditions appertaining to new plant will become operative, but within five years modified standards must be met.

Member states were required to bring into force the laws, regulations and administrative provisions necessary to comply with these directives before 1 December 1990. Kermode and Wells[3] have emphasised that the installation of more complex equipment will be necessary to meet the new operating and monitoring standards, and this will increase substantially the cost of incineration in the UK.

Widespread interest in incineration has been revived because of the increasing costs and difficulties in providing new landfill sites, as described earlier in the chapter. Several island communities have adopted this approach in order to preserve their limited land space. All new projects incorporate maximum energy recovery and the production of income-producing electricity.

For example, at Brest in France, an incinerator with energy recovery was completed in 1990, at a total cost of FF160m, consuming 140 000 t annually of waste and the income from the electricity generated is expected to pay off the installation costs in 17 years. In the Bab district of France, which has an average seasonal population of 160 000, an incinerator was constructed in 1990 to deal with household, commercial and industrial wastes, hospital wastes and non-toxic sludge. Income will be generated by recycling, and the production of energy and high grade compost.[3]

In West Germany in 1990, the AGR waste disposal contractors Essen commissioned a special waste incinerator to treat 30 000 t annually and a second incinerator processing 10 000 t annually of household waste. This company invested over £63m in incineration plants over a 12 month period. In Bonn, a new incinerator plant is planned for completion in 1993.[3]

The UK consortium SELCHP, which involves both the public and private sectors, was in 1990 planning to build an incineration plant to process waste from the London boroughs of Greenwich, Southwark and Lewisham, and it will generate 30 MW of power for a large combined heating and power project.[3]

Kermode and Wells[3] have pointed out that incineration is a very expensive disposal process, involving high maintenance costs and the provision of specialised emission control equipment to comply with environmental standards, which were being upgraded in 1990. Furthermore, landfill capacity is still required to accommodate the incineration residues which are reduced to 10% by volume and 25% by weight of the original waste. An alternative method of utilising the energy content of waste is by the production of waste derived fuel, which is examined later in the chapter.

Edmonton Solid Waste Incineration Plant

General Introduction This plant was commissioned in 1970 by the former Greater London Council and was the first of its size to be built in this country, with the design based on data obtained from home and abroad, but particularly from West Germany. It has been selected as providing a very successful method of disposing of waste, avoiding pollution of the environment and reducing substantially long hauls by heavy waste vehicles. The boiler plant associated directly with the incinerator produces steam from the heat of combustion, and the steam is then used in the production of electricity. Each of the five boilers comprise vast lengths of steel tubing inside which water is converted to steam at high pressure and temperature.[27]

Building Design The site is bounded to the west by industrial development and to the east by the Lee Valley Regional Park, into which it has been skilfully blended. The incinerator block is 97.5 m long by 30.5 m high and the chimney is 100 m high and 9.75 m in diameter. To minimise the impact of these large structures, colour has been used to differentiate and define the sub-elements. A light neutral tone was used for the main block and a dark tone on the turbine house and residuals plant. Out of sight of the park, but where the impact will add to the vitality of the scheme, primary colours were used on the precipitators and cooling plant. To ensure a permanently smart and hygienic appearance all cladding materials (plastic coated sheeting, white frost tiles and acrylic finished windows) are largely maintenance free.[27]

Waste Delivery and Handling Each working day some 1600 t of crude waste is delivered to the plant which incinerates some 400 000 t of waste annually. The vehicles enter by a dual road system and then ascend a ramp to the enclosed tipping apron. Before each vehicle mounts the ramp, its load is weighed and recorded as it passes over one of three weighbridges. An illuminated display system directs drivers to one of twenty three unloading bays. Gravity discharge from the loading bays into the bunkers, through hydraulically operated doors is controlled from the tipping apron control room. The bunkers are 12 m square and 24.5 m deep and have a total capacity of 3900 t, which is sufficient storage to maintain 24 hour continuous operation of the plant seven days a week including bank holidays. The normal daily throughput is 1150 t with occasional peaks of up to 1300 t.[27]

Waste is transferred from the bunkers by two overhead grab cranes into furnace feed chutes and pushed on to the grates by a hydraulic ram, as illustrated in Figure 5.5. Each crane has a safe working load of 9.5 t and each grab has a capacity of 4 m^3, and a third crane is provided for standby duties. Dust arising from falling waste during vehicle discharge is contained by very fine water sprays across the tops of each bunker.[27]

Incineration Of the five boiler units, four are normally in operation and one under maintenance, and each boiler can consume up to 12 t of waste per hour. The combustion chamber is designed around a KVW stepped roller type grate consisting of an inclined series of seven parallel hollow rollers, 1.5 m in diameter and 3.5 m long, each driven through infinitely variable gearing to produce a speed range from 1/2 to 5 revolutions per hour, and primary air is fed through the rollers. The temperature of combustion is controlled between 925 and 1040°C, with complete combustion achieved by the agitation resulting from burning waste turning and falling from roller to roller. From the final roller, burnt out clinker and ash pass through a quench bath on to conveyors and into the residuals handling area.[27]

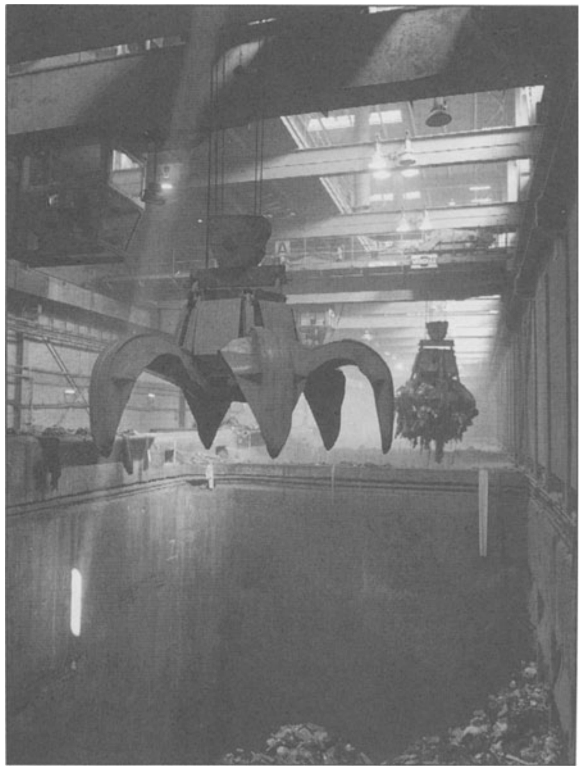


Figure 5.5 *Edmonton solid waste incineration plant, grab cranes (Source: NLWA)*

Exhaust gas from the economiser passes through 50 kV electrostatic precipitators before discharge to the atmosphere from the twin flues of the main chimney. The precipitators reduce the dust content of the effluent gases to less than

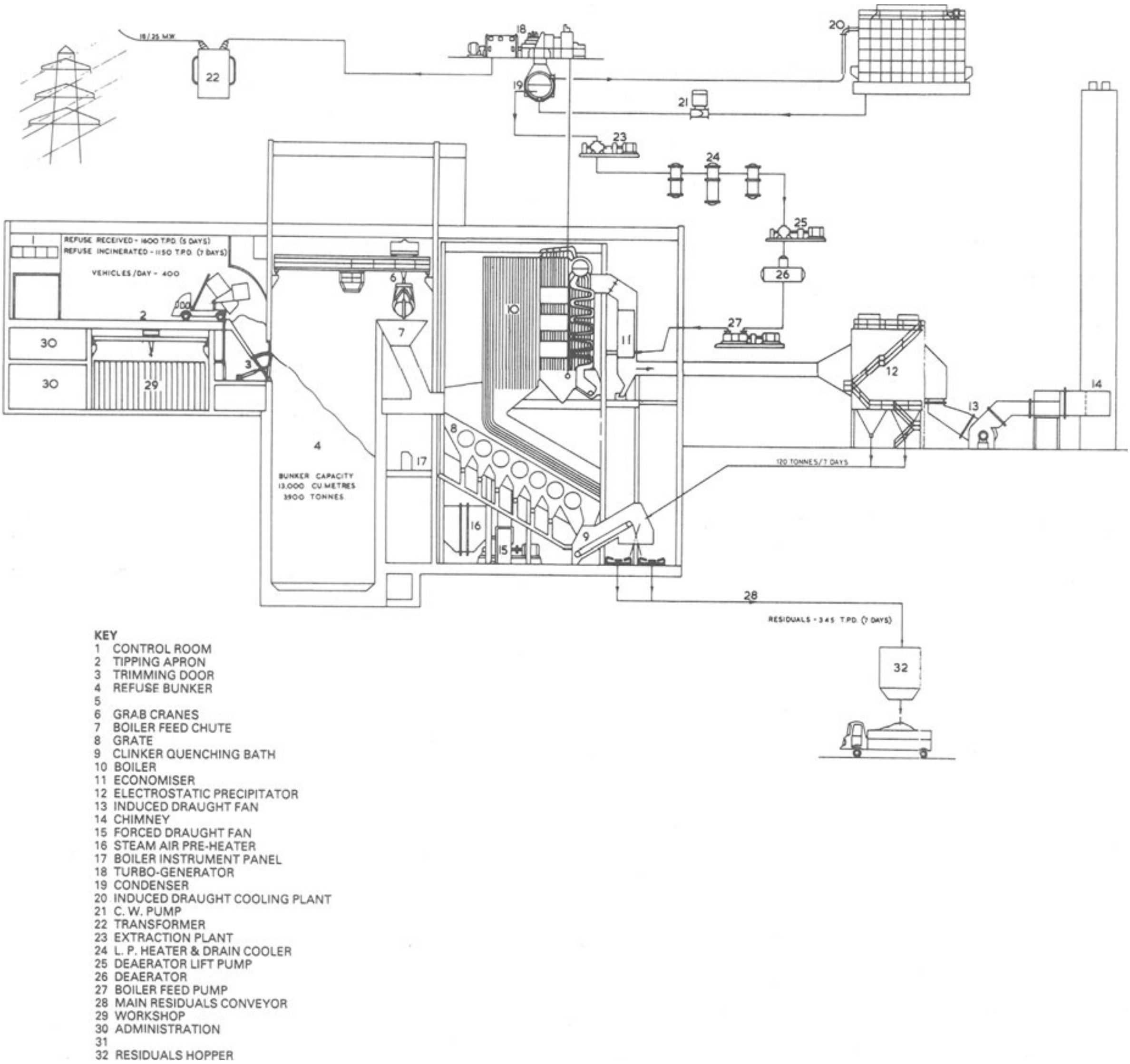
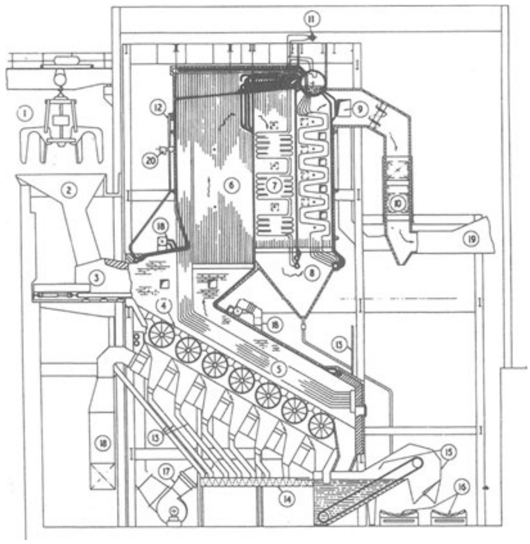


Figure 5.6 *Edmonton solid waste incineration plant: schematic arrangement of plant (Source: NLWA[27])*

116 mg/m^3. Figure 5.6 shows the arrangement of the plant and Figure 5.7 illustrates in greater detail the steam raising unit and incineration plant.

Residuals Handling and Disposal Residuals from the boiler grates consist primarily of clinkered ash and metals. These are conveyed by two 1.8 m wide belts from the boiler house into the residuals building from which they are removed by road transport. Fly ash from the precipitators is conveyed to the quench bath of the boiler where it is mixed with the residual ash from the furnace and water, under controlled conditions, prior to disposal by road transport.

Power Generation Under normal conditions, steam from the boiler units is used to drive two of the four 12.5 MW turbo alternators and, in addition, one of two 2.5 MW house sets supple-



1 Bunker refuse grab
2 Refuse hopper
3 Refuse feeder
4 Incineration grate
5 Combustion chamber
6 Radiation shaft
7 Superheater
8 Boiler bank (entrance)
9 Economiser gas by pass
10 Economiser
11 Superheater outlet
12 Downcomer tubes
13 Dust chutes
14 Dust conveyor
15 Residual quenching tank
16 Residual conveyors
17 Secondary air fan & ducting
18 Forced draught fan discharge to grate
19 Flue gas to precipitation & I.D. fan
20 Sootblowers

Figure 5.7 *Steam raising unit with Dusseldorf system incineration plant (Source: NLWA[27])*

ment the electrical requirements of the plant. The main sets are direct-coupled units with single cylinder turbines, the generators having closed circuit air cooling arrangements incorporating water coolers. A dump condenser is provided to condense any steam which may be produced in excess of the turbines' ability to utilise the steam. Circulating water for the condensers is passed through induced draught counter-flow cooling towers. Figure 5.8 shows the turbine hall where steam from burning waste in boilers is used to drive the turbo alternators in the production of electricity, and in the top righthand corner of the illustration is the control room, where electricity connections are made through to the grid network and this is manned 24 hours a day and 365 days a year.

Electricity is generated at 11 kV. Duplicate feeders give a supply to Deephams Sewage Treatment Works in addition to being transformed to 33 kV for sale to the local electricity board. The plant generates about 20 MW of electricity per annum providing an income of £4.2m in 1989/90.

Clinical Waste Incineration Plant This modern purpose-built plant was commissioned in 1985 and provides an acceptable method of disposing of clinical waste, drugs, and expired pharmaceuticals from hospitals, dental and GP practices and veterinary surgeons. The plant can also deal successfully with the destruction of confidential papers and related items, excluding nitrate based film. The plant comprises hydraulically operated bin loaders and feeder rams, which push each load into a starved air primary combustion chamber operating between 800 and 900°C. The released gases pass through a secondary combustion chamber, where combustion is assisted by a gas fired burner ensuring an operating temperature of 1000 to 1200° C. The gases then pass through a cyclone grit arrestor and then into the main plant chimney ducting assisted by an induced draught fan. The plant normally operates on a five day week, during which 40 t of clinical waste can be incinerated.[27]

Other Plants

Other but smaller incineration plants incorporating heat recovery facilities were provided in the 1970s. These included Nottingham (1973) serving various city centre premises and dwellings, Coventry (1975) serving car manufacturers and Sheffield (1976) serving a flats complex.[28] The Nottingham Incineration Plant which burns annually about 120 000 tonnes of waste and cost £5m in 1973, is augmented as necessary by a local refurbished industrial coal-fired power station for combined heat and power generation. They serve a large district heating scheme which incorporates some 5000 dwellings and associated facilities in redevelopment areas, the central public buildings and two large enclosed shopping centres. The power is supplied to the local electricity board.

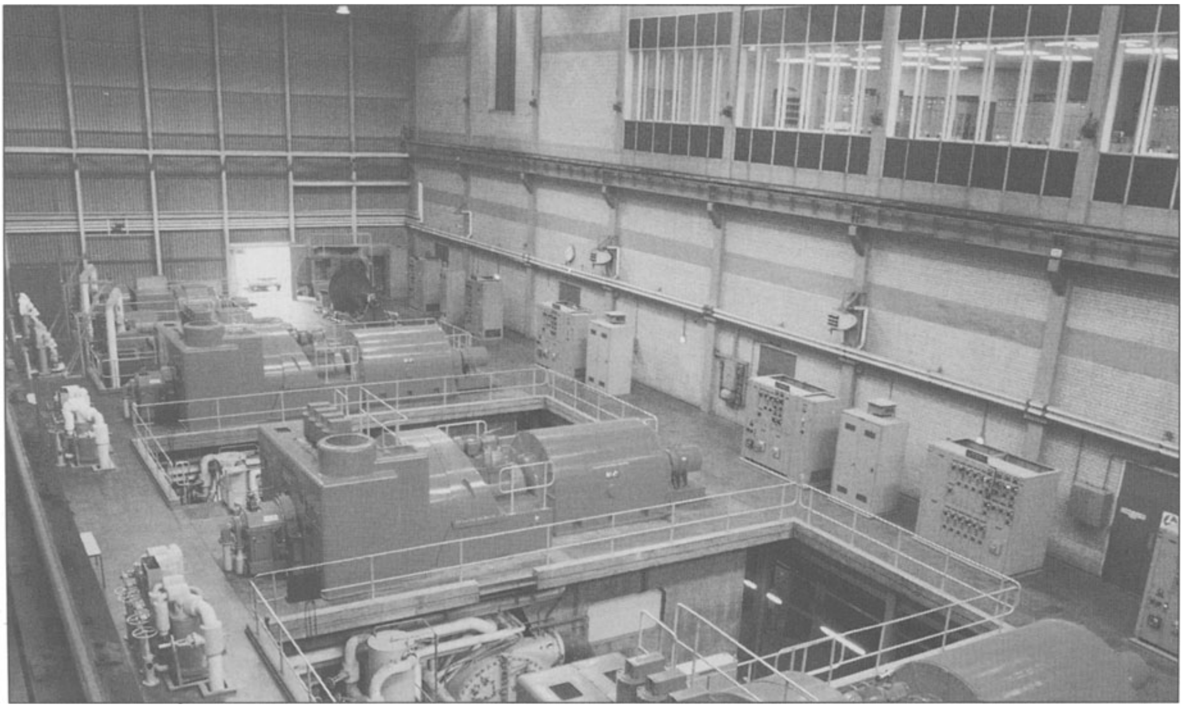


Figure 5.8 *Edmonton solid waste waste incineration plant, turbine hall (Source: NLWA)*

Waste Derived Fuel Plants

General Background

Kermode and Wells[3] have described how in the private sector, the use of waste as a heat source for industrial purposes was being examined as early as 1970. Cement manufacturers co-operated with county councils in carrying out trials and culminated in Blue Circle using 80 000 t of waste annually combined with pulverised coal at the Westbury Cement Works. Concurrently, Warren Spring Laboratory and various overseas establishments were carrying out research into the production of fuel from waste, and this encouraged several county councils to undertake recycling and to produce fuel from waste, either in the form of loose floc or pellets. These developments led to the construction of several waste derived fuel plants in the 1980s, some of which are listed in table 5.3.

Kermode and Wells[3] have identified the following advantages to be gained from the WDF process:

(1) the process is relatively simple, flexible and robust
(2) the fuel can be produced economically with a stable calorific value at each plant and can be mixed with coal as a supplementary fuel
(3) the fuel can be produced to a uniform standard and density
(4) reduction in volume of waste reduces transport costs
(5) less land is required for landfill
(6) fine screenings are being developed as growing media
(7) existing fossil fuels are preserved, which is in accordance with the principles established in the Electricity Act 1989, s.32.

The WDF process has many environmental advantages as waste is screened, pulverised and classified, and the residual material for landfill

Table 5.3 *Some UK waste derived fuel plants*

Plant	Treatment method	Reclaimed materials	Status
Byker – Newcastle City Council	Screening, primary shredding, classification, secondary shredding, pre-densification, pelletization	Waste derived fuel pellets Ferrous metals	Operational since 1980
Govan – Glasgow City Council	Primary shredding, screening, classification, secondary shredding, pelletization	Waste derived fuel pellets	Operational since 1983
Castle Bromwich – City of Birmingham/ Secondary Resources plc	Screening, primary shredding, classification, secondary shredding, pelletization	Waste derived fuel pellets Ferrous metals Waste derived humus	Operational since 1985 Joint venture with private sector 1989
Huyton – Merseyside WDF Ltd	Primary shredding, screening, classification, secondary shredding, pre-densification, pelletization	Waste derived fuel pellets Ferrous metals	Operation since 1986
Isle of Wight – IOW County Council	Screening, primary shredding, classification, secondary shredding, pelletization	Waste derived fuel pellets Fines Ferrous metals	Operational 1988
Pebsham, Hastings – East Sussex County Council	Screening, primary shredding, classification, secondary shredding, pelletization	Waste derived fuel pellets Fines Ferrous metals	Operational 1989

Source: Kermode and Wells[3]

can be analysed and monitored to produce safer and more acceptable landfill. In all cases the process involves the separation of the lighter combustible elements of waste from the heavy non-combustible components by screening, pulverising, air classification and, ultimately, pelletisation.

Two modern plants which have been designed and commissioned by East Sussex Enterprises Ltd (a company established by East Sussex County Council) are located at Newport, Isle of Wight, producing 20 000 t of fuel annually, and Hastings, with an annual fuel output of 30 000 t. These two plants are described in more detail in the next section of the chapter.

Hastings WDF plant

The plant accepts domestic waste and suitable commercial waste and mechanically separates it into the following components: fuel pellets (30%), ferrous metals (4%), fine screenings (40%), and reject material (20%), with the remaining 6% being water driven off during the separation process. The fuel pellets, primary paper and plastic film, can be sold for heating purposes or, alternatively, can be used for electrical generation with the waste heat being made available to local premises or other processes on the site. Ferrous metals are sold for de-tinning with the resultant scrap being recycled by the steel industry. Aluminium extraction is undertaken using eddy current separation. Furthermore, a grant towards the cost of development and installation of plant was given by the EEC in 1990.

In 1990 the company was actively investigating the anaerobic digestion of the fine screenings to produce a growing media. During this process, glass and dense plastic will be recovered, together with methane gas for conversion to electricity to run the plant. When all these developments become operational it is anticipated that the final reject to landfill should not exceed 15% by weight of the input of waste.

Waste is delivered to the plant by conventional waste collection vehicles and a variety of trade vehicles, and then discharged on to an apron storage area for handling by shovel loaders. Waste is then pushed on to plate feeder conveyors and discharged into a primary screening drum, which separates the over-size material, as this requires milling before proceeding to the air classifier. The remaining material is further screened to remove the fine material and then combines with the milled product to go forward to the classifiers. The light fraction from the classifiers is dried to the required moisture content, shredded and pelletised in a twin line process before being cooled from 100° C prior to discharge and storage.

The Hastings plant treats 100 000 t of waste annually, being approximately 47% of the domestic waste of East Sussex, and produces 30 000 t of fuel/year. It was completed in 1989 at a cost of £4.7m, and part of the plant is shown in Figure 5.9.

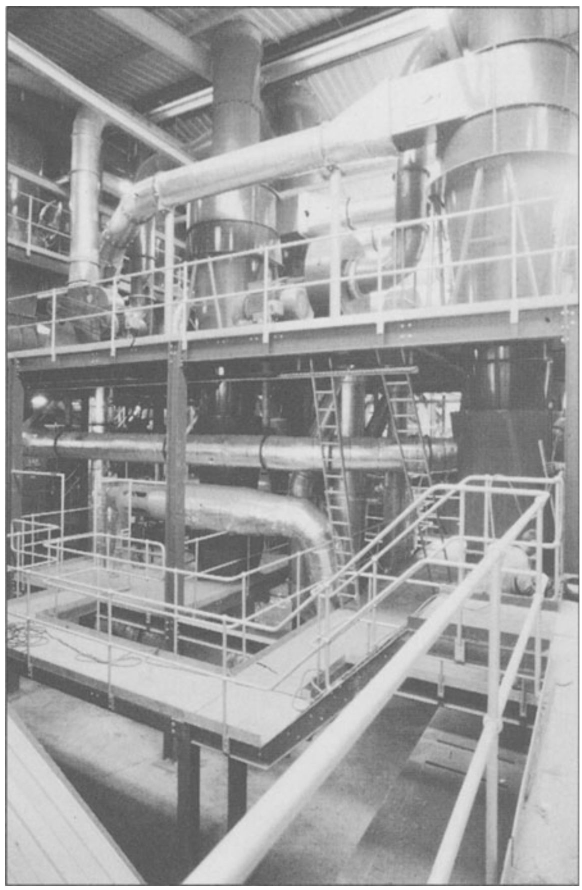


Figure 5.9 *Hastings waste derived fuel plant (Source: East Sussex Enterprises Ltd)*

The fuel supplied by the Hastings and Isle of Wight plants is named 'Easiburn' and is supplied in bulk to users by tipper lorries, possibly with a blower attachment. The fuel must be kept under cover unless consumption is substantial. Easiburn can be burnt on fixed grates, chain grates, reciprocating grate bars, retort type stokers and also pulverised fuel burners, but the retention time in the combustion chamber must be such that a temperature of 850° C can be maintained for a sufficiently long period. Easiburn has an ash content of about 9% by weight, thus approaching that of bituminous coal, and a calorific value approaching 19 MJ/kg, compared with a typical coal CV of 28.1 MJ/kg.

Isle of Wight WDF plant

In 1984 the Isle of Wight County Council decided that a WDF plant was appropriate for the Island, because it offered a resonably economical opportunity to recycle wastes into one or more useful products in addition to reducing the need for landfill space. In 1986, the County Council contracted with East Sussex Enterprises Ltd to design and build a WDF plant costing £4m in Newport. The plant had to be capable of handling an input of 63 000 t/year of household and commercial waste, and to produce a minimum quantity of 30% fuel pellets of a guaranteed quality from these wastes. The plant was commissioned in 1989 following an 18 month construction period.

The plant process can conveniently be divided into three stages, namely: (1) initial sorting and grading; (2) classification and drying; and (3) pellet production, and these are each described and illustrated diagrammatically (figures 5.10, 5.11 and 5.12).

Stage 1: Initial Sorting and Grading of Waste Incoming waste is deposited in the reception hall, where it is shovel loaded on to the conveyor which takes it into the plant. Waste is initially size-graded by being passed through a rotating primary drum sieve (dark blue), before being pulverised in a hammer mill. Smaller wastes, rejected by the primary drum sieve, pass on to a secondary drum sieve (grey) for further size grading. Wastes accepted by the secondary drum sieve as being of adequate size join pulverised waste emerging from the hammer mill and go on to stage 2. Wastes rejected by the secondary drum sieve as still being undersized (less than 50 mm) leave the plant as fine rejects, which include clinker and ash, small pieces of glass and metal, and potato peelings, which may ultimately be recycled as compost.[29] Note colour coding used for main plant components.

Stage 2: Classification and Drying Waste from stage 1 passes along a levelling conveyor to a stream splitter (green). From here until the pellet presses, waste may be processed by either of two identical streams. From the stream splitter wastes pass through an air classifier (green), where they fall from top to bottom against an upward current of air. Heavier particles or items which reach the bottom of the air classifier leave the plant as heavy rejects, for example tin cans which can be extracted for recycling, shoes and pieces of wood. Lighter particles, carried on the air current to the top of the air classifier, pass on to a primary cyclone (green), where the air is separated from the waste particles, the former being returned to the classifier while the waste passes on to a rotating drier (silver). Here the waste particles

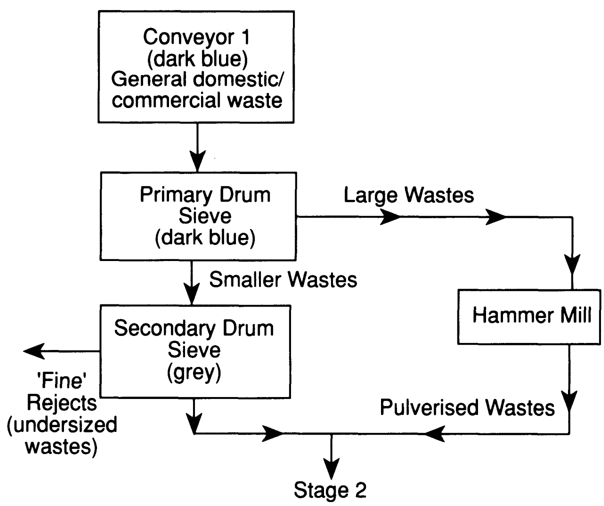


FIgure 5.10 *Isle of Wight waste derived fuel plant: stage one (Source: Isle of Wight County Council[29])*

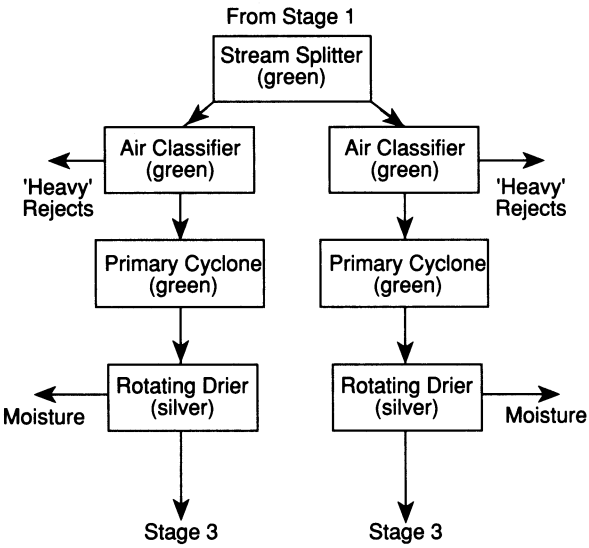


Figure 5.11 *Isle of Wight waste derived fuel plant: stage two (Source: Isle of Wight County Council[29])*

are 'tumble-dried' to control their moisture content as necessary before passing on to stage 3.[29]

Stage 3: Pellet Production Waste particles from stage 2 pass through a secondary shredder (light green) where they are finely chopped up to a size suitable for compressing into pellets. From the secondary shredder particles pass along a thermopneumatic line in a current of air hot enough to sterilise the particles and eliminate any unwanted residual moisture to a secondary cyclone (red) where the air and product are separated. The product is then passed by a screw feed conveyor to one or more of the three pellet presses (orange). Here particles are compressed into fuel pellets by being extruded through a fixed circular metal die. The newly made pellets emerge from the presses at approximately 100° C, and require cooling to eliminate handling problems and reduce the likelihood of crumbling. The output from the pellet presses is therefore carried by a bucket elevator to a pellet cooler (orange), before finally passing through a sieve (orange) which returns any mal-formed pellets or crumbled particles to the presses for repressing. Acceptable pellets are conveyed from the sieve out of the plant into storage containers.[29]

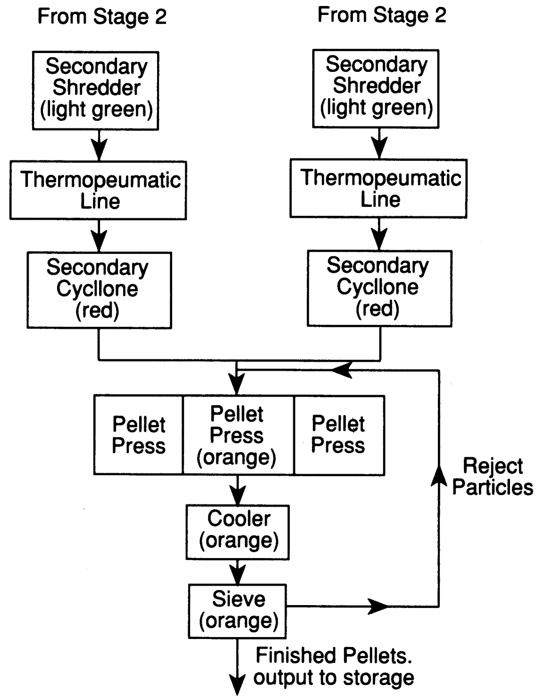


Figure 5.12 *Isle of Wight waste derived fuel plant: stage three (Source: Isle of Wight County Council[29])*

Composting

General Background

Composting is the aerobic decomposition of organic wastes, such as leaves, waste paper, food wastes, grass and sewage sludge, to form a humus-like material. Micro-organisms fueled by oxygen cause the organic material to heat and decay into a useful fertiliser and soil conditioner. Epstein and Williams[30] describe how although many attempts have been made to start composting operations on a community-wide scale, it has generally proved difficult to persuade people to use the resultant material in the quantities in which it is being produced.

There are several essential requirements in the composting process which are now listed:

(1) the product needs to be kept at the optimum moisture content, by adding water or sewage sludge

(2) there must be sufficient oxygen to allow the micro-organisms responsible for the degradation of organic substances to survive
(3) the mass of product must be effectively exposed to the thermophilic phase of fermentation and the waste must be effectively pulverised, screened and homogenised
(4) the compost requires adequate refining after treatment to provide an acceptable appearance to assist in the marketing of the product
(5) the equipment must be reliable and relatively simple in both design and operation.[31]

Weber and Meyer[32] have emphasised that the demand for organic substances is growing worldwide, as problems are encountered even with good soils because of their humus impoverishment resulting from chemical-fertiliser farming. As the demand for suitable grade composts increases, so will the requirements relating to toxic substances control. The prospects for the future of composting are reasonably optimistic, provided the ever stricter regulations concerning environmental pollution by harmful substances can be met.

Ambrose[33] has described how compost is customarily applied to land at about 40 t/ha, between harvesting one crop and sowing the next and ploughing it in. It can also be used as a mulch to assist moisture retention and inhibit weeds, when it is not ploughed in until after the harvest. Thus cropping cycles often determine the time for compost application, making the demand for the product a seasonal one. This can result in the need for a large storage area at the composting plant.

Another use for compost is as tip cover as applied at the Chai Wan plant in Hong Kong, as it offers a 4:1 reduction in volume, with consequent savings in transportation and landfill space. In this case the waste is retained in enclosed fermentation chambers, where the organic content is converted into a hygienically safe and inoffensive compost.

Composting Plant at Singapore

This plant has been used as a case study as it effectively provides a high quality compost from solid waste. The flow chart for the compost production process is shown in figure 5.13, commencing with the sorting of bulky and non-combustible waste followed by the homogenising of the waste in a Dano-biostabiliser, which consists of a large diameter horizontal drum manufactured by Dano, as illustrated in Figure 5.14. It is not necessary to pretreat waste prior to feeding into the drum as its continual rotation and the addition of moisture breaks down the refuse in its 3½ days passage through the unit. Partial grading of the compost can be carried out in the final section of the drum when it is provided with perforated plates and acts as a screen. The biostabiliser is sometimes referred to as a primary digester. An alternative form of

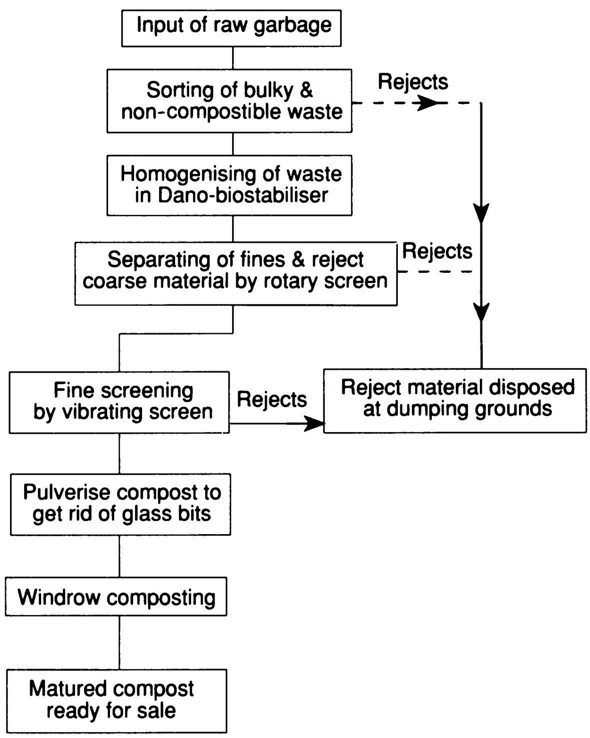


Figure 5.13 *Flow chart for compost production, Singapore (Source: Colex (Singapore) Pte Ltd)*

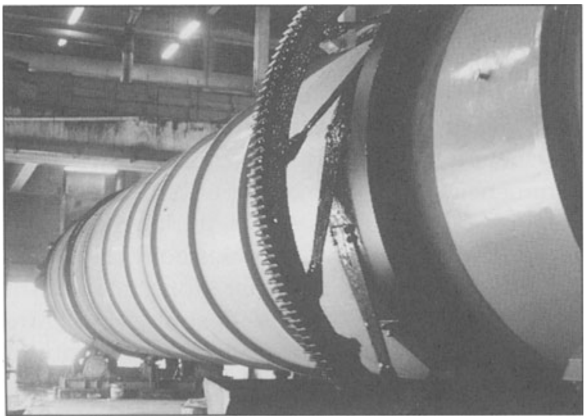


Figure 5.14 *Dano-stabiliser in composting plant, Singapore (Source: Dr Lee Sing Kong)*

digester is a large diameter tower usually consisting of six floors with each floor holding one day's supply of waste. In this case waste is agitated by horizontal rotating rabble arms and the supply of air and moisture into the tower can be controlled.

The separating of fines and reject coarse material is carried out in a rotary screen and further fine screening by a vibrating screen, with the reject material disposed of at dumping grounds. The glass is pulverised into dust, the plastic converted into blocks for reuse, and the metal separated for recycling. The compost from the plant is laid out in the open on a large concrete apron in heaped rows, described as windrows. The windrows can be turned with a mechanical shovel or a windrow turning machine to provide adequate aeration and a reduction in foul odours. The fine grey compost has excellent humus forming qualities and is mainly collected by lorries by the Parks Department and market gardeners. The total capacity of the plant is determined by the demand for the finished product. The plant produces an output of compost amounting to 40 to 50% of the total waste, a further one third consists of rejects and there is over 20% of water. The plant receives about 6% of Singapore's waste with the remainder either incinerated or disposed of as landfill.

Table 5.4 shows the results of two independent chemical analyses of compost from the Singapore plant, and illustrates the high organic content and the proportions of other useful components.

Table 5.4 *Chemical analyses of compost samples, Singapore*

	Colex-Apr	Colex-Mix
pH value (1:5)	7.50	7.68
Total Nitrogen (as N) %	1.96	2.29
Total Phosphorus (as P_2O_5) %	1.51	1.77
Total Potassium (as K_2O) %	0.49	1.01
Total Calcium (as Ca) %	2.21	1.95
Total Magnesium (as Mg) %	0.28	0.41
Total Sodium (as Na) %	0.30	0.24
Organic matter %	62.60	62.30
Moisture content %	38.97	47.95

(Source: Colex (Singapore) Pte Ltd).

Waste Composting in Developing Countries

Holmes[5] has described how the waste in many developing countries is ideal for conversion into organic fertiliser and how economic factors favour composting in those countries where high food production is of great importance. In the poorest countries, very simple screening and maturing can produce good results within the economic capabilities of the population. In the richer countries, composting is common in cities where the waste is wet and highly organic, normally using rotary drum and screening systems with windrow fermentation. This solution is particularly advantageous where the climate is arid and the soil is in serious need of organic supplements.

The World Health Organisation (WHO) has suggested the following conditions for successful waste composting:

1. suitability of the wastes
2. a market for the product within 25 km of the city
3. the support of the agricultural authorities, particularly the Ministry of Agriculture
4. a price for the product which is acceptable to most farmers
5. a net disposal cost (plant costs less income from sales) which can be sustained by the local authority.

Holmes[5] found that these conditions can be met in many parts of the developing world.

Recycling

Recycling is becoming an increasingly important aspect of waste collection and disposal as some other alternatives become less attractive. For example, municipal waste incineration plants will face costly adaptations in the 1990s to satisfy the EC directive on the cleaning of incinerators to reduce foul emissions, and landfill sites are becoming more difficult to find and are likely to become prohibitively expensive. However, not all recycling projects of the past have been entirely successful in the UK, as for instance with waste paper collection where the low prices offered made the operation uneconomic. In 1989 it cost £300m to build a new paper mill and the industry needed reassuring that a constant supply could be maintained and that there would be an adequate market for its products. Recycling of materials depends on mass participation and a demand for recycled goods equal to supply, which did not exist in the early 1990s.

The greatest strides in recycling in the UK in the late 1980s centred around the reclamation of glass through bottle banks, which proved popular with the general public and reduced landfill space requirements. Scrap metal has long been a material in which an active market operates. For example, in 1989 the London Waste Regulation Authority (LWRA)[23] estimated that there were in London alone some 500 registered scrap dealers and possibly 300 who were unregistered. A magnetic extraction unit for the recovery of West Yorkshire's used steel cans for recycling was commissioned in 1990 at Huddersfield, at which it was planned to recover 35 million cans annually. At that time it was one of 25 locations in the UK magnetically extracting steel cans for recycling. The cans are then melted down to make new steel products. More attention needs to be paid to the separation and resmelting of aluminium cans as they require only 5% of the energy required to forge the product from its bauxite ore. It also makes environmental sense as aluminium mining ravages natural landscapes. It takes four tonnes of raw bauxite to produce one tonne of aluminium. In 1990 aluminium scrap was being imported into the UK, while most aluminium cans were being thrown away as waste. It was encouraging to find that British Alcan were planning a £25m plant at Warrington in 1990 which could melt down 50 000 t of used aluminium cans annually.

Recycled plastics can be reused in various ways, including the production of stakes and fencing posts, fabric conditioner bottles and black plastic bin bags. However, in 1989 in the UK recycled plastics production was restricted to 10% polythene film and 7% polypropylene, with no figures available for polystyrene. The British Plastics Federation believe that the recycling of domestic plastic waste can be economically viable. Another method of reusing plastics is to burn them in waste incineration plants as a source of heat in the production of energy, as carried out at the Edmonton plant described earlier in the chapter. More building debris could be put to much more fruitful uses than merely disposing of it by dumping, in a similar way to the reuse of pulverised fuel ash (PFA) from power stations in bricks, concrete blocks, grout, soil stabilisation, and a variety of fillers and binders.

Rainer[6] has postulated that if most of the paper products were collected separately at source, 50% of the waste management problem would be removed, and at least another 10% with the recycling of glass and cans. If source separation could be operated at local level and industry cooperated in the use of recycled materials, solid waste disposal problems would be drastically reduced. However he had to admit that in the United States raw materials were still too inexpensive in 1990 to make recycling generally acceptable. The United States recycled 25% of paper and 7% of glass, whereas by comparison Japan recycled 50% of paper and 43% of glass, because of the limitations on natural resources and landfill areas.[34]

In the UK, the government issued a white paper 'This Common Inheritance' in 1990, in which it set a target to recycle 50% of domestic waste by 2000. Friends of the Earth estimated that only 2% of British domestic waste was recycled in 1989 so that substantial progress would have to be made in the 1990s in both reducing the quantity of waste and increasing the proportion that is recycled if this ambitious target is to be met. The Association of Metropolitan Authorities (AMA) doubted whether this could realistically be achieved and considered that no more than 20% could be recycled on a cost effective basis, despite the incentives and encouragement to be offered by the government.

Holmes[5] has described how recycling is carried out to a significant extent in the poorer parts of the developing world, in the absence of any national waste disposal plan. Scavengers and beggars perform the task aided by the communal storage of waste awaiting collection, and contained in a variety of bins, oil drums, concrete drain pipes and purpose-built ground drums, which provide an excellent opportunity for hand-sorting and recovery. Many waste materials have several life uses, and the more developed countries, facing diminishing reserves of metals and fossil fuels, would be wise to positively encourage more recycling.

Table 5.5 shows cost comparisons and ranges of different waste disposal methods.

Hazardous Wastes

Introduction

Hazardous or special wastes came under the Control of Pollution (Special Waste) Regulations 1980, which were under review in 1990. Although the movement of special wastes from the point of production to the place of disposal is controlled, it was still a matter of concern that other less toxic but still hazardous wastes could only be controlled by site licences. Kermode and Wells[3] have

Table 5.5 *Range of waste disposal operating costs in the UK in 1990*

Method/treatment	Cost of waste disposed £/t	Comments
Landfill – direct	5–15	Higher costs for difficult sites requiring special protective measures
Road transfer	9–12	Operation of transfer station and haulage to landfill only
Rail transfer	13–20	Operation of transfer station and haulage to landfill only
Barge transfer	15–18	Operation of transfer station and haulage to landfull only
Bailing (medium density wired)	6–12	Bailing and haulage to landfill only (high density baling and haulage costs up to £15/t)
Incineration – direct	12–35	Mass incineration without energy recovery; higher costs relate to new equipment
Incineration with energy recovery	10–25	Net cost with income; higher costs relate to new equipment
Composting	15–20	No operation plants in UK
Waste derived fuel	13–20	Net of sale proceeds
Hazardous wastes		
Landfill	10–50	Site and waste type specific
Treatment	100–3000	Simple incineration to high temperature incineration and special treatment

Source: Kermode and Wells[3]

rightly emphasised the need for the registration and control of hazardous waste handlers, as once these wastes have been deposited, irreversible damage may have been caused to the environment. It cannot be overstressed that hazardous wastes can cause serious pollution, damage to health or even death unless proper measures are taken for their transport and disposal.

Within the UK the disposal of hazardous wastes is mainly carried out by individual companies for their own waste products or by specialist waste disposal contractors offering a service. The public sector is not involved to any great extent although some incineration units may handle small quantities of materials such as clinical waste. Greenpeace claimed that in 1989 Britain imported over 80 000 t of toxic waste for disposal, mainly from other European countries and the United States.

Rechem[35] have described how industrial societies produce a wide range of chemical products and by-products that require safe means of destruction. They arise in various forms such as waste solvents; solids – as in certain resins; or as liquids in containers like polychlorinated biphenyls (PCBs) which are used in electrical capacitators and transformers. However, the government plans to phase out and destroy all identifiable PCBs by 1999.

Methods of Disposal

The principal methods of disposal are landfill, sea dumping, solidification, chemical treatment and incineration. In selecting the means of disposal, the main criterion must be the relative likelihood of the escape of dangerous chemicals into the environment, which could lead to damage to flora and fauna, the accumulation of unacceptable chemicals in the food-chain, and/or seepage into the water table. Each of these processes is now examined.

Landfill This is the cheapest option and comprises co-disposal with other essentially inert wastes at landfill sites, and is used for both solid and liquid hazardous wastes, although in the latter case it is customary to excavate trenches or lagoons in the landfill surface to receive the liquid waste. In theory, within the complex mechanisms of biodegradation of the waste, hazardous components may be broken down, immobilised, or dispersed and be released from the site. Unlike some other developed countries, the UK supports the use of landfill for many categories of hazardous waste, but problems can arise if the sites are not managed effectively and/or the range of wastes fall outside those which are officially accepted, pointing to the need for stricter controls on landfill sites.

Sea Dumping It was thought in the past that the oceans and seas were capable of receiving and making safe the wastes deposited in them. This theory has been proved unsound as was evidenced at Minamata Bay in Japan, where the discharge of mercury was absorbed by the fish which formed the staple diet of the inhabitants, and this resulted in extensive brain damage and terrible physical deformities, particularly among young children. The government planned to stop the dumping of industrial wastes in the sea by 1992.

Solidification This is a method whereby suitable wastes may be chemically treated and solidified, and so become inert and insoluble and thereby avoid leaching toxic constituents into groundwater. The more common solidification processes are cement based, lime based, thermoplastic, organic polymerisation, encapsulation, and glassification.[3]

Chemical Treatment A variety of chemical processes are used to change the characteristics of a hazardous waste in order to render it acceptable for landfill disposal.

Incineration Official scientific evidence suggests that high temperature incineration offers the best practicable environmental option for dealing with most hazardous wastes. Even the most dangerous substances, such as PCBs, when burnt for a sufficiently long period and at a high enough temperature are broken down into harmless by-products. Rechem operates two such plants, located at Fawley, Hampshire and Pontypool, South Wales, and the latter plant is now described and illustrated.

Rechem Pontypool Plant

In 1988, this plant had a total waste throughput of 27 000 t, comprising a range of solids, liquids and sludges, and contaminated plant and equipment, all of which were or contained chemicals suitable for thermal destructive purposes, and including wastes from other countries who do not possess suitable plant. The Pontypool Plant is illustrated in Figure 5.15.

The incinerator system is based on a very large and very hot furnace into which solid wastes are fed and liquid wastes pumped. Liquid fuel is also pumped into and burnt in the first chamber and a temperature of 1100 to 1200° C is maintained. The whole operation is computer controlled and constantly monitored, so that if the temperature were to fall slightly, more fuel would be automatically injected causing the temperature to rise. All liquid waste input ceases immediately an emergency shut-down occurs. Sufficient heat is supplied by an emergency afterburner system to complete the burn-out of any solid materials remaining on the hearth.[35]

The gases that are formed in the incinerator pass through a series of chambers, in the last of which more fuel is burnt to ensure complete combustion. A quench tower cools the gases, a caustic soda tower neutralises them, and electrostatic precipitators take out a high proportion of the particles. Burnt out solid packages, like the outer casings of transformers, are left on a refractory hearth for at least one hour before removal and laboratory testing to ensure that their decontamination is complete.[35]

Inorganic wastes, such as acids, alkalis and cyanides are subjected to appropriate chemical processes to render them safe for disposal. The solids are precipitated from the effluent and the resulting neutralised liquid is discharged as trade effluent complying with the conditions of the water authority. The solid is transported as filter cake to licensed landfill sites.

Samples are monitored from the reception, preblending and processing stages, to final disposal of the inert residues. In addition regular independent monitoring is carried out by HMIP and other official bodies concerned with maintaining

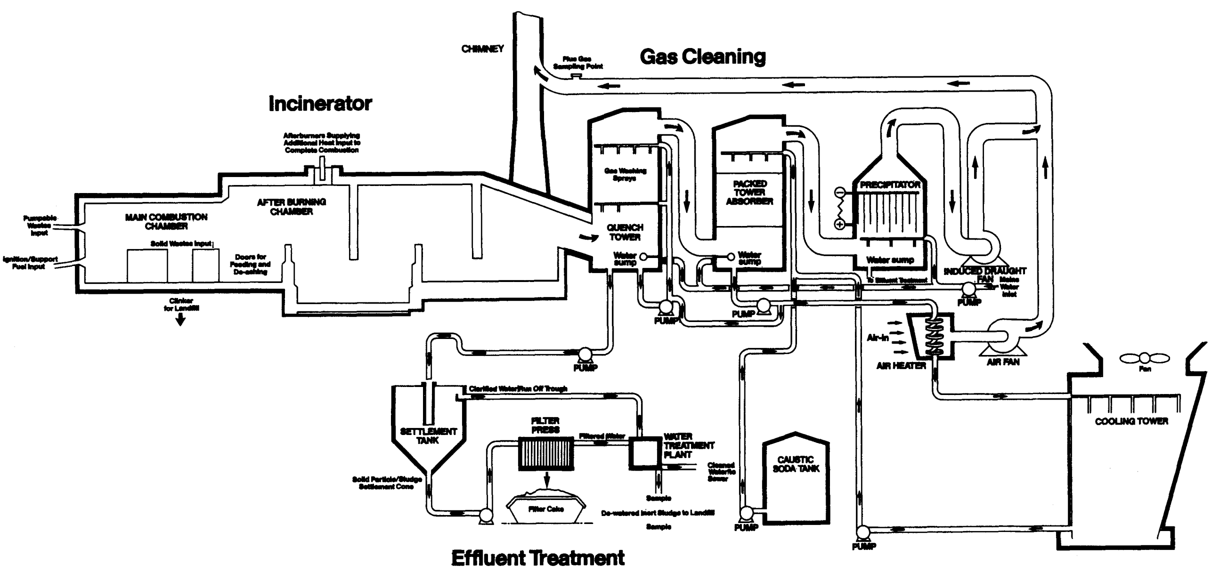


Figure 5.15 *Rechem Pontypool Plant (Source: Rechem)*

rigorous standards of disposal efficiency and environmental protection. Rechem also keep full records of inputs, incineration temperatures and other operational conditions.[35]

Radioactive Wastes

General Background

Radioactive wastes are and have been used for many years in the generation of electricity and in industry, medicine, research and defence. The resultant wastes can be dealt with by disposal or long term storage, and in the UK the government formulates the appropriate strategy, entailing strict supervision and high standards of safety. For high level heat generating wastes this entails storage for at least 50 years to allow them to cool, while low level and intermediate level wastes should be disposed of as soon as possible. NIREX was charged with the task of designing, locating and developing a single deep underground disposal centre for both low and intermediate wastes to be commissioned soon after year 2000 and to operate for about 50 years, paying full regard to safety, technical feasibility, transport and public acceptability, and subject to a full public inquiry.

The main management methods rely upon keeping radioactive wastes away from people until its energy naturally fades with time. This can be achieved by using steel drums and/or concrete to absorb radiation and to immobilise waste into solid blocks. These sealed blocks can then be moved to a national disposal centre located deep within protective rocks.[36]

Nature of Radioactive Wastes

Low level waste consists mainly of rubbish such as discarded protective clothing, used wrapping materials and worn-out or damaged plant and equipment. Since 1959 most of it has been taken to a site operated by British Nuclear Fuels (BNF) at Drigg in Cumberland.

Intermediate level waste is about a thousand times more radioactive than the low level waste. It consists of metal fuel cans which originally contained uranium fuel for nuclear power stations, reactor metalwork, chemical process residues, ion exchange resins and filters. In 1990 this was stored at producing sites. It requires shielding in order to protect people from exposure during storage, transport and disposal. On retrieval from storage, it will be 'fixed' in a form of concrete and packaged in steel or concrete containers for transport to a disposal centre.

High level waste is concentrated waste that results from the reprocessing of 'spent' nuclear fuel. It contains more than 95% of the total radioactivity which is created by the nuclear industry's waste products and needs artificial cooling because of the heat it generates. The producers of high-level waste store it for several decades to allow the radioactivity to decay before disposal is considered.

Disposal

The comparatively small volumes of radioactive waste means that only one national disposal centre will be required which will operate for half a century or more. Detailed records will be maintained and designs adopted to make it possible to recover the waste, if this were deemed necessary. It is important that wastes are safely sealed in underground caverns or tunnels as soon as possible in order to isolate them from damp air and people.[36]

The Government has laid down stringent safety targets for the selection, design, construction and operation of a disposal centre for radioactive waste.[37] In searching for sites the International Atomic Energy Agency (IAEA) suggested a three stage process, encompassing a national survey and evaluation, site identification, and site confirmation.[38] In looking for a site, safety considerations must be paramount and a deep disposal centre is best placed in a formation with very little groundwater movement. Following these guidelines, Nirex[39] identified the following five potentially suitable environments.

1. hardrocks in low relief terrain
2. small islands
3. seaward dipping and offshore sediments
4. inland basins comprising deep basins of mixed sedimentary rocks
5. low permeability basement rocks under sedimentary cover.

Packaging and Transport

Low level wastes (LLW) contain such small quantities of radioactive material that they can be packaged in normal steel drums and containers. The drums can be transported in a reusable freight container, and conventional handling equipment can be used for handling both the drums and the freight container. The drummed wastes will be compressed before disposal, thus conserving space in the repository. The compressed drums will be stacked in a steel box, and any empty spaces filled with cement grout. Items too large for 200 litre drums will be packaged in a steel box, and the box will have a usable volume of approximately 3 m^3 with any empty spaces filled with cement grout. In the future the packaging of large items of low level decommissioning wastes from dismantled power stations will require larger packaging boxes, possibly of steel with a volume of about 12 m^3.[40]

Intermediate level wastes (ILW) are mainly packaged in special 500 litre steel drums, with the wastes loaded into the drum and immobilised using cement or some other suitable material. Items of waste which will not conveniently fit into this sized drum will be packaged in a 3 m^3 steel box and immobilised using cement. The drums and boxes will be transported in a reusable shielded transport container, which will carry four 500 litre drums or one 3 m^3 box. Items of intermediate level waste from the decommissioning of nuclear facilities which are too large for packaging in the 3 m^3 box will be conveyed in a box having an approximate usable volume of 12 m^3, which will be disposable and have concrete walls to provide radiation shielding.[40]

Transport to a Deep Repository The heavier packages such as the large LLW and ILW decommissioning boxes must be transported by either rail or sea, since frequent road transport of such very heavy packages over long distances would be undesirable. Road transport is an option for the lighter packages. The transport modes selected will be largely influenced by the siting of the repository. Sea transport will be used to an island or offshore structure and may be used to a coastal repository. If rail transport were to be used for all waste traffic, Nitrex have estimated that about 15 train loads would be required each week, reducing to 10 if the lighter packages were sent by road. The resulting increase in road traffic would amount to less than 100 lorry deliveries weekly.[40]

References

1. R. Khan, T. Husain, H.U. Khan, S.M. Khan & A. Hoda. Municipal solid waste management – a case study. *Mun. Engr, 1990, 7, Apr., 109–116*
2. J.J. Field. Refuse collection. *Mun. Engr, 1988, 5, Dec., 329–37*
3. B. Kermode & C. Wells. Waste disposal options – a review. *Mun. Engr, 1990, 7, June, 147–61*
4. SERPLAN. *Guidelines for waste disposal planning in the South East.* SERPLAN (1987)
5. J.R. Holmes. Waste management decisions in developing countries. *Chart. Mun. Engr, 109, Jan., 1982, 11–16*
6. G. Rainer. *Understanding Infrastructure.* Wiley (1990)
7. DOE. *Refuse storage and collection.* HMSO (1967)
8. Audit Commission. *Securing further improvements in refuse collection.* HMSO (1984)
9. D. Moir & P.S. Winterton. Waste collection and disposal in the East Midlands. *ICE, East Midlands Association Year Book, 1989*
10. Chartered Institute of Public Finance and Accountancy. *Waste collection statistics* (1988)
11. L. Chrichton. Wheeled bins: implications of a new approach to refuse collection round planning. *Wastes Management, 1987, Dec., 752–3*
12. J.M. Stoke. The change to 17 tonne GVW – its effect upon open back and bin lift vehicles. *Wastes Management, 1987, Nov., 707–12*
13. H. M. Steels. Household waste reception: development of the service in Cheshire. *Mun. Engr, 1988, 5, June, 127–35*

14. F.A. Sims. An account of waste management developments in West Yorkshire. *Mun. Engr, 1984, 1, Aug., 91–7*
15. Lancashire County Council. *Blackpool Waste Transfer Station* (1984)
16. GLC. *Solid Waste by Road: Newham Transfer Station* (1981)
17. GLC. *Western Riverside Transfer Station* (undated)
18. GLC. *Solid Wastes by Rail: Hendon Rail Transfer Station* (1979)
19. EEC. *Directive on environmental assessment*. EEC/85/337 (1985)
20. DOE. *The control of landfill gas*. Paper 27. HMSO (1988)
21. J.F. Crawford & P.G. Smith. *Landfill Technology*. Butterworths (1985)
22. GLC. *The disposal of London's waste by landfill* (1985)
23. LWRA. *Annual Report 1988/89* (1990)
24. DOE Air Quality Division. *Air pollution control in Great Britain: works proposed to be scheduled for prior authorisation*. HMSO (1988)
25. EEC. *Directive on new municipal incineration plants*. 89/369. EEC, Brussels (1989)
26. EEC. *Directive on existing municipal incineration plants*. 84/492. EEC, Brussels (1989)
27. NLWA. *Edmonton Solid Waste Incineration Plant* (undated)
28. Waste Management Advisory Council: Waste as fuel working party. *Energy from Waste*. HMSO (1979)
29. Isle of Wight County Council. *The Isle of Wight Waste Derived Fuel Plant* (1989)
30. E. Epstein & T. Williams. Solid waste composting gains credence. *Solid Waste and Power, June 1988*
31. J. P. Levasseur & W. B. Saul. Composting of urban solid waste. ICE. *Reuse of Solid Waste*. Telford (1982)
32. H. Weber & M. Meyer. Utilization of compost in agriculture – experiences in Europe and especially in the Middle East. *Reuse of Solid Waste*. Telford (1982)
33. J.A. Ambrose. Composting. *Reuse of Solid Waste*. Telford (1982)
34. A. Herschkowitz. Garbage management in Japan: Leading the way. *Inform*, New York (1987)
35. Rechem. *High temperature incineration* (undated)
36. UK Nirex Ltd. *Going Forward* (1989)
37. DOE. *Disposal Facilities on Land for Low and Intermediate Level Radioactive Wastes: Principles for the protection of the human environment*. HMSO (1985)
38. IAEA. Disposal of low and intermediate level solid radioactive wastes in rock cavities. *Safety Series No. 59* (1983)
39. N.A. Chapman, T.J. McEwen & H. Beale. Geological environments for deep disposal of intermediate level wastes in the United Kingdom. *IAEA-SM-289/37* (March 1986)
40. UK Nirex Ltd. *The packaging and transport of radioactive wastes* (1988)

6

Water Engineering

Water Supply Management

Statutory Water Controls in England and Wales

It is vital that water resources and supplies are well managed and safeguarded against pollution. The Water Act 1989 provided for the protection of the environment, changed the role of the water industry and enabled the Secretary of State to set new statutory standards with a view to improving the quality of the water environment in England and Wales. The principal changes introduced by the Act were as follows:

(1) The setting up of the National Rivers Authority (NRA) as an independent watchdog to improve the standards of rivers, lakes and coastal waters and to keep them clean and suitable for water sources and recreation, by controlling pollution from the water authorities, in the implementation of their sewage purification functions, as well as other industries and agriculture. The river management functions of the NRA include pollution control, land drainage, water resource management, flood defence, fisheries and navigation. In addition, apart from the provisions of the Act, the water authorities are subject to control by Her Majesty's Inspectorate of Pollution (HMIP).

(2) The establishment of an independent Drinking Water Inspectorate to support the Secretary of State in seeking to ensure that the strict legal standards for drinking water quality are met, some of which go beyond those required by the EC directive on drinking water. It also imposes new duties and powers on local authorities relating to the sufficiency and wholesomeness of water supplied by the water companies. For the first time the Act made it a specific criminal offence to supply water which is unfit for human consumption.

(3) The separation of the work undertaken by the ten water authorities in England and Wales to treat and supply water and to collect and dispose of sewage from their river management duties which passed to the NRA. About three quarters of the population of England and Wales are supplied with water by the 10 water and sewage companies and the remainder by 29 statutory water companies. Together the water industry supplies drinking water to over 99% of the population of England and Wales.

(4) The protection of the customers' interests by placing a limit on increases in prices and by creating a Director General of Water Services, whose main aim is to ensure that the companies carry out their tasks without overcharging consumers and provide good service. Ten customer service committees, representing all the major interested parties, were set up to investigate complaints about the companies. Each water company must have a code of practice showing the service it offers and its charges to domestic customers. The companies will also have to measure their performance and show how far they have met previously set targets, and the Director General can intervene if he is not satisfied. Domestic customers are entitled to claim a £5 cash payment or credit for each occasion on which certain standards are not met.[1]

Privatisation

In 1989 the new water holding companies took over the water supply and sewerage services of the water authorities of England and Wales. They consist of Anglian, Northumbrian, North West, Severn Trent, Southern, South West, Thames, Welsh, Wessex and Yorkshire. The public were given the opportunity to apply for shares in the new water holding companies, who concentrate on the provision of water supply and sewage disposal services but can also diversify into other activities. They are free to borrow money in the private capital market and thus have the incentive to cut costs and improve services, although they were all faced with large capital investment programmes. The financial markets are able to compare the track records of individual companies competing for capital, and the companies are able to compete in the wider provision of commercial services, both in the UK and overseas.

Land Conservation and Recreation

About one third of the estimated 172 000 ha of land and water owned by the ten water companies is in National Parks or Areas of Outstanding Natural Beauty, and conservation is important to preserve the national heritage and safeguard and enhance the recreational uses. In 1987/88 the former water authorities invested more than £10m in environmental services, including fisheries, recreation and other amenities.

The Water Act 1989, so far as is consistent with their primary functions, requires the water and sewage companies and the NRA to:

(1) further the conservation and enhancement of natural beauty; and
(2) make their land and waters available for recreation.

A code of practice issued by DOE in 1989 gave guidance on the conservation, access and recreation duties of the companies and the NRA. If water industry land is sold, any proposed development is subject to planning controls and, where the land is in a National Park, the Norfolk Broads, an Area of Outstanding Natural Beauty or a Site of Special Scientific Interest, the Act enables the Secretary of State to impose special conditions on disposal. For example, management agreements or covenants may be used to protect the land, or it may be required to be offered for sale first to a conservation body.[1]

Severn Trent Water

Severn Trent Water has been selected for study as a large progressive water holding company, constituting the second largest private water company in the UK and the fourth largest in the world. It provides water services for people living in an area stretching from the Humber to the Bristol Channel and from Wales to East Anglia, occupying an area of 21 600 km^2, and encompassing the major parts of 10 counties and parts of others on its boundaries. In 1990 it supplied 1950 megalitres of water daily to more than 6¾ million people occupying 2.9m properties, and treated the wastes of nearly 8 million people in 3.5m properties. In 1990 Severn Trent supplied water through 38 000 km of water mains and operated 205 treatment works and 731 service reservoirs. In addition, it operated 1062 sewage treatment works and 38 280 km of sewers. The company employed about 8000 people. Like any other water company, Severn Trent has to ensure that it does not pollute watercourses and it has to buy the 'raw' water it needs from the NRA. It co-operates with the Water Research Centre (WRc) which is the national centre for water research in the UK.

In 1989/90 the company had a turnover of £544m and investment expenditure of £262m. Its investment programme over the 10 year period from 1989 is planned at £4080m. The headquarters of Severn Trent is in Birmingham and the region is divided into 15 operational districts which manage water supply and/or sewage treatment in their own areas, supported by administrative and specialist services. Each division has two emergency centres manned around the clock on every day of the year.

Severn Trent Industries is a separate subsidiary of Severn Trent and has taken the initiative in diversifying into a range of marketing areas embracing: managerial and operational expertise in both developed and emerging countries; three well equiped and automated laboratories; operation of waste disposal on landfill sites; and provision of process plant design and construction services.

Water Consumption

Twort *et al.*[2] have effectively divided water consumption into five broad categories:

(1) *Domestic* used in drinking, cooking, ablution, sanitation, house cleaning, car washing, clothes washing, garden watering and fountains.
(2) *Trade* subdivided into industrial (factories, industries, power stations and docks); commercial (shops, offices, restaurants, small trades and allied uses); institutional (schools, hospitals, higher educational establishments, government offices).
(3) *Agricultural* (crops, livestock, horticulture, greenhouses, dairies and farmsteads).
(4) *Public* (street watering, public parks, sewer flushing and fire fighting).
(5) *Losses* (consumer wastage, distribution losses, metering and other losses).

Published figures of water consumption vary widely, often because of differing standards of supply. For example, losses may vary from 5 to 50% of the total supply, meters may not register correctly, consumers may waste differing proportions of water, and there can be a number of other causes. The proportion of trade consumption also shows wide variations irrespective of the size of population served, largely depending on the amount and type of industry.

Twort *et al.*[2] examined the consumption figures for middle class housing in a variety of situations in the UK and overseas, and the average centred around 115 lcd, while Rofe[3] arrived at an average domestic consumption of 200 lcd in England and Wales in 1976–78. By contrast Severn Trent estimated an average domestic consumption of 125 lcd in its area in 1990, made up of cooking, drinking, ablutions and washing up: 36%; toilet flushing: 32%; baths and showers: 17%; washing machines: 12%; and other uses: 3%.[4]

Procedures in Developing Countries

The United Nations International Drinking Water and Sanitation Decade 1981–90 set as its goal the provision of safe drinking water and sanitation for all the world's people, more than two thirds of whom live in rural areas. This is a most worthy objective and is sorely needed, but the author from his travels in India, Thailand and several African countries doubted whether such an ambitious programme was capable of fulfilment. Pickford and Speed[5] have aptly described how most Third World countries suffer crippling shortages of foreign exchange which restrict the import of even basic essentials. The consequent shortages demand simple, hard wearing low technology solutions for rural water supply. Also, community involvement is essential for successful implementation and maintenance.

Engineers embarking on water engineering projects in underdeveloped countries need to discard any preconceived ideas about people's attitudes and aspirations. For instance, rural dwellers are unlikely to be aware of the connection between water and health. Motivation comes principally from the desire to cease carrying water for long distances and to overcome the problems of empty wells in dry seasons.[5]

The components of *demand* are population and per capita consumption. In one West African country it was found that an occupancy rate of 14 or 15 people per dwelling was quite common. In addition, account must also be taken of seasonal variations in population as, for instance, fisherman may migrate between coastal villages at certain times and elsewhere villagers may move with their cattle to seasonal grazing or may migrate temporarily to rice growing areas.[5]

The amount of water used by a household in East Africa[6] has been shown to depend on whether it has piped water or, if not, on the distance that water has to be carried. Villagers with access to standpipes are estimated to use 10–40 lcd and those using wells slightly less. A figure of 50 lcd is considered to be a reasonable target for schemes where supply is by standpipe.

Pickford and Speed[5] have emphasised that it is essential to select *sources* which are inherently safe and to ensure that, wherever possible, schemes are independent of power driven plant. Hence the optimum sources are groundwater, and adequately protected springs and streams.

Resources generally fall into the two categories of external finance from a donor and village based resources. External funding is often limited to the provision of project engineering, materials and supervision, and all manual labour is supplied by the beneficiaries. In order to mobilise village resources the community must be involved. Life expectancies of 20 years for pipe-based schemes are accepted by most funding organisations.[5]

The *climate* can have important consequences and must be considered. For instance, intensities of 200 mm in 24 hours are not unusual in parts of West Africa and annual rainfall often exceeds 5000 mm. Thus dry gullies can become raging torrents in which large boulders are displaced and groundwater levels rise to surface level or above.

The selection of *materials* is another major consideration, as it is unlikely that pipes, valves and even cement will be home produced, and so will have to be imported, involving heavy shipping costs and use of scarce foreign currency. Materials must be light and sufficiently robust to withstand considerable manhandling. Hence, galvanised mild steel pipes are frequently selected because of their ease of handling, strength and moderate transporting cost, but they have limited life because of corrosion.[5]

The lack of mechanical excavating equipment means that pipes are normally laid on the ground where there is rock or laterite hard pan. It is not feasible to excavate trenches using basic hand tools except for lengths of a few metres. Pipes laid on the surface require anchoring and are subject to various hazards.

Village water committees can be established or responsibility may be accepted by an existing village hierarchy. One or two villagers can be given the tasks of maintenance and repair, but the donor or supervising organisation must provide adequate training. A reasonable stock of spares must also be handed over with the works.[5]

Radhakrishnan[6] has described a number of simple water supply processes used in rural Tanzania and other developing countries. They include the wood lever system incorporating a wooden lever with a rope and bucket pivoted lifting device over a shallow well; step well with brick or concrete walls and a rope drawing method; tube wells with a concrete platform and bailer; bucket pump; animal-powered gear using two oxen, two buckets and rope and pulley; flywheel connected with mono pump; and windmills. All these methods use local materials and local labour for construction and maintenance at minimum cost.

Sources of Supply

All water supply is essentially derived from rain, hail or snow, the three main forms of precipitation. Some of the rain falling on the ground flows into streams and rivers, into natural ponds and lakes, or into man-made impounding reservoirs. These are the main sources of surface waters.

Taking Severn Trent Water as an example, although annual rainfall for the company's area averages 777 mm, allowing for annual variations, there are also wide variations throughout the company's catchment area. In the Welsh uplands it is 2400 mm, while in the Vale of Evesham and parts of Nottinghamshire it is only 600 mm. After allowing around 450 mm for evaporation it is evident that large reservoirs are required to store water in upland areas.

Some of the rain soaks into the ground until it reaches impervious rocks. For example, much of the English Midlands lies on bunter and keuper sandstones which are porous or water-bearing, known as aquifers, and act as underground sources of water. The water may then be obtained by sinking boreholes or wells or it may emerge on hillsides in the form of springs. These are the main sources of groundwaters.

Because of the fluctuating demand for water, the capacity of water resources and supply works have to be large enough to meet demand appreciably higher than the annual average. In fact Severn Trent Water's reservoirs and resource systems are sufficient to meet demands during droughts of up to 18 months' duration. The company's treatment works and major treated storage meet peak weekly demands and the local service reservoirs even out hourly demand fluctuations.

Supply Sources of Severn Trent Water

It is considered helpful to examine the water sources of a large UK water holding company covering a wide variety of sources. Later in the chapter, reservoirs, wells and boreholes, and river intakes will be considered in more detail.

Surface Sources Two thirds of Severn Trent's water comes from surface water sources – reservoirs and rivers. The run-off from the winter rains are collected off the gathering grounds of impounding reservoirs in the hills and mountains, such as the Derwent Valley reservoirs in Derbyshire. The company also pumps water directly from the cleanest rivers, such as the Severn, Dove, Derwent and Leam. Some reservoirs are used to top up river flows during summer months, to permit water to be pumped from the river without the danger of it becoming too low or even drying up. Some reservoirs, such as Draycote in Warwickshire, are filled wholly or partly by pumping from rivers. Water has to be pumped from the reservoirs to treatment works and some aqueducts are over 100 km long. Riverside reservoirs with sufficient capacity to hold several days supply, in case the river is accidentally polluted, were constructed at Trimpley, Worcestershire, and Church Wilne, Derbyshire. The main reservoirs and rivers are shown in Figure 6.1.

Underground Sources Around one third of Severn Trent's water supplies are from underground sources, where water passing through the soil reaches an impermeable or water-sealing layer, such as clay, through which it cannot pass. Some rocks termed aquifers hold large quantities of water, and may be dense like sandstone, or have natural cracks or fissures along which water can flow freely, such as chalk. Much of the Midlands lies on bunter and keuper sandstones which are porous and form major sources of water. Water passing through rocks is purified naturally by filtration and normally only requires chlorinating to make it suitable for drinking.[7]

Impounding reservoirs such as the Elan Valley and Derwent Valley reservoirs are filled by natural run-off from the gathering grounds. Furthermore, the water usually flows to the treatment works by gravity, resulting in low operating costs. For example, water from the Elan Valley reservoirs in Wales, of which one is illustrated in Plate 14, flows 116 km along an aqueduct to Birmingham by gravity. Upland water is generally soft but these sources are likely to become vulnerable in times of drought. They contribute about 33% of Severn Trent's supplies.[7]

Pumped storage reservoirs are filled by pumping from nearby rivers. Fluctuations in the river water quality are evened out by storage before treatment. The lowland rivers tend to produce a hard water but are more reliable than impounding reservoirs, and they contribute some 12% of Severn Trent's supplies.

Supported river abstractions refer to water drawn from rivers which are supported by regulating reservoirs at times of low flow. Pumping and treatment costs are relatively high since water quality varies and treatment processes may have to cope with a wide range of conditions, including accidental pollution. These sources have good reliability because of the regulating reservoirs and the River Severn is the principal example. These sources contribute about 19% of Severn Trent's supplies.[7]

Triassic sandstone groundwater is drawn from sandstone aquifers which are recharged by infiltration and percolation. Costs are moderately low because of the negligible chemical costs resulting from the customary good quality of these sources, although there is a substantial pumping element. Reliability is very good because of the very large volumes of storage being tapped and they contribute about 30% of the company's supplies.[7]

Figure 6.1 *Severn Trent Water, main water resources (Source: Severn Trent Water)*

Small local sources and *small imports from neighbouring authorities* generally serve isolated areas from impoundments, springs, adits, intakes on small unsupported rivers, and groundwater – other than from the main triassic units. Costs are high because of the fragmented nature of sources and the generally poorer quality water. They usually offer only limited reliability because of the dependence on shallow water tables or small impoundments, and contribute only about 6% of Severn Trent's supplies.[7]

Linking of water sources and distribution systems has many benefits, because the severity of drought often varies from place to place, and supplies from one area can then be used to augment those of another. Many links connect the resources and supply systems, making a complex grid of gravity aqueducts, pumped raw water mains and treated water mains. A significant link is the link main from Coventry to Leicester, whereby either city can be supplied in part from the major resources of the River Severn and the Derwent Valley.[7]

Pollution of Water during Collection and Storage

Pollution can be divided into two broad categories, namely natural and man-made, and each of these are now briefly described.

Natural pollution is caused by rain absorbing dirt, dust and grease from the air, water flowing over the ground collecting mud, clay and decayed plant matter, and also bacteria derived from soil and vegetation. Also in the ground, water dissolves soluble salts from rocks while water containing carbon dioxide can dissolve carbonate rocks, such as chalk, to form bicarbonates.[8]

Man-made pollution may take the form of sewage or contamination resulting from farming, animal rearing, mining and other activities. Sewage introduces putrefying organic matter and, in particular, bacteria and other disease organisms. Good, clear water discourages disease while polluted water helps to spread it. Farming often causes soil, manure and organic debris to be washed into streams and rivers, while mining may result in harmful mineral contamination and the discharge of fine suspended matter. Chemical manufacturers may discharge toxic substances into waters which can cause taste and odour problems and destroy natural life in rivers.[8]

As a result, natural waters may possess one or more of the following undesirable characteristics:

Colour: caused by dissolved organic matter, such as from peaty land and mineral salts of iron or manganese.
Suspended matter: mineral and vegetable debris.
Turbidity: fine mineral or organic matter in suspension.
Disease germs.
Excessive hardness: particularly in groundwaters from boreholes or wells. Temporary hardness unlike permanent hardness can be removed by boiling.
Taste and odour: contamination by sewage, decayed vegetation or stagnant conditions caused by lack of oxygen in the water.
Harmful mineral content: absorbed from soil or introduced by industrial activities.[8]

Toxic algae caused problems to some water supplies in 1989 and 1990. NRA confirmed in 1990 that toxins from blue-green algae had killed dogs and sheep drinking from reservoirs and could harm people through tap water. Furthermore, there were toxic blooms in more than 400 lakes and ponds, many of which had warning notices displayed around them.

In 1989, Rutland Water – Europe's largest man-made reservoir – was plagued by toxic algae which were thought to have killed dogs and sheep in contact with the water. Anglian Water reassured the 700 000 consumers served by the 1240 ha reservoir that drinking water was safe, as the intake tower did not draw water from the algae affected edge of the lake, but banned leisure activities on the lake and told the public to keep away from the water. The blue-green algae multiplied in hot weather and calm conditions and bloomed, collecting along the shoreline, assisted by a reduction in the volume of water and consequent increase in phosphate concentration. Scientists also suspected that algae from the 1989 outbreak could have left spores on the bed of the 9 m deep lake, which could be reactivated by sunlight in a subsequent period of hot weather.

The steady increase in water borne phosphates since 1950, stemming mainly from sewage and farming, has caused more algae blooms, and greater concern as more people take up water sports. Common sources of phosphates include household washing powders and modern agricultural techniques.

One remedy is to install machinery in reservoirs, such as electric or wind-powered aerators, which agitate the water and prevent the algae forming, coupled with the application of phosphate strippers at sewage treatment works to cleanse the discharges on which the algae feed. In early 1990 Anglian Water were dosing sewage flows into Rutland Water with iron sulphate and were in the process of extending this treatment to all of its reservoirs. Iron sulphate reacts with phosphates in solution to produce a solid which sinks to the reservoir bed, away from the algae which feed on the surface. By contrast, Thames Water considered that their reservoirs were relatively free of risks of large outbreaks of algae because they were up to 25 m deep.

Reservoirs and Dams

Implementation of the Reservoirs Act 1975

In Great Britain the implementation of the Reservoirs Act 1975 has caused considerable attention to be paid to the safety of existing dams and embankments, in addition to new structures. The Act requires an inspection of the structure every ten years and that the owner appoints a Panel Engineer to provide continual supervision between the statutory inspections. Panels of qualified engineers for construction and supervision were assembled, and as from 1986 all owners of large reservoirs were obliged to conform to the Act's requirements. Extensive remedial or improvement work has been carried out on many larger older dams to prevent overtopping in severe floods and to give protection against wave surcharging.

Advances in flood estimation resulting from a better understanding of hydrological data affect the design of diversion structures and flood spillways. Similarly, the ICE[9] have pointed out how an understanding of seismic risks in many parts of the world demands more stringent design of structures to resist seismic effects. These and other considerations, such as the environmental impact of dams and reservoirs and the importance of safety of such structures, place heavy responsibilities on designers. Numerical modelling is often used in design and reduces reliance on physical models. Some advances have been made in finite element analysis techniques for the evaluation of stresses in fill dams following the Carsington Dam failure in 1984 and research is continuing on testing and controlling alkali-silica reaction in concrete dams.[9]

Types and General Requirements of Reservoirs

Reservoirs formed by an embankment, whether in whole or in part, can be classified as either:

(1) Offstream (or non-impounding), where the inflow is either pumped or diverted by gravity to the reservoir, or
(2) Impounding, where the reservoir is formed by a dam built across a natural watercourse, and the works generally require a spillway to allow the safe passage of flood water around or over the dam, as provided in the Clywedog Dam (mid-Wales), as shown in figure 6.2.

Apart from forming reservoirs by raising existing lakes or enclosing with artificial embankments, they may be formed with earth or rockfill dams or concrete dams, which can be of various

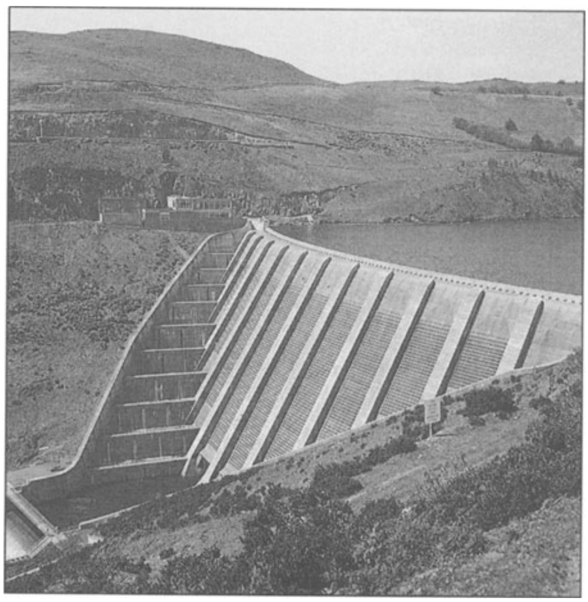


Figure 6.2 *Clywedog Dam (Source: Severn Trent Water)*

types, such as gravity, arch, multiple arch, cupola, buttress, reinforced or prestressed. In addition to the dam forming the reservoir, certain ancillary works are normally required, such as drawoff tower, overflow and diversion works.

General requirements or criteria can conveniently be considered under the following three broad heads:

(1) The engineering planning, design and construction of the works must ensure the reservoir's safety and suitability for its purpose.
(2) Economic factors usually require that the construction and operating costs shall be kept to an acceptable level.
(3) Environmental aspects related to both the natural and human environment must be considered at the outset, as there is often considerable environmental opposition to the provision of large reservoirs, as will be evidenced later in the chapter in connection with the damming of Queen's Valley, Jersey.

General Principles of Dam Design

Twort *et al.*[2] has listed the paramount conditions for satisfactory construction of a dam to be as follows:

(1) The valley sides of the reservoir must be sufficiently watertight up to the proposed top water level of the reservoir, and they must be stable under all conditions.
(2) Both the dam and its foundation must be sufficiently watertight to prevent dangerous or uneconomic leakage through or under the dam.
(3) The dam and its foundations must be strong enough to withstand all the forces to which they may be subjected.
(4) The dam and all its associated works must be durable to prevent premature failure or costly maintenance.
(5) Provision must be made to discharge all flood waters safely past the dam.
(6) Adequate facilities must be provided for drawing off water from the reservoir for supply purposes.

Drawoff Arrangements

Reservoirs usually have a drawoff or valve tower designed to draw off the water at different levels according to the quality of the water, which often varies with the season of the year. A common arrangement is to have three drawoff valves on tee branches off a vertical standpipe at upper, middle and lower levels, with the lowest drawoff positioned at about 1 m above the bottom of the reservoir to allow for silting. Some of the drawoff towers form very attractive architectural features such as the circular stone tower with steeply pitched copper turreted roofs, which have turned green with the protective patina, at Lake Vyrnwy in North Wales which provides water for Liverpool.

Overflow Arrangements

Overflows must be able to carry the peak floods safely over the dam. An earth or rockfill dam must not be overtopped by water as it could fail in a matter of hours, and it should only be permitted with concrete dams where the design provides for it. Overflow weirs may be formed along the crest of the dam, or as side weirs on one or both sides of the dam in tunnel or in an open channel as a spillway, as shown in Figure 6.2 at Clywedog Dam, or as a series of siphons over the crest of the dam.

In the UK the procedures for sizing the spillway and freeboard of a dam are prescribed in *Floods and Reservoir Safety*[10] and *Flood Studies Report*[11], whereby dams are classified according to the risk category into which they fall. For dams in the highest risk category, the spillway must accommodate safely the probable maximum flood (PMF), taking into account the effect of reservoir lag as water is temporarily stored above overflow level. PMF is the worst flood estimated to be possible from the probable maximum precipitation (PMP) that could reasonably be expected to fall on the catchment area combined with the worst possible flood producing condition. A dam whose failure would endanger the lives of persons living in a community below the dam must be designed for the PMF, whereas in other cases the spillway need be designed for only half or less than half of the PMF according to the risks posed to life and property down river.[2]

Selection of Type of Dam

Geology largely influences the type of dam that can be built. On weak foundations it is customary to build an earth embankment with flat side slopes and berms and sometimes with an upstream blanket to reduce seepage losses under the dam. On stronger foundations rockfill dams with steeper slopes or possibly concrete or rollcrete mass concrete gravity or buttress dams would be appropriate. Where there are very strong abutments, elegant arch concrete dams can be provided, as in the Clywedog Dam, Wales, shown in Figure 6.2 and Mudhiq Dam, Saudi Arabia, illustrated in Figure 6.3 and Plate 15. The principal types of dam will now be described.

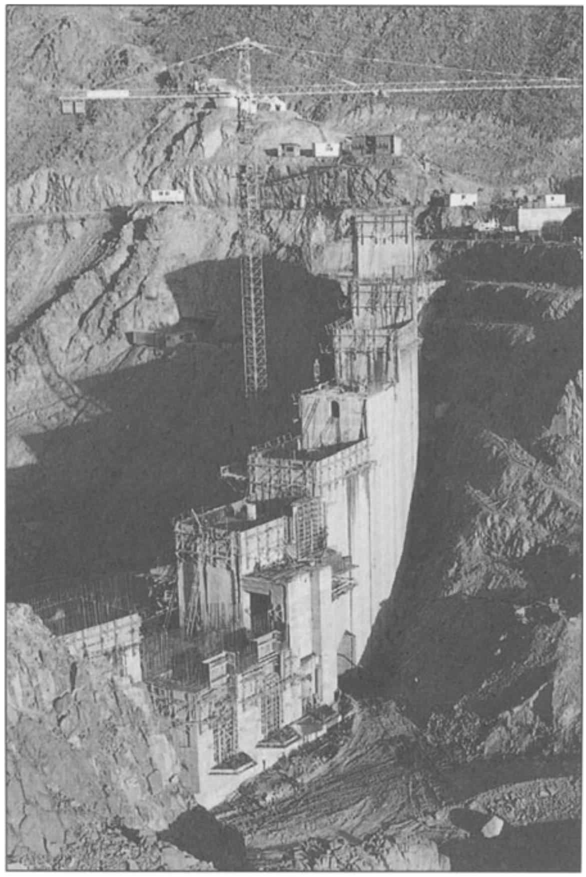


Figure 6.3 *Mudhiq Dam, Saudi Arabia, under construction (Source: Binnie & Partners)*

Earth Dams

Earth dams usually rely for watertightness upon a puddled or rolled clay core, both in the body of the embankment above ground and the cut-off trench below ground. Concrete cutoff trenches became quite common but were subsequently largely replaced by grouting permeable strata with cement or chemical mixtures. These embankments depend for their stability by placing rubble or other selected material on either side of the core. The upstream face of the dam must be safeguarded from erosion by water and wave action from the reservoir by covering the surface with large rock or concrete slabs, while the downstream face is normally soiled and seeded to protect the surface from erosion by rain. Common slopes are 3:1 upstream and 2:1 or 2½:1 downstream, with flatter slopes on higher dams.

Hoyle[12] has identified the following three potential methods of failure of a reservoir earth embankment:

(1) structural failure with the embankment slipping, caused by an over-steep slope or weak foundation coupled with high internal pore pressure

(2) external erosion arising from water overtopping a dam and/or excessive settlement

(3) internal erosion caused by water leaking through the embankment, artesian pressure in the foundation or leakage from a defective outlet pipe.

The progressive failure of the 1225 m long Carsington Dam, Derbyshire, in 1984 was considered to have been caused by brittle or strain softened fill, foundation and core material, exacerbated by a non-uniform strain distribution given by the boot shaped core, probably coupled with shear planes in the existing ground. Severn Trent Water's consultant (Babtie Shaw & Morton) recommended a new £18m dam of shale fill with flatter slopes (average of 1:4½) and the introduction of an impermeable blanket at foundation level upstream to prevent seepage. Alternatives of concrete or rockfill construction were rejected on cost or technical grounds.

Rockfill Dams

Rockfill dams need plenty of broken rock and fines to fill the voids and so reduce the amount of settlement of the fill, and the rockfill is graded with the coarsest material on the outside. A rockfill dam must incorporate a watertight membrane, which must be flexible because of the movement in the rockfill. For example, High Island West Dam, Hong Kong, designed by Binnie & Partners, is 107 m high crossing a sea inlet, and contains an internal asphaltic concrete core ranging in thickness from 0.8 m on the upper section, 1.20 m on the middle section and duplicated in the lower section, encased by a transition zone on either side of the membrane. A corewall of rolled clay fill is often provided with protective zones of transitional material between the clay and the rock. The transitional material is usually placed in two layers, graded from clayey-sand against the corewall to a crushed rock with fines against the rock.[2] A good example of a rockfill dam is the 55 m high Ainzada dam in Algeria, impounding a reservoir of 125m m^3 and providing water supplies to the towns of Setif and Bordj Bou Arreridj. The dam was designed by Howard Humphreys to withstand an earthquake intensity of 7.5 on the modified Mercalli scale.

Concrete and Masonry Dams

Gravity Dams These dams rely primarily on their own weight to prevent them being overturned by the pressure exerted by the impounding water. A dam must be sufficiently wide at its base to prevent sliding (probably about 18 m wide for a 30 m high straight dam), and adhere adequately to strong solid rock foundations. To ensure stability, the resultant of the three main forces (uplift, water thrust and weight of dam) should be within the middle third of the section of the dam under consideration. To reduce the amount of uplift below the dam resulting from leakage through the foundations, a concrete filled cutoff trench is normally formed at the upstream toe of the dam.[2]

With *concrete gravity dams*, the key factor is to reduce the amount of shrinkage which occurs as the large masses of concrete cool after placing. Twort *et al.*[2] has described how the usual procedure is place the concrete in isolated blocks, which are then left to cool as long as possible before adjoining blocks are placed. Other measures to reduce shrinkage include the use of low heat producing cement and to lay water cooling pipes within the concrete in large structures. Concrete dams are usually constructed in valleys where there is an abundance of rock capable of being used for concrete aggregate. The concrete is generally vibrated to eliminate air pockets, prevent leakage and increase setting time, and this necessitates the provision of strong, well constructed formwork.

An alternative to mass concrete is to use 'rollcrete', which consists of lean concrete rolled in place by earth moving equipment to produce a greater strength than conventionally placed concrete. Precast concrete blocks keyed together on both faces eliminate the need for formwork and the cost may be as little as one third that of conventional concrete. Their main advantage over fill dams is that they are essentially impermeable and thus the impermeable cores or upstream blankets of fill dams are not required.[13]

Masonry gravity dams are expensive because of the large amount of labour required in working and laying the stone. Hence, in Britain masonry dams have been replaced by masonry facing and concrete hearting, thereby improving the appearance of the dam and eliminating the need for temporary formwork. In emerging countries where labour is much cheaper, masonry gravity dams are still being constructed. The very impressive appearance of a masonry gravity dam is displayed in the Craig Goch Dam to the Elan Valley Reservoir, which is illustrated in Plate 14.

With *concrete arch dams*, much of the strength needed to resist water thrust is obtained by arching the dam upstream and transferring loads to the abutments. The dam resists the water load partly by cantilever restraint at the base and partly by arching action between abutments, permitting it to be much thinner than a gravity dam. The elegant concrete arch dam at Clywedog, mid-Wales, built downstream of a river regulating reservoir in 1964–67 and rising 72 m above the river bed with supporting buttresses, is illustrated in Figure 6.2.

Another version of a concrete arch dam is the *buttress dam* or *multiple arch dam*, which is constructed where a valley in rock is too wide for a single arch dam, and hence a multiple series of arches between buttresses is used. Each section, consists of a single arch and buttresses and secures its stability in a similar manner to a gravity dam. They provide simply designed, stable dams of good appearance, and their use will be largely determined by the depth of sound rock below ground surface.[2]

Mudhiq Dam, Saudi Arabia

The Mudhiq Dam at Wadi Najran, Saudi Arabia, was constructed for the Ministry of Agriculture and Water during 1977–80, and entailed the use of 110 000 m^3 of concrete. The dam under construction is illustrated in Figure 6.3, and is sited in a gorge with a bed width of 40 m on a river liable to flash floods of considerable magnitude; the design flood was 15 000 m^3/s. Its purpose is to control floods passing down the wadi and to regulate floods by controlled releases to give enhanced recharge of the aquifer downstream.

The tender design by Binnie and Partners was for a concrete gravity dam. Tenders were received in 1977 and the lowest tenderers also submitted an alternative arch dam design which showed cost savings compared with the gravity design. After detailed studies the arch dam proposal was accepted.

The completed dam is illustrated in Plate 15, and consists of a cylindrical arch dam, 9.5 m thick and 73 m high, with a centreline radius of 140 m and a crest length of 274 m, with an overflow spillway discharging into a plungepool formed by a subsidiary downstream dam. The originally planned radius of 105 m was subsequently flattened to 140 m to improve the angle of thrust on to the abutments and this resulted in a thickening of the dam from 9.0 m to 9.5 m. A full stress analysis for the arch dam was carried out by the consultants[14] and, since completion, they have been responsible for advising on operation and monitoring performance of the dam.

Boreholes and Wells

Boreholes

For most community water supply projects a borehole capable of discharging at least 5 Ml/d is usually needed, and this requires a boring with a minimum diameter of 300 mm to accommodate the pump. However, in practice they are likely to be 450 or 600 mm diameter, since allowance must be made for possible lack of verticality in the borehole, the need for satisfactory flow characteristics in both the boring and the vertical main, and the possible need to reduce the boring diameter with depth.[2]

It is generally necessary to line the upper part of a boring with solid tubes, which are then grouted into the surrounding ground, to provide a seal which prevents surface water entering the borehole. This has the double function of preventing surface contamination and also entry of water from the upper strata which may be of poorer quality than the main aquifer. When penetrating weakly cemented or uncemented sands, gravels or clays, further linings may be necessary, slotted when adjoining water-yielding aquifers and solid when passing through clays. Where additional lining is required below the top sealing tube, it is customary to 'step in' the diameter of the lower lining so that it can be placed separately. Below the additional lining the borehole diameter may need to step in again to facilitate entry of the boring tools for drilling the unlined boring below.[2]

Boreholes are formed by rotary drilling, when precise cores are obtained, or by percussion methods, which pound up the material. In sandy formations, boreholes are sunk by the mud flush system, when the mud holds back the sand as drilling proceeds, and permits gravel to be inserted outside the perforated tubes, and this also prevents sand entering the borehole after commissioning. Boreholes in chalk are uncertain as they may miss water-bearing fissures. It is therefore advisable to make a geophysical survey of the site to determine where there is least electrical resistance and hence the most likely locations of fissures, while aerial photographs and satellite images (LANDSAT) may be used to establish fissure patterns and the presence of swallow holes.[3]

Wells

Wells are expensive and are unlikely to be economic if the pumping water level exceeds 50 m below ground. It is also important that the base of the well is substantially below the anticipated pumping water level, since the pump suction needs ample submergence to avoid air entrainment and there is a possibility that future water levels in the well may be lower than when the first pumping test is carried out.

A well is required if adits are to be driven from the sides of the shaft. The purpose of an adit, which is a tunnel often about 1.2 m wide by 2.0 m high, and having a slight fall to the well, is to intercept additional water-bearing fissures in such formations as chalk, limestone and sandstone.[2]

Pumps for Boreholes and Wells

These are usually either vertical spindle centrifugal pumps or submersible pumps. Vertical spindle pumps are robust with a long life and are highly efficient, can handle water containing suspended matter and can be of variable speed. They are however expensive in initial cost, require housing and take several days to remove and install. By comparison, submersible pumps are relatively cheap, require no housing and take only hours to remove or install. They cannot, however, embrace such a wide range of functions as vertical spindle pumps, and they tend to have a lower efficiency because of the restricted size of the electric motor by which they are powered.[2]

River Intakes

Side Intakes Twort *et al.*[2] have described how the conventional solution for a river intake on rivers of moderate size which do not carry cobbles and boulders during a flood, consists of a weir across the river to raise its level, with a gated side intake a short distance upstream from the weir. On wide rivers the cost of the weir becomes prohibitive because of the extensive works required to prevent the weir from being undermined and destroyed during a flood, although on a rock foundation the weir is less costly but there remains the problem of dealing periodically with the gravel, cobbles and boulders brought down by the river, which can in some cases fill the weir basin every time a flood occurs. One solution to this problem, used in Cyprus, was to install a groyne weir projecting partly into the river, which was sufficiently low to be overswept in a flood. Other alternatives comprised a hump-backed weir with slots in its crest feeding an offtake conduit or to allow the water to pass through a sluice gate and heavy duty self-cleansing band screen.[2]

Other Intakes A type of intake commonly used for lakes and occasionally rivers encompasses a piled crib from which submersible or suction pumps are suspended and the access bridge supports the delivery pipes. An unusual type of intake was installed in the Plover Cove scheme, Hong Kong, located immediately upstream of a siphon weir across the river, incorporating a trash rack, 4 m diameter vortex intake drop shaft, air release chamber and discharge tunnel.[2]

Water Treatment Processes

Water treatment processes are extensive, diverse and often complex, hence it is only possible to deal with the most common processes in outline, followed by some useful case studies which provide an overall perspective. Readers requiring more detailed information on the construction, design and operation of the various items of plant are referred to *Water Supply*[2] and *Basic Water Treatment*.[15] On occasions this information can be usefully supplemented by reference to plant manufacturers' literature. The principal objectives of water treatment are to produce an adequate and continuous supply of pure and palatable water. The main processes involved and the purposes that they serve are now examined.

Raw Water Storage

Storage in impounding reservoirs or smaller open storage reservoirs often forms the first stage of treatment, as it encompasses a complex combination of physical, chemical and biological changes. It is generally recommended that storage provided solely to improve quality should be equivalent to 7 to 15 days average water demand, as this is sufficient to reduce pathogenic bacteria and river algae, yet not long enough to encourage other organisms to form.

Screening

The water usually passes through mesh screens before entering the main pumps, to remove floating debris. Sometimes the intakes are fitted with coarse bar grilles of about 25 mm diameter, spaced at 75 to 100 mm centres, to hold back any large floating debris, and inclined for ease of cleaning by rake. In addition, it is now common practice to install one of the many proprietory forms of mechanical screen on the endless band or drum principle and cleaned continuously by water jets washing the strainings along channels or troughs. Microstrainers were becoming quite common by 1990, consisting of revolving drums of stainless steel wire fabric or other material having a very fine mesh.

Aeration

Aeration is effected by bringing water into contact with air and in its simplest form can be achieved by cascading water down a tower structure or spraying the water through air. More effective designs allow the water to pass downwards through support media such as metallurgical coke wich is subject to a forced upflow of air.[8]

Water is aerated for the following reasons:

(1) to increase the dissolved oxygen content of the water
(2) to reduce or eliminate certain tastes and odours caused by dissolved gases in the water, such as hydrogen sulphide
(3) to reduce the carbon dioxide content of the water and thereby reduce its corrosiveness and raise its pH value
(4) to oxidise some metal salts, such as iron and manganese, and bring them out of solution into a filtrable form.

Aeration can be effected by specially designed nozzles which discharge thin jets of water against metal plates to produce a fine spray in the atmosphere. The spraying area is usually sheltered by louvres set in a surrounding wall. By contrast, cascade aerators depend upon the turbulence created in a thin stream of water flowing rapidly down an incline and striking fixed obstacles, although cascading through beds of coke, limestone or anthracite is considered to give more effective CO_2 removal than the other methods. Another method is to use about five perforated trays, increasing in size from top to bottom, through a total depth of 2 to 3 m, and the water splashes on, through and off the trays. It is a simple and cheap method but has a number of disadvantages. An efficient aeration process is provided by diffused air aerators, which consist of tanks in which air bubbles upwards from diffuser pipes, on the floor, containing fine air holes which produce a cloud of small bubbles.[15]

Coagulation

Coagulation comprises the formation of floc or precipitate which is achieved by adding a coagulant, such as alum, ferrous or ferric salt. The coagulant reacts with the material in the water to form a floc which settles rapidly, carrying with it finely divided suspended matter The floc also entraps bacteria and absorbs colour from the water. The dosage of coagulant must be carefully controlled, as inefficient coagulation leads to difficulties in filtration.

There are also a number of coagulant aids available, mostly consisting of synthetic, organic, water-soluble, high molecular weight polymers, known as polyelectrolytes, although their use on potable water has not been universally approved. However, their use in developed countries is increasing, where their high cost is claimed to be offset by the very small dosage (around 0.1 mg/l) and the saving in coagulants, provided their use is strictly controlled.[15]

Flocculation

The second stage of the formation of settleable particles is termed 'flocculation' or the formation of a floc, which visibly resembles a tuft of wool. The process of flocculation occurs by chemical bridging and enmeshment of particles as they are gently mixed together. This results in the submicroscopic coagulated particles agglomerating into discrete, visible, suspended particles. At this stage the particles are large enough to settle under the influence of gravity and are removed in the settlement or sedimentation stage of treatment. The floc also entraps bacteria and absorbs colour from the water.

This process requires thorough mixing of the coagulant with the water in a special mixing channel or flash mixer, to build up the particles of floc to a larger size. The channel may be designed to ensure a velocity >1 m/s and the water is then forced to reverse abruptly through 180°, or the water can be passed through a measuring flume in which a standing wave is formed to ensure adequate mixing. Where hydraulically agitated flash mixers are used the chamber may have a retention capacity of no more than 20 to 60 s and a pump keeps the water in a state of agitation.[15]

Clarification

Various types of settlement or sedimentation tank are used for the clarification of flocculated waters, and Twort *et al.*[2] have described the various alternative tank designs in use and their relative merits. The most commonly used tanks are hopper shaped upward-flow sedimentation tanks of the type illustrated in Figure 6.4. The floc produced in the bottom zone of the hopper forms itself into a suspended mass of sludge called a sludge blanket. The sludge blanket, being denser than water, settles to the bottom of the tank and the settling rate is balanced by the upward flow of water. The concentration of the sludge blanket is controlled by allowing it to bleed off from suitably placed automatic sludge bleed valves or 'concentrators'. The flow rating of these tanks is usually in the range of 1.3 to 4.3 m/h, the lower velocity being sometimes required for an alum floc formed in the removal of colour from a soft reservoir water. The detention time is normally between 1.5 and 2.0 hours.

By continuous or intermittent sludge bleeding, the sludge blanket level can be maintained automatically at practically constant level, a little above the sill of the concentration pockets. The best procedure is to discharge only when the level of the blanket is at, or near, the upper limit.[8]

Twort *et al.*[2] have described how sludge blanket clarifiers are not recommended for heavily silted water unless preceded by rectangular or circular basins. Another form of clarifier, developed in Sweden, consists of parallel plates and is sometimes referred to as lamella flow sedimentation, and it produces high settlement rates and a greater density of sludge.

Dissolved air flotation is being used increasingly instead of sludge blankets, and incorporates an upward flow of tiny air bubbles to carry the floc particles to the surface of the tank. Continuously revolving mechanical scraper blades then remove the floated floc material into a waste channel.[8]

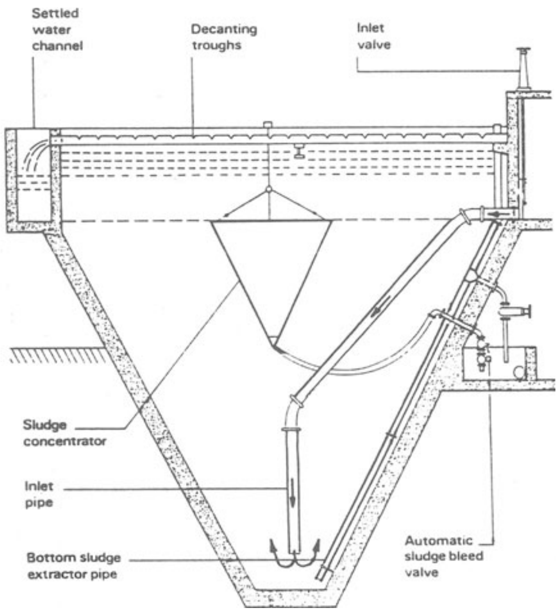


Figure 6.4 *Section through upward-flow sedimentation tank (Source: Severn Trent Water)*

Filtration

The purpose of filtration is to remove particles from the water whether these exist in the raw water naturally or whether they have been produced by a prior coagulation process. Filtration is usually achieved by the downward passage of water through about 1 m of finely divided inert material (sand or anthracite) on a support bed of coarser material, usually gravel. Pipes to collect the filtered water (underdrains) are provided at the bottom of the filter. As particles are removed the filter becomes clogged, thereby making the passage of water through it more difficult as the loss of head increases, and ultimately the filter has to be cleaned.[8]

The efficiency of the filter depends upon the following factors:

(a) the nature of the particles
(b) the size and shape of the media
(c) the rate of flow through the filter.

The following types of filtration are in use:

(i) *Slow sand filtration*, whereby water is filtered through sand at a comparatively slow rate, usually in the range of 100 to 250 $l/m^2/h$. At these rates algae and bacteria develop on and below the sand surface and result in an improvement of the bacterial quality of the filtered water. This type of filter is not however suitable for heavy loads, for example where colour and turbidity are high, they require a large ground area and, since cleaning involves the removal of the top layer of sand at regular intervals, they make heavy demands on labour.

They are suitable for use on reservoir or lake derived supplies for small communities where technical supervision is lacking.

(ii) *Rapid sand filtration* is generally used for water which has previously been treated by coagulation and sedimentation, achieving much higher filtration rates in the order of 5000 to 7400 $l/m^2/h$. They are not, however, as effective as slow sand filters in removing bacteria or taste and odours. This type of filter, since each unit is comparatively small, can be washed clean by first introducing an air scour under and upward through the sand and then following this by a high rate backwash to remove dirt collected during filtration.[8]

A distinction is made between pressure filtration which is achieved in a closed metal shell under pressure, and gravity filtration where the unit is open-topped and filtration is achieved by gravitation. Pressure filter shells commonly have a diameter of 2.4 m and can be installed horizontally or vertically. In large installations, it is usual to install horizontal units, since too many vertical units would be required because of their small sand area.[15]

(iii) Activated carbon is capable of removing from water, undesirables, trace organic compounds, particularly those materials which give rise to taste and odour problems. These materials are absorbed on to the carbon until it becomes almost saturated. At this point the carbon is removed from the process and heated under controlled conditions to regenerate it for subsequent use.[8]

pH Adjustment

pH values are used to measure the degree of acidity or alkalinity of a water. The pH scale runs from 0 to 14 and a pH of 7.0 is neutral; below this figure the water is acid and above it is alkaline. It is necessary to control the pH value in various treatment processes, for example, in coagulation, alkalis such as lime, sodium carbonate and caustic soda added to waters increase the pH; conversely, adding acids decreases it.

In the final stage of any water treatment sequence it is desirable that the water leaving the works is not acid, since acid water will attack metal fittings in the distribution system, nor should it be too alkaline since this can lead to deposits in the distribution system. The pH of the final water is therefore adjusted to a point where it is neither corrosive nor depositive, and this is termed the saturation pH.[8]

Disinfection

It is essential to ensure that the final treated water shall be safe to drink and not contain any bacteria capable of producing disease. Disinfection, which comprises the removal of pathogenic or disease producing bacteria, can be achieved by various methods, and while filtration and storage can contribute to improvement in bacteriological quality, they cannot be relied upon as a sole line of defence.[8]

Reliable disinfection can best be achieved by chemical methods, notably the addition of chlorine or its compounds in regular controlled doses in a system designed to give the disinfecting action time to be fully effective before the water passes to the consumer. For preference, the point of application should be just upstream of a weir, Venturi tube or other component where turbulence of the water will ensure thorough mixing of the chlorine.

Occasionally the nature of the water being treated is such that chlorination gives rise to the formation of unacceptable taste and odour. Ozone gas is an alternative disinfection treatment which can be applied without resulting in the same problems. Ozone is normally used in conjunction with activated carbon. Ozonation is fairly common, particularly in France and Switzerland, but it is a costly process requiring skilled maintenance and is not likely to be adopted in developing countries instead of chlorination.

Softening

Many waters, notably those from underground sources are hard and so destroy soaps, resulting in substantially more soap being required to produce a lather with the water, making washing more expensive, although this disadvantage does not apply to the use of synthetic detergents. However, there still remains a substantial objection to hard water as when heated in boilers and heating systems, the hardness compounds precipitate to form a hard scale on the surface of the boiler and interior of pipes, thereby reducing their efficiency. The hardness results essentially from the presence of the salts of calcium and magnesium, and softening involves the removal of these salts. This can be achieved in either of the following two ways:

(i) *Precipitation softening*. Lime added to hard waters will precipitate calcium and magnesium salts, which can then be coagulated, settled and filtered from the water to produce a softer product. This system produces a substantial volume of solids at the treatment works, which can present a problem in disposing of the waste.
(ii) *Ion exchange softening*. Ion exchange resins have the ability to exchange calcium and magnesium salts for sodium salts, which do not themselves cause hardness and the water is in consequence softer. The resins are retained in a metal shell in a similar way to sand in a pressure filter and are first treated with salt in a regeneration operation, to supply them with a source of sodium salts which are retained in the resins.

Water can then be passed through the bed of resin and the calcium and magnesium salts in the water are removed by the resins and sodium salts substituted for them, resulting in a softer water. The resins can, however, only carry on this exchange process for a limited time, as when the sodium salts originally on the bed are used up the resin is exhausted. The unit is then taken from service and treated with salt at a high concentration which removes all the calcium and magnesium salts held on the bed to waste and enables the bed to retain sodium salts ready for use for a further period of softening.[8]

Fluoridation

Fluoride may occur naturally in a water or it may be added in controlled amounts during the treatment process. Some UK waters naturally contain several mg/l of fluoride and they mainly occur in deep well waters from chalk or limestone under clay formations, particularly London and Oxford clay. It is generally accepted that fluoridation of water supplies to a level of 1 mg/l is both safe and effective in substantially reducing dental caries, although some public opposition has been encountered in the UK. The greatest reduction of dental decay occurs if fluoridated water is drunk in childhood during the period of tooth formation. Fluoride levels have to be closely controlled as excessive amounts can result in fluorosis causing mottling of the teeth or even skeletal damage in both children and adults, and specialised treatment to remove excess fluorides is very expensive. The additive is often in the form of hydrofluosilicic acid, requiring the provision of tanks with corrosion resistant linings, such as rubber.[2]

Case Studies of Water Treatment and Supply Schemes

A variety of water treatment and supply schemes are examined to show the differing problems and solutions resulting from variations in climate, water source, population, location and available finance, and the changes that have taken place over the last century and that are likely to occur in the foreseeable future.

Mythe Water Treatment Works

Introduction Mythe Water Treatment Works is operated by Severn Trent Water and is located on the east bank of the River Severn at Tewkesbury, and supplies on average 56% of the Gloucester District's water needs. In 1989/90 the average output from Mythe was 85.2 Mld with a peak daily supply of 106.8 Ml, and the plant is capable of abstracting and treating up to 139 Ml of water per day from the River Severn. This water is supplied to approximately 320 000 customers from a large area including Tewkesbury, Gloucester and Cheltenham.[16]

Brief History In common with many of the UK older plants, Mythe first supplied water to Tewkesbury in 1870 by means of powered beam engines.

Plant capacity increased as the demand for water grew. The Patterson rapid gravity filters, constructed in 1911 (now the museum building), are believed to be the first of their kind in the world, and the associated use of bleaching powder is one of the earliest recorded cases of the use of chlorine for disinfection of a public water supply, hence the Works is quite unique. In 1939 Gloucester received its first supply from Mythe and further extensions in 1941 and 1964 increased the capacity up to 109 Mld. Since 1964 various alterations, improvements and plant replacements have been implemented with a major extension scheme completed in 1984 increasing the Works treatment capacity up to 139 Mld.

River Intake Mythe is the last abstraction point for public supply from the main river. The raw river water flows into the intake through bar screens and then through rotating band screens, with a 6 mm square mesh. The water passes into the centre of the band screens leaving the debris to be washed off the outside of the screens. Low lift pumps then pump the water direct to pretreatment tanks from whence it flows by gravity through the other treatment processes. A minute, carefully controlled dose of sulphuric acid is applied to the raw water, when necessary, to maintain the correct pH value of the water to optimise the treatment capabilities.

Pre-treatment Tanks These facilitate the removal of soluble manganese salts from the raw water, which had previously caused discoloured water problems in the distribution system, and also the extraction of ammonia to economise on the use of chlorine and maximise its efficiency. Each of the 12 tanks is hopper shaped, upward flow, as illustrated in Figure 6.4. A 'sludge blanket' of suspended particles is formed on which micro-organisms grow and these remove the ammonia and convert soluble manganese into an insoluble state for removal in the subsequent sedimentation and filtration stages. Some of these tanks are illustrated in Figure 6.5.

Pre-chlorination As the water leaves the pre-treatment tanks a solution of chlorine in water can be injected and mixed with the pre-treated water to disinfect it, but this is now little used.

Coagulants Before the water passes into upward flow sedimentation tanks, a solution of aluminium sulphate or ferric sulphate is added to and mixed with the water. The resultant 'floc' of small gelatinous flakes attracts the small particles in suspension, to form larger and heavier particles which are more easily settled out.

Upward Flow Sedimentation Tanks/Clarifiers The water containing heavy particles is fed into the bottom of the tanks which, in the case of the sedimentation tanks, are of similar design to the pre-treatment tanks, as illustrated in Figure 6.4. The newer clarifiers are flat bottomed tanks, with the sludge blanket forming in a similar way, by the process described earlier in the chapter.

Rapid Gravity Sand Filters These remove all remaining sediment and organisms from the settled water to provide a water fit for drinking. The filter beds in the 1941/64 filter house and those provided in 1984 consisted of sand on gravel with a total depth of 1 m through which the water passes downwards. The filtered water is collected in a drainage system laid in the floor of the filter, passes through a control valve and then into the treated water reservoirs. The cleaning process has been described earlier in the chapter.

Figure 6.5 *Mythe water treatment works, Tewkesbury, pre-treatment tanks (Source: Severn Trent Water)*

Advanced Water Treatment During 1988/89 the sand in 23 of the 24 filters in the 1941/64 filter house was replaced with granular activated carbon. This material is equally effective as sand as a filtering media and has also proved to be efficient in removing taste and odour problems that can occur in water derived from lowland rivers such as the Severn. Some of these filters are illustrated in Figure 6.6.

Final Chlorination On its passage to the treated water reservoir, chlorine is added to ensure that the water is free from harmful bacteria.

Lime/Caustic Soda Treatment The treated water is also subject to lime or caustic soda treatment, to correct the water's acidity and pH value and thus prevent corrosion in the iron and steel mains and pipes.

Treated Water Reservoirs and Pumps There are three reinforced concrete underground treated water reservoirs with a total capacity of 14.8 Ml, in which the final water is stored before being pumped up to service reservoirs as well as into the local distribution system.

Sulphonation Sulphur dioxide is dosed into the pumping mains to react with and remove any

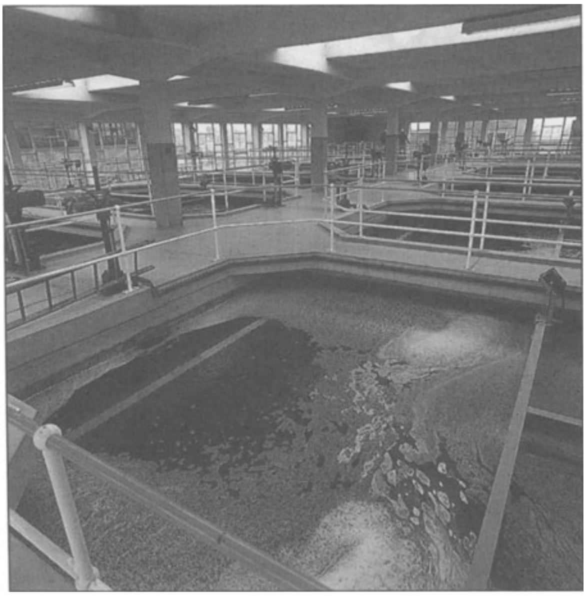


Figure 6.6 *Mythe water treatment works, Tewkesbury, activated carbon filters (Source: Severn Trent Water)*

excess chlorine in the supply from the Works.

Pumps Each of the three high lift pumps in the 1964 pumphouse can deliver 42 Mld at 152 m head, while the three high lift pumps in the 1941 pumphouse are capable of pumping 23 Mld. The medium lift pumping station houses two fixed speed pumps of 35 Mld capacity and two variable speed pumps each capable of delivering a maximum of 20 Mld.

Control Room The 1984 control room accommodates the highly automated central processor unit which, as well as controlling the newer plant, monitors the whole works in addition to the Cheltenham and Gloucester area telemetry system. It should lead to a reduction in running costs by selecting the most economical pumping combinations and times and chemical dosing rates. Scientific and operating data collection will indicate areas where further operating improvements can be made. Various security systems at Mythe are also monitored from the control room.[16]

Future Developments Whilst the quality of water produced at Mythe generally complies with EC directives, further improvements were planned in 1990 to achieve higher standards. Projected schemes included the installation of secondary granular activated carbon absorbers, following conventional filtration, ozone treatment, additional/modified sedimentation tanks and modified waste water discharge and treatment plant.

Lentini Water Supply Scheme, Syracuse, Sicily

The Lentini water supply scheme was designed by Watson Hawksley and commissioned in 1982 at a cost of US$25m (1981 prices). It supplies up to 320 000 m^3/day from the basin of the River Simeto to the industrial area of Syracuse. For drinking water, a plant treating 45 000 m^3/day was commissioned in 1981 to supply the nearby town of Augusta. A pumping station to lift up to 130 000 m^3/day to the existing storage reservoir at Ogliastro was constructed to offset low flow periods during the summer, until the completion of the Lentini Reservoir could guarantee a supply of raw water throughout the year.[17]

The treatment works, illustrated in Plate 16 includes clarification in six 36 m diameter circular tanks, following which the treated water is stored in four 20 000 m^3 storage tanks. The sludge produced is thickened in three 30 m diameter gravity thickening tanks, and dewatered by two centrifuges. The plant for Augusta included rapid gravity filtration and chlorination.[17]

Bombay Water Supply

Binnie and Partners were commissioned by the Government of Maharashtra and Bombay Municipal Corporation to design and supervise the construction works for the supply of water to Bombay, whose population was forecast to increase from 6m in 1970 to 9m in 1990. The very extensive work was carried out in three phases between 1970 and 1991 to provide an additional fully treated supply of 2820 Mld.

In phase I, raw water from the Bhatsai River was settled in upward flow clarifiers at the 455 Mld Panjrapur Works and then pumped to the

Bhandup Works through existing mains. At Bhandup the supply from all sources was treated by coagulation using alum, clarification in solid recirculation clarifiers, rapid gravity filtration with single media filters operating on a declining rate principle, and pH correction using caustic soda and simple terminal chlorination. A total of 72 filters each with a bed area of 151 m^2 were provided. The base capacity of the Bhandup Works was 1910 Mld.[18]

In phase II the Panjrapur Works was extended to provide full treatment by the construction of declining rate filters and a contact tank where caustic soda was added for pH correction and chlorine for sterilisation. The Works was laid out to permit an eventual output of 1820 Mld. This phase also included the installation of 34 pumps and increased reservoir capacity.

In 1983 a feasibility study was carried out for phase III to identify the work required, and this included additional pumping plant, further extension of the Panjrapur Works and a master balancing reservoir. At the same time, projections of the demand in the Greater Bombay supply area to year 2001 were prepared. Work was completed in the early 1990s providing an addition to the supply of 455 Mld.[18]

Hong Kong Water Supply Schemes

Binnie and Partners have been associated with water resource studies, the design and supervision of construction of impounding reservoirs, tunnel and pipeline aqueducts, water treatment works, pumping stations, a desalination plant and concrete service reservoirs for Hong Kong water supplies over a fifty year period (see Figure 6.20). The alternative water resources considered included the exploitation of additional catchments within Hong Kong territory encompassing a series of new catchwaters and storage reservoirs, reuse of sewage effluent, reduction of waste through improved leak detection, groundwater and seawater desalting. A detailed hydrological study was carried out and computer programs were developed to assess reservoir yields in relation to the reliability of supply and to minimise operating costs.[19]

Nine dams have been constructed to form reservoirs, using earthfill, rockfill and concrete gravity types. The two High Island dams in the New Territories are of particular interest, and were constructed in 1972/78 at either end of a marine strait between High Island and the mainland to form a freshwater reservoir of 274m m^3 capacity. They were founded on bedrock 32 m below sea bed level and 47 m below mean sea level, and have heights of 107 and 103 m. Both dams have central asphaltic concrete cores as described earlier in the chapter under rockfill dams. Plate 17 illustrates one of the High Island dams and the reservoir and shows the drawoff tower and overflow. The permanent cofferdam to the East dam is protected by 25 t concrete dolosse units, as it is exposed to the typhoon waves generated in the South China Sea. This reservoir is linked with the Lau Shui Heung, Hok Tau and Plover Cove Reservoirs by an extensive system of tunnel aqueducts and stations. The integrated system incorporates 15 pumping stations with a total capacity of about 4150 Mld.[19]

The Sha Tin Treatment Works, serving the new town of Sha Tin, has a capacity of 1230 Mld and was constructed during 1965–68 in three stages. It treats water from the Plover Cove Reservoir and from intakes on rivers and streams in the surrounding catchment and from the People's Republic of China. The works were initially equipped with mixed flow clarifiers, rapid gravity mixed media filters and automatic control, with solids recirculation clarifiers being added at a later stage. Aluminium sulphate is the primary coagulant with polyelectrolyte being used to aid coagulation, and pH correction is by hydrated lime. The works are illustrated in figure 6.7.

Karkh Water Treatment Works, Iraq

Binnie and Partners were appointed by the Baghdad Water Supply Administration in 1978 to study the water supply needs for the Khark district of Baghdad up to the year 2000. The population in 1978 was 1.5m and was estimated to increase to 2.5m in 2000. The treatment works

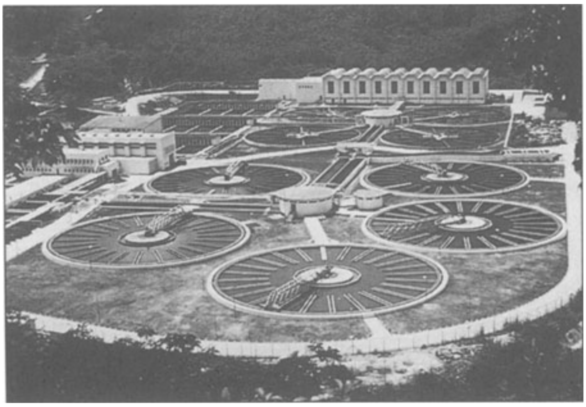


Figure 6.7 *Sha Tin water treatment works, Hong Kong (Source: Binnie & Partners)*

and associated transmission and distribution pipelines, reservoirs and pumping stations were designed and supervised by Binnie and Partners and were let on a single turnkey contract for over US$1b, with all major structures on piled foundations.[20]

The treatment works, 40 km upstream of the city, had a capacity of 1365 Mld, and was designed to treat water abstracted from the River Tigris with a suspended solids concentration ranging from 30 to 30 000 mg/l. The works were laid out in three independent hydraulic streams each with a capacity of 455 Mld, and the final stream was completed in 1987.[21]

The main features of the treatment works were as follows:

1. raw water intake and pumping station housing 14 pumps with 2300 Mld total installed capacity
2. pre-chlorination
3. alum and polyelectrolyte dosing and mixing
4. 24 horizontal flow pre-settlement tanks each of 3155 m^3 capacity, fitted with mechanical sludge scrapers, and tanks can be bypassed when required
5. 18 radial flow clarifiers, 56 m diameter and each of 13 500 m^3 capacity
6. 60 rapid gravity filters, each of 854 m^3 capacity and 140 m^2 surface area
7. pH correction with hydrated lime
8. disinfection with chlorine
9. washwater and sludge disposal
10. treated water storage, 100 Ml capacity
11. treated water pumping station, containing 8 pumps of 1800 Mld total installed capacity
12. standby power generating station with two 8 MW gas turbine generating sets
13. pipelines – 40 km dual 2100/2300 mm diameter ductile iron.

Brown[22] described how this massive water project faced crucial problems resulting from the decision to award a turnkey contract on a scheme that had been partially pre-engineered under a conceptual design assignment. The contractor thus had to solve difficult problems and was, in reality, unaware of the real difficulties.

For example, the intake structure had to be designed for construction with insufficient time to assemble data on rating curves for the river and siltation effects, and to save time better records downstream had to be extrapolated. In consequence, normal criteria for intake design were ignored and an exceptionally smooth hydraulic design was adopted to obtain the best possible pumping conditions with high velocities and practically no turbulence. The empirical design was substantiated against model tests as a further safeguard. Furthermore, the buildings were complicated by the need to incorporate Islamic architecture which avoids the use of straight lines.[22]

Malaysian Rural Water Supply

The multi-disciplinary Biwater Group designed and supervised construction of a complete rural supply network for Malaysia, stretching from Thailand in the north to Singapore in the south and including the provinces of Sarawak and Sabah. The water demand for the year 2000 was assessed using a growth factor of up to 1.5 based on the 1980 census, with a maximum per capita demand of 230 l/d. Work on the £425m turnkey contract, encompassing 137 projects in 13 states, started in 1986 when Antah Biwater, a British Malaysian joint venture, began detailed design and planning of the national scheme. The Biwater Group comprises many companies which manufacture the bulk of the components needed for water treatment and supply. Britain donated £60m and the remaining £365m was funded by the Malaysian government.[23]

The works included 69 treatment works, 112 reservoirs and four large dams. All the units are designed and constructed using a modular system developed by Biwater and comprise a series of standard, off the shelf designs for treatment units, pumping stations and reservoirs. This entails calculating the volume of water required at any one works and then selecting the nearest standard size design, thereby saving considerable time and money. Minor changes are made on site where necessary to suit local conditions. Many constructional and procedural problems had to be overcome, including the provision of extensive piling to cope with the very soft ground conditions.[23]

For example, at the Kerian Works in Kedah near the border with Thailand, after abstraction the water passes through an 1800 m^3/h single drop aerator to three sludge blanket flat bottomed clarifiers, each rated at 480 m^3/h, and dosed with aluminium sulphate. From the clarifiers, it flows through five 307 m^3/h rapid gravity filters containing washed, graded and screened river gravel and sand, which is in short supply in Malaysia. The filters have a combined air and water back washing system with waste water being pumped through a 7 km long, 150 mm diameter pipeline into the River Kurav. Disinfection is by gas chlorination with a 30 minute control time in a 1440 m^3 ground level contact and balancing tank. A treatment building houses alum, lime and chlorine dosing equipment and also contains a laboratory, stores, offices and other facilities.[23]

Following treatment, water is pumped to five elevated storage tanks, of which one also acts as a backwash tank to provide water for cleaning the filters. The elevated reservoirs are Permastone enamelled, glass coated, steel tanks with capacities ranging from 700 to 2280 m^3, supported on reinforced concrete towers up to 24 m high. To cope with high pressure, surge suppression vessels are provided as required. Treated water from the works, to World Health Organisation (WHO) potable standards, is distributed to the supply reservoirs through eight 150 to 400 mm diameter pipelines of locally made steel pipes, concrete lined to protect the inside from corrosion.[23]

Jersey Water Supply

Introduction The island of Jersey with a population approaching 80 000 forms part of the Channel Islands and is a very popular tourist resort, hence the summer period becomes a critical period as far as water supply is concerned. For many years it has been evident that a new source of supply was required. Indeed, as early as 1965 T.E. Hawksley identified Queen's Valley as a potential reservoir site, but long and protracted proceedings were experienced before approval to the scheme was finally obtained. Watson Hawksley, consulting engineers for the scheme, and the client, The Jersey New Waterworks Company Ltd, have made extensive documentation available to the author to enable him to describe this exciting project in considerable detail, and supplied Figures 6.8 and 6.9.

History of the Queen's Valley Reservoir Scheme In 1974, the Jersey New Waterworks Company instructed T. & C. Hawksley to investigate the development of further water resources in Jersey in response to rising demand. Ultimately, after fully examining all possible alternatives, Queen's Valley was recommended for development.[24]

Detailed proposals were then prepared and presented to the States, the Jersey legislative body. However, there was, and remains, a considerable body of opinion in Jersey which is opposed to the scheme, mainly on conservation grounds. At stake was a picturesque valley on the east side of the island containing several hectares of water meadow and a cottage used by the BBC for the filming of the TV detective series Bergerac, although the loss of these features will be partially offset by the extensive attractive landscaping work included in the project.

Consequently, there were several investigations into the need for the flooding of Queen's Valley sponsored by the States and by protest groups. These examined the potential for water saving by improved leak detection and metering, the use of alternative sources including increased use of groundwater, desalination and strengthening and extending an existing reservoir (Val de la Mare) which was suffering from alkali silica reaction (ASR), and also examined the possibility of reduced demand and improved forecasting. These investigations identified an approximate limit on foreseeable demand of about 7735 Mla, but still recommended additional reservoir capacity with Queen's Valley as the only suitable location. JNWC maintained that it had no choice but to go ahead with the flooding of Queen's Valley, as demand for water on the island was rising steadily, resources were limited and there was very little land suitable for use as a reservoir. Queen's Valley was the only one of two or three remaining dam sites which would provide sufficient capacity for the future. A desalination plant although expensive produces up to 15% of the annual water consumption as a last resort. Eventually, in 1980 the States resolved by a narrow majority to proceed with the scheme prepared by Watson Hawksley.[24]

Land acquisition by compulsory purchase encountered legislative difficulties, accompanied by further moves to reverse the decision by the States to proceed, which were defeated. As JNWC, because of a legal oversight, was not empowered to make compulsory purchase, it was necessary to promote a Bill in the States which finally received the Royal Assent in 1988. Planning permission for the scheme had previously been granted by the Island Development Committee, so the way was at last clear to proceed with the implementation of the project.[24]

Main Components of the Reservoir Scheme

A. *Main Dam*
   (i) Rockfill embankment, incorporating a dense bituminous concrete core and an access and inspection gallery.
   (ii) Draw-off and overflow tower.
   (iii) Draw-off and overflow tunnel driven through rock.
   (iv) Stilling basin and stilling pond.
   (v) Pumping station for transferring water from the reservoir to Augres treatment works or the Mont Gavey balancing tank.
   (vi) Associated roads, paths, fencing, landscaping, instrumentation and demolition.

B. *Intermediate Dam*
   (i) Rockfill embankment incorporating a concrete upstream membrane, spillway and stilling basin with a bridge over.
   (ii) Draw-off tower.
   (iii) Associated roads, paths, fencing, grouting and instrumentation.

C. *Silt Pond*
   (i) Silt pond formed by the construction of an earthfill embankment incorporating a concrete channel and weir.
   (ii) Associated roads, paths, fencing and pipelines.

D. *Hospital Valley*
   The filling of an existing valley with spoil from the site and the construction of a terrace garden.[24]

The scheme involved extensive and skilful landscaping which was incorporated on completion of the works in 1991, to make the valley as attractive as possible. The capacity of the reservoir is 1.2m cubic metres and the estimated cost of the scheme was £12.5m (1985 prices).

Reservoir Yield The safe yield of the Queen's Valley scheme is 2050 Mla with an effective reservoir storage of 1200 Ml. The safe yield is the average demand that can be satisfied in a design drought year, which Watson Hawksley adopted as 2% or 1 in a 50 year return period and refilling at the end of 12 months. Refilling after a summer drought period relies on surplus water from other existing catchments being pumped into the reservoir. In most years, which are wetter than the design year, Queen's Valley will refill by itself without the use of other catchments and in these years the yield could also be higher.[25]

Main Dam Using the ICE guidelines on Floods Reservoir and Safety,[10] Queen's Valley secured the highest safety classification, category A, and is thus capable of dealing with the worst possible storm or 'probable maximum flood' (PMF). The PMF peak outflow is 42 m^3/s, which the spillway is designed to take. The flood lift is the rise in reservoir level that occurs during the flood, and the top of the dam has to cope with this flood rise plus an allowance for wave surcharge occuring at the same time.[25]

Watson Hawksley[25] have shown how the *geology* of the site dictates the choice of type of dam in relation to foundation strength and seepage. On this site there was up to 6 m of soft alluvium, requiring removal, overlying bedrock consisting of granite and ignimbrite intruded by dykes of dolerite and quartz porphyry. Linked to geology is *seismicity* (earthquake activity), which can affect the stability of dams and other structures. This dam must not fail during a maximum credible earthquake (MCE) as in January, when the peak acceleration would be 20% of that due to gravity (i.e. 0.25).

Watson Hawksley selected a rockfill dam with most of the materials being obtained from quarries in the valley. A concrete dam was not preferred because of potential ash problems and would have been expensive. Figure 6.8 shows the main dam layout in plan and a typical cross section is illustrated in Figure 6.9. There is a tarmacadam crest road to provide access for future maintenance.

The upstream slope of 1 in 2 has rock rip-rap protection which is designed to be stable against wave attack and hence prevent erosion of the dam, while the downstream slope, also 1 in 2, is grassed. A tunnel was driven through the abutment at the start of the work to divert the stream and leave the foundation free for dam construction. The diversion tunnel was subsequently converted into a permanent tunnel for access, overflow discharge and draw-off pipes. At the reservoir end is a tower which contains the draw-off works and the overflow spillway, with an access bridge from the top of the dam.[25]

A buried stilling basin is provided on the downstream side of the dam to control the overflow discharges and this flows into an ornamental stilling pond as shown on Figure 6.8. The draw-off pipes pass through the tunnel to the

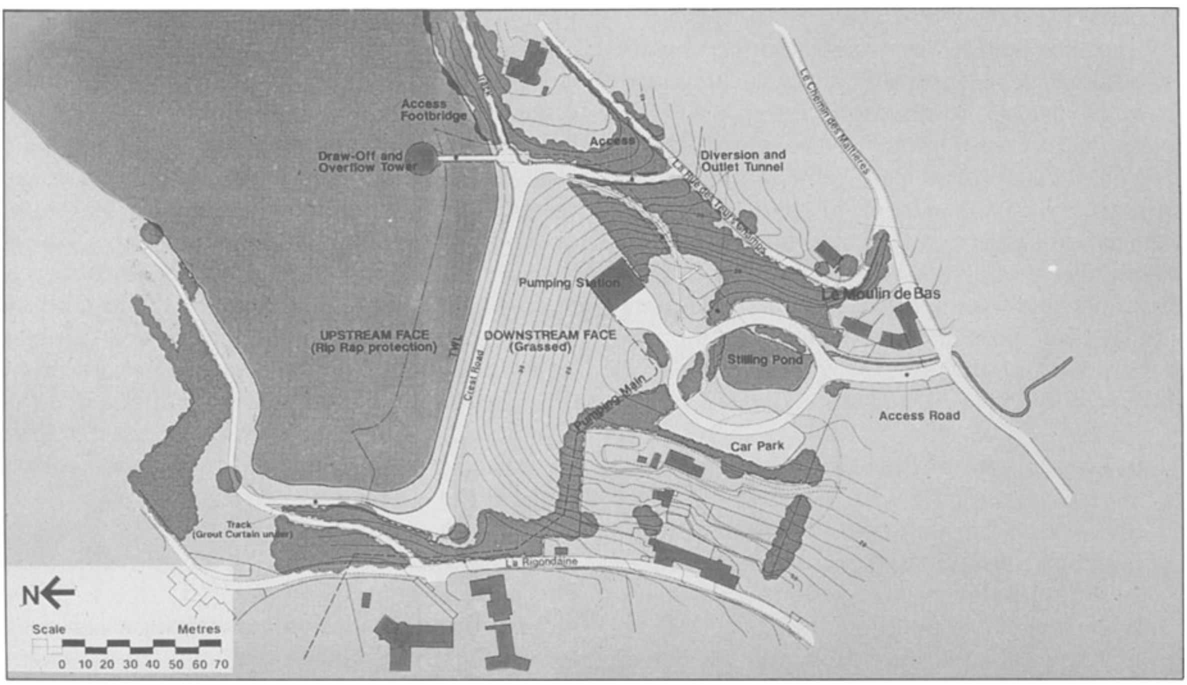


Figure 6.8 *Queen's Valley Reservoir, Jersey, plan of dam (Source: Watson Hawksley)*

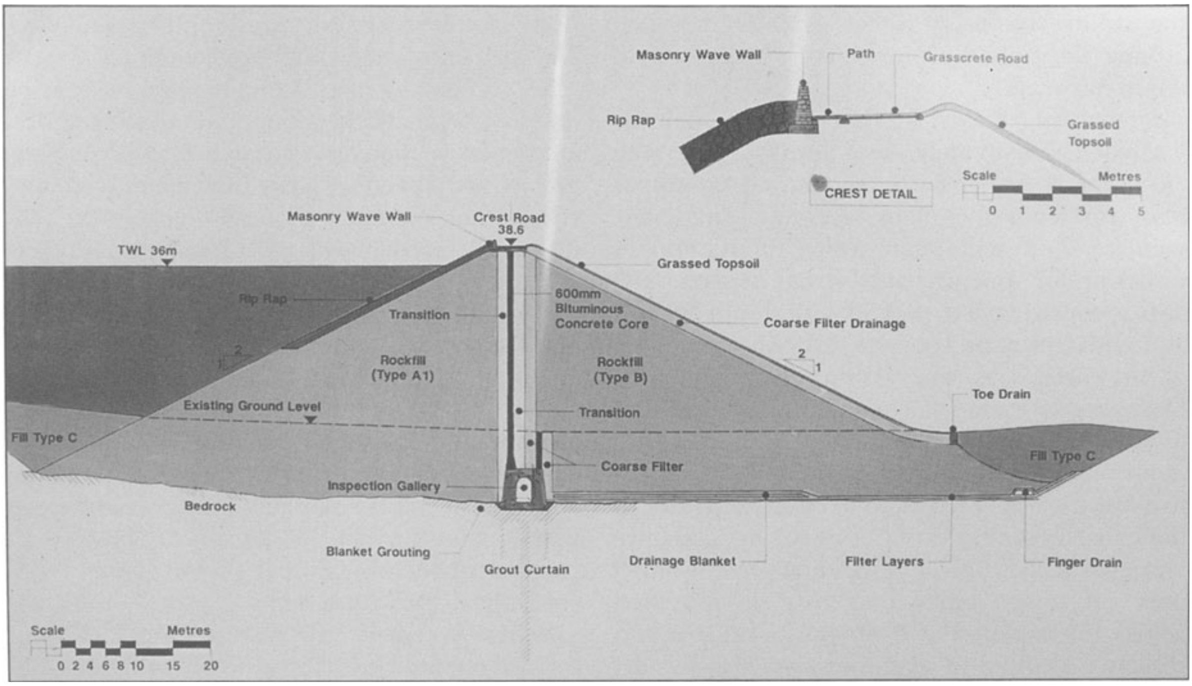


Figure 6.9 *Queen's Valley Reservoir, Jersey, main dam cross section (Source: Watson Hawksley)*

pumping station which is set slightly into the bank with a delivery pipe to the treatment works.

The dam section in Figure 6.9 shows the concrete inspection gallery constructed on the centre line of the dam running across the valley. This gallery permits easy monitoring of the performance of the core, provides a convenient bottom seal to the bituminous concrete core and would permit post construction core repairs and grouting if necessary, in addition to providing convenient access for instrumentation tubing. Below the inspection gallery is the grout curtain, which used 2:1 water:cement or thicker grout in holes varying from 3 m to 35 m deep. Above the inspection gallery is a bituminous concrete core forming the waterproof membrane of the dam. It is supported by fine material transition zones and by the rockfill shoulders of the dam.

A system of filters and drainage layers has been provided on the downstream side of the dam to collect any seepage water and to prevent any rise in water pressure in the dam which would reduce its stability. At the crest the rip-rap is smoothed into an attractive masonry wall and a slight rise is formed in the grass to reduce the visual impact from the downstream side and it also acts as a safety barrier, the details of which are illustrated in Figure 6.9. The stability of the dam was checked by computer analysis and critical surfaces and safety factors assessed.[25]

Outlet Works and Spillway A draw-off tower contains three draw-off pipes at different levels in the reservoir which feed through to a guard sluice valve and a control sluice valve and into a common standpipe which then runs down the base of the outlet tunnel to the pumping station. There is also a scour pipe at the base for keeping silt levels down near the draw-off works and which can be used for additional drawdown in an emergency. Various platforms and access staircases were also provided.[25]

The overflow consists of a bellmouth weir around the perimeter of the tower over which the water flows and falls down a drop shaft, through a specially designed transition section to smooth flows and then down the top half of the tunnel to the stilling basin. A screen wall is provided around the bellmouth for safety reasons and to damp out waves.[25]

Intermediate Dam An intermediate dam is located approximately two thirds of the way along the reservoir basin, separating the upper reservoir from the main reservoir. The intermediate dam will retain water in the upper reservoir for amenity and visual aspects. The dam is constructed of rockfill with slopes of 1 in 2 and with upstream concrete slabs and a shallow grout curtain as the waterproof membrane. Downstream there is a concrete spillway section to allow floods to pass over it safely. A draw-off/scour pipe is provided through the embankment to allow the upper reservoir to be drawn down in the event of severe drought or for maintenance work, with the control valves housed in a small draw-off tower. An access road is provided across the top of the dam and a bridge, and masonry walls and cladding have been used extensively to ensure that the dam harmonises with the local environment.[25]

Silt Pond A silt pond is provided at the north end of the reservoir in order to trap sediment carried into the reservoir by the incoming stream. The pond is between 1 and 2 m deep and will be drained down every few years and the accumulated silt removed. The location of the pond is formed by a low earth embankment formed with alluvium excavated from the adjoining valley floor, with a concrete cut-off wall. The overflow consists of a concrete shallow 'V' measuring weir at the eastern end of the embankment. Exceptionally large floods will pass over the embankment itself and hence the central section is set at a low level and protected with reinforced grass surfacing, which also permits vehicular access over the embankment. Drainage of the pond for desilting is effected by passing stream water through a bypass pipe.[24]

Water Services and Fittings

Pipes

The major part of water distribution is through pipes and there has been a considerable increase in the numbers of new types of pipes of all sizes and their associated joints in recent times. Cast or 'grey' iron has been largely superseded by ductile iron, and other commonly used materials are asbestos cement, steel, reinforced concrete, prestressed concrete, glass fibre reinforced concrete, unplasticised polyvinyl chloride (uPVC), glass reinforced plastic (GRP) and polyethylene of low, medium or high density. Protective coatings for iron pipes include bitumen sheathing and the application of centrifugally applied concrete or bitumen lining, and a tubular polythene sleeve may be used to give protection in aggressive soils. Iron pipes can be jointed in a variety of ways, ranging from run lead joints with spigot and socket pipes, flanged joints, compressed gasket joints, Viking Johnson couplings with patent rubber rings, and Tyton joints with specially shaped rubber rings.

Asbestos cement pipes are resistant to most corrosive conditions but tend to be brittle and require careful handling. Prestressed concrete pipes have a number of disadvantages, including limited flexibility at joints, heavy weight in pipes of large diameter and connections are not easy to make after laying necessitating the provision of tees. Reinforced concrete pipes have proved reasonably popular because they can be designed for relatively high heads and are rigid and offer good resistance against rough handling and poor backfilling. uPVC pipes are resistant to corrosion, are light in weight, flexible and easily jointed, but are liable to distortion in pipes over 200 mm diameter. GRP pipes are used mainly for carrying aggressive waters or for laying in exceptionally aggressive ground, are light in weight and can be supplied in lengths up to 12 m and diameters over 2.5 m. Polyethylene pipes should only be used for cold water mains in moderate climates. Readers requiring more detailed information about the various types of pipes and their jointing are referred to *Water Supply*.[2]

Valves

Valves can take various forms of which probably the most common is the standard gate or sluice valve to BS 1218. They are usually flanged to enable them to be removed, repaired and reinserted without disturbing the remainder of the pipeline. The nonrising spindle type has the screw totally enclosed within a casing and is operated by a key. For special purposes there are valves with spigots and sockets, double spigots, Victaulic joints, hand wheels, exposed screw rising types, and anticlockwise opening or a combination of any of these.[3]

Other valves and fittings in common use include the following:

1. butterfly valves to BS 3952 which are easier to operate than gate valves, are smaller in size and usually lower in cost
2. reflux valves, which are also known as non-return, recoil, retaining, foot and flap valves, made up to 1.5 m diameter and more and of many types
3. air valves are located on the highest points of mains and on flat gradients of under 1 in 500 on distances of more than 750 m for releasing surplus air
4. hydrants usually consist of an 80 mm branch from the main with a duckfoot on which rests the screwdown hydrant and standpipe and hose attachment
5. washouts are normally branches of 80 to 150 mm diameter, leading from the main to a watercourse with sluice valve control, to clear the main of contaminated water or sediment, and sized to achieve a flow of at least 0.5 m/s in the main if possible
6. valves for special purposes include pressure reducing, pressure retaining, pressure relief, and flow control.

Readers requiring further information on valves and fittings are referred to *Water Supply*[2] and *Civil Engineers' Reference Book*[3]

Developments in Laying of Services

Moles, which are mechanical devices that burrow under the surface of the earth or through existing pipes, enable new pipes to be laid with considerably less disruption and expense than traditional trenching.

Fast continuous water pipeline installation and trench reinstatement equipment has been developed jointly by Welsh Water and Worcestershire based trencher manufacturer Bruff. The all in one machine cuts narrow trenches, lays medium density polyethylene pipe, backfills the trench with excavated material and discharges unsuitable spoil into a driverless dumptrunk, in one continuous operation. The machine lays 200 m/day of 100 mm medium density pipe in a road, including asphalt reinstatement, compared with around 200 m/week by normal laying methods.[26]

In another innovative development Subterra's Rolldown pipe replacement technique squeezes and reforms oversize polyethylene pipe into old mains which have an internal diameter the same or slightly smaller than the new pipe's overall dimension.[27]

Digital mapping allows all the information conventionally plotted on a map to be stored in computers as part of a vast database. The system catalogues the position of underground pipes, valves and other components.

Leakage Control and Metering

Leakage Control Methods

Field *et al.*[28] have identified five basic methods for the control of leakage. Each method is capable of reducing leakage, although each is accompanied by a corresponding increased cost. Figure 6.10 illustrates a detailed procedure developed by WRc for determining the most appropriate method in any given network and has been successfully employed in many systems in the UK and elsewhere. The procedure also enables the effort necessary for the economic operation of the selected method to be determined.

The five methods of leakage control comprise passive control; regular sounding; district metering; waste metering; and combined metering. Only one method is economic for a particular system, and each method will show further

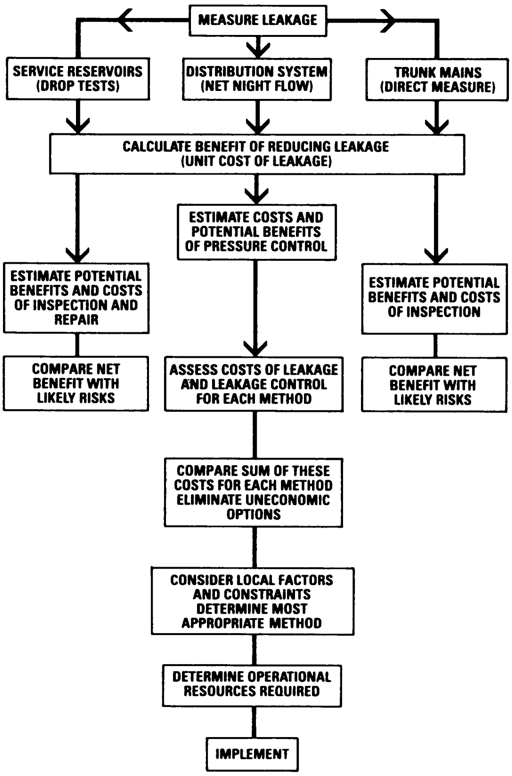


Figure 6.10 *Procedure developed by the Water Research Centre for determining the most appropriate leakage control method (Source: Field et al.[28])*

savings by pressure control. However, the consequences of choosing the wrong method of control can be as expensive as not implementing any leakage control measures at all.[28]

Field *et al.*[28] assert that a fundamental requirement for the employment of most methods of active control is network simulation. This enables districts to be selected, the siting and sizing of meters to be determined and the scope for leakage reduction by pressure control to be assessed. The available devices associated with leakage control were improved in the 1980s. For example, third generation leak noise correlators to locate the position of leaks accurately were lighter, smaller and more sensitive, while flow measurement recorders/data loggers are capable of recording the output from a large number of flow meters used for both district and waste metering. The importance of leakage control programmes is evidenced by North West Water reducing its leakage rate from 34% to 29% between 1985 and 1989, thereby saving 40 Mld and eliminating the need for a new water source in the north west this century.

Metering

Water metering is not a new process as STW found that water had been metered in Malvern for over 100 years. Water consumption was expected to drop by 10% in the UK if water metering was introduced on a large scale. In other countries consumption has fallen by between 4 and 45% after fitting meters. The Council for the Preservation of Rural England (CPRE) argued that metering can provide a fairer way of paying for water and ensure that wasteful users pay the real costs of the water they consume, but it should be introduced with a suitable pricing framework as, for example, adopting a two part tariff where water charges increase with excess use above a basic quantity.

Following initial trials in the UK in 1989/90 with meters installed in over 60 000 selected properties, WRc published a second interim report in which it concluded that it would be feasible for 95% of UK properties to be fitted with meters. The cost of installing external meters was assessed at £200 per property and internal meters at £165 each, including management costs (1990 prices). On completion of the trials in 1992, the Director General of the Office of Water Services (OFWAT) will make a final decision, which is expected to support metering probably on a two tier tariff.[29]

It seems likely that most UK water companies will opt for metering in line with the long standing practice in other EC countries. In 1990 new houses were being built to accommodate meters in the future which will more than halve the cost of installation. However, Welsh Water rejected metering in 1990, believing that customers would be better off with a flat rate charge phased in over five years. The principal problem will be the enormous task of fitting meters to over 19m homes by the year 2000, when the old domestic rateable values can no longer be used for the assessment of water charges. This would place very heavy pressure on the engineering and construction industries in training a qualified workforce to install, maintain and read the meters, which would then require overhauling every few years.[29]

Water Conservation

In Singapore, following an unusual prolonged dry spell water stocks fell from 95% of total capacity in December 1989 to 67% in April 1990. In consequence the Singapore Public Utilities Board (PUB) warned that if reservoir stocks fell to less than 65% of the total capacity, water would be banned for watering of gardens or grounds with sprinklers or hoses; washing of vehicles with hoses; use of high pressure jets or hoses for washing buildings or other equipment with potable water; operating public and private ornamental fountains or cascades; and draining and refilling swimming pools and ornamental ponds. Offenders would be liable to a maximum fine of S$5000 and a further fine of S$250 for each day the offence continued after conviction. The PUB and the Singapore government used maximum publicity by newspapers, radio and television, to persuade people to economise in the use of water and they were informed daily of the preceding day's consumption and the reservoir stocks. By comparison, in the UK in the long dry summer of 1990, hose bans were in force in many parts of the country and those found ignoring the ban were fined.

Twort *et al.*[2] have described how demand constraint measures are being promulgated in the UK and by the World Bank for overseas projects. Within the UK, dual flush or low volume (6 litres) flushing cisterns for use with water closets, using less water when flushing away liquid waste and more for solid waste, is estimated to reduce water consumption by about 10 lcd, but the change over process is likely to be slow. The increased installation of bidets offers potential savings. The public have been encouraged to use showers instead of baths as part of an economy drive but the savings may be largely offset by the greater frequency of use of showers as compared with baths. The design of compact hot water supply systems also assists in reducing consumption.

In Singapore it has been found that the insertion of small coin sized thimble devices made of tough polythene in domestic water services saved over 10% of the total water consumption of an average household. The Singapore PUB fitted 288 000 thimbles between 1978 and 1990, under a pilot scheme, to water pipes in high rise apartment blocks where water is supplied from tanks on the tops of the blocks. They are fitted when new meters are installed or old meters replaced on a seven year renewal system. However, they are not suitable for use in private houses as the water is supplied from PUB mains with consequent fluctuations in pressure, but people living in these dwellings can still save water by installing dual flush cisterns, as previously described, or constant flow regulators, which supply a lower volume of water by ensuring a fixed rate of flow of water through the pipes.

London Water Ring Main

Introduction

Thames Water adopted a radical long term strategy for the trunk distribution of potable water from sources and treatment works into the local mains network serving 5.25m customers. In common with the problems facing many of the world's large cities, the long term planning of London's water supply system presented a choice between orthodox mains extension together with replacement of the aging trunk main system or relief of the existing pumped system by a new gravity fed system of tunnels constructed deep in the clay underlying the city. The new tunnels required sufficient capacity to meet increasing demand and to relieve those parts of the trunk main system which are progressively giving less satisfactory service. In terms of both economics and operational advantage, the provision of a gravity fed tunnel ring with necessary cross links was the preferred option.[30]

Needs and Operational Aspects in the Late 1980s

Seventy per cent of London's water supplies are abstracted from the River Thames, and stored and treated in the Thames Valley reservoirs and filtration works. Supplies are supplemented by abstraction from the River Lee and underground aquifers in Kent and the Lee Valley, but the latter are now fully exploited, such that future growth in demand must be met from the Thames. The quantity of water supplied to London has been growing at an average rate of about 1% per year and in 1988 had reached 2000 Mld or 380 lcd, including commercial and industrial consumption. Quantities supplied are estimated to rise by 15% overall between 1988 and 2006, after allowing for improved leakage control.[30]

Figure 6.11 shows an outline of the trunk distribution system in 1987, incorporating 20 trunk main links of steel and cast iron pipes varying in diameter between 750 and 1500 mm, mostly laying alongside other services under urban streets. A combination of age, heavy traffic and increased working pressures has resulted in more frequent leakage and bursts in the trunk mains. Traffic flow in London streets is fre-

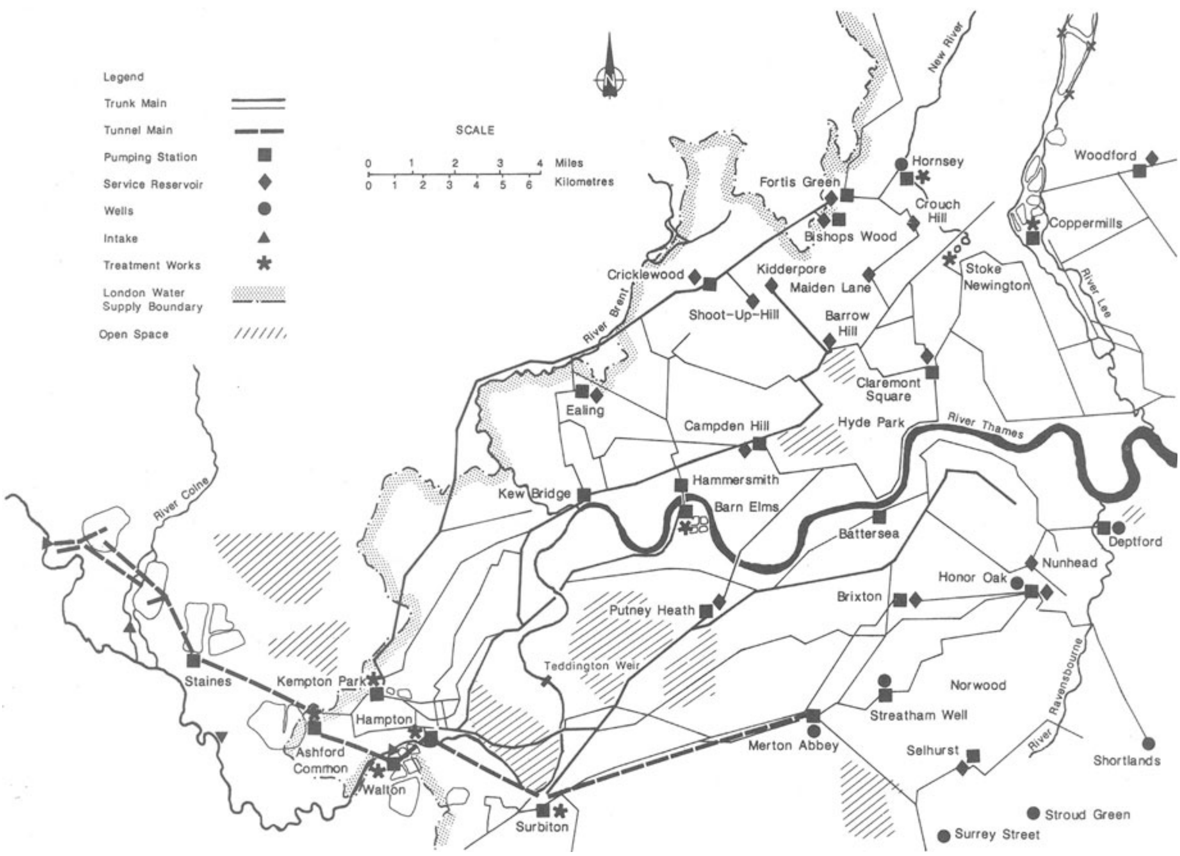


Figure 6.11 *London water supply system, 1987 (Source: Dickens & Bensted)*

quently disrupted by repairs to services buried beneath the roads and pavements. In many streets there is no surplus space to accommodate new or replacement services, hence routeing and detailing of large orthodox mains is a difficult and expensive task. Furthermore, during construction there is serious disruption of the commercial and social life of a busy city and a risk of damage to existing services.[30]

Difficulties have arisen in taking trunk mains out of service for essential maintenance and leakage is thereby increasing. Trunk main leakage in 1988 was estimated to average 200 Mld, equivalent to the capacity of a major reservoir, and there are about 50 trunk main failures annually. At times of peak demand deficiency of trunk main capacity causes substantial depletion of service reservoir supplies and reduces the margin available to maintain supplies after major bursts, sometimes putting many customers at risk of inadequate pressure.

The bulk transfer system is energy intensive and becomes increasingly so as greater quantities are pumped eastwards. For example, high lift pumps at the Thames Valley treatment works pumped an average of 1000 Mld at heads of up to 100 m across London in 1988, supported by a number of booster pumping stations, such as those at Kew Bridge, Hammersmith, Cricklewood and Fortis Green, pumping the water eastwards where it is needed. Furthermore, the maintenance and replacement costs of mechanical and electrical plant are high. By providing trunk distribution links from the larger works to the areas served by smaller and less efficient works, and increasing thoughput at the larger works, the smaller and less economic works can be closed with a saving in overall costs, indicating the close interrelationship between the development of trunk distribution systems and treatment works.[30]

Ring Main Concept

The alternative to orthodox mains and treatment works extension was to build a ring main in tunnel, mainly in London clay, with the following advantages:

1. The cost of a 2.5 m diameter tunnel is approximately equal to that of a 1200 mm diameter orthodox water main having a capacity of about one quarter of the tunnel.
2. The natural features of the London clay are exploited, as its strength and impermeability prevent leakage and contamination, and the possibility of bursts is eliminated.
3. Surface disruption is minimised as most of the shafts can be sited within the existing Thames Water network for ease of connection, as are also route lengths and disruption of existing services. Using the wedge block method any settlement will not be significant.
4. Maintenance requirements are kept to a minimum, there is good security and only limited surveillance is required.[30]

Water flows in the ring main by gravity and is pumped out at shafts suitably positioned near the zonal distribution demand areas. This greatly reduces the need for high lift pumping from the Thames Valley, thus saving energy, avoiding the need for continual remodelling of high lift pumping stations and relieving existing mains of high pressure. Any outlet shaft on the ring main can be supplied from either of two directions, which improves security of supply and operation of planned maintenance.

Comparative Costs and Construction Programme

There is a strong economic case for the ring main strategy as it produces capital cost savings over a twenty year period, reduces operating costs and releases land for alternative uses. The capital cost of the ring main and associated works, uprating of treatment works, pumping stations in shafts, modifications to the existing distribution system, and modern telemetry and control systems, was estimated at £231m at 1987–88 prices, as compared with the alternative orthodox approach of £313m.

Construction of the ring main and associated works started in 1986 to provide a link across London from east to west by 1990 and a complete ring by 1994. The timing of further extensions is dependent on the rate of growth of demand and the extent of leakage reduction. The ring main will revolutionize London's water supply and will place Thames Water in the forefront of a new technology in the operation and management of one of the most complex distribution systems in the world.[30]

Operational Considerations

The ring main will supply 1100 Mld of treated water from west to east, which amounted to about 50% of London's average daily supplies in 1988. An optimum flow rate of 1.25 m/s has been assumed to keep friction losses at a low level, and the ring main will normally operate at full capacity. The majority of the surface trunk mains will be retained to satisfy and regulate major demand fluctuations, with considerable interaction between the two systems, but even at peak periods, these mains will be operating well below their normal pressures. Their future performance and the profile of future demand will largely determine the timing of a third west-east link within the ultimate ring main configuration as shown in Figure 6.12.

Computer Modelling

Prior to selecting the final route, computer modelling of both proposed ring main configurations and the existing trunk system was undertaken. A simple ring configuration, incorporating parts of the existing trunk distribution system and simplified zones was set up using the WRc WATNET network analysis program. The most onerous constraint placed on the simulations was the requirement for reversibility of flow should a length of tunnel be out of use. Several route options were simulated and the results

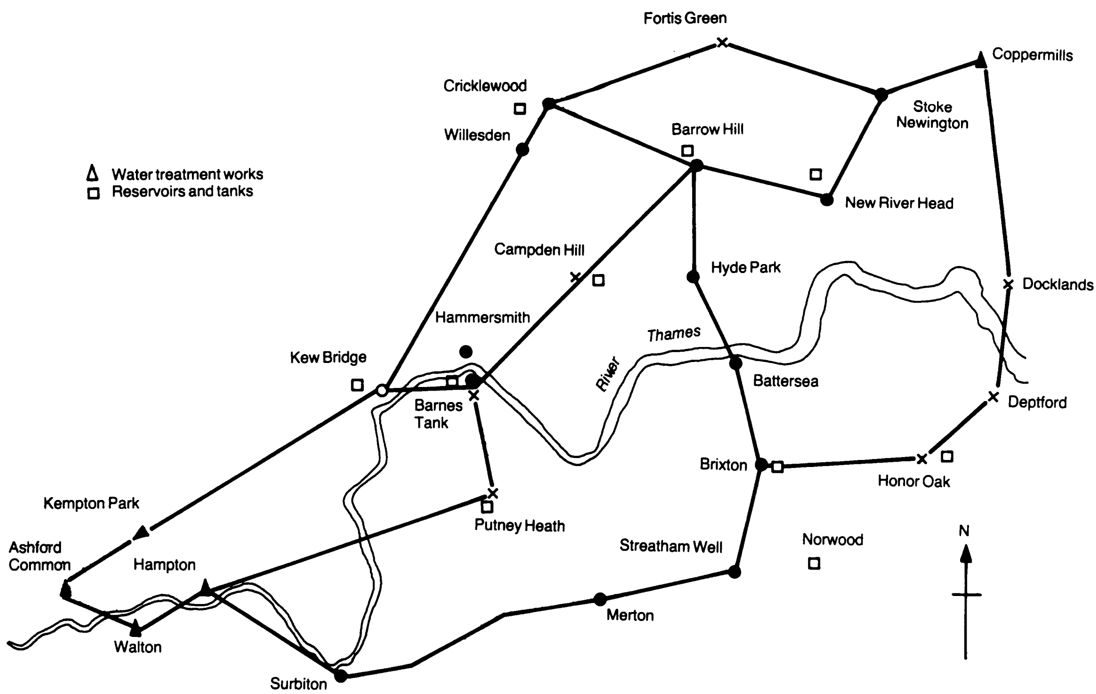


Figure 6.12 *London water ring main (possible ultimate configuration) (Source: Dickens & Bensted[30])*

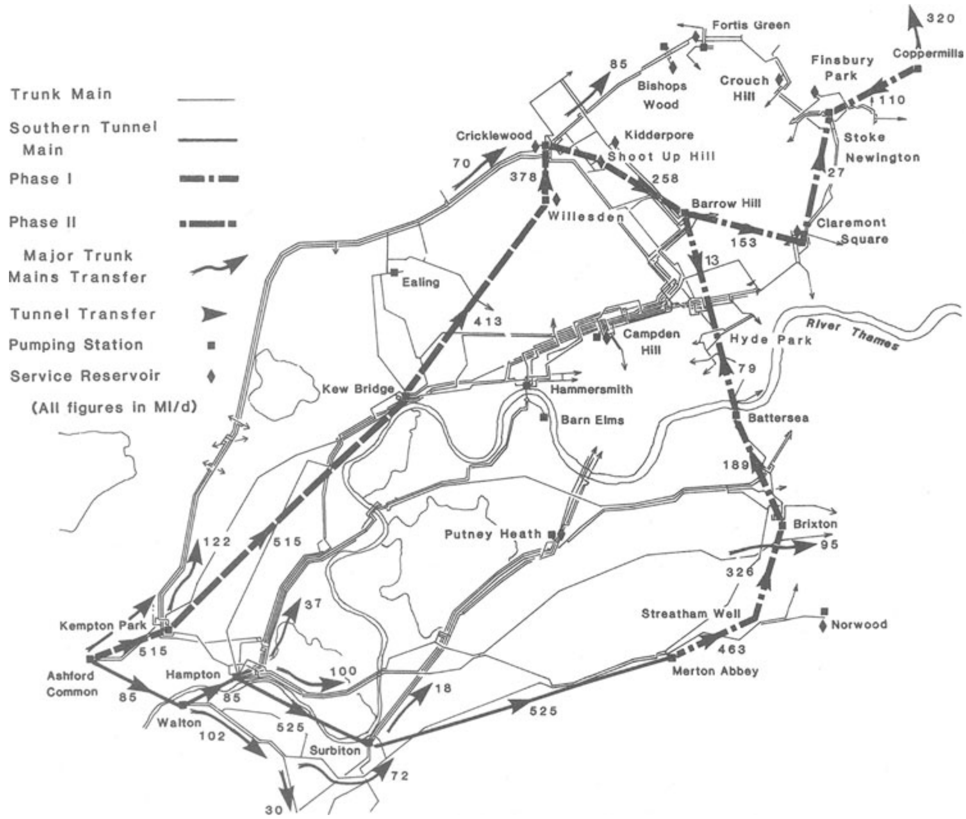


Figure 6.13 *London trunk distribution 2001, phase 2 (Source: Dickens & Bensted)*

showed that these had minimal effect on the hydraulic gradient to the demand centres. The conclusion reached was that, within limitations, the location of and quantity fed into the distribution system was more critical than the physical configuration of the tunnel. The WATNET analysis provided a comparison of the route options, based on pumping costs, and provisional routes for phases 1 and 2 were agreed and incorporated into the design layout shown in figure 6.13.[30]

Service Reservoirs

Service reservoirs store drinking water for immediate use and their object is to balance the daily fluctuations of demand from the distribution system against the output from the source. They are invariably covered to prevent contamination of the stored water and are located at the highest point necessary to serve the buildings being supplied. If there is no ground high enough for this purpose, the water is raised by pumping (boosting) or by the provision of water towers. The normal capacity of service reservoirs is 24 hours consumption to cope with variations of demand, trunk main bursts and sourceworks plant breakdowns. In seaside towns the influx of visitors at weekends may increase consumption by as much as 50%.

The design of service reservoirs varies between shallow reservoirs with long walls and a large floor area and a deep reservoir with high retaining walls and a smaller floor area. Twort *et al.*[2] have given typical depths in the following ranges:

Size (m^3)	Depth of water (m)
Up to 3500	2.5 to 3.5
3500 to 15 000	3.5 to 5.0
Over 15 000	5.0 to 7.0

The depth can be influenced by a number of factors, including depth of suitable stratum for foundations, depth of outlet main, slope of ground and type of backfill, balancing excavation and fill, and shape and size of site. Where a reservoir is divided into two compartments by an internal wall, a rectangular reservoir with a sides ratio of 1.2:1.5 will be advantageous.[2]

Concrete roofs can be designed as flat slabs on columns, cast *in situ* slabs supported by beams, or as precast and prestressed beams laid side by side and grouted together. A common practice is to use reinforced concrete slabs spanning 3.5 to 4.5 m and 150 to 200 mm thick, and in large roofs it is necessary to make provision for expansion and contraction with changes of temperature. The roofs are often covered with a layer of gravel to improve drainage underlying about 300 mm of topsoil for subsequent grassing to improve its appearance and to keep the concrete at an even temperature. Supporting columns are generally of cast *in situ* reinforced concrete. Reservoir walls can be of various types, such as mass concrete gravity walls, reinforced concrete walls, and prestressed concrete walls. For normal conditions mass gravity concrete walls offer the best solution.[2] Service reservoirs are often built partly above and below ground and the upper part surrounded by grassed banks.

In 1987 the costs of service reservoirs in the UK varied from £195 000 for 2.25 Ml capacity up to £780 000 for 13.5 Ml capacity.[3] These costs include the valves and fittings associated with these structures, comprising an inlet, supply and washout valves, overflow arrangements, roof air inlets, depth indicator and recorder, and outlet meter and recorder.

Water Towers

Rofe[3] has emphasised how the capital and maintenance costs of water towers need to be balanced against those of boosting plant, although in many cases the decision is influenced by the greater security of water supply achieved with an elevated tank.

Towers are constructed in various forms from the globular steel type which is common in the United States to the rectangular tank built up of steel plates which is used extensively for industrial purposes in the UK and also in developing countries, because of the ease of design and fabrication. However, the majority of towers for public water supply consist of reinforced concrete cylindrical structures either supported on columns or totally enclosed and are often lined with asphalt for waterproofing purposes. Another type which is finding favour comprises a cylindrical steel tank surrounded with a thin external shell of reinforced concrete, with a space of 1 to 1.3 m between the steel tank and the shell. The shell can be designed to pleasing architectural effect and the steel tank permits inspection for leakage and preservation by painting.[3]

The largest towers rarely exceed 5 Ml capacity or 30 m in height, since they are subject to significant wind loading and require substantial foundations. The 1990 cost of a 1 Ml capacity tower 30 m high was around £800 000.

Dubai, in the United Arab Emirates, adopted a programme of reusing treated sewage effluent to beautify city amenity spaces and this required a number of elevated towers to feed six irrigation water distribution zones. The Jumeirah tower, 36 m high, is the tallest and provides a spectacular feature in the city landscape. It has a capacity of 1000 m^3, feeds one third of the six distribution zones, acts as a buffer against fluctuations in demand and provides some emergency storage. It is illustrated in Plate 18.

Although it is not uncommon to decorate towers for drinking water with some flair, it is not often that a stucture storing non-potable water is afforded such prestige. The Dubai Municipality wished to produce a prestigious, yet functional, structure that would stand as a fine piece of engineering in its own right. They required a tower which would be striking in appearance, yet appropriate for its surroundings. Watson Hawksley's design engineers worked closely with

Dubai's Town Planning Department to develop the tower shape, and then to produce a pattern reflecting traditional Islamic designs, boldly defined in contrasting colours.

The design uses grooving with the pattern highlighted by painting. Chocolate brown and cream were chosen to blend with the colours of the petroleum company offices on one side and schools on the other. The 750 mm thick concrete walls of the shaft and bowl are formed with the design grooves as 50 mm rebates. Although the colour scheme is notionally two colour, the effect of the rebates is to create a further thin band of cream in stages of shadow, fringing the darker brown, all applied in a double coat of acrylic paint. Maintenance of the finish is carried out at 5 yearly intervals.

Specialist formwork contractors for circular structures using their own patented system, worked closely with the contractors on the project, assisting with the construction of the 6 m diameter shaft using self-supporting climbing formwork, and the 26 m diameter bowl from a hanging system of 128 load bearing beams.

Pumping Stations

Pumping Plant

While the majority of pumps used for water supply purposes are centrifugal, with a rotating impeller, reciprocating pumps still have their uses. There are various types of centrifugal pump and the principal ones are now listed:

Multistage pumps consist of several impellers and diffuser chambers clamped together in series, with the impellers fixed to one shaft.

Vertical spindle pumps are often used for pumping water from wells, with a driving motor at the surface and the pump immersed in water below and driven by a vertical spindle.

Submersible pumps have the pump directly connected to an electric motor located immediately below it and capable of running under water; they are quickly and easily installed and can be of small diameter.

The horizontal centrifugal pump is well suited for all waterworks duties, except the handling of very large quantities of water against low heads and pumping from wells and boreholes. Its main advantage is its relative cheapness and the large variety of designs available to satisfy a wide range of pumping conditions. For a single unit the output can range from 50 Mld by 60 m head to 10 Mld by 200 m head. The electric motors used for driving the pumps are mostly a.c. fixed speed induction motors.[2]

There are a wide range of different layouts available for pumping stations but there are certain basic features which are almost universal. For example, high tension switchgear and transformer are usually needed with a grid supply and should be located in a separate locked room. A chlorination room generally forms an important component. The main engine room should have reasonable working space around the machinery and a crane will be required in all but the smallest pumping stations. All moving machinery must be securely bolted to adequate foundation blocks and, where pumps are sited over a well or tank, they should preferably be fixed to steel joists.[2]

Portland sewage pumping station was described in chapter 4 and illustrated in Figures 4.16, 4.17 and 4.18. The final section of this chapter deals with two very unusual but quite different water pumping stations adjoining Plover Cove Reservoir in Hong Kong, and the background to their provision.

Pumping Stations at Plover Cove Reservoir, Hong Kong

Introduction

The rapidly increasing demand for water in Hong Kong, rising from 248 000 m^3 in 1958 to 1 930 000 m^3 in 1986, has been met by importing substantially more raw water from China. These increases have necessitated major additional works at Plover Cove Reservoir in the north east New Territories (converted from a sea inlet into a freshwater reservoir in the 1960s) including two large pumping stations (Tai Mei Tuk B and Harbour Island). Operational requirements that the reservoir remained in use while the pumping stations were under construction and the location of the works in a scenic area imposed special design considerations. The Country Parks Authority required the structures and installations to be hidden as far as possible and otherwise blend with their surroundings. Heavy construction traffic through the country park was not permitted, resulting in the construction of a jetty on Harbour Island and contractors were required to import all bulk and heavy materials by sea, and construction noise had to be controlled to a performance specification.[31]

McMeekan and Yue of Binnie and Partners, who designed the works,[31] have described how the new stations required deep draw-offs and economic studies dictated different solutions for each station. Tai Mei Tuk B is a wet well station of 1390 Mld capacity sited in the reservoir and connected to the shore by a 300 m long bridge, all supported on deep piled foundations. The pumps deliver water through siphon pipes laid over the bridge. While Harbour Island is a dry well station built onshore largely below sea level. Pumps deliver up to 1182 Mld through a 9 km delivery aqueduct including twin 2 m diameter sub-

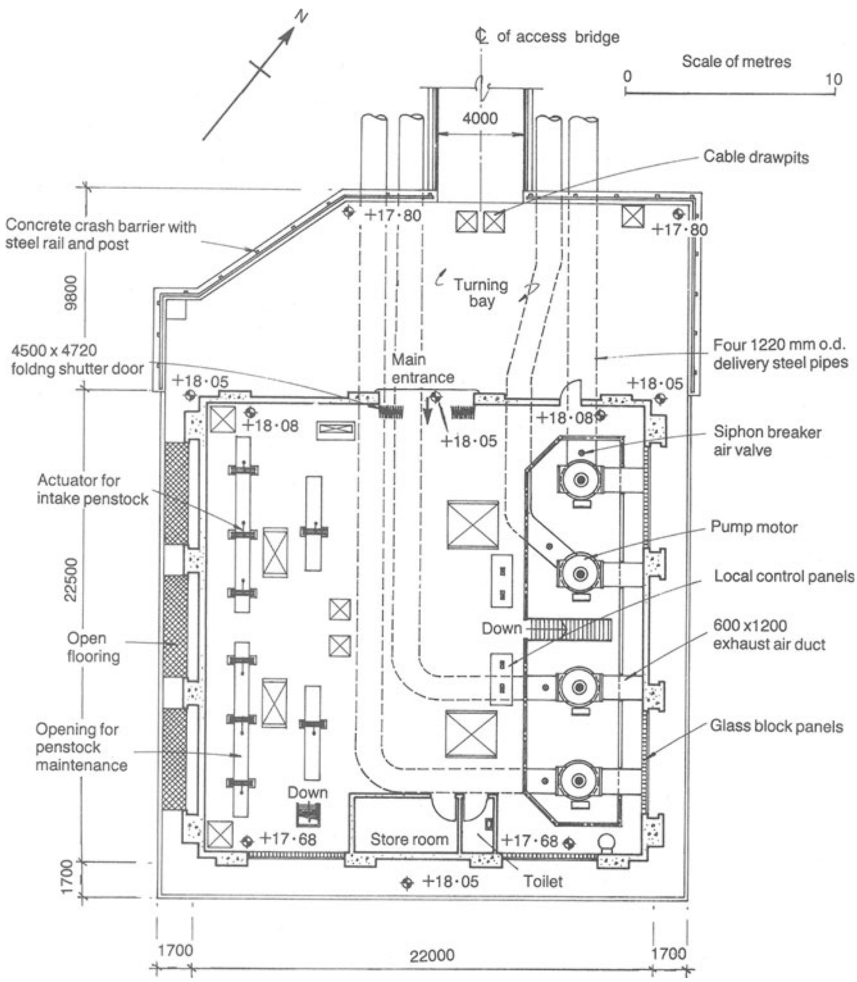


Figure 6.14 *Main entrance floor plan of Tai Mei Tuk B pumping station, Hong Kong (Source: McMeekan & Yue[31])*

marine pipelines and a tunnel. The intake consists of a draw-off tower built in deep water above a shaft and connected to the pumping station by a 780 m long rock tunnel. An intermediate shaft on Harbour Island provides isolating facilities at the end of the tunnel to protect the station from flooding. A major factor in the design and contract documentation was the need to leave scope for ingenuity to overcome the unusual construction conditions. Because of the shortage of working space and the access restrictions requiring Tai Mei Tuk to be serviced from Harbour Island, all major civil engineering works for the two pumping stations were included in a single contract, carried out between 1985 and 1987 at a cost of HK$147.15m.

Tai Mek Tuk B Pumping Station

The possible area for an onshore pumping station was restricted as encroachment into the country park was not permitted. An economic study of relative construction costs of intake culverts or channels, pumping stations, access bridge and delivery systems resulted in an offshore pumping station with direct intakes to extract down to –4.20 m PD, being located approximately 300 m offshore where the reservoir bed is at about –8 m PD. A pump-assisted siphon system was selected with four vertical spindle wet well pumps, each rated at 2.66 m^3/s at 17.8 m total head, delivering into individual 1200 mm diameter pipelines.

McMeekan and Yue[31] have described how the offshore works are in a very exposed location and wind and wave loads were thus a major factor in the design. The reservoir level can range from a maximum top water level (TWL) at 14.02 m PD at overflow to the minimum draw-off level at –8.23 m PD. The offshore works must be capable of withstanding the hydrostatic pressures and uplift when the station is dewatered for maintenance as well as wind and wave forces. Mean hourly typhoon wind speeds with a return period of 100 years were assessed to be 179 km/h and 284 km/h for gusts. The significant wave height at TWL was calculated to be 2.29 m with a period of 5 s but the average height of the highest 1% of all waves at 3.82 m was used for the design of rigid structures.

At the feasibility stage, discussions were held with leading contractors to assess the various options that could be adopted for construction of the offshore pumping station. Possibilities included *in situ* caisson (lowering system), cofferdam and float-and-sink methods. The policy adopted during design was to allow as much flexibility as possible in the permanent works to suit potential construction methods. As the *in situ* caisson method was considered the most suitable, a rectangular sump was adopted with a stilling well and two independent pump sumps each provided with coarse screens at the inlet. The layout of the station is illustrated in Figures 6.14 and 6.15.[31]

It was considered important to minimise the visual impact of the pumping station by keeping the roof line as low as possible, while securing

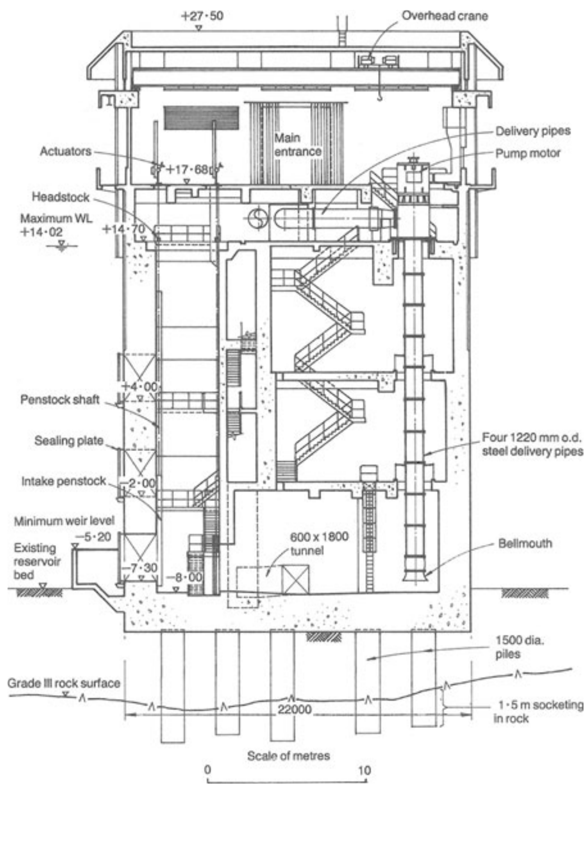


Figure 6.15 *Cross section of Tai Mei Tuk B pumping station, Hong Kong (Source: McMeekan & Yue[31])*

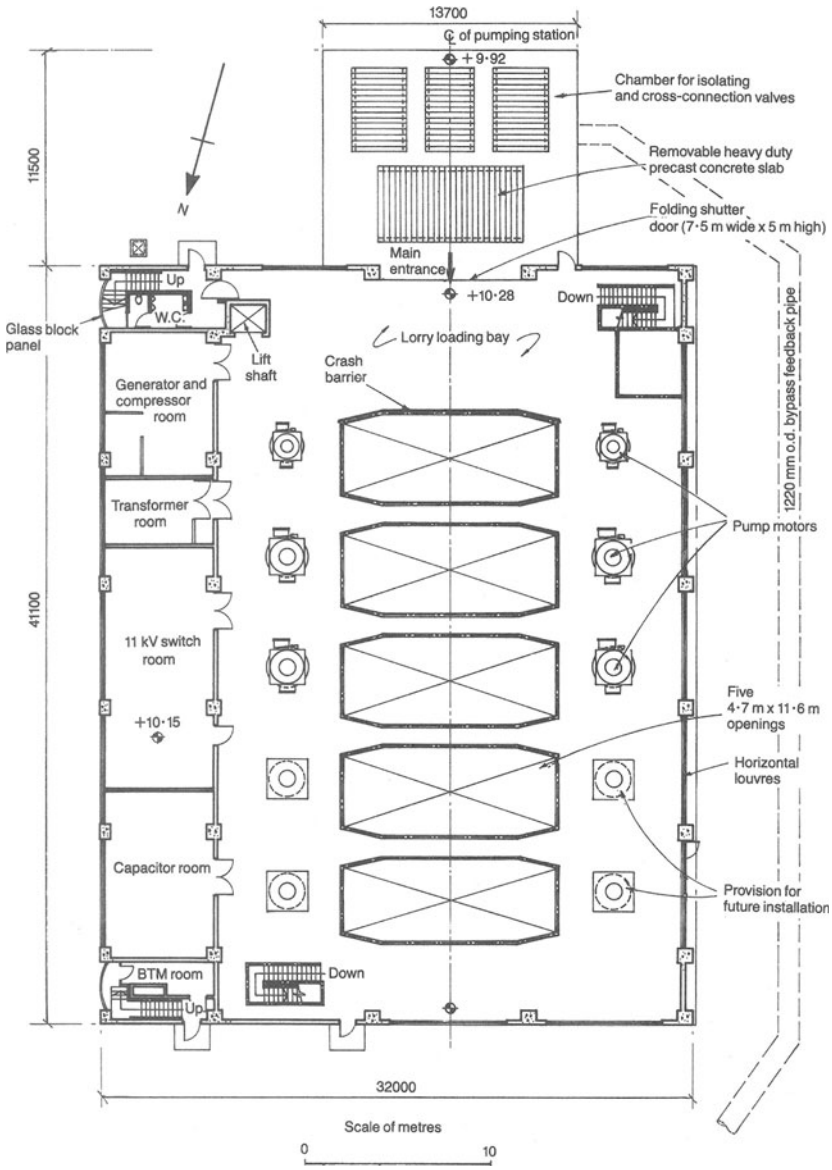


Figure 6.16 *Main entrance floor plan of Harbour Island pumping station, Hong Kong (Source: McMeekan & Yue[31])*

maximum headroom for withdrawing the 21.5 m long pump casing in sections. Hence only the top 13.5 m of the 38.2 m high structure is visible at TWL, when the reservoir is at its most attractive, but the exposed height increases to 35.7 m at BWL, which is not very noticeable amidst large areas of brown topsoil and sea mud. The roof line is attractively shaped, brown textured paint was applied to the superstructure above +17.0 m PD and the top 11 m of the substructure has a fluted finish to good architectural effect.[31]

The substructure was designed to the water retaining code BS 5337 as a structural box, reinforced by a 'tee' in the centre, formed by the dividing wall between the two pump sumps and buttressed by the guide walls of the forebay. The box is further strengthened by intermediate service floors, interconnected by staircases, and by struts at the forebay. The superstructure was designed to CP 110 and consisted of four main portal frames interlinked by crane beams and roof beams, with walls spanning between the frames. A solid foundation was provided by twenty four 1200 mm diameter bored piles. The 300 m long access bridge provides a 4 m wide roadway designed for HA loading, and supports the four siphon delivery pipes.[31]

Harbour Island Pumping Station

Harbour Island forms the southern abutment of the Plover Cove dam with mainly rounded hills up to 104 m PD. The pumping station is designed to extract water from Plover Cove down to −8.23 m PD and pump it through the Tolo Channel aqueduct, 9 km long, to a new treatment works at Pak Kong, with a connection midway for a further treatment works at Ma On Shan. At Pak Kong, there is provision to transfer excess flows into the High Island tunnel and for up to 500 Mld to be fed back through the aqueduct by gravity from High Island to Plover Cove.[31]

The selected site is at a rock outcrop off the

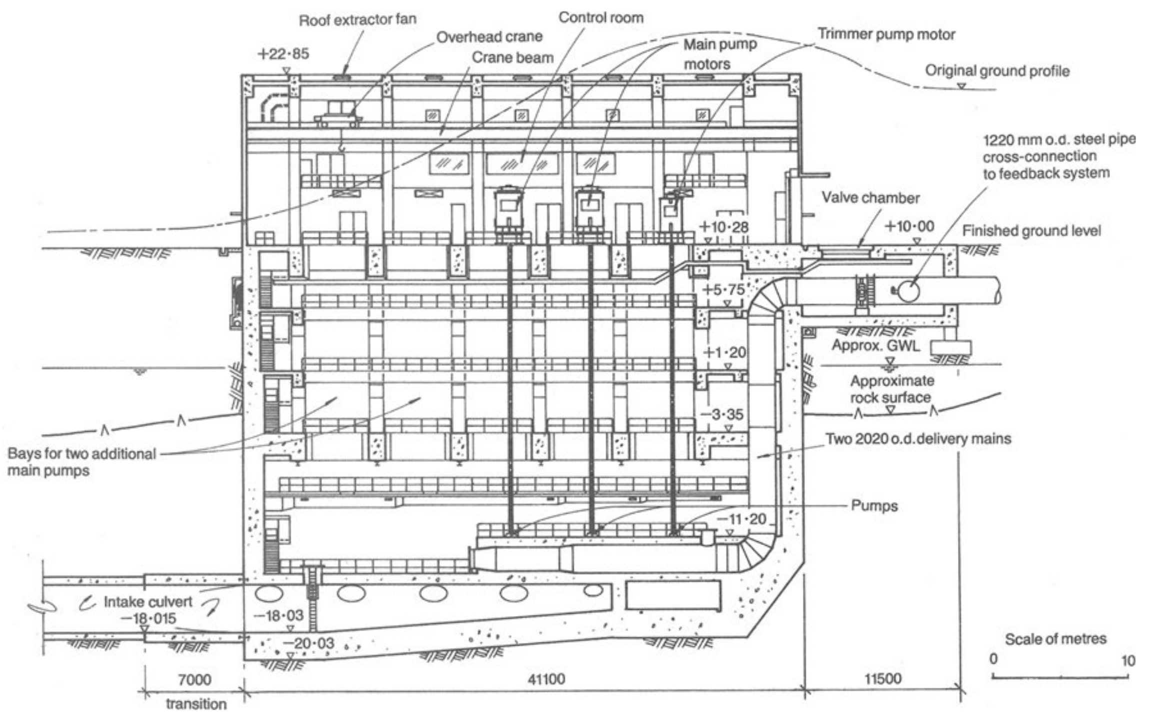


Figure 6.17 *Longitudinal section of Harbour Island pumping station, Hong Kong (Source: McMeekan & Yue[31])*

northern tip of Harbour Island, where soft seams were expected down to substantial depths, but an adequate foundation on rock for the intake tower was anticipated at about 8 m below the reservoir bed at −10.5 m PD. The 780 m long tunnel linking the intake to the pumping station followed an indirect route to obtain better tunnelling conditions under Harbour Island.

Following a hydraulic and economic study, four bottom entry pumps rated at 1.38 m^3/s at 55 m head and two half duty pumps were specified for stage 1 with an additional four main pumps for stage 2. The layout of the station is shown in Figures 6.16, 6.17 and 6.18.[31]

The walls were designed to the water retaining code BS 5337 as panels supported by three horizontal frames, the top frame being the motor floor at +10 m PD, an intermediate frame at −3.5 m PD and the bottom support is the floor. Three further intermediate floors provide access and support to the motor drive shafts. During construction, the contractor elected to cut the rock vertically and to cast the wall concrete against the rock. The reinforced concrete suction twin box culvert contains a number of transitions to provide smooth flow into the pump suctions, and was designed for a maximum head of 40 m during surge conditions. Architectural treatment

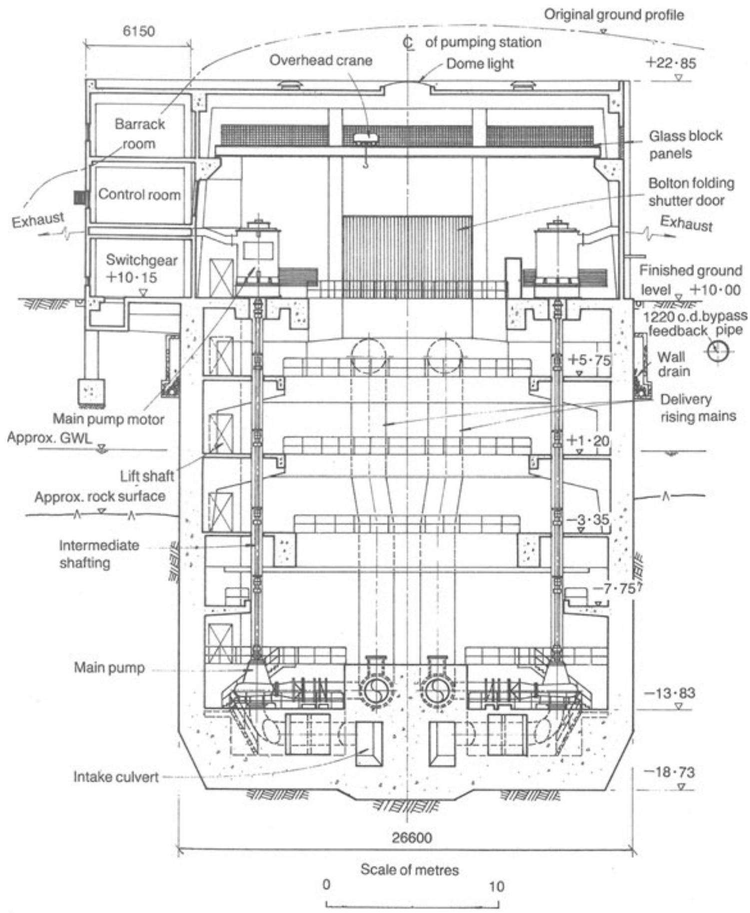


Figure 6.18 *Cross section of Harbour Island pumping station, Hong Kong (Source: McMeekan & Yue*[31]*)*

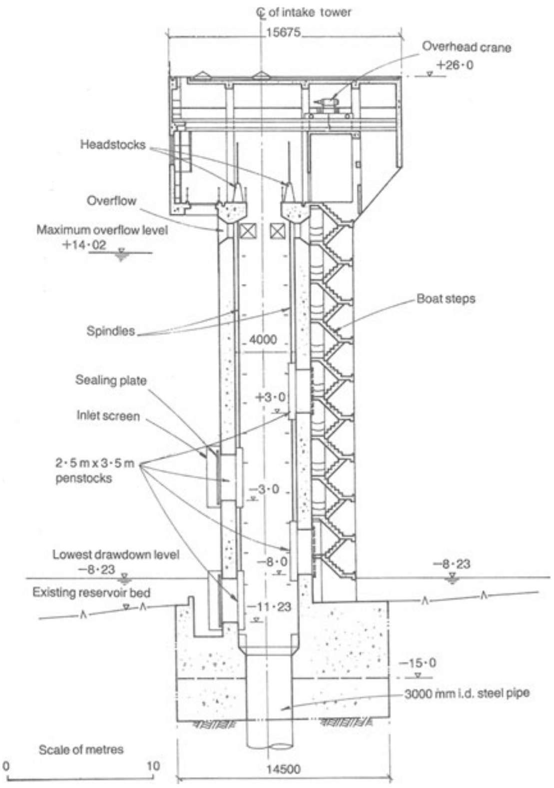


Figure 6.19 *Cross section of Harbour Island intake tower, Hong Kong (Source: McMeekan & Yue[31])*

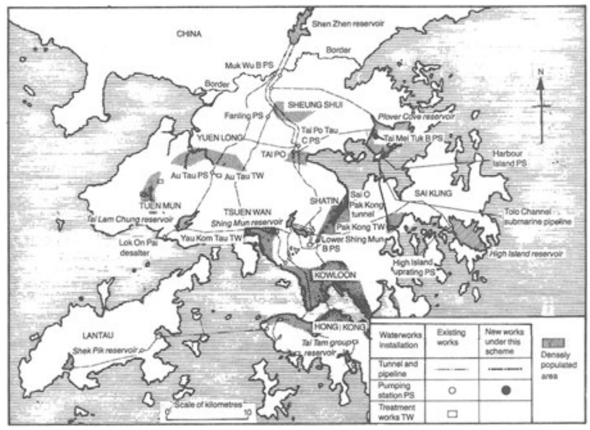


Figure 6.20 *Water supply in Hong Kong (Source: McMeekan & Yue[31])*

is similar to Tai Mei Tuk but without the shaped roof canopy, since the building will be shielded from the access road across Harbour Island by landscaped earth bunds.[31]

The intake tower in the reservoir is a tall slender structure as shown in Figure 6.19. The tower shaft was designed as a core wall with four inlet penstock openings and overflow slots at +15.2 m PD. External stairs allow boat access over the 22.2 m range of water operating levels. The 3 m diameter steel lined shaft connecting the tower with the tunnel at –44 m PD was driven through the variable sandstones. Other associated structures on Harbour Island consist of the 70 m deep pumping station shaft with a submerged discharge chamber for reverse flow from High Island reservoir, a surge vessel pit with twin 150 m^3 pressure vessels and a 1200 m^3 surge feed tank connected to the twin 2000 mm delivery mains.[31] The locations of these pumping stations and other water supply works in Hong Kong are shown in Figure 6.20.

References

1. DOE. *The Water Act 1989: A new structure for the water industry in England and Wales* (1989)
2. A.C. Twort, F.M. Law & F.W. Crowley. *Water Supply.* Arnold (1985)
3. B.H. Rofe. Water supplies. *Civil Engineers' Reference Book.* Ed. L.S. Blake. Butterworths (1989)
4. Severn Trent. *Water Facts: Severn Trent Water – after privatisation* (1989)

5. J.A. Pickford & H.D.M. Speed. Low technology water supply and sanitation in developing countries. *Mun. Engr, 1985, 2, Apr., 69–76*
6. C. Radhakrishnan. Appropriate least cost reliable water supply technologies for developing countries. ICE. *World Water '86: Water technology for the developing world.* Telford (1987)
7. Severn Trent Water. *Water Resources* (1988)
8. Severn Trent Water. *Water Supply: We make it work* (1990)
9. ICE. *Construction research and development; Vol 2: Marked sector priorities.* Telford (1986)
10. ICE. *Floods and reservoir safety: an engineering guide.* Telford (1978)
11. NERC. *Flood Studies Report* (1975) and Institute of Hydrology. *Guide to the Flood Studies Report* (1978)
12. N. Hoyle. Safety of old embankment dams. *Mun. Engr, 1989, 6, Apr., 63–73*
13. P.S. Bulson, J.B. Caldwell & R.T. Severn. *Engineering Structures: Developments in the Twentieth Century.* University of Bristol Press (1983)
14. Carlyle & Field. Mudhiq Dam - abutment stability. *International Congress on Large Dams, New Delhi* (1979)
15. G. Smethurst. *Basic Water Treatment.* Telford (1988)
16. Severn Trent Water. *Mythe Water Treatment Works* (1990)
17. Watson Hawksley. *Lentini Water Supply Scheme, Syracuse, Sicily.* WE/8/81
18. Binnie & Partners. *Bombay Water Supply.* EX9/WSC/18–20/9/88
19. Binnie & Partners. *Water Supply Schemes: Hong Kong.* EX9/WSC/2–4/9/88
20. Binnie & Partners. *Karkh Water Supply, Iraq.* EX9/WSC/25–6/9/88
21. Binnie & Partners. *Karkh Water Treatment Works, Iraq.* EX9/WTOS/20–1/8/88
22. P.A. Brown. The impact of technical problems on the project. *Overseas projects – crucial problems.* ICE (1988)
23. B. Dumbleton. Tapping natural resources. *New Civ. Engr, 5 Oct. 1989*
24. Watson Hawksley. *The Jersey New Waterworks Company Ltd. Queen's Valley Reservoir: Design Report (Main Report)* (1986)
25. Watson Hawksley. *The Jersey New Waterworks Company Ltd. Queen's Valley Reservoir: Presentation to Directors and Staff* (1988)
26. R. Byles. Perfect piping. *New Civ. Engr, 27 July 1989*
27. M. Winney. Replacement mains squeeze in. *New Civ. Engr, 2 July 1987*
28. D. B. Field, G.F. Moss & S.H. Whipp. Distribution and collection systems. ICE. *World Water '86: water technology for the developing world.* Telford (1987)
29. J. Robbins. Bringing charges. *New Civ. Engr, Water Supplement, Sept. 1990, 65–6*
30. W.J. Dickens & I.H. Bensted. London water ring main. *Proc. Instn Civ. Engrs, Part 1, 1988, 84, June, 445–74*
31. J.F. McMeekan & K.P. Yue. Pumping stations at Plover Cove reservoir and Tolo Channel aqueduct, Hong Kong. *Proc. Instn Civ. Engrs, Part 1, 1987, 82, Dec., 1089–1119*

7

Development and Redevelopment of the Built Environment

Planning and Building Regulation Control and Environmentally Friendly Buildings

Planning Control

Outside Greater London, each county has two tiers of local authorities concerned with town and country planning. Some planning functions – notably the preparation of structure plans are the responsibility of the county council as 'county planning authority', but many matters have been entrusted to the district councils. In Greater London, all aspects of town and country planning rest with the Greater London borough councils and the metropolitan district councils.[1]

Structure plans are in the form of policy documents covering the main planning problems of the area and the best way of dealing with them. The detailed solutions, including land allocations to specific uses, are contained in the local plans. In preparing these plans, the local planning authorities are required to consider measures for the improvement of the environment and the management of traffic, and they are expected to identify action areas that require comprehensive treatment in the foreseeable future by way of development, redevelopment or improvement or by a combination of these methods. The structure and local plans also have an important role to play in the consideration of an application for planning permission, since the local planning authority will need to have regard to the policies laid down in the structure plan and the more detailed provisions of an operative local plan, when making a decision.[1]

The requirements as to planning permission are a key feature in the regulatory planning system. They are largely dependent on the definition of 'development' in section 55 of the Town and Country Planning Act 1990 – namely, the carrying out of building, engineering, mining or other operations or the making of any material change of use of buildings or other land. Where an applicant for planning permission is aggrieved by the decision of the local planning authority, he may appeal to the Secretary of State, whose decision is final except for an appeal to the High Court on points of law. In certain instances, he may have a right to compensation or be able to serve a purchase notice where the land has become incapable of reasonably beneficial use. Where development is carried out without planning permission or in breach of the operative conditions, the authority may issue an enforcement notice.[1]

Local planning authorities also have powers of control relating to the preservation of trees and woodlands, display of advertisements, tidying up of waste land, control of hazardous substances and the preservation of buildings of special architectural and historic interest. They may also designate conservation areas in which special attention will be paid to conservation and improvement. The Secretary of State has the power to designate an urban development area (UDA) and set up an urban development corporation to secure the regeneration of the area, and can designate enterprise zones within which developers have considerable freedom to carry out commercial and industrial development without the need to apply for planning permission, and they have certain fiscal advantages, such as relief from local authority business rates.

In 1986, 'simplified planning zones' were introduced to extend the type of planning arrangements operating in the enterprise zones to other areas.

There is a tendency for many towns to spread outwards into the surrounding countryside, with the consequent disadvantages of making the countryside more remote from town dwellers, imposing even longer and more congested journeys to and from work for those living outside the town, and the possible coalescing of neighbouring towns. The establishment of 'green belts' is one important way of checking the unrestrained sprawl of towns. Since 1955, local planning authorities have been urged to designate green belts, which also serve the following functions: safeguarding the surrounding countryside from further encroachment; preventing neighbouring towns from coalescing; preserving the character of historic towns; assisting in urban regeneration; and retaining relative ease of access for urban dwellers to the countryside.[1] In 1988, green belts in England Wales covered approximately 1.8 million ha.[2]

The Town and Country Planning Association (TCPA) in 1989 strongly advocated the creation of regional strategic plans which identified the regional needs and suitable locations for the main land uses, and areas which should not be built upon. These plans would also need to define ways of dealing with the development pressures arising from major infrastructural projects, such as Stansted Airport, and of resolving the economic disparities occuring between different parts of the region. In 1990 the only regional plan was the guidance framework provided by SERPLAN (a federation of local authorities in South East England) which TCPA considered needed strengthening. TCPA identified the need to include a range of healthy free standing communities, such as market towns and garden cities, offering a good quality of life for the residents. It was argued that for all too often in the past peripheral growth has been on such a scale at to ruin the character of formerly pleasant towns and villages and the infrastructure has been stretched to the limit. By planning entirely new settlements in suitable locations, the pressure can be removed from existing vulnerable settlements and urban sprawl curbed.[3]

Building Regulation Control

Proposals for most new buildings, extensions and material alterations or changes of use are subject to the Building Regulations 1985 and subsequent amendments. This entails notifying the appropriate local authority and complying with the Regulations. The main purpose of the Regulations is to ensure the health and safety of people in or about the building, and they are also concerned with energy conservation and access to the buildings for the disabled. The client may choose either the local authority or a private approved inspector to supervise the work.[4]

Where the client opts for local authority supervision, he has a further choice of depositing full plans or submitting a much less detailed notice, and a fee is payable to the local authority. The local authority can prosecute if work is started without taking either course of action. Where a private approved inspector is selected, the client and the inspector must jointly give the local authority an initial notice accompanied by a site plan. Work must not be commenced before the notice has been accepted by the local authority.[4]

Move towards Environmentally Friendly Buildings

Apart from statutory requirements for buildings, there was in 1990 a strong and increasing awareness of the urgent need to produce more environmentally friendly buildings. This was accompanied by a statement from the Engineering Council Assembly in July 1990 which emphasised the role and responsibilities of the engineering profession and individual engineers in creating a cleaner environment, urged the government to formulate national policies on energy, transport and waste management coupled with tax and fiscal incentives where appropriate, following the government initiative in the 1990 White Paper on the Environment *This our Inheritance*, and encouraged industry to develop energy efficient and environmentally friendly products suitably coded.[5]

Chlorofluorocarbons (CFCs) are man-made chemicals mostly used in the building industry and they constitute a main cause in the thinning of the ozone layer and the 'greenhouse' warming of the earth, culminating in the Montreal Protocol in 1987.[6] The UK government expressed its intention to eliminate all sources of CFCs by year 2000 and to significantly reduce the production of halon. BRE information paper IP 23/89[7] detailed how the use of CFCs can be minimised in the short term and completely replaced in the long term. The implications for users and specifiers of air conditioning equipment, and of using alternative insulation materials in roofing, walls, flooring and timber frame construction, are given, including technical risk issues.

The most important greenhouse gas is carbon dioxide (CO_2), the levels of which have risen by 25 to 30% since 1840. The single largest source of CO_2 results from burning fossil fuels to supply energy needs and, in the UK, over one half of all energy production is consumed in buildings. Levinson *et al.*[8] identified the following three straightforward techniques which could assist significantly in producing environmentally friendly buildings:

1. to produce energy efficient buildings with a minimal need to burn fossil fuels or use expensive electricity, and generating large cost savings
2. to ensure that materials used in buildings are environmentally friendly, such as ceasing to use tropical hardwoods
3. to ensure that buildings are managed so that they continue to have a low environmental impact.

Developers of new buildings designed to be more environmentally friendly can seek recognition through a BRE environmental assessment method (BREEAM), which was introduced in 1990, starting with office buildings, to cover a range of issues affecting the global, neighbourhood and internal environments, and gives credits for each aspect of design where specific targets are met, and this was extended to new homes and superstores in 1991. Global issues encompass global warming, ozone depletion, rain forest destruction, and resource depletion. Neighbourhood issues comprise Legionnaires' disease (from cooling towers), local wind effects and reuse of existing sites. Indoor issues embrace Legionnaires' disease (from water supplies), lighting, indoor air quality and hazardous materials.[9]

Housing Development

This section of the chapter examines post war housing experience in the UK, Hong Kong and Singapore, to illustrate their diverse approaches faced with very different situations, conditions and philosophies, and their varying degrees of success. The engineering aspects centre mainly around the infrastructure and the frameworks of high rise buildings, but it was felt that an appreciation of the general background would be helpful to the reader.

The UK Experience

Housing Agencies, Stock and Dwelling Types

Smith[10] has usefully categorised housing in a number of different ways, such as form of tenure, type of agency carrying out the development, physical form, standard, price, age and condition, giving an indication of the complexity and variety of this type of development. In the past housing has been broadly classified as public or private, but these divisions are becoming less clear as, for example, private finance is channelled into some housing associations and partnership arrangements are entered into between local authorities/housing associations and private developers. Housing associations, which are charitable organisations, largely supervised and funded by the Housing Corporation, were in 1989/90 being encouraged by central government to take over stocks of local authority dwellings and to become the main providers of social housing. At the same time, the government was encouraging owner-occupation, including the sale of local authority houses and drastically reducing the funds available to local authorities for providing new houses or, indeed, to adequately maintain existing houses. The total maintenance backlog in housing was estimated at £50b in 1990. The private rented sector shrunk from 45% in 1953 to 8% of all housing in 1990, in sharp contrast to most other European countries.

The housing stock in the UK increased from a little over 14m in 1951 to nearly 22.5m in 1985. Since the second world war, about 1.5m dwellings have been demolished under slum clearance programmes and most of the households in them rehoused in local authority accommodation. Despite a considerable improvement in the supply of basic amenities, the house condition surveys in 1981 and 1986 showed an increase in the number of houses needing major repairs and that about 1.2m occupied houses were unfit for human habitation. The housing needs of single persons and the elderly were increasing rapidly in the late 1980s with little action being taken to satisfy their requirements, and the number of homeless was increasing at an average rate of 14% annually. As central government cut back investment, local authority annual house building starts dropped from 110 000 in 1975 to 13 000 in 1989, and was expected to fall to 5000 in 1992. This was exacerbated by housing association new housing starts also being substantially reduced in 1989/91 because of inaccurate forecasting by the Housing Corporation. In 1990 the private sector was struggling to sell many of the new houses it had built because of the high interest rates and a substantial downturn in the property market, resulting in a 30% reduction in private sector house starts from the first quarter of 1989 to the first quarter of 1990. These statistics show how housing supply is influenced to a great extent by economic and political factors, at the very least in the short term. In 1990, about 64% of dwellings were owner-occupied and this proportion was expected to increase ultimately to around 80%.

The choice of dwelling types to be built on any site is influenced by many factors, and it is often a compromise between the ideal mix of houses and flats to meet the requirements of the householders and the prices which they can afford. Britain's housing stock consists of approximately 80% of houses stemming from the preferences of the occupiers and the availability of sufficient building land, in contrast to the conditions prevailing in Hong Kong and Singapore, described later in the chapter. In 1983 the proportions of different dwelling types in Britain were detached houses: 17%; semi-detached houses: 31%; terraced houses: 32%; purpose-built flats or maisonettes: 14%; converted flats or maisonettes/rooms: 5%; and other dwellings: 1%. As to the numbers of bedrooms per dwelling, the approximate proportions on an average estate could be one bedroom: 10%; two bedrooms: 20%; three bedrooms: 60% and four bedrooms: 10%.

Housing Contracts and Layouts

In the late 1970s and 1980s the concept of value for money in housebuilding assumed greater importance and the traditional division between design and construction was considered by some to be a major obstacle to achieving greater efficiency in the building process. A DOE report[11] in 1978 proposed several ways of reducing building costs by linking the design and build processes on design/build contracts, adopting a vigorous approach to designing for buildability, using standard designs and particularly detailing, and providing continuity of work for reliable and competitive builders.

A subsequent paper *Homes for the Future – Standards for New Housing Development*[12] rightly stressed the importance of adequate briefing and feedback, embracing all relevant design and maintenance personnel and, preferably, future residents especially where the development involved high densities and a preponderence of rented housing. The brief should, at the very least, secure agreement on site boundaries, dwelling mix, form of building, including possible use of prefabrication, industrialised housing techniques or timber frame construction, type of access, layout features, management of scheme, capital/maintenance cost budgets, heating arrangements, vehicular servicing of the development, waste disposal, children's play, and policy towards housing elderly and disabled persons.

As to densities of housing development, detached houses rarely exceed 20 dwellings/ha, semi-detached: 30, and terraced houses: 50. However in cities densities can be as high as 500 persons or bedspaces/ha, but even when land is scarce it is generally considered undesirable for densities to exceed 350 persons/ha. Furthermore, there is often little saving with high densities because of the ancillary needs of access, car parking, waste disposal units and essential open space between and around building blocks.

The planning and design of public housing schemes since the early 1960s have often been directed towards the separation of the pedestrian from the motor vehicle. and this concept has been particularly extensively used in new and expanding towns. Reliance on footpaths and a variety of forms of pedestrian precincts as the means of approach to dwellings, combined with suitably screened parking or garage courts located within acceptable walking distance, has provided unique opportunities for the informal grouping and siting of dwellings to obtain maximum privacy and sunlighting. The principle of traffic segregation has thus resulted in visually attractive environments, where the pedestrian has pride of place and children can move in relative safety.

BRE digest 350[13] deals with the practical effects of microclimate on site layouts, showing that solar access and wind control/design are both likely to have significant effects on the size, form, massing and orientation of buildings. Shelter from northerly winds is likely to be most appropriate in general inland sites with no strong directionality. In other cases, such as where funnelling occurs, on or near coasts, or where protection from driving rain is sought, other criteria could apply. The main implications of solar access for the layout of dwellings are:

1. aim for maximum road length running within 15° of E-W
2. arrange plot shapes to allow wide, south-facing frontages, to maximise solar gain through windows
3. plant coniferous trees to the north of houses and deciduous trees to the south
4. select the dwelling type and form to limit overshadowing, as illustrated in BRE digest 350.[13]

The former GLC identified two general principles governing the layout of housing, namely the need for privacy and community, which might at first sight appear to be in conflict. Privacy can be assured by density, distance and geometry, while community is determined by the number of dwellings and their relationship with one another. In *An Introduction to Housing Layout*[14] the GLC endeavoured to throw light on these important aspects to provide designers with a framework on which to proceed. The reader will find this book on housing layouts instructive as it describes and illustrates the four main factors of organisation of space, access roads, parking and pedestrian movement, which are analysed in terms of scale, territory, visual interest and order, supported by numerous examples of developments illustrating these themes, and including four useful case studies of GLC housing schemes. One GLC layout comprising traffic segregation is illustrated in Figure 7.1.

Post War Experience

Immediately after the war in the late 1940s, many prefabricated bungalows were built to assist in overcoming the acute housing shortage. These were of two main types: one with a design life of 10 years and usually clad in asbestos cement sheeting, and others with a design life of up to 60 years with aluminium sheeting or precast concrete panels externally. These dwellings were much liked by the occupants as they were convenient with plenty of fittings, well insulated and generally had whole house warm air heating. However, they were relatively expensive, had long frontages and were aesthetically unattractive.

Subsequently, public housing comprised a mixture of system built houses and traditional bricks ones, of which the former had the advantage of faster erection times but the latter were more durable and of improved appearance. The former London County Council (LCC) pioneered 'mixed development', with point blocks, slab blocks, 4-storey maisonettes, terraces and single storey houses, to accommodate varying family sizes and houses, which proved to be both successful and popular.[15] The best known example is probably the Roehampton Estate completed by the LCC in 1951, containing a

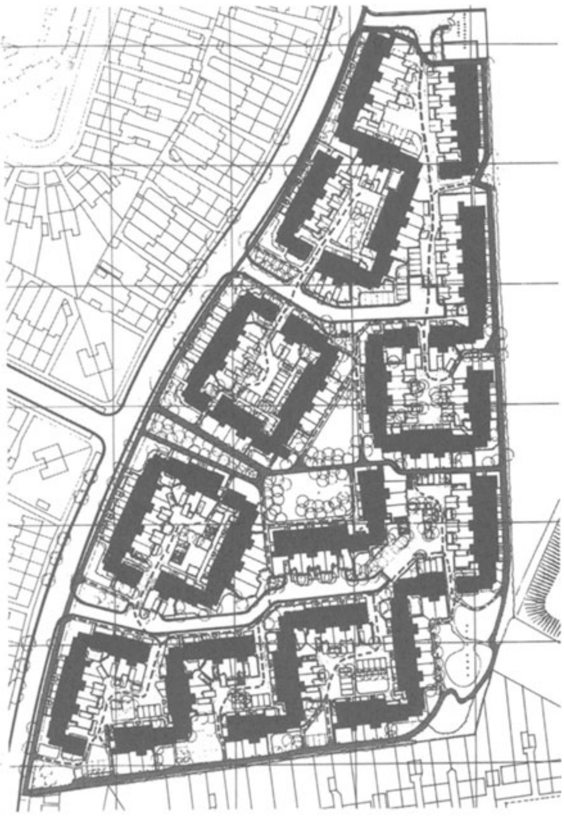


Figure 7.1 *Housing layout comprising traffic segregation (Source: GLC, An Introduction to Housing Layout*[14])

mixture of 11-storey point blocks, 4-storey maisonettes and 2-storey houses in a picturesque parkland setting in south-west London.[16]

This was followed by central government encouraging local authorities by advice and grants to use system building to achieve housing targets more swiftly, incorporating steel frames, timber frames and concrete panels. This culminated in the building of high blocks of flats using prefabricated techniques, attracting higher grants, to partially offset much higher construction costs, to quicken erection times and increase densities, thereby taking less land to accommodate an incorrectly estimated large increase in the country's population. Despite their general unpopularity with occupants, poor appearance and the many constructional and maintenance problems, and extensive demolition of tower blocks, there were still 4600 such blocks in Britain in 1988.[15]

The principal defects associated with system built dwellings encompassed the breakdown of precast concrete panels, spalling of concrete, rusty and defective reinforcing bars, insecurely fixed wall ties, water penetration, excessive condensation, additional fire risks and inadequate refuse disposal systems. Dissatisfaction with high rise flats rose dramatically following the gas explosion and progressive collapse encountered in the Ronan Point flats in London in 1968, which resulted in 5 people being killed and 17 injured. The subsequent report on the disaster showed that the structure merely followed national design trends which had been inadequately researched, and all owners of high rise blocks with large precast concrete panels forming load-bearing walls and/or floors were requested to undertake appraisals and strengthening of the structures where necessary. Following the high alumina cement scare of the 1970s, locating, investigating and sometimes rebuilding about 50 000 structures that contained HAC cost the UK over £70m.

Deck access housing has been condemned as producing a combination of problems, most of which are associated with poor design and construction, and by 1990 many of these blocks had been demolished. Bacon[17] identified the problems as threefold – construcion, access and appearance. Water penetration, inadequate sound and heat insulation, poor ventilation and expensive heating were among the construction defects. Decks which gave access were often used for anti-social purposes, such as dogs' excreta and vandalism in deserted common areas. The unusual and inhuman appearance of most of the estates had contributed to the spiral of decline. On the Hulme Estate in Manchester over 3750 deck access dwellings were system built between 1967 and 1971, and structural and design faults had developed within five years of their completion. In the long term the Council were committed to eliminating deck access dwellings, approximately

£1.5m was spent up to 1986 on design improvements, remedial works and disinfestation, with a further £3m required to maintain them prior to demolition, compared with the prohibitive cost of £75m required to bring them up to a standard suitable for human habitation (1986 prices).[19] Hence many local authorities returned to the development of low rise estates, because of the many disadvantages of high rise blocks.

In the mid 1980s, timber frame housing was being used to a significant extent until a BRE interim report in 1985[18] identified faults relating to fire resistance, strength and stability, durability and differential shrinkage. There was a sharp decline in the use of this technique, although a survey carried out jointly by TRADA and DOE in 1986 identified the underlying factors for the deficiencies as lack of supervision, care and information, despite all the guidance information available and, in particular, poor storage and lack of protection of components was prevalent.

Hence much of the post war housing in Britain has created a massive legacy of urban housing problems, which was highlighted in the RIBA report on decaying Britain[20] and other reports emanating from the Committee chaired by HRH the Duke of Edinburgh[21], the Committee commissioned by the Archbishop of Canterbury[22] and the RICS report *Housing: The Next Decade*.[23] However, there have also been numerous low rise housing developments which have been skilfully designed and soundly built and there are many good examples in new and expanding towns, rural areas and elsewhere.

A considerable improvement in architectural standards could, the author believes, follow from consideration and implementation of many of the main criteria advocated by HRH the Prince of Wales, [24] who has made a detailed study and investigation of the design of the built environment. His main themes were harmony (each building in tune with its neighbour); enclosure giving a feeling of well being, neighbourliness, cohesion and continuity; materials (using local materials as far as practicable to retain and enhance local character); community (providing the right sort of surroundings to create a community spirit, with community involvement); and quality of character, fostered by attention to detail and human scale. In a reference to tower blocks, the Prince of Wales very aptly described how all over Britain local authorities were subsidised to build gaunt and unlovely towers which rose like great tombstones from pointless and windswept open spaces, like the unattractive, badly sited and over- conspicuous blocks he illustrated in Newcastle. In stark contrast, he indicated how the traditional English village shows how buildings can enhance the landscape, being designed as part of it and developed in an organic way.

Hong Kong Experience

General Background

The population of Hong Kong increased dramatically from 3.1m in 1961 to 5.4m in 1986, with immigration, both legal and illegal, having a significant influence until the early 1980s. By 1981, population densities in the older urban areas were as high as 170 000 people per km^2 (Mongkok district), while squatter areas were another symptom of overcrowding and makeshift living conditions. The total population is projected to reach 6m by 1996.[25] To combat these pressures the Hong Kong government introduced a 10 year housing programme in 1972 to serve 1 800 000 people, and established the first New Towns at Tsuen Wan, Sha Tin and Tuen Mun, where the greater availability of land enabled the new generation of estates to be planned with a housing density of about 2500 people/ha, with space provided for recreational purposes, schools and kindergartens, commercial centres and other supporting services required by the new communities.[26]

Hong Kong's latest housing strategy aims to provide 1m public and private housing units by the begining of the next century, including the redevelopment of obsolete public housing estates and the fostering of wider home ownership. Despite times of high bank lending rates and escalating land prices, private provision has continued at a brisk rate and a variety of large scale multi-million dollar projects have been completed on Hong Kong Island and in Kowloon and the New Territories.

Housing Policy and Provision

Lim Yew-guan[27] has described how public housing was started in Hong Kong in 1955, following a devastating fire in a densely populated squatter area of Kowloon (Shep Kip Mei) on the mainland, which left 50 000 people homeless. In the first 25 years, the public housing programme concentrated on the production of rental housing for low income families, those affected by government clearance operations and people made homeless by natural disasters. In 1980, the home ownership (HOS) scheme was introduced by the government to help those who wished to own their own homes, with an initial target of 5000 flats per year. By 1989, almost half of the 5.6m population were accommodated in public sector housing with nearly 0.5m people still in temporary housing.

An example of public housing has been taken from Junk Bay (Tseung Kwan), which is one of the youngest of the New Towns, covering 1400 ha, with a dramatic setting close to the coastal and mountain recreation areas of Sai Kung District, and connected with good road access by twin tube tunnel and no doubt subsequently MTR to Kowloon. The town is built around four main self-contained districts with a total projected population of 440 000, and the third university is sited by the coast just outside the town. The first public housing estates were completed in 1989 and Plate 19 shows the distinctive trident housing blocks, further work under construction, the roads winding up the mountainside and the spectacular coastal and landscaped mountainous scenery.[25]

The private sector participation scheme (PSPS) was introduced in 1979 as a supplement to the main home ownership scheme. Later it was expanded doubling the number of flats made available for sale to a target of 10 000 flats each year from 1985. Under the scheme, land is offered for tender by private developers who are required to build flats conforming to pre-set specifications, including the number of flats, sizes, standards, finishes, and the provision of estate amenities. The sale of flats is underwritten by the housing authority.[27]

Figure 7.2 shows an unusual and quite spectacular private development in the Kornhill Estate, Quarry Bay, which was carried out by the Mass Transit Railway Corporation. It comprises around 5920 dwellings in 24-storey blocks, varying in size from 74 to 93 m^2.[28]

Engineering Aspects

Daughton[29] has described how Hong Kong's housing development can offer virtually every challenge a geologist could envisage, as building on difficult ground is the only solution to Hong Kong's chronic overcrowding. In Lam Tin in the New Territories, it was necessary to remove 4.5m cubic metres of mainly granite rock, in order to provide low cost rental housing to accommodate 17 000 squatters, from make-shift homes, in the new development, which will eventually increase in population from 55 000 to 120 000, with supporting schools, shopping complexes and sporting facilities.

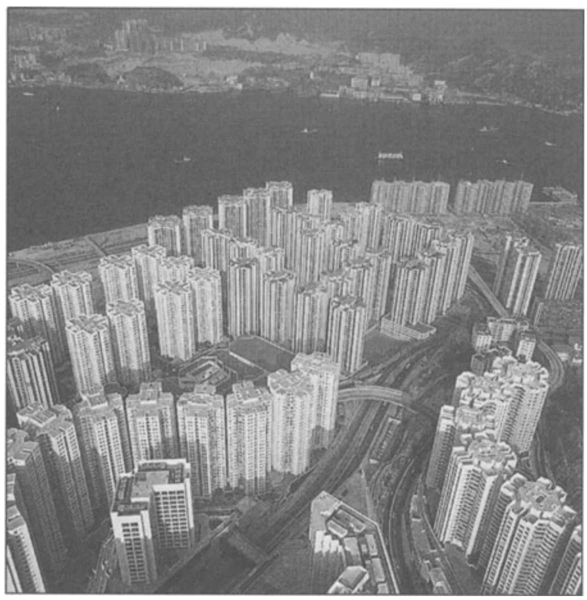


Figure 7.2 *Kornhill housing estate, Quarry Bay, Hong Kong (Source: Territory Development Department, Hong Kong)*

The technical difficulties were highlighted in 1972 when construction work resulted in a fatal landslip that destroyed a high rise block and many smaller dwellings. Since then, the Hong Konk government created a department which checks geotechnical designs for all new developments. At the design stage in Lam Tin, in depth surveys of the rock included impression packer testing down boreholes, which enables geological fracture patterns to be measured in places that are not easily visible. Rock joint discontinuity surveys were also carried out to check the direction and inclination of joints in the rocks so that they could be studied for potential failure. In addition, the engineers had to take into consideration the closeness of the existing housing estate, three schools and two reservoirs. A study of early blasting results made possible the prediction of ground vibrations and determination of permissible charge weights, so allowing the blasting work to proceed within safe limits.[29]

The excavated material was transported along a 2 km haul road, purpose built for the contract, across steep terrain to Junk Bay, where it was used in reclamation work preparatory to further housing development. Crushers reduced the rock to less than 200 mm maximum dimension, which has proved to be an acceptable size to allow driven pile foundations to be used for the new housing blocks. Included in the contracts was the construction of a 1.5 km road and two 75 m multi-span two lane bridges over the steeply sloping site to link the new extension to the rest of the estate.[29]

Land formation is the key to much of the development process in Hong Kong, because 80% of the Territory is very hilly terrain, and much development is dependent on the relamation of land from the sea, river valleys and other low lying land prone to flooding in prolonged periods of torrential rain, and this aspect will be considered in more detail in chapter 8.

Reclamation involves a continual search for sources of suitable fill materials, and the most common method in the past has been to extract fill from the hillside 'borrow areas'. Borrow areas are selected to yield top layers of soft, decomposed rock, which is excavated, transported and dumped in or near the sea. This approach to reclamation is particularly productive because many borrow areas themselves, once excavated, can be levelled to form platforms for development, besides facilitating development of the land reclaimed, as shown in Plate 20, illustrating early borrow developments at Sha Tin. The slopes to the borrow areas must be cut back carefully and, if necessary, supported by retaining walls to guard against landslips.

A typical public housing estate of 20 000 or more residents involves a lead time of about five years from the inception of the planning brief to completion. The main development stages are usually 12 to 15 months for acquisition and site clearance, 12 to 15 months for site formation, 6 months for piling and 24 to 30 months for building. A typical 35-storey public housing block needs stabilisation piling to a ground depth of 20 to 40 m (the equivalent of 7–13 storeys), depending on geological conditions.[25]

Plate 21 shows very dramatically housing development stretching out from Tsuen Wan New Town to Tsing Yi Island. It illustrates the enormous tower blocks under construction with extensive ancillary works, including the dual lane carriageway and three span bridge, with the substantial waterside frontage and mountains in the background.[25]

Singaporean Experience

General Introduction

The Singapore Housing and Development Board (HDB) was established in 1960 when 9% of its population occupied low cost public housing, inherited from the British Colonial Government, but by 1989 the Board had completed about 650 000 dwelling units, housing 2.3m people or 87% of the population. In just over 30 years, HDB went through four phases of development – first the critical housing shortage of the 1960s, second to meet the rising housing needs of a fast expanding population in the 1970s, third to encourage the care of the aged through special housing schemes (1978 to 1984), and finally to improve the quality of flats.[30] The objectives have also changed from providing basic shelter for the poor to providing a good housing environment for both the lower income and middle income groups, and housing ownership for practically all HDB residents who cannot afford private housing.[31]

Housing Characteristics

With a population of 2.6m and a total land area of 625.6 km^2 in 1989, the population density of Singapore was approximately 4231 persons/km^2, being about double that of London and New York but less than that of other Asian capitals, and is expected to reach 5000 persons/km^2 by year 2000. Between 1960 and 1984, the urbanised area of Singapore rose from about 25 to over 45%, and there is a limit to how much more land can be reclaimed from the sea. Hence the gross residential density for a new town as a whole is pegged at 64 dwelling units or 280 persons/ha, while the net density of residential areas is 200 dwelling units or 880 persons/ha. At this density, and given the relatively large flat sizes, the plot ratio of the built up area is around 1.6 to 2.3. The building blocks are mostly 10 to 13 storey slab blocks generally about 100 m long with 5 to 20% in 4-storey buildings, without lifts, and another 5 to 10% in 20 to 25 storey point blocks.[31] Table 7.1 shows the numbers and percentages of different types of properties under HDB management at the end of 1989. HUDC stands for Housing and Development Corporation Pte Ltd, a government owned company which started its housing programme in 1974 and handed the properties over to HDB in 1982.[32] In 1991, Town Councils took over the management of all housing estates from HDB, and the Board's main future function is to improve the quality of flats and facilities and to provide and promote efficient services to the public.[30]

Table 7.1 *Properties under HDB Management, Singapore (as at 31.12.89)*

Flat type	Total under management	
Sold flats		%
1-room	1,212	0.23
2-room	5,428	1.03
3-room	237,361	44.88
4-room	191,682	36.24
5-room	69,301	13.10
Executive	18,635	3.52
HUDC	5,290	1.00
Total	528,909	
Rental flats		
1-room	27,529	33.73
2-room	36,798	45.09
3-room	15,180	18.60
4-room	1,856	2.27
5-room	134	0.16
HUDC	121	0.15
Total	81,618	
Commercial premises	19,313	
Industrial premises	11,240	
Motor car parking lots	291,537	

(Source: HDB, Singapore[32])

Layout and Design of Housing Blocks

It has been found in Singapore that variations in block design need not be complex and costly. By varying the small details of the block, it is often possible to achieve different and attractive visual impacts. The blocks can be accentuated by the different use of material, colour, column and facade detailing, treatment of roof and other components, with the blocks bent, curved and even looped around to enhance the environment, all built in an attractive landscaped setting. Distinctive roofscapes, block designs, vibrant colours and geometric shapes all help to create a character and identity for the buildings and to reflect the multi-cultural heritage.[33]

The layout patterns have changed considerably since 1960. Initially, the primary concern was the correct solar orientation of residential buildings. Thus to minimise solar penetration in a tropical climate, slab blocks were orientated with their short sides, usually a blank end wall, facing east-west, as carried out in Queenstown and Tao Payoh. By contrast, in the new towns of the 1970s, such as Ang Mo Kio, Bedok and Clementi, solar orientation remained a criterion, but there was also more flexibility in the arrangement of blocks, resulting in a better relationship between building and street, and an attempt was made to distribute open spaces more evenly throughout the new town. At the same time, some low rise blocks were built amidst the high rise blocks to provide added interest and an improved sense of human scale. Figure 7.3 illustrates the layout plan of a neighbourhood of Ang Mo Kio New Town with its extensive landscaping and a neighbourhood centre, swimming complex and primary school. Figure 7.4 shows an aerial view of part of Ang Mo Kio New Town.

In the new towns of the 1980s, precincts were introduced as the basic planning concept. A precinct consists of a grouping of four to eight residential blocks accommodating between 500 to 1000 households. With this smaller scale of division within neighbourhoods of 4000 to 6000

Figure 7.4 *Housing development at Ang Mo Kio New Town, Singapore (Source: HDB, Singapore)*

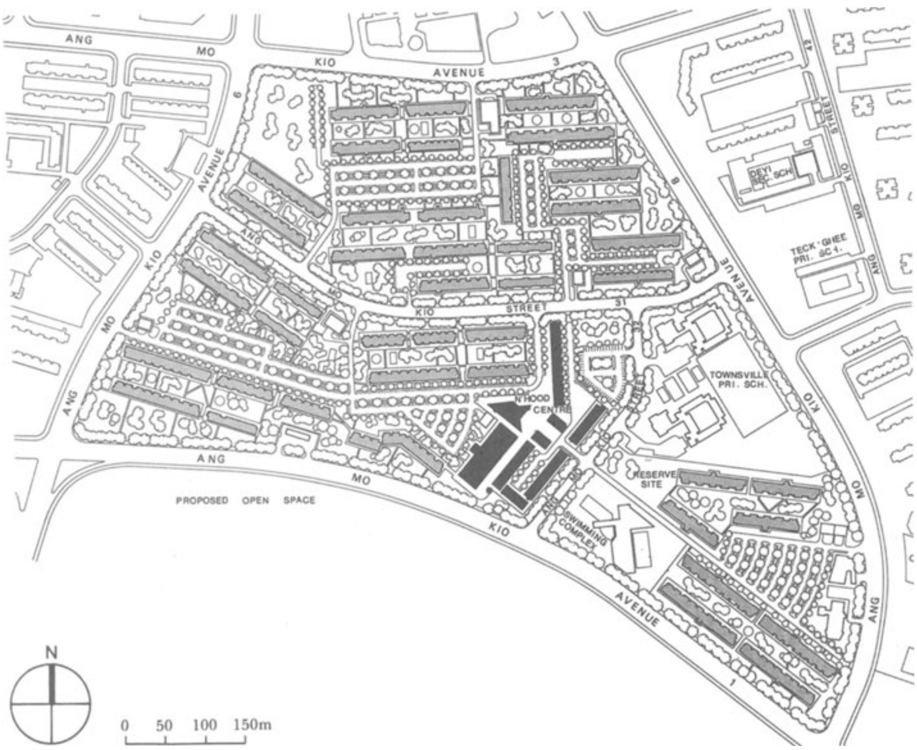


Figure 7.3 *Layout plan, Ang Mo Kio New Town, neighbourhood 3, Singapore (Source: A.K. Wong & S.H.K. Yeh[31])*

dwellings, it was possible to give the blocks a defined visual identity as a unified group of buildings, with a consistent application of selective architectural elements and themes, down to quite fine details. Thus enclosures of communal space were created connected by a network of footpaths and encompassing children's playgrounds and other communal facilities. There was also an emphasis on street architecture and continuity, as illustrated in Figure 7.5, showing part of a neighbourhood in Yishun New Town, surrounding a school site.

Further details of some of the later new towns are shown in figure 7.6 and Plate 22. Figure 7.6 shows part of the housing development at Pasir Ris New Town, overlooking the town park. Pasir Ris had 3284 dwelling units completed in 1988/89, and provides an excellent example of the Board's new design approach – picturesque, with a resort-like ambience and a distinctive character.[34] The town park was designed around an existing pond to preserve the beauty of the natural landscape.[35] Pasir Ris also contains precinct centres with games courts, resting places and playgrounds to give residents a sense of belonging and landscaped linkways define precinct boundaries. Plate 22 illustrates some of the housing at Bishan West New Town, showing an entrance to a car park which marks the precinct boundary and forms a link between two residential blocks. Bishan New Town had 5585

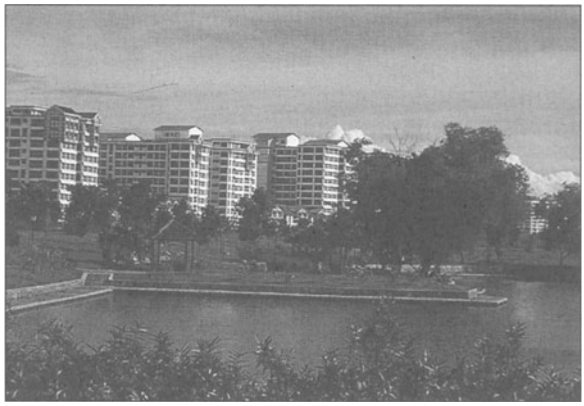


Figure 7.6 *Housing overlooking town park, Pasir Ris New Town, Singapore (Source: HDB, Singapore)*

Figure 7.5 *Layout plan, Yishun New Town, neighbourhood 2 (part), Singapore (Source: A.K. Wong & S.H.K. Yeh[31])*

dwelling units under construction in 1989 and they were characterised by their unique pitched roofs, bands of red bricks and concrete columns and beams.[34]

Civil Engineering Facilities

As soon as a new town master plan is finalised, the civil engineers are among the first to investigate the physical constraints on the site. Subsequently, they initiate the site investigation, earthworks and piling. Next, while the structural engineers start constructional work, the civil engineers have to ensure that the sewers, roads, drains and car parks are completed ahead of the buildings. Then the electrical and mechanical engineers step in to install the lifts, electricity and water supplies, after which the residents can take up occupation, leaving only the other road related facilities such as overhead pedestrian bridges and bus stops to be completed by the civil engineers. Hence the Board's civil engineers are sometimes referred to as the 'first-in, last-out' professionals within the organisation. A typical surface car park consists of well defined parking lots, 4.2 m × 2.4 m in size, and access driveways, 5.4 m wide, with a peripheral drainage system to cater for surface water run-off.[31]

HDB blocks are usually high rise and often have to be built on sites with difficult subsoil conditions, but do not involve the removal of large quantities of rock as encountered in Hong Kong. Where soil conditions permit, buildings are founded on footings, otherwise piling is required. The piling systems used by the Board have changed considerably over the years, resulting from changes in building block design and in technology. For example, in the early 1960s, most blocks were less than 12 storeys high and small and medium reinforced concrete (RC) driven piles were found to be cost effective. In the late 1960s, however, more blocks had larger column loads requiring the use of larger capacity bored piles. Then in 1970, RC spun piles were introduced to meet the anticipated demand for medium capacity piles. Subsequently, these were superseded by the more versatile and speedier steel driven piles. Since 1980 small capacity RC square piles and timber treated piles have been adopted for low rise buildings and large diameter bored piles and H section steel driven piles for high rise blocks.[31]

Retail Shopping Development

Introduction

In the UK in the 1950s and 1960s, there was a growing move towards the pedestrianisation of shopping streets and the establishment of pedestrian shopping precincts, to allow shoppers to enjoy a safe and quiet environment away from the noise and fumes of motor vehicles. The Coventry precinct, built in the early 1950s, was the first wholly pedestrian shopping centre in Europe and was achieved against strong opposition. Subsequently, in 1963 to 1965, a series of planning manuals[36] gave strong support to this type of layout. One of the major difficulties in pedestrianising existing shopping streets is the provision of rear access to 'land-locked' shops to provide adequate unloading space off the highway, and another problem stems from the varying depths of shops.

Segregation of pedestrians and vehicles in shopping streets may be complete or time separated. Complete separation is only possible where it does not adversely affect the ordered existence of the community, permitting goods vehicle access to all premises without entering the precinct or extensive man-handling of heavy packages, bus services can operate effectively, adequate parking space is available, and traffic not requiring access can move around it without impedance. By contrast, time segregation is where separate goods vehicle servicing areas or access to them is only possible at certain times of the day.[37]

In the 1970s and 1980s, extensive developments took place in the provision of out-of-town shopping centres and the construction of large in-town enclosed shopping precincts and examples of some of the modern developments in these areas are described later. Abrams[38] has postulated that one significant force for change in the 1990s will be the continued growth of out-of-town regional shopping centres and the increasing concern of local authorities to protect their towns from economic competition.

Developers, retailers, local authority planners and architects need to consider shops in the context of the street, the street in the context of the town and the town in its region. Furthermore, civic responsibility includes facing up to the problems of traffic, and there is widespread support for tighter restrictions on traffic, and radical transport policies integrated with town centre development are required, as described in chapter 2.

Another important aspect is the desired lifespan of buildings. Whereas development funding seeks and local authorities grant 125-year leases, and developers and architects are asked to design buildings with permanent characteristics, it has become common knowledge that most shopping centres become obsolete within 20 to 30 years of construction. Paradoxically, clients want buildings that are traditional externally but continually renewable inside. A major difficulty results from the long lead time in the development of shopping centres, which creates problems for designers because they do not know how buildings should look in five years time. A regular cycle of refurbishments wastes scarce resources and discourages people from erecting buildings that are appropriate at that time.[38]

In-Town Retail Shopping Centres

The revolution in retail shopping in the 1980s consequent upon rising rents and out-of-town developments, began to change the face of Britain's town centres. Shops were smaller and becoming increasingly specialised. However, the recession at the end of the decade emphasised the desirability of the retail market being retailer-led and not developer-led. During 1987, 55 shopping centres of 4600 m^2 or more were opened, providing between them a total shopping area approaching 710 000 m^2.

Emslie[39] asserted that in 1990 the UK was leading the way in shopping centre design and she believed that it was as good if not better than anywhere in Europe. Emslie also identified two principal reasons for this:

(1) developers could no longer afford to 'let and forget' as investments were too high, returns too important and margins too narrow
(2) developers and retailers were faced with a dramatic change in the public's attitude towards shopping, which had graduated from a necessary chore to a prime time leisure activity, and customers were becoming more selective about where they spent their time and money.

Hence there was an increased visual awareness and appreciation, with emphasis on quality and style, with virtually everything in the customer's view receiving more attention to detail, from brickwork and balustrading, lighting and landscaping, signing and shop fitting to security, fire control and ventilation systems.[39]

Furthermore, local communities often had strong feelings about the kind of shopping centre they would like, actively supported by civic societies. Sometimes the community wanted a development that reflected the historic character of their town or city. At Chester the shopping centre featured the city's Roman heritage, at Carlisle the new Lanes harmonised with the old, while at Guildford historic symbols were interpreted in modern detailing. But history is not the only starting point in shopping centre design, as demonstrated at Birkenhead, where the aim was to create a lively atmosphere within a noble space which provided an escape from outside pressures.[39]

Craft operatives and local materials are also playing a role in restoring detail and character to shopping and town centres. In Carlisle Lakeland slate was used for the roofs, while the patterns of the old streets were recreated in Yorkshire paving and the intricate brickwork required two hundred patterns of specially moulded bricks. There has also been a significant change to the use of natural materials, such as floors of marble, terracotta or even mosaic; balustrading in metal; and wood, glass and brass are preferred to imitation finishes. Emslie[39] rightly emphasises the desirability of handling materials with honesty and sensitivity, such as the plasterwork in the refurbishment of Whiteleys in London's Bayswater which has a human touch, castings and mouldings are genuine and balustrading is manufactured to a design that is sympathetic to the original. Sculpture and art can also form interesting focal points.

Apart from the major new projects such as the 46 500 m^2 of retail space in Canary Wharf, part of London Docklands, the world's largest commercial project in 1990, there have been many major refurbishment schemes. They range from the sensitive restoration and part new build of the world's first department store, Whiteleys of Bayswater, London, to extensive and stylish refurbishments at the Kirkgate Centre, Bradford and Tunsgate Square in Guildford. The Victoria Centre in Nottingham was the first purpose-built shopping centre in Britain in 1972, forming part of a comprehensive urban renewal project, and this was completely refurbished in the mid-1980s, as by that time the centre was looking decidely shabby and outdated, and a £30m expansion scheme was planned for the early 1990s.

In addition, in the early 1990s, it was planned to enhance the second large enclosed shopping centre in Nottingham (Broadmarsh), following its refurbishment in the mid-1980s and to extend it significantly at an estimated cost of £60m. At the same time a new large shopping development was under construction in Leicester, enabling these cities to compete more effectively with out-of-town shopping centres.

Two large modern in-town shopping centres at Ilford and Wakefield will now be examined to identify their main features.

The Exchange, Ilford

In 1991 a major retail shopping centre was provided in the centre of Ilford, funded by Norwich Union and the Prudential, and the work under construction is illustrated in Figure 7.7, and this also shows the bridge link over the main railway line to the right of the illustration. It was estimated that over a million people live within 20 minutes drive of the centre, which also has a commuter railway station beside the development. The centre provides about 28 000 m^2 of retail space in the three level complex, and comprises a major department store, 100 shop units, a themed food court and multi-storey parking for over 1000 cars.

A special feature is the central atrium which provides the trading areas with natural daylight, and contains extensive planting, water features and observation lifts, with seating for 400 people overlooking the area. High quality materials, including terrazzo tiling and marble, have been used to provide an attractive and stylish retail environment.

The Ridings Shopping Centre, Wakefield

Capital and Counties financed the extensive, attractive and innovative city centre shopping development, which was built by Shepherd Construction in 1981 to 1983 at a cost of £16m. The design by Chapman Taylor Partners ensured sympathetic integration with Wakefield's existing city centre and required first class craftsmanship to make the best use of high quality materials and innovative applications. The scheme was awarded the European Shopping Centre Award of the International Council of Shopping Centres at their Annual Conference in Berlin and part is illustrated in Plate 23.

A sloping site was exploited with three split level shopping malls occupying 32 500 m^2 and containing seven major stores and 64 standard shop units. A special feature is the atrium with access from all levels and a glass-walled scenic lift. An Edwardian pavement café seats some 375 shoppers amidst a bandstand, waterfall, well designed fittings, and plants and trees imported from Florida, surrounded by ten fast food outlets. Full use has been made of high quality traditional and modern materials, such as ceramic floor tiles, tinted toughened plate and mirror glass, and stainless steel handrailing. Externally there is car parking space for 1100 cars and extensive use of traditional materials such as buff and multi-red facing bricks and Welsh roofing slates, to harmonise with the West Riding commercial buildings surrounding the site.[40]

The reinforced concrete frame is hidden behind

Figure 7.7 *The Exchange Shopping Centre, Ilford, under construction (Source: Norwich Union)*

good quality brickwork, and elaborate service installations included varied and exciting lighting, 22 lifts and 6 escalators and a fully co-ordinated, computer controlled, multiplex security system. The building extends 8 m below the initial ground level to form an underground roadway and service area. Adequate support was obtained by shoring with 80 close bored piles, each approximately 10 m long by 1 m in diameter, to form a continuous wall, while the adjacent floor was supported by 3 m diameter concrete linings inside which concrete columns were constructed. The placing of 22 000 m^3 of concrete entailed the use of four tower cranes supplemented by 9000 m^3 placed by pumps.[40]

Out-of-Town Retail Shopping Centres

In addition to the in-town shopping centres previously described, there has been substantial development of out of town facilities, where customers can satisfy all their weekly shopping requirements under one roof, with ample free surface car parking facilities. For example in 1989, Sainsbury, the grocery business market leaders at that time, opened 22 out-of-town stores and planned a further 19 stores in 1990. Meanwhile Tesco also opened 22 stores in 1989, adding a further net sales area of 72 000 m^2. Confirming the importance of the car-borne shopper, 16 of the new stores included a petrol filling station. In 1990, the development programme provided for 23 stores, creating a further 92 000 m^2 of net sales area, and 20 had petrol filling stations.[41]

One of Europe's largest combined retail and leisure centres, *Meadowhall*, was completed in 1990 on the outskirts of Sheffield. The site comprised 55 ha in the middle of a 800 ha former wasteland resulting from the closure and demolition of eight large industrial units, mainly steelworks, between 1974 and 1986. This extensive development cost £230m, creating over 2500 jobs during construction and approximately 10 000 additional jobs after its opening. Construction requirements included 11 500 t of steel, 100 000 m^3 of concrete, 10 700 piles, 5580 m^2 of glass for rooflights, 18 600 m^2 of marble for interior tiling and 15 000 new trees planted around the site and along the adjoining Don Valley linear park. The roof measured some 150 000 m^2 and was one of the largest commercial roofs ever constructed in the UK in one phase.

Meadowhall contains 116 200 m^2 of retail shopping space situated on two levels of the immense shopping mall and includes 223 shops and a foodcourt seating 1000 people. There is also 23 240 m^2 of leisure and entertainment facilities within the shopping malls, multi-screen cinema, children's play area and supervised centre, and dancing fountains and water features. The immensity of the development creates its own problems in that some customers have found it all very overwhelming and criticised the paucity of seats for resting.

All modes of travel to the site are well catered for with a £12m new road network connecting with a nearby junction off the M1, computerised car park with 12 000 free car spaces, a bus station capable of handling up to 120 buses/hour, coach park with facilities for handling over 400 coaches/day, two sprinter railway stations, and all persons arriving by bus or rail are brought into the complex by an overhead link. Plans were also being developed for a £50m supertram system, mentioned in chapter 2, to connect the city, Meadowhall and the Lower Don Valley.

The developer estimated that there were 9m potential customers within one hour's drive of the site, but what is much more difficult to assess is the actual numbers that will continually or even periodically visit the site. There is no doubt that shops in Sheffield and Rotherham will suffer but the likely effect on towns further afield is much more uncertain.

Retail Warehouses

Retail warehouses need to be located on suitable sites on main roads, in strategic locations with a sufficient catchment, and be easily accessible to the car-borne shopper. Clive Lewis and Partners[42] reported that a sustantial rate of expansion in the retail warehouse market was maintained at about 10% p.a. in 1988/89, bringing the total number of retail warehouses to well over 2000. The DIY sector still continued to dominate the market, occupying 55% of all accommodation.

Examples of large modern retail warehouse parks include West Thurrock Retail Park; Sticklepath Terrace, Barnstaple; Linkway Retail Park, Cannock; Wings Road, Wakefield; Chestnut Avenue, Eastleigh; Cheetham Hill, Manchester; Nottingham Road, Nottingham; Kingsway West, Dundee; Alexandra Retail Park, Grimsby; Twinches Lane, Slough; and London Road, High Wycombe; all of which are illustrated in Clive Lewis and Partners Report.[42]

Industrial Estates and Business and Science Parks

Industrial Estates

All industrialists are looking for a number of common essential features – a sufficient area of land for present and likely future needs which is reasonably level and has all essential services readily available and of sufficient capacity, water supply of adequate quantity and suitable quality, good communications and access, relatively low level of local taxation and ample pool of local labour. Some industrial processes have special requirements such as clean air or specific climatic conditions, and all welcome the provision of suitable living accommodation for operatives.

Above all the industrialist should be anxious to establish his plant at the 'least cost' location. He will usually have regard to market areas, ease and cost of transportation, labour position, probable operating costs and even the effects of rivals. However, in practice, it has been found that it is comparatively rare for a scientific study of alternative sites to be made before production is commenced, and even when a study has been made, more than one optimum site might be indicated and the final choice may be determined by some quite trivial consideration.

The financial implications of an industrialist moving from old unsuitable premises to a new factory on an industrial estate, such as in a new town, can be conveniently considered under three heads:

(i) the provision of a new factory
(ii) removal expenses and dislocation of trade
(iii) settling in period, training new staff and related matters.[43]

Figure 7.8 *Tai Po Industrial Estate, Hong Kong (Source: Territory Development Department, Hong Kong)*

The majority of modern industrial sites are well laid out and generously landscaped with ample car parking spaces for employees and visitors. The immensity of some of these estates is well illustrated in Figure 7.8, showing the extensive industrial development at Tai Po New Town, Hong Kong, constructed on land reclaimed from the sea and aimed at attracting high technology industries. In the UK, many of the buildings on industrial estates have been designed in isolation by different architects and there is a noticeable lack of cohesion and harmony, indicating the need for co-ordination of design to achieve some basic common standards. Very small factories of the 'unit' or 'nest' variety, with floor areas of around 185 to 230 m^2 have often been erected on a speculative basis, and have proved popular with new small business ventures.

Business Parks

There seem to be almost as many definitions of a business park as there are schemes, with considerable abuse of the term in the property industry. Hence a development consisting of little more than two or three offices with a few flower beds can be given the same title as a development of 100 000 m^2 (10 ha), with a sophisticated infrastructure of roads, shops, restaurants, parking and landscaping. Jones Lang Wootton's criteria is a development of at least 46 000 m^2 with good parking provision (one space/18 to 23 m^2 gross). The larger the park, the more infrastructure and services it can sustain, and the more likely it is to develop into a business community. A report by Debenham Tewson & Chinnocks[44] contains the following comprehensive definition: 'A business park is a large tract of land, often in excess of 40 ha, developed in phases to a low density offering occupiers an attractive working environment and adequate parking provision ... capable of meeting the needs of a wide range of business sectors and functions.'

A report by Applied Property Research in 1990[45] identified 800 developments in the UK describing themselves as business parks. Other sources showed 400 to 500 individual developments under construction or planned in 1990, which could in aggregate provide more than 18m square metres of usable floor space, being sufficient to accommodate all new businesses and light industries until the end of the millennium. This over-provision was exacerbated by depressed interest from investors resulting from low 1989 yields, and this could force developers into upgrading the specification of their construction, finishes, landscaping and amenities, to meet potential tenants' increased expectations. It could also be argued that many British business parks were neither sufficiently low density nor sufficiently high quality, and that much landscape management was unskilled and well below National Trust or US standards. Hence the rush into business parks with their glossy publicity brochures may not prove to be the great success story of the late 1980s. Two case studies of very different schemes are provided to give an indication of the types of development undertaken and some of the civil engineering problems encountered.

Stockley Park

General Characteristics The Stockley Park project is a large and complex development scheme in West London, which was commenced in 1985, based on the conversion of 140 ha of former gravel workings and rubbish tips into a major business park of 40 ha, and 100 ha of landscaped parkland, lakes, playing fields and an 18-hole golf course, developed by Stockley plc under a section 52 agreement with the London Borough of Hillingdon. The site is well placed in relation to Heathrow Airport, the motorway network, British Rail and two Underground lines. The business park contains buildings grouped around a loop road 7.3 m wide, reinforced by landscaping, lakes and a necklace of lime trees, with car parking based on 32.5 m^2 of gross building area/car, creating the need for 4300 car spaces.[46]

Buildings The new buildings within the business park consist of a combination of two and three storey structures and provide a total of 140 000 m^2 gross floor area, built at a density of 4180 to 4650 m^2/ha, compared with about 2800 m^2/ha on many earlier business parks, and around 8130 m^2/ha on mid-town business developments. The buildings were designed in accordance with the following criteria:

(1) Medium depth buildings which achieve good levels of outside awareness and natural light, while providing sufficiently adaptable space for a variety of activities.
(2) Buildings planned with central atria to provide added amenity and efficient layouts.
(3) Buildings planned with pitched roofs to create a distinctive profile and to rationalise positions for mechanical plant.
(4) Buildings related to open space amenities, particularly water.
(5) Car parking screened by buildings and landscaping wherever possible.

An aerial view of the development is shown in Figure 7.9.[46]

Landscaping Because the site was a former waste tip, specialists from Holland, skilled in soil reclamation, were engaged to reconstruct the soil and create a healthy medium for plant life. The top capping was scraped off and the ageing layers of waste rearranged, thereby creating interesting land contours. A special feature of the site is a string of lakes, linking the buildings, with each water area, complete with fish, designed with a different type of wildlife or plantlife in mind.

The plant species vary depending upon their location, elevation and soil conditions. They

Figure 7.9 *Stockley Park, West London, Business Park (Source: Arup Associates/Ove Arup & Partners)*

include scrub/heath on high ground, light woodland on the sloping flanks, and damp woodland and wetland plants in the valley conditions. The green belt is formed mainly of mass forest type trees, with alder, poplar and willow, and longer term species like oak and ash for the mature landscape. The business park is generally formally planted with semi-mature species directly into clay or topsoiled zones, with hornbeams as screening to car parks and maples along secondary access routes. Yew hedges are used to screen service areas and define pedestrian routes, together with extensive shrub and evergreen ground covers. The majority of the trees have been imported from Belgium.[46]

Civil Engineering Aspects It was necessary to transfer the landfill from the business park site to the green belt in the north. This required the use of structural fill to create safe, stable building sites and to avoid the need to provide piled foundations and ventilated undercroft space normally associated with buildings on polluted sites. Landfill was partially left in place in defined car parking zones, thus reducing civil engineering costs and at the same time establishing the limits of the building sites. Clay was used in zones where lakes or other related features were required.[46]

The development necessitated the removal of 3m tonnes of toxic waste which had been placed to depths exceeding 12 m over a period of 50 years. Crucial to the success of the scheme was the effective control of leachates and groundwater. Water infiltrating the landfill percolates towards the leachate collection drain from which it is pumped to the Thames Water foul sewer. Following storms of high intensity, any surface water run-off will gravitate to a continuous land drain at the site perimeter.[47]

Clean structural fill introduced for the building formation is separated from the landfill by clay bunds, which protect the fill from the effects of both leachate and methane gas. The scheme includes a cut-off wall and drain along the northern boundary which can either deflect groundwater around the site or intercept the groundwater and discharge it directly to the Grand Union Canal. Details of the extensive and very unusual earthworks and land drainage works on the site are shown in Figure 7.10.

Watchmoor Business Park, Camberley
The second case study covers a smaller but different type of business park developed by London & Metropolitan plc and Pos Tel Property Services on a 11 ha site with good access to the M3 and M4 motorways and neighbouring social and communal facilities at Frimley and Camberley. At the same time the Park takes full advantage of the rural setting provided by the valley of the River Blackwater which, combined with the lakes and extensive landscaping, generate a feeling of tranquillity.

The seven main blocks completed in 1990 are shown in Figure 7.11 and have a combined floor area of some 26 400 m^2, and the ultimate provision will amount to 40 900 m^2. Block 3 is a business centre comprising 22 suites ranging from 54 to 310 m^2. The buildings offer large uninterrupted space which can readily be adapted to meet occupiers' changing needs. The architectural style is bold and impressive with overhanging pitched slate roofs and cantilevered first floors clad in dark brick, white curtain walling and tinted glass. The main entrances feature classical pediments and columns. Each building stands prominently on its own landscaped site and some overlook the lakes as shown in Figure 7.11 and Plate 24. Parking provision of at least 4 cars/90 m^2 adjoin each building surrounded by trees and shrubs.[48]

Science Parks

Attracting fledgling high-tech companies in the rapidly expanding computer field became a high priority in the early 1980s, and it was against this background that two universities decided to import the American 'science park' concept, albeit along British lines. Thus in late 1980, Birmingham's Aston University contacted the city council and arranged the purchase of surrounding sites. Meanwhile, in Coventry, Warwick University was formulating a similar proposal, culminating in the 10 ha Warwick Science Park.

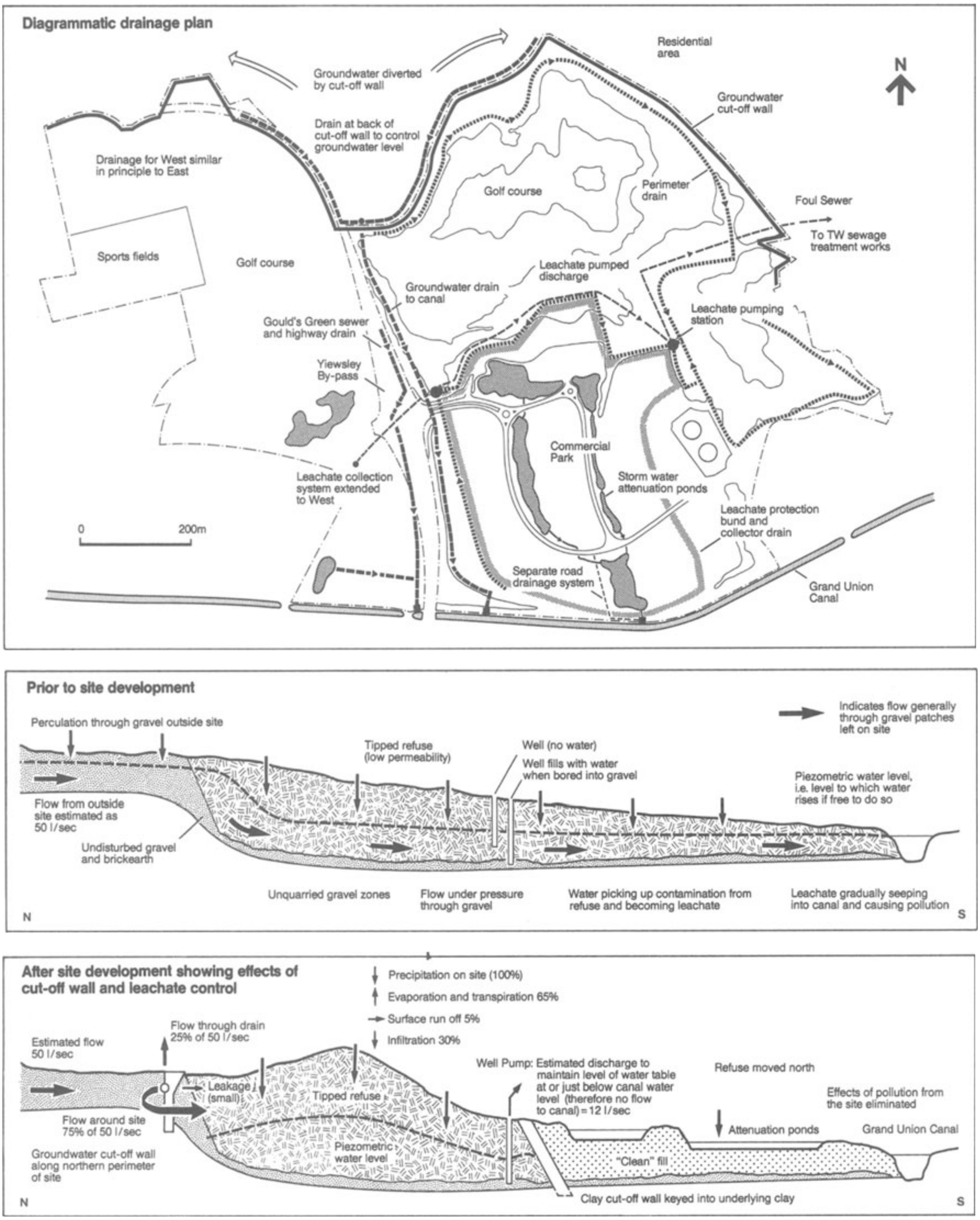


Figure 7.10 *Stockley Park drainage (Source: Ove Arup & Partners[47])*

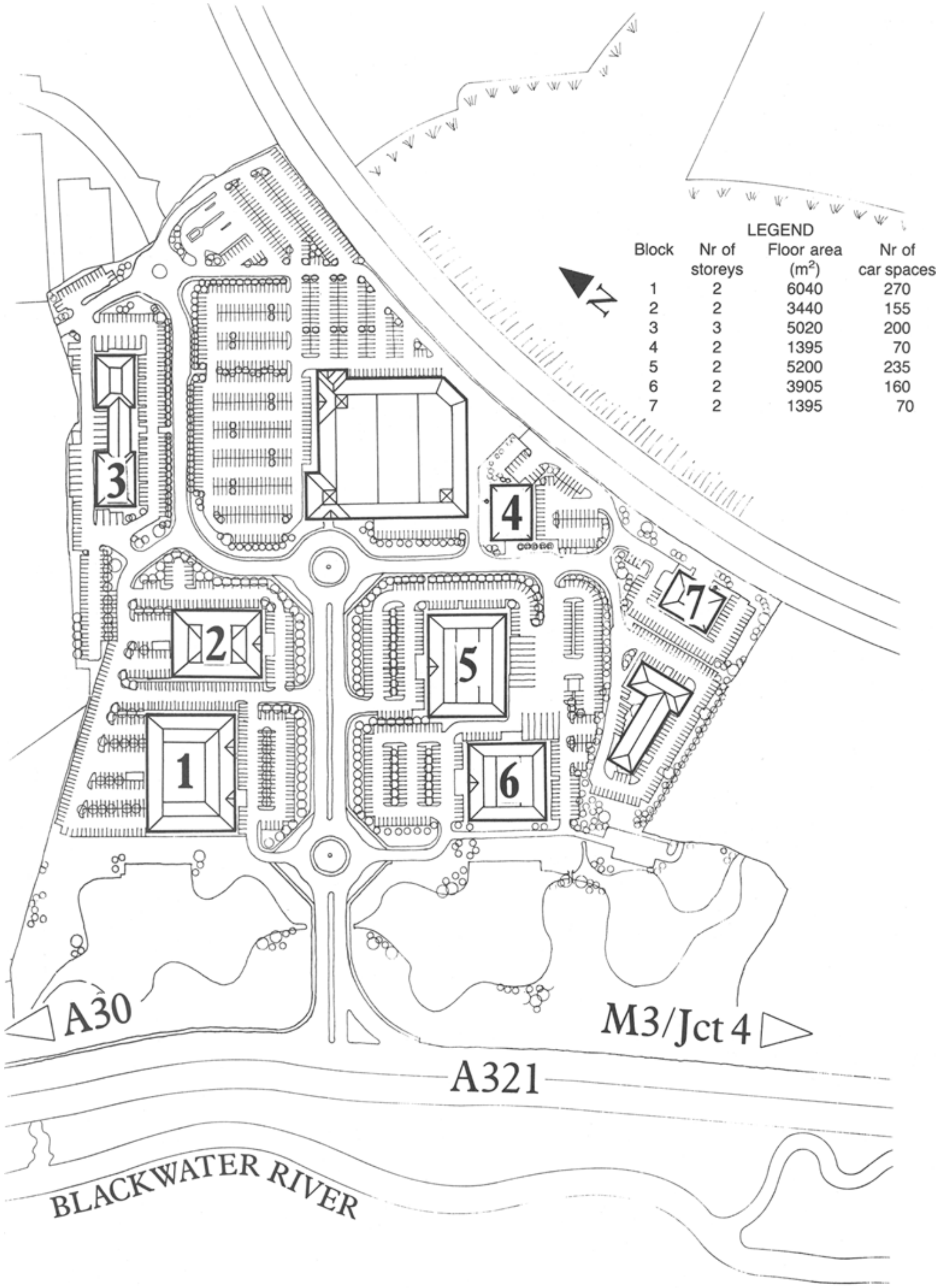


Figure 7.11 *Watchmoor Business Park, Camberley, layout plan (Source: London & Metropolitan)*

But starting up a science park is not without its problems, as finance has to be obtained to develop the park and provide some capital assistance to new companies. Aston University formed a partnership with Birmingham City Council and Lloyd's Bank, whereby Birmingham Technology Ltd was set up to finance the park and manage a £2m venture capital fund for business start-ups. Similarly, Warwick University linked with Coventry City Council and the West Midlands and Warwickshire County Councils, whereby venture capital was acquired from international banking advisors MGM.

By 1989 there were 38 science parks in the UK, and in 1990 Oxford was proceeding with the 6 ha Oxford Science Park, adjoining Oxford City Airport to the north of the city and the 10 ha Magdalen College Science Park to the south of Oxford. While at the same time yet a third science park on a 225 ha site at Harwell and Culham was planned by AEA Technology (formerly the Atomic Energy Authority).

One of the UK's most impressive science park developments is the St John's Innovation Centre at Cambridge, which gained a national Civic Trust Commendation, and Figure 7.12 shows the centre section and two adjoining units. R.H. Partnership, Cambridge, won the St John's College sponsored competition to design a scheme of 41 lettable units, with a total lettable floor area of 2800 m^2 for new technology based companies on a new science park in Cambridge. The design allows for future linear expansion of the building and contains central reception, exhibition area, conference room and restaurant facilities which are available to all tenants. Shepherd Construction built the project which featured extensive use of exposed steelwork, exposed and pointed internal blockwork and timber work in beech hardwood.[49]

Figure 7.12 *St John's Innovation Centre, Cambridge (Source: Shepherd Construction Ltd)*

Building Conservation

Conservation Areas

Many parts of built up areas of the UK have been designated as Conservation Areas, and in 1989 there were no less than 6000 such areas designated in England and Wales. They are described in the Town and Country Planning Act 1971[50] as 'areas of special architectural or historic interest, the character or appearance of which it is desirable to preserve or enhance'.

Taylor[2] has described how apart from the obvious central areas of historic towns and cities, conservation areas sometimes include substantial areas of mundane buildings with little architectural or civic design interest, and undeveloped areas on the outskirts of towns and villages. For example, the Hertford Conservation Area encompasses much of the town and includes numerous post-war buildings of little, if any, architectural design interest.

Conservation and Re-use of Redundant Buildings

DOE[51] have described how in the 1980s rehabilitating old houses and the re-use of old industrial and commercial buildings, instead of demolishing them and redeveloping the sites, became widespread. There are numerous large old buildings in the UK which are no longer needed for their original purposes, especially in the older towns and cities. They frequently have more character than the modern buildings which would replace them, but if left empty they soon decay and blight the area around them, and it is often cheaper to adapt an existing building than to erect a new one although it may create more problems. In the late 1980s and early 1990s, interest grew in the conversion and re-use of old buildings, not only amongst those who wish to conserve our heritage, but also those who wish to bring back economic life into run-down areas or just to carry out their own innovative projects, as in the Lace Market area of Nottingham. This form of adaptive re-use has an important role to play in urban regeneration.

DOE has supported many conversion schemes through the Urban Programme (UP), and in 1990 the EC, which had already provided substantial financial assistance for regeneration schemes in the UK, introduced a working paper which, among other environmental matters, recommended the international listing of historic buildings and towns and other conservation initiatives, which aimed to achieve real improvements in the quality of the urban environment within the community through guidelines and legislation. The DOE Handbook on re-using redundant buildings[51] aptly explains what is involved in devising and implementing successful re-use schemes and provides practical information on the organisational and management aspects. It also contains 14 case studies describing how different organisations from the public, private and voluntary sectors carried out successful conversion schemes in a wide variety of circumstances, and embraces the conversion of old factories, warehouses, mills, railway stations and other buildings. There was a wide range of new uses to which 400 converted buildings in the UK had been put in the mid-1980s, encompassing workspaces (44.5%), leisure/retail (32.0%), housing (9.25%) and mixed use (14.25%). In conservation areas, particular emphasis needs to be placed on scale and the use of local materials.

There are several informative and well illustrated books covering the rehabilitation and re-use of old buildings and some of them are briefly described. *Saving Old Buildings*[52] provides numerous examples of the conservation of buildings of character in many countries and their re-use for a variety of purposes, including cultural, commercial and housing, and the adaptation of churches, railway stations, small rural buildings and large country houses and castles. *The Housing Rehabilitation Handbook*[53] gives guidance on basic repairs, improvements and conversions and provides case studies on the rehabilitation of housing for the disabled, single persons and the elderly. Highfield[54] emphasises the potential value of the vast stock of old buildings in the UK and estimates that the cost of rehabilitating an existing building could amount to 50 to 80 % of the cost of new construction, although it is likely to have a shorter life span.

Registered housing associations provide many thousands of good homes every year in the UK by improving older neglected dwellings, many of them in long blighted inner city areas. They provide accommodation for rent to those least able to compete in the housing market and also take nominations from local authority housing lists. Housing associations set out to be caring landlords who deal with repairs and tenants' other problems sympathetically, efficiently and effectively.

In the UK, all government departments and the Property Services Agency (PSA) are required to conform to the government's policies for the conservation and improvement of the environment when carrying out their responsibilities, and to meet the costs involved. Government departments should set an example of the highest order in the care of historic buildings and protected areas, and good procedural guidelines are contained in *The Conservation Handbook*[55].

Albert Dock, Liverpool

Introduction This project has been selected as one of the most unique and challenging restoration schemes in the UK, situated in Liverpool's docks close to the Pier Head, and the Liver, Cunard and Port of Liverpool buildings. There are 2.4 ha of enclosed water surrounded by five blocks of 5-storey warehouses, a dock traffic office and pumphouse. The total site area is 10.8 ha and the total floorspace of the buildings is 108 000 m^2. The whole area, which had fallen into extreme disrepair is being restored and developed into a leisure-based complex containing a museum, art gallery, public house, shops, offices and flats.

The £100m programme which retains the old dock character, began in 1982 and is due for completion in the mid-1990s, is the responsibility of Merseyside Development Corporation, who funded the civil engineering works and the structural restoration of most of the buildings, with the commercial development carried out by the Arrowcroft Group. Parts of the dock have been open since 1984 and have been successful in attracting tenants and many visitors.

Historical Background The dock and warehouses were constructed in the 1840s and was the first of the South Docks to have fireproof warehouses built close to the quaysides to allow goods to be unloaded directly from the ships into the buildings. The warehouses were supported on beech piles and constructed of brick walls up to 900 mm thick around a cast iron frame. Brick piers were formed inside the hollow cores of the cast iron columns on the quayside frontages. Brick vaulted arched floors span between columns and beams along the length of each building. The roofs, shaped in most places like the upturned hull of a ship, consisted of wrought iron plates, riveted and galvanised, with supporting wrought iron trusses. The windows were of cast iron with small panes.

For fifty years or so, Albert Dock was a thriving centre mostly used for unloading trading ships from the Far East. By the turn of the century, however, sailing ships accounted for only 7 % of the vessels using the Port of Liverpool. Built for sailing ships, Albert Dock did not offer the transit ships and other distribution facilities needed by the now flourishing deep-water steamship trade and its use declined, resulting in little commercial activity from 1920 onwards. The dock was disused for many years before it was closed in 1972.

The national importance of Albert Dock was recognised in 1952 by its listing as Britain's largest group of Grade I Buildings of Architectural and Historic Interest and in 1976 by its designation as a Conservation Area. However, little was done to prevent the docks, buildings and quayside from falling into serious disrepair. By 1981, the picture was one of complete dereliction, and deterioration of the river entrance gates and internal passage gates resulted in the area becoming tidal, and Mersey silt to a depth of 13 m had accumulated within the docks and only at high tide was this covered with water, as shown in Plate 25.

Restoration Work The Merseyside Development Corporation (MDC) was formed in 1981 and charged with securing the regeneration of some 346 ha of inner Merseyside, which included the Albert Dock. Its initial strategy was to use public funds in the form of pump priming to create confidence in the area and attract private investment. Restoration of the dock system took place between 1982 and 1984, and this involved dredging docks to remove accumulated silt, replacing river entrance and passage gates, stabilising the dock walls by ground anchors secured into the sandstone bedrock as much as 20 m below the quayside, rebuilding parts of walls, restoring historic bridges and constructing two new bridges and a slipway.

Initial structural and architectural surveys revealed that the beams would withstand likely future design loads through composite action with the brick vaulted floors. Material sampling of ironwork and brickwork proved the quality of the original construction, and very little repointing was necessary because of the hardness of the original mortar. Random exposure of timber piles at depths of up to 16 m below quayside level, a study of the settlement patterns of the building, and extensive load testing of existing piles in one warehouse block proved the foundations generally to be in good condition. Where piles were defective, needle piles and more conventional bored piles would be suitable for stabilising the structure. Visual and sonic testing of the hollow cast iron columns and end scope viewing of the inside of some of them showed that they had withstood the years of neglect. The results of the survey and a detailed assessment of repair costs were made available in 1982 and formed the guidelines for all future developments. Readers requiring more detailed information on the structural survey of the Albert Dock are referred to the paper by Parkinson and Curtin.[56]

The major repair works comprised the restoration and strengthening where necessary of the original warehouse roofs to take the additional loadings of a 'terne coated' stainless steel (lead/zinc alloy bonded onto stainless steel) roof covering over cork insulation and vapour barrier; providing gutter linings and upstand flashings in lead; replacing the original windows with small paned polyester-coated cast aluminium windows; sealing cracks in brickwork with resin based or cementious grouts; and treating the bond bars running horizontally at most floor levels with a patented system of vacuum and pressure grouting. Readers requiring more information on the restoration work are referred to the paper by Tallis, Taylor and Dishman[57]. An aerial view of the restoration work on the site in 1990 is shown in Plate 26, while Figure 7.13 shows part of a renovated warehouse converted to shops and offices overlooking the quayside.

Work was also undertaken on external works and services in order to make the external areas of the dock servicable and provide new water and other mains services. Where possible existing road surface materials were reused particularly in areas by the Maritime Museum to retain the old dockland character. Later, trees and other soft landscaping were added in the commercial areas of the dock. Yorkstone flags were used to provide smooth walkways, and elsewhere cobbles and granite setts provided a foil for the tarmacadam roads dressed with red chippings.

The bulk of the quayside and mezzanine floors of the warehouses were converted to shops and offices, with a few flats on upper floors of one block, all funded by MDC. In general, the fitting

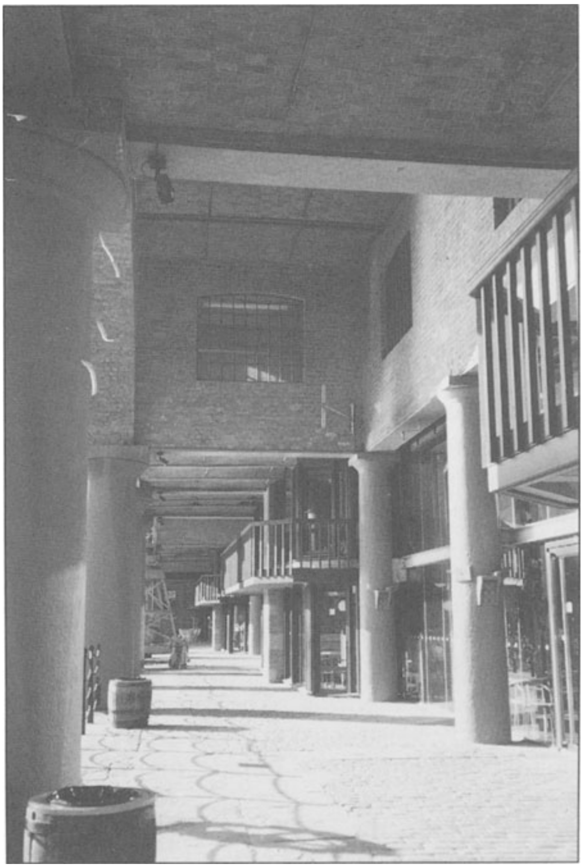


Figure 7.13 *Albert Dock, Liverpool, part of restored warehouse in use as shops and offices (Source: Author)*

out of the warehouse upper floors will be carried out in the 1990s using mainly private investment. Other major uses in the renovated warehouses included the provision of a modern art gallery, the fascinating Maritime Museum and Granada TV studios and offices. The attractive pumphouse was restored and converted into a public house. The waterspace is in use and a marina for 500 yachts in the Coburg and Brunswick Docks will be completed in the 1990s. While the Wapping Warehouse, shown in Plate 26, has been converted into 114 waterside flats. The £35m of public funds invested in Albert Dock by MDC between 1982 and 1988 included £7m for civil engineering works and £2.25m for landscaping.

Singapore's Conservation Policy and Practice

Singapore has been selected as a progressive multi-racial country which is actively pursuing a sympathetic and skilful approach to building conservation and to examine in some detail the implementation of one fascinating project embracing the restoration of some 200 Chinese shophouses. The Urban Redevelopment Authority (URA) was established to facilitate the balanced development of Singapore City by means of a Central Area Structure Plan and to promote the conservation of selected historic districts, with their rich history, architectural style and ambience, as opposed to the conservation of isolated buildings. These districts include Chinatown, Kampong Glam, Little India, Singapore River, the Heritage Link, and Emerald Hill, with a total area of 2600 ha, representing 4% of the land in the central area, and are actually the same areas which were allocated by Raffles for the different races in his 1828 town plan of Singapore.[58]

These districts provide contrasting forms and a sense of time and place in the city. The vernacular architecture which blends Malaccan, European, Chinese and Indian styles is unique. Their intimate scale, diverse facades and rich ornamentation perpetuate a kind of charm that is not found in new architecture, and they serve to remind Singaporeans of their rich heritage and form valuable tourist attractions.[58]

The URA plans for each historic district have the following aims:

(1) preserve as much as possible of each area's architecture and ambience
(2) improve the physical environment by providing pedestrian walkways, plazas, landscaping and control of signage
(3) enhance the special character of each area by introducing new activities while sustaining the old traditional activities which have tourism value
(4) provide guidelines for the private sector to be actively involved in the conservation effort.[58]

Tanjong Pagar Conservation Area This has been chosen as representing an impressive and understanding example of conservation work, embracing some 200 Chinese shophouses built in the 1860s and occupying some 4.1 ha at the southern end of the Chinatown area of Singapore, and involving a partnership between government and the private sector. The restoration work on the seriously dilapidated buildings was commenced in 1987 and completed in 1990. The restored shophouses accommodate a variety of uses, ranging from shops, restaurants and eating houses to offices and residential uses, with priority given to pedestrian circulation. The first 32 shophouses were restored by URA and the remainder were progressively released for sale to the public for restoration on 99 year leases. Plates 27 and 28 illustrate some of the shophouses before and after restoration and show the great attention to detail and the attractive embellishments and overall appearance. Figure 7.14 shows some of the principal architectural elements used in shophouse facades.

The more important components of the restoration work are now described.

Wall Ornamentation The facade walls are beautifully decorated with ornamental plasterwork of lime mortar and intricately moulded motifs, which have been carefully restored in the same material.

Roof Form The existing double pitch roofs is one of the most distinctive features and considerable effort has gone into ensuring that the profile of the roof, colour of the tiles and character of the ventilation jack roofs are retained, necessitating the provision of a specially profiled secondary metal decking to replace timber battens and support the roof tiles, in order to retain roof pitches not exceeding 25°, without the risk of rain penetration during heavy rainfall. All rainwater downpipes and gutters, which were of galvanised iron, were replaced by new ones of similar size and materials.[59]

Timberwork The existing timber doors and casement windows with fixed and adjustable timber louvres have been retained. Existing timber floorboards which had deteriorated were replaced with new boards of the same width and

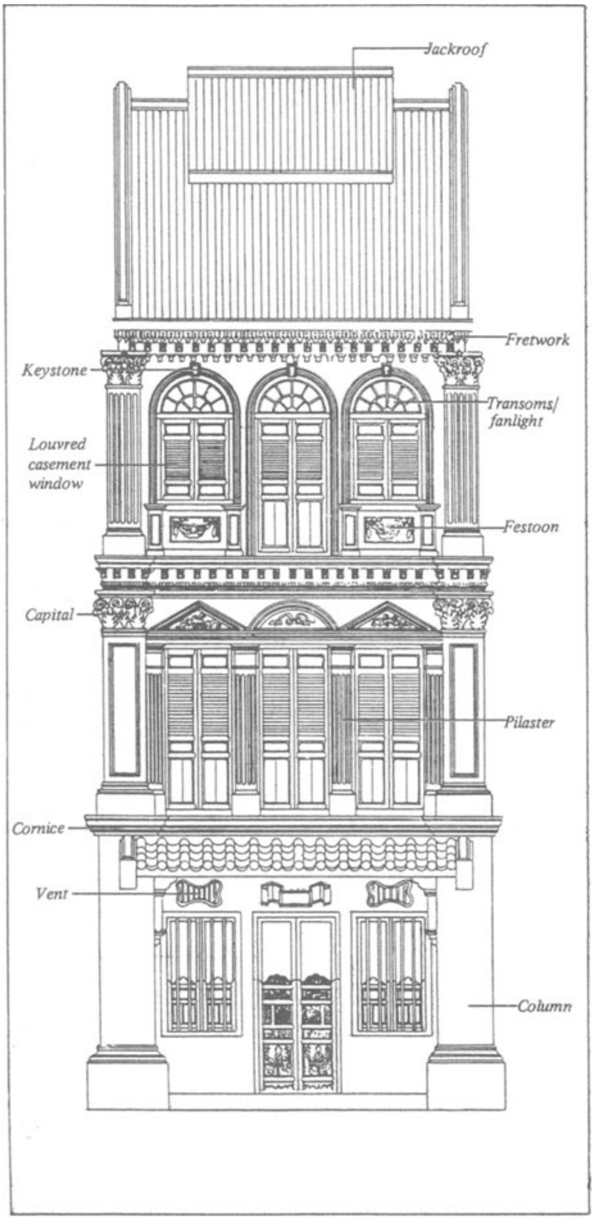


Figure 7.14 *Common architectural elements in shophouse facades, Singapore (Source: URA, Singapore)*

thickness as the original. The grains of the timber are exposed to capitalise on the natural beauty of the wood. In the restoration work, new staircases of the original design were installed but, as a fire precaution measure, some of the staircases were repositioned to lead to external walkways.[60]

The Rocks Conservation Area, Sydney

Sydney's earliest development, in the 'Rocks Area' in the early 1800s around the quays, became a slum in the early 1900s when many buildings were burnt or demolished in an effort to remove the disease-spreading rats. In 1970 the Sydney Cove Development Authority was established to restore, renovate and develop the area. A major review was undertaken in 1983 to reconcile the economic realities of real estate development and the desire for preservation based on history, sentiment and environmental studies. The subsequent judicious restoration of elements of historical or architectural significance and blending them with new buildings for commercial, retail, residential and recreational purposes, has created a popular tourist and local attraction.

Urban Renewal

Introduction

A DOE report[61] described how the process of economic and social change has left large areas of UK towns and cities with severe environmental problems, notably derelict land and buildings. It also brought functional problems of congestion, antiquated road patterns and poor access, all of which contribute to diminishing confidence and urban malaise.

These aspects have been further expanded by Gloster and Smith in a RICS discussion paper[62] in which they describe how the decline and subsequent decay of our inner cities often resulted from the closure of basic industries on which the former prosperity of the city was founded. For example, the vast textile mills in Lancashire and Yorkshire, closed steel plants in Sheffield, redundant metal-bashing factories in the West Midlands, run down docks in Liverpool and worked out mines in South Wales. The land was exploited by traditional industries and left in a neglected state with little or no regard for the impact on future generations. Thus the coal and steel industries extracted minerals and left mine workings and slag heaps, and statutory undertakers rationalised their operational land but failed to bring the surplus land back into a suitable condition for development. Major public and private industrial facilities have been closed, leaving problems of deep concrete foundations, machine bases, contamination and tipped waste material.

In many derelict areas, new infrastructure is required to open up the land for development, to provide suitable access, services, an acceptable environment and the removal of abnormal development costs to make its redevelopment profitable.[63] Inner areas of cities frequently suffer from poor housing, residents with lower skill levels, and exceptional concentrations of poverty and deprivation, occasionally ameliorated by housing improvement work mainly carried out by housing associations. Doubtless, post-war planning policies have contributed to the decay of the inner areas by promoting decentralisation from them and, in consequence, making it difficult for industries to flourish in these locations. There is an urgent need to tackle the problems, as the components of urban decline reinforce each other to make the decline steeper with the passage of time. In the absence of appropriate action, badly affected areas may become excessively costly to retrieve.

Organisational Aspects

The characteristics of urban decay and deprivation vary greatly from one locality to another both in substance and degree, so that no single form of organisation is suited to all situations. Hence there is a need for flexibility in operation to best serve the needs of the local community and the powers necessary to deal with the particular problems of the area. The main urban renewal agencies and approaches are as follows.

Enterprise Zones. These were first introduced in 1980 as a means of reviving the local economy in areas of high unemployment, and the responsible authority for the area was invited to prepare a development scheme. The designation order granted planning permission for particular classes of development and there were substantial tax concessions, including exemption from rates. It is unlikely that any new zones will be designated and the planning aspects are being extended in the form of simplified planning zones (SPZs) to local authorities.

Urban Development Corporations The land assembly powers of these corporations rendered them ideally suitable for dealing with areas suffering from severe and widespread dereliction, with fragmented ownership. Their corporate structure allowed quick and single minded decisions to encourage the speedy recovery of their areas.

Local Authorities These have a role in urban development as well as urban management, and thereby differ from other development organisations. On occasions this combination of functions, which may be in conflict, has resulted in a lack of success in urban regeneration.

Urban Development Agencies These normally take the form of local authority and private sector partnerships. Their strength lies in combining the commercial viability interests of the private sector with the local authorities' concern for the development of viable communities.[63]

In the 1980s, enterprise zones and urban development corporations were two of the spearheads of government efforts to regenerate the inner cities, although opinions differed as to how successful they were, given the resources and inducements to development that had been deployed. Nevertheless, they do contain some of the most important development opportunities in Britain. It seemed probable that in the early 1990s, problems were exacerbated by the downturn in the property market, pressure on the government's finances, the transfer of the British economy from its reliance on manufacturing to a more service oriented base, and confusion caused by the proliferation of agencies and organisations concerned with urban regeneration, including the possible entitlement to finance from the European Regional Development Fund (ERDF) for urban regeneration, which is then offset against assistance from British Government funds.

Urban Renewal Projects

In 1990 the National Audit Office[64] reported that the *Action for Cities* initiative launched by the Government in March 1988 had achieved many individual successes but that there was a considerable imbalance in the distribution of grants of more than £3000m to specific projects and local authorities. For example, by June 1988 about one half of approved urban development grants were concentrated in ten local authority areas. It queried the justification of assisting a £38m retail project in Gateshead with a private-public sector investment ratio of 21:1, raising doubts at to whether any public funding was strictly necessary. A £32m luxury hotel development in Birmingham was awarded a £6m grant at a very high cost of £19 300 per job created by the project. It believed that government departments had made no overall assessment of inner cities' special requirements, and that there was a need for improved performance and communication. DOE recognised the weaknesses and planned to commission a series of research studies of the overall impact of inner city programmes. Derelict land grants amounting to £81m in 1987/88 have been valuable in accelerating the reuse of derelict land.

Over the five year period 1981 to 1986, £65.6m was spent in Bolton, Middlesbrough and Nottingham through the Urban Programme (UP), which had a total annual programme of £221m in 1989. The main aims of the programme were as follows:

(1) to improve employment prospects in the inner cities by increasing both job opportunities and the ability of those who live there to compete for them;
(2) to reduce the number of derelict sites and vacant buildings; and
(3) to reduce the number of people in acute housing stress.[65]

The work undertaken through the UP in the three areas over the review period were as follows:

(1) the provision of 350 industrial, craft, retail and office units for small firms
(2) the development of a comprehensive range of business support services
(3) the provision of financial assistance to firms, especially small and start up firms, and firms making improvements to their premises
(4) improving the operating environment of businesses in the inner cities through improvements made to infrastructure and environmental works, and the setting up of 18 Industrial and Commercial Improvement Areas
(5) supporting the creation or preservation of nearly 9700 jobs.

Probably one of the most informative reports on urban renewal is the DOE report on *Improving Urban Areas*,[61] which highlights some of the achievements and facets of good practice in combating urban dereliction and drawing new life and investment into urban areas. The report contains details of 14 area based approaches to urban environmental improvement, through a combination of specific activities such as landscaping, reclamation, building refurbishment and modernising infrastructure. This report complements the DOE report *Greening City Sites*,[66] which highlights many interesting examples of good practice for site based projects.

The facets of good practice presented in the DOE case studies[61] can be broadly summarised under the following five main categories:

(1) Responsiveness to local priorities and opportunities, which has been largely achieved through the involvement of local interests in the planning process, selecting areas according to clearly defined priorities and boundaries, and making the most of

existing features within the areas.

(2) Good management and the resolution of complex problems, through careful consideration of all relevant issues, and ample co-ordination and commitment.

(3) Special features can provide a focus for projects which have helped to generate interest, commitment and financial support.

(4) Resources are often limited and most successful schemes have secured a creative combination of resources from a variety of public sector sources, the private sector and the involvement of the community and voluntary sectors.

(5) The impact of the projects has varied, reflecting the wide variety of objectives pursued, including visual, new investment and employment, modernising the areas to improve future investment prospects, and improvements to housing conditions.

The DOE report[61] case studies show a remarkable range of projects including the Lace Market Industrial Improvement Area, Nottingham, embracing improvements to the urban fabric, and encouragement of new office, industrial and retail uses in this rapidly declining industrial area which has so much character; Smethwick High Street, Sandwell, West Midlands, where functional and environmental improvements were undertaken in a declining shopping centre; Operation Clean-Up, Bolton, encouraging improvements to the built fabric of Bolton, concentrating on priority areas and prominent sites and buildings; Wirksworth, West Derbyshire, comprising the regeneration of a small English town which had a declining industrial base and poor environment; and Hull Old Town and Docks, where refurbishment and renewal activities have brought life back to the previously rundown historic centre of Hull and the Hull Docks area.

The sources of funding of the projects are many and varied and include the Urban Programme, Urban Development Grant, Derelict Land Grant, Urban Housing Renewal Unit (DOE), Housing Investment Programme, Inner Area Programme, Local Authorities, the Private Sector, Countryside Commission, English Tourist Board, MSC, Derbyshire Historic Buildings Trust, British Waterways Board and British Rail. The most common source of funds has been the Urban Programme.

Readers wishing to research this important area of activity more closely are referred to *Urban Renewal: Theory and Practice*,[16] *Urban Wasteland Now*,[67] *Private Housebuilding in the Inner Cities*,[68] and *Cost Effective Management of Reclaimed Derelict Sites*.[69] Civil engineers have an important part to play in derelict land reclamation and the provision of an improved and/or new infrastructure, and many consulting engineers are now undertaking large environmental improvement projects.

Canary Wharf Development, London Docklands

Introduction This development has been selected for the leading case study of urban renewal because of the breathtaking scale of the development and the enormous impact it will have in the rejuvination of London Docklands. In years past Telford's docks served Britain well but their contribution declined quickly in the 1960s when technology and markets changed so much that they became obsolete. Hence in 1981 the London Docklands Development Corporation (LDDC) was formed 'to provide new homes, new places of work and the amenities of modern life, not only for those who live and work in the area today, but also those who will live and work in the area in the future'. The objective was regeneration – to develop over 20 km^2 of Docklands into the 'Metropolitan Water City of the 21st Century' based on the legacy of a magnificent waterscape environment, with substantial locational and financial advantages.

Transportation Initially, the attraction of London Docklands was marred by inadequate transport facilities, presumably because the impact of the enormous development on transportation needs was badly underestimated, as described in chapter 2, but by the early 1990s these deficiencies were being rectified, with the government investing £3b on a transport infrastructure. In fact, London Docklands is the only area of the capital where a co-ordinated programme of public and private investment in the transport infrastructure is being implemented. In 1990, work was proceeding on important projects such as the Docklands Highway, the Docklands Light Railway expansion and the Dartford Bridge, and the extension of the Jubilee Line was being promoted with a likely completion date of 1995/96. Other transport facilities include London City Airport, Thames River Bus to Charing Cross Pier and Waterloo and Stansted International Airport, which is reasonably accessible to the development.

The Development Canary Wharf is located on the northern part of the Isle of Dogs, about 4 km east of the city of London, and the location is shown in Figure 2.13. The site extends over 1.25 km eastwards from the River Thames along Canary Wharf to Blackwall Basin and occupies a total area of 28.5 ha. Furthermore, the bulk of the site is located within the London Docklands Enterprise Zone with all the benefits that flow from it, as described earlier in the chapter.

Olympia and York, the developers of Canary Wharf, assembled a team of local and international consultants who prepared a master plan to ensure a co-ordinated layout of the project and to establish design guidelines to secure cohesive architectural designs of a high standard, drawing on experience in Toronto, New York and other North American major cities. The development consists of 26 separate building sites of which the majority overlook water along the perimeter of the Wharf. The total project comprises 930 000 m^2 of net office floor space, up to 46 500 m^2 net of retail, restaurant and leisure facilities, a 400 bedroom hotel and associated conference and banqueting facilities, and approximately 6500 car parking spaces. The project is planned as four neighbourhoods grouped around major public spaces and a group of 8–10 storey buildings, surrounding extensively landscaped Westferry Circus, form the main entrance to the project. Over one third of the site (10 ha) is devoted to public open space and the planting will embrace 920 mature trees from 32 different species, 3000 shrubs from 32 different species and 83 100 assorted bulbs.[70]

The most prominent and probably the most spectacular building on the site, from a civil engineering viewpoint, is the 245 m high, 50-storey Canary Wharf Tower, shown under construction in 1990 in Plate 29. Besides being the tallest building in Britain, the structure is the second largest after Germany's concrete framed 256.5 m high Frankfurt Messeturm. It aroused considerable interest and some controversy while it was under construction from 1988 to 1991. The structural steel and aluminium clad shell is supported by a massive concrete raft capping 222 piles, and the steel superstructure contains 16 000 bolted members weighing 28 000 t. The tower dominates the view from all vantage points within 30 km or more of Docklands, and light will shine through the pryamid cap, providing a warning to aircraft and an unmistakable beacon to city travellers.[71]

Plate 29 also shows the immensity of the civil engineering work being undertaken on this site from the extensive roadworks and structural frameworks to buildings, to the Docklands Light Railway shown crossing the site and the enormous length of waterside frontage works. Roadworks on the cut and cover tunnel for the Limehouse link lead into Westferry Circus, the major two deck roundabout at the entrance to Canary Wharf, which is shown under construction in the forefront of Plate 29.

The size of the project is quite staggering, estimated to cost some £4000m over a construction period of 7 to 10 years, transforming the site into the world's largest commercial development and enabling London to face the economic challenges of the 1990s with renewed confidence. The project will replace and extend the decaying and inadequate supply of trading facilities in central London and will ultimately amount to 10% of the central London market, and transfer the emphasis of the capital from west to east. It will also redress the balance that has arisen between the three great trading centres of the world, namely Manhattan, Tokyo and London, apart from rejuvinating a large area of derelict dockland. The first phase of Canary Wharf was completed in 1991 as part of a five phase development process. Mallett[72] has, however, rightly postulated that a strong case can be made for allowing the LDDC more flexibility in structuring deals with developers and in the pricing of sites and of the need for a more intensive marketing campaign, as greater success in Docklands will mean greater success for London and the UK generally.

Swansea Maritime Quarter

Introduction

This project has been selected as a very imaginative and successful urban renewal scheme of a type which is in direct contrast with Canary Wharf, and which was the winner of the RICS 1988 Inner City Awards Scheme. The City of Swansea is the second largest town in Wales having a population of almost 190 000. It is situated at the mouth of the River Tawe and is one of the major South Wales ports but, in common with other ports, the decline of trade had its effect in reducing the facilities required. In 1969 the City Council purchased the redundant South Dock, which comprised dock basins, obsolete buildings and old quays.

Regeneration Strategy

By 1991, the process of revitalising the once derelict dockland area was substantially complete and the speed and success of the development was largely attributable to the City Council's action based planning framework responding to new opportunities since 1974. A major new building programme was complemented by the sensitive conservation of the best of the dockland features and fine Georgian and Victorian buildings to retain strength of character and identity.

The City Council was determined that full use should be made of the water area and to provide a significant number of dwellings close to the city centre, and that the Maritime Quarter should form a key element in the emergence of Swansea as an important tourist centre. An admixture of land uses, including housing, restaurants, hotels, licensed premises and boating facilities, was therefore envisaged from the outset.

The Council established a threefold role in the redevelopment process:

(1) direct investor in the programme of work to reclaim and enhance a derelict site
(2) direct investor in a building programme to provide specialist recreational facilities and to achieve a balanced housing mix, which also formed pump priming activities
(3) promoter seeking to attract the interest of the private sector in implementing development projects.

Development Work

The infrastructure projects included new access roads, clearance of derelict buildings, repairs to dock walls, installation of new high speed sector lock gates and swing bridges, the surfacing of quaysides to form the basis of a new pedestrian system, and the provision of a new sea wall and promenade. The Council's direct investment programme secured the construction of 49 residential units, a sheltered housing complex and a leisure centre, the conversion of a former warehouse into a Maritime Museum and a Victorian pumphouse into a restaurant, and the construction of five industrial units at Fishmarket Quay.[73]

The positive effects of direct council action were to prepare a foundation for the involvement of the private sector. Design briefs were prepared for the various development parcels to ensure there would be no compromise in terms of overall design quality. The briefs aimed to capture the interest and imagination of the private sector, whilst securing basic design and land use principles. Private investment has been substantial, comprising residential flats, housing units, the 'Maritime Village', shops and a Holiday Inn, which is built on a domestic scale with pitched roofs and a maximum of four storeys.[74] Figure 7.15 shows a view looking west across the main dock basin (South Dock), with the renovated quayside, towards the Holiday Inn Hotel and two flat developments.

The water area consists of the old South Dock and the half tide Tawe basin, which provide good harbour facilities. The marina, part of which is

Figure 7.15 *Swansea Maritime Quarter, main dock basin and surrounding buildings (Source: Swansea City Council)*

shown in Figure 7.15, and which forms a central focus, became operational in 1982, and will have an ultimate capacity of 580 berths. The development of the riverside was deferred pending the construction of the Tawe Barrage, funded by the City Council with the aid of an ERDF grant, which was completed in 1991.

The maritime development was substantially completed in 1991 at a total cost of around £79m, which included £68m of private investment and £11m of public investment, the latter including £2.6m of housing association dwellings for rent and £2.2m of Urban Development Grants.[74]

Darling Harbour, Sydney: Regeneration

Darling Harbour, Sydney was opened in 1988 at a cost of A$1.5b on the 200th anniversary of the European settlement in Australia, on the site of 54 ha of derelict dockland to form parkland and a riverside promenade close to the city centre. It comprises impressive exhibition, convention and powerhouse museum buildings, united by sea, sky and ships, with a monorail which encircles the site and extends unto the city centre. Other attractions include an aquarium, Chinese garden, restaurants, shops and cruises.

New Towns

British Policy and Practice

Early Developments

The new town movement originated in the writings of Ebenezer Howard in 1899, the formation of the Garden Cities Association, later to become the Town and Country Planning Association (TCPA), the building of garden cities at Letchworth and Welwyn, the war-time Barlow and Scott reports, and finally the passing of the New Towns Act 1946, which provided for the creation of new towns and their implementation by development corporations who could compulsorily acquire any land in their designated area, and for the disposal of the assets on completion of the development. Hence the main function of the development corporations was to construct the towns and they were wound up on their completion.

Early new towns were characterised by three basic criteria:

(1) to relieve the housing pressures of London and other large cities
(2) to provide 'self-contained and balanced communities for work and living'
(3) the development was to be carried out by government sponsored development corporations.

The first group of 14 new towns was designated between 1947 and 1950 and included eight in the London ring, like Crawley, Harlow and Stevenage, located some 30 to 50 km from London. They are sometimes described as the Mark I or first generation new towns, had average design populations of 50 000 to 60 000, and were based on the neighbourhood concept, which the designers believed would simplify the provision of community facilities and each have their own character and identity. For example, in Stevenage the original town formed the nucleus for the first neighbourhood of 10 000 population, and five more neighbourhoods of similar size were located to the east and south of the original town and the main industrial area was sited to the west, beyond the main railway line. In practice, residents tended to associate themselves more strongly with smaller residential areas such as streets, blocks or wards, and the neighbourhood principle proved to be too rigid on occasions and should not necessarily be applied universally.

Subsequent Developments

In 1956, Cumbernauld within commuting distance of Glasgow in Scotland, was designated a new town and was subsequently categorised as a Mark II or second generation new town. It moved away from seeking social balance by complete integration and community structure and was much less physically determined than the earlier new towns. There was less emphasis on the architecturally designed neighbourhood unit, less physical division of the town, higher densities and almost complete pedestrian-vehicle segregation. The new towns designated in the early 1960s were concentrated around Birmingham and in Merseyside, the North East and Scotland; all planned with increased mobility and planned accessibility and they moved even further away from the concept of a fixed residential neighbourhood size.

The next phase of development encompassed the designation of Northampton, Peterborough and Warrington, all of which had original populations around 100 000, and were developed on a partnership basis between development corporations and the existing local authorities. Finally, the ultimate size of the new town received an enormous boost with Milton Keynes with a design population of 250 000, on the premise that the earlier new towns of 20 000 to 60 000 had been found too small to stimulate the necessary economic growth and balanced employment. Milton Keynes will be examined in more detail in the next section of this chapter. There are in total 28 British new towns, as shown in Figure 7.16, ranging in possible ultimate size from 13 000 (Newtown, mid-Wales) to 200 000 (Milton Keynes). They differ considerably in density, character, location and economic potential and, on occasions, changing objectives. It is unlikely that all the desirable site requirements can be met, embracing optimum site conditions, adequate services, good communications, sufficiently distant from other large towns, avoidance of areas of outstanding beauty or historic interest, mining subsidence, large surface workings and high quality agricultural land; leaving the final decision to be made by balancing costs and benefits.

Milton Keynes New Town

In 1967 it was officially designated for a new city of 250 000 population to become the largest totally planned new urban development in British town planning history, to enable the residents to combine suburban living with quick and easy access to places of work and a wide range of

Figure 7.16 *British New Towns*

Figure 7.17 *Milton Keynes: the strategic plan (Source: Milton Keynes Development Corporation)*

recreational facilities. Its location is ideal alongside the M1, about midway between London and Birmingham, and served by the London to Glasgow railway line.

It is based on a grid of major roads spaced about 1 km apart with roundabouts at the intersections, and on each 1 km length there are usually two pairs of junctions serving adjoining developments, and three underpasses or overbridges linked by a city-wide network of footpaths, which may also be used by cyclists. The roads are moulded into the landscape to avoid interesting features but still retain views of them, and densely planted with a selection of species, to give a sense of identity to each part of the city, and are coded H or V and numbered for ease of identification. Figure 7.17 shows the general layout including the main road network, town centre, scattered employment areas, extensive open space and other land uses.

The town centre known as 'Central Milton Keynes' is, unlike Stevenage, situated in the geographic centre of the designated area and provides the social, cultural and commercial heart of the new town. Figure 7.18 gives an aerial view of this area. Employment and housing areas are separated and protected by landscaping, yet close enough to permit short commuting times.

Figure 7.18 *Milton Keynes New Town, central area (commercial development) (Source: Milton Keynes Development Corporation)*

Industrial development comprises advance factories and purpose-built projects, serving a variety of different industrialists with varying requirements. The latest trend has been towards high quality buildings finished to a shell standard with a number of fitting out packages to suit each tenant's individual space and plant requirements. Advanced factory units are available in sizes ranging from 50 m^2 to 4650 m^2. These units are suitable for adaptation to various uses including warehousing, distribution, research and development and office space. There are also ample shopping facilities in the form of shops, superstores, retail warehouses, and markets with free car parking.

Milton Keynes offers a wide range of *housing* with over 2000 dwellings being built each year. New property is built for sale by a number of developers and agencies with a wide range of properties from one bedroom flats to four or more bedroom executives houses and marina properties with individual boat moorings. Special provision is being made for the elderly and disabled, shared ownership schemes with active housing association input, rented accommodation, sales to sitting tenants and self-build properties. Much of the housing built in the late 1980s has been designed to high energy saving standards. The city houses an energy park where all properties must comply with an energy performance standard, and this requirement applies to all new house building in the 1990s.

The Development Corporation has recognised to the full the importance and value of *outdoor recreation* and *environmental aspects* in the provision of the following facilities, supplemented by substantial indoor and commercial recreational facilities:

Urban style park in the city centre with a mixture of woodlands, landscaped gardens and bulb fields.

Linear parks are open spaces in and around the canal and river valleys which meander through the city. Within their total area of 1650 ha is a variety of landscape settings such as informal grassed areas, animal grazing, formal gardens and woodlands. There is easy access for pedestrians, cyclists and horse-riders, with more limited access for motorists from car parks on the fringes. There are also two lakes, one a recognised centre for bird watching and the other a major water sports centre.

District parks are located within or adjoining the linear parks, taking advantage of special natural features or integrated with district playing fields.

Local parks and *playgrounds* are provided within the residential areas, principally for children and the elderly, and include spaces for informal casual use, walking, sitting, children's play and ball games.

With regard to *utility services* the water supply to the rapidly growing city has been augmented by Grafton Water and Rutland Water. One of the main natural gas pipelines supplying the southern region runs close to the city and there is an adequate electricity supply from two grid substations. British Telecom distribute radio and TV signals to every new house in the designated area, all fed from a single master aerial at Linford Wood.

Surface water and foul sewage are dealt with in separate piped systems, with foul sewage treated at the Cotton Valley Sewage Treatment Works and surface water discharged into local streams and rivers. The designated area has been liable to valley and local flooding for many years. Hence Anglian Water and the Development Corporation have provided a system of balancing lakes so that in heavy storms, when river levels are high, surface water can be stored for a period of time and then released at a controlled rate when river levels fall. The lakes are of two types – those which are normally dry open spaces but retain water during long storms, and those which are permanent water features, the water level rising and falling to effect balancing. These permanent lakes are used for recreational purposes such as boating, water skiing and fishing. Oil interceptors are provided on many surface water outfall sewers, particularly from employment sites.

The Development Corporation's Economic Development Strategy in 1989[75] included the following objectives:

(1) to develop at least 100 000 m^2 of new speculative and purpose-built office floorspace during the period 1989 to 1992
(2) to provide opportunities for the development of at least 50 000 m^2 of speculative industrial floorspace per annum, to be funded predominantly by the private sector
(3) to commit all employment land and Central Milton Keynes by 1992, when it is possible that the third generation new town will be handed over to local authorities and the Development Corporation disbanded
(4) to ensure the provision of housing and facilities relevant to the employment growth.

Table 7.2 provides a wealth of factual information on the development position as at 31 March 1989, and indicates the exceptional progress that has been achieved, even if one hears some criticisms of the rigid grid layout.

Hong Kong New Towns

New Town Programme

Hong Kong's New Town Development Programme is probably the largest and most ambitious of its kind in the world. It originated in 1972 with a plan to provide modern low cost living quarters for 1 800 000 people. Many of these units were built in the New Territories in satellite new town communities located away from the older densely populated Urban Areas of Hong Kong Island and Kowloon. Hence with an average annual expenditure of HK$2.8 billion during the mid-1980s, large parts of the New Territories were transformed from typical rural areas into bustling new communities, providing homes for 3m people by the mid-1990s. While civil engineering and housing have been the main items of expenditure in the past, the 1990s will see a greater proportion of spending in the new towns on social facilities.[25]

The programme started with three first generation new towns – Tsuen Wan (see Plate 21), Sha

Table 7.2 *Facts on Milton Keynes (as at 31 March 1989)*

Population	*Designated area*	*MK Borough*
At designation	40,000	60,000 (est)
At present	141,800	174,600
Employment development		
Jobs at designation	18,350	21,350 (est)
Jobs at present	79,500[1]	90,000[1]
Unemployment rates % – March 1989[2] *Including school leavers*		
Great Britain		6.7
MK travel to work area		3.0
East Midlands		6.2
South East		4.3
Commercial floorspace (m^2) **in the designated area**	*Completions in 1988/89*	*Existing stock at March 1989*
Industry	99,849	1,680,322
Offices	4,495	283,545
Shopping (local)	–	99,736
Shopping (central Milton Keynes)	5,827	119,267
Floorspace totals	110,171	2,182,870
Houses and facilities in the designated area	*Completions in 1988/89*	*Existing stock at March 1989*
Housing stock		
Owner occupied (including shared ownership)	1,620	(66%) 35,804
Private and Housing Association rent	142	(4.5%) 2,434
Public rent	20	(29.5%) 16,066
Total dwellings	1,782	54,304
Facilities stock		
Schools	2	80
Pupil places	892	30,647
Health centres	1	9
City roads	5.03 km	92.2 km
Finance		
Net capital expenditure throughout the designated area (£m)	*Expenditure in 1988/89*	*Cum. figures*[3] *to March 1989*
Private	294	1,486
Milton Keynes Development Corporation	(56)	435
Other public	31	392
Total	269	2,313
Expenditure under MKDC control (£m)		*During 1988/89*
Direct MKDC expenditure		58
Financed by: Capital receipts	114	
Net contribution to Treasury	(56)	
Other private		14
Total		72

[1]Total jobs as result of Employers' Survey. Not comparable with previous years. [2]New base. [3]Provisional outturn March 1989. *(Source: Milton Keynes Development Corporation)*

Tin and Tuen Mun. Subsequently development work started on six further areas to meet Hong Kong's pressing housing needs in the form of the second generation new towns of Yuen Long, Tai Po, Fanling/Sheung Shui and the extension of Sha Tin New Town at Ma On Shan; and the third generation new towns of Junk Bay (see Plate 19) and Tin Shui Wai. In parallel with the new housing development came major improvements to the road and rail networks, some of which were described and illustrated in chapters 2 and 3, the provision of a wide range of community facilities and open space, and industrial and commercial growth.[25]

Each new town has been planned around two important objectives:

(1) to be well balanced and reasonably self-contained
(2) to provide a modern and spacious living environment.

The HK new towns have been planned as complete communities incorporating all necessary supporting facilities together with a variety of housing types to meet different tastes and needs. Hence most public housing estates contain a shopping centre and market, community centre, open spaces, primary schools and a public transport terminus, and they are designed to accommodate a broad spectrum of housing types, from a flat in a modern public or private housing estate to a 2-storey villa.

Industry is a key planning component in every new town. Hence sufficient industrial land has been set aside to accommodate the potential demand for light manufacturing jobs from the resident workforce, and the new towns are becoming important industrial centres in their own right.

Environmental Aspects

In environmental terms, the new towns offer much improved facilities in lower population densities, provision of numerous landscaped open spaces, careful siting of different land uses and segregation of people and traffic. Great emphasis has been placed on providing a comprehensive network of green open spaces in each new town. These spaces provide a much needed break from the hectic pace of modern city life and are designed to accommodate a variety of activities, from sitting or strolling to more active pursuits such as soccer and tennis. Most new towns also have a network of segregated cycle-tracks, some extending into attractive country-side and coastal areas.

Special attention has been paid to safeguarding the natural landscape in the vicinity of new towns, including the restoration of hillside borrow areas which are unsuitable for development purposes, and extensive tree planting programmes. In the new towns themselves, a sense of identity has been enhanced by the creation of recognisable focal points within each development area, such as town parks, new town centres and civic complexes, large sports centres and open space promenades, many taking advantage of striking landscape settings. An excellent example of such a project is shown in Plate 30, which illustrates the attractive Chinese style town park at Sha Tin New Town, with the landscaped waterfronts to the Shing Mun River, beautiful arched bridge and the high rise housing in the background, taking the form described earlier in the chapter.

Sha Tin New Town

Sha Tin has been selected for study as the second largest and probably the best known of Hong Kong's new towns. It is situated around the southern end of Tolo Harbour and, since 1976, has been transformed from a rural township of 37 000 people to a modern city housing over 400 000 residents, which is expected to rise to 700 000 by the mid-1990s. Although the development of Sha Tin itself is substantially complete, work on the new town extensions at Ma On Shan, which started in 1981, has enlarged the total new town area to 3600 ha. Development sites were formed initially in and around the Shing Mun River Valley while later stages, including Ma On Shan, have turned increasingly to sea reclamation, and this aspect features in chapter 8. Extensive river training work has turned part of the Shing Mun River into a straight man-made channel over 4.5 km long and 200 m wide, suitable for canoeing, rowing and Dragon Boat racing. Figure 7.19 provides a fascinating view of Sha Tin, looking up the coast towards the Ma On Shan extension, and illustrates its dramatic setting in the river valley between the mountains.

Like other Hong Kong new towns, Sha Tin offers a wide range of employment opportunities, social, recreational and community facilities, and a controlled mix of public and private housing. The New Town Plaza, the Town Park, the Jubilee Sports Centre and the popular Racecourse, enclosing the Penfold Park, are all features which have contributed to the success of this modern community. Sha Tin is well connected by rail and road to Kowloon and Tsuen Wan, and further afield to Canton. By 1996, expenditure on land formation, and the provision of infrastructure including roads, sewers, water supply and sewage disposal facilities is estimated to amount to HK$5800m. Table 7.3 contains the basic data relating to Sha Tin up to 1996.

Many of the principal civil engineering works connected with Hong Kong new towns have been dealt with in earlier chapters, but to supplement this information readers are referred to the paper by Butler and McKittrick[76] covering the development of Tuen Mun New Town. The paper provides a useful overview of land reclamation, excavation and land formation, storm water drains, foul drains, transport system (buses and LRT), roads, highway bridges, footbridges and pedestrian subways and ancillary structures, and interesting information is supplied on programming and co-ordination and construction contracts. The location of most of the new towns is shown in Figure 6.20.

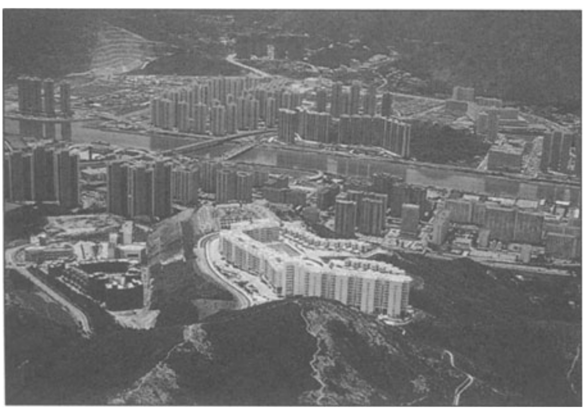


Figure 7.19 *Sha Tin New Town, Hong Kong, looking up the coast towards the Ma On Shan extension (Source: Territory Development Department, Hong Kong)*

Singapore's New Towns

Development of New Towns

A Singaporean new town often houses 250 000 to 300 000 residents and, at this size, it attracts all the essential features that sustain a town centre with a mixture of commercial, institutional and recreational establishments. Scarcity of land results in most of the buildings being high rise with the main exception of those in town and neighbourhood centres. In 1989 there were 20 new towns as listed in Table 7.4, which also shows the land areas, housing development programmes and the position at 31 March 1989.

New town planning has evolved in Singapore since 1965 and each subsequent new town has incorporated new concepts and refinements. The first new town development was at Toa Payoh, commenced in 1965 with a target population of 180 000, a town centre and a range of complementary facilities. The town centre mall was pedestrianised, there were good industrial employment opportunities and two flyovers connected the new town with the island-wide road network.[31]

The second stage of new town development was undertaken in a more systematic way as exemplified by Ang Mo Kio New Town which was commenced in 1973, when HDB had developed a prototype new town model (see Figure 7.4). The hierarchy and distribution of the town centre, neighbourhood centres and sub-centres were clearly defined. For example, the neighbourhood centre should be 4 ha in size to serve a population of 4000 to 6000, industrial developments were rationalised, and steps were taken to meet the higher expectations of residents by providing larger flats at lower densities and more and better communal facilities.[31]

The third and current stage of new town development introduced the precinct concept, as

Table 7.3 *Sha Tin New Town Fact Sheet*

New Town Area (hectares)	Sha Tin Proper	Ma On Shan	Total
Land area	2,809	828	3,637
Development area			
Existing and committed (1)	1,657	243	1,900
Potential (2)	–	200	200
Total	1,657	443	2,100
Green belt	1,150	385	1,535

(1) Area with definite development programme.
(2) Area with no definite development programme which depends on the optimisation of existing and planned infrastructures.

Population	*Up to 31.3.86*	*Up to 31.3.96*
Total	394,000	750,000
% by housing type		
Private residential	31	34
HOS/PSPS	12	18
Public rental housing	57	48
Education		
Primary school	25	47
Secondary school	20	53
Post-secondary school	4	5
Special school	2	3
Community facilities		
Children and youth centre	14	25
Community centre	7	14
Fire station	1	5
Ambulance depot	1	5
Hospital beds	1,330	2,985
Polyclinic/specialist clinic	1	2
General clinic/health centre	2	7
Police station	3	7
Cultural complex	0	2
Library	1	3
Magistracy	0	1
Sports stadium/complex	2	4
Swimming pool complex	1	3
Indoor recreation centre	0	7
Hostel for the elderly	9	17
Post office	5	12
Market	16	22
Open space (hectares)		
Local open space	37	88
District open space	19	99
Land production (hectares)		
Total land formed	1,182	1,602
Expenditure (in $ Millions)		
Engineering	3,415	5,789
Community facilities	1,669	3,213
Housing authority expenditure	2,893	5,647

(Source: Territory Development Department, Hong Kong.)

Table 7.4 *Singapore New Town Development*

New Town	***Estimated population As at 31.3.89	*Total land Area (Hectares)	**Residential Area Allocated (Hectares)	Projected Total Dwelling Units	Dwelling Units Completed in FY 1988/89	+Dwelling Units Completed as at 31.3.89	Dwelling Units under Construction As at 31.3.89
Ang Mo Kio	209,800	742	248	49,500	0	49,480	60
Bedok	229,430	979	285	57,100	0	54,110	110
Bishan	49,400	704	115	22,000	1,321	12,970	5,585
Bukit Batok	111,510	813	170	28,000	376	26,680	0
Bukit Merah	246,170	854	263	60,800	0	58,060	35
Bukit Panjang++	47,830	475	173	30,000	1,697	12,980	396
Choa Chu Kang	17,380	466	211	35,000	2,278	6,380	4,200
Clementi	101,970	433	146	25,000	0	24,050	0
Geylang	146,870	1,085	173	37,300	496	35,140	0
Hougang	125,120	1,196	245	41,000	945	30,460	4,670
Kallang/ Whampoa+++	151,370	813	152	57,400	217	35,920	0
Jurong East	83,060	300	129	21,000	0	19,590	123
Jurong West	147,760	918	411	65,000	2,761	37,610	3,434
Pasir Ris	3,770	998	208	36,000	3,284	4,170	2,242
Queenstown	143,180	716	183	40,600	0	33,770	0
Serangoon	56,560	634	123	21,000	2,638	15,980	1,672
Tampines	167,860	1,035	377	65,400	4,085	43,680	403
Toa Payoh	169,430	417	167	44,200	1,320	41,280	0
Woodlands	96,970	1,244	358	66,000	259	23,130	0
Yishun	191,520	919	315	60,000	172	45,340	589

* Including private developments
** Excluding Neighbourhood Centre and Town Centre
*** Estimated population based on full occupancy and household size of 4.24 persons as at Dec 1987
\+ Figures refer to units under management and are rounded to the nearest ten
++ New Town renamed from Zbengbua to Bukit Panjang
+++ New Town renamed from Jalan Besar to Kallang/Whampoa
Source: HDB, Singapore. Annual Report 1988/89
Note: The location of most of the new towns is shown in Figure 2.14.

described earlier in this chapter, to express character and individuality and also foster community development. The latest new towns also respond more sympathetically to existing natural features which can accentuate the character and individuality of the new town. Additionally, large parcels of land were omitted from current development and safeguarded for meeting future needs with possibly changing requirements to permit more flexibility.

Main Components of New Towns

Apart from the housing provision which has been dealt with extensively elsewhere in this chapter, there are a whole range of facilities that are required to serve the needs of a progressive population expecting ever higher standards. The nucleus of each new town is its town centre which contains the large emporiums, supermarkets and cinemas. Beside the town centre is often located the town park which greatly enhances the area both environmentally and practically, as illustrated in Plate 31, showing part of Bishan town park, with typical high rise housing in the background. Town parks are increasingly being developed from the natural elements on the existing sites. Thus, in Woodlands New Town the park is built around a pond reclaimed from swampy ground, while in Ang Mo Kio natural vegetation was retained.[33]

In the neighbourhood centre, there is always a market and supporting essential services such as banks and medical clinics and the administrative area office, and it serves as the terminal point for public transport systems. Other facilities such as schools, community centres and sports complexes are scattered throughout the town at selected locations to provide an adequate level of socio-economic self-sufficiency, amply served by a convenient road network.[33]

The simplicity of the functional requirements of swimming pool complexes, comprising several pools, changing rooms, refreshment kiosk and spectator stands, give architects ample opportunity for individual design expression. A variety of roof forms is to be found, ranging from high-tech in Clementi to prestressed off-form concrete in Buona Vista and cubistic skylights in Bedok.

A more orthodox complex with red tiled pitched roofs at Bukit Batok is illustrated in Figure 7.20. The design of community centres, being free-standing structures enclosed by residential blocks have also attracted creative approaches, with some seeking continuity with the existing environment, others invoking traditional architectural themes or inventing their own idioms to generate interest and character. Probably the most picturesque landmark building in a new town is the mosque, with its tall minaret standing high above surrounding buildings and distinctive facades.[33]

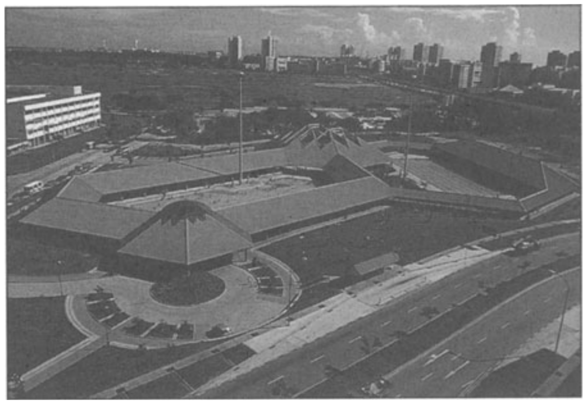


Figure 7.20 *Bukit Batok New Town, Singapore, swimming complex (Source: HDB, Singapore)*

Canberra – Australia's National Capital

The final section in this chapter briefly examines the history, layout and development of Canberra, which is largely based on the winning design of Griffin, an American architect, in 1912 in a worldwide competition. Early progress was very slow and it was not until the 1950s that the development gained momentum. By 1990 the population of the national capital on its new site and the three surrounding new towns had reached 240 000 and was expected to reach 500 000 by the end of the century.

The national city is built on both sides of a the large man-made Lake Burley Griffin, with extensive landscaping and vistas based on distant hills. The capital is laid out symetrically with the civic area, law courts, commercial area and university to the north of the lake, connected across the lake by Commonwealth Avenue with Capital Hill, where the new Parliament House was completed in 1988. The prestige buildings of the National Library, High Court and National Gallery overlook the south shore of the lake. The aim was to build a National Capital which was an efficient centre for the administration of the nation and also symbolised Australia's culture, learning, history and system of justice – a garden city of light, space, dignity and aesthetic appeal.

The new Parliament House is a spectacular building of 'firm, clear geometry, not rigidly imposed on the terrain but sensitively adjusted to it, and derives its strong presence by merging built form with landform'. It is built in two sections between two curvilinear walls, with a park on top of the central dividing mall. The focal point is a gigantic Australian flag supported by a tubular stainless steel structure spanning the centre of the complex.[77]

The new towns are being planned and built with many of the characteristics of independent cities with their own commercial, employment and retail centres, with each having the potential to develop its own individual character. All will be linked by roads, cycleways and a public transport system and each will accommodate some of the national capital functions.

The strong natural landscape of hills and the river have been further strengthened by extensive planting to provide a most attractive setting. In 1990 the city still had an unfinished feel about it but doubtless this will change with time.

References

1. A.E. Telling. *Planning Law and Procedure*. Butterworths (1990)
2. N. Taylor. *Development Site Evaluation*. Macmillan (1991)
3. C. Gossop. The need for new planning laws to curb the urban sprawl. *The Guardian, 14 Sept. 1989*
4. I.H. Seeley. *Building Technology*. Macmillan (1986)
5. The Engineering Council. Engineering assembly statement. *Engineering Council Newsletter, Issue 12, Oct., 1990*
6. United Nations Environment Programme. *Montreal Protocol on Substances that deplete the Ozone layer* (1987)
7. BRE. Information Paper IP 23/89. *CFCs and the Building Industry* (1989)
8. Levinson, DSSR and Gleeds. *A Guide to Environmentally Friendly Buildings*. (1990)
9. BRE. First green assessment for buildings. *BRE News of Construction Research, Aug., 1990*
10. M.E.H. Smith. *Guide to Housing*. Housing Centre Trust (1989)
11. DOE Development Management Working Group. *Value for Money in Local Authority Housebuilding Programmes* (1978)
12. IOH and RIBA. *Homes for the Future – Standards for New Housing Development* (1983)
13. BRE. *Digest 350*. Climate and site development, part 3: Improving microclimate through design (Apl., 1990)
14. GLC. *An Introduction to Housing Layout*. Architectural Press (1978)
15. P. Nuttgens. *The Home Front: Housing the People 1840–1990*. BBC Books (1989)
16. C. Couch. *Urban Renewal: Theory and Practice*. Macmillan (1990)
17. C. Bacon. Deck access housing. *Housing and Planning Review, 54.2, Apl., 1985*
18. BRE. *Quality in Timber Frame Housing* (1985)
19. Manchester City Council, Planning Department. *Housing in Manchester, 1980–85* (1986)
20. RIBA. *Decaying Britain* (1985)
21. Committee chaired by HRH the Duke of Edinburgh. *Report of the Inquiry into British Housing* (1985) and *Second Report* (1991)
22. Committee commissioned by the Archbishop of Canterbury. *Faith in the City* (1985)
23. RICS. *Housing: The Next Decade* (1986)
24. HRH The Prince of Wales. *A Vision of Britain: A personal view of architecture*. Doubleday (1989)
25. Hong Kong Government, Lands and Works Branch. *Hong Kong: The Development Challenge* (1989)
26. Hong Kong Government. *Year Book: Housing and Land in Hong Kong* (1980)
27. Lim Yew-guan. High rise owners. *Housing, Apr., 1989, 27–9*
28. Hong Kong Government, Lands and Works Branch. *Metroplan: The Aims* (1988)
29. G. Daughton. City steps. *Halcrow Now, Sept./Oct., 1989, 4–5*
30. HDB, Singapore. *Public Housing in Singapore* (1989)
31. A.K. Wong & S.H.K. Yeh. *Housing a Nation: 25 years of public housing in Singapore*. HDB (1985)
32. HDB, Singapore. *Facts about Public Housing in Singapore* (1990)
33. HDB, Singapore. *Designed for Living: Public housing architecture in Singapore* (1985)
34. HDB, Singapore. *Annual Report 1988/89*
35. HDB, Singapore. *Annual Report 1987/88*
36. MHLG/MoT. *Planning Bulletins: Town Centres*
    1. *Approach to renewal*. HMSO (1962)
    2. *Cost and control of redevelopment*. HMSO (1963)
    4. *Current practice*. HMSO (1963)
37. E. Dalby. *TRRL Laboratory Report 577: Pedestrians and shopping centre layout: a review of the current situation*. TRRL/DOE (1973)
38. R. Abrams. Whatever happened to civic pride. *Chartered Surveyor Weekly, Town Centre Retail Supplement, 18 Oct. 1990*
39. G. Emslie. Retail is detail. *Directions nr 6*. Building

Design Partnership (1990)
40. Shepherd Construction. *A New Concept in Regional Shopping* (undated)
41. G. Chase. Now we are carborne. *Chartered Surveyor Weekly, Retail Supplement, 19 Apr. 1990*
42. Clive Lewis & Partners. *Midsummer Retail Report* (1989)
43. I.H. Seeley. *Planned Expansion of Country Towns*. Godwin (1974)
44. Debenham Tewson & Chinnocks. *Business parks – Out of town or out of touch* (1990)
45. Applied Property Research. *Living with B1* (1990)
46. Ove Arup. Stockley Park. *The Arup Journal, Spring 1987*
47. Ove Arup & Partners. *Stockley Park drainage, West London* (undated)
48. London & Metropolitan and Postel. *Watchmoor Park, Camberley* (undated)
49. Shepherd Construction. *St John's Innovation Centre, Cambridge* (undated)
50. *Town and Country Planning Act 1971, section 277*
51. DOE. *Re-using Redundant Buildings: Good Practice in Regeneration*. HMSO (1987)
52. S. Cantaouzino & S. Brandt. *Saving Old Buildings*. Architectural Press (1980)
53. J. Benson, B. Evans, P. Colomb & G. Jones. *The Housing Rehabilitation Handbook*. Architectural Press (1980)
54. D. Highfield. *Rehabilitation and Re-use of Old Buildings*. Spon (1987)
55. PSA. *The Conservation Handbook* (1988)
56. G. Parkinson & W. G. Curtin. Albert Dock, Liverpool – structural survey, appraisal and rehabilitation. *The Struct. Engr/Vol. 64A/No. 10/ Oct. 1986*
57. J.A. Tallis, R.D. Taylor & T.J. Dishman. Restoration of Albert Dock. *The Struct. Engr/Vol. 64A/No. 10/Oct. 1986*
58. URA, Singapore. *Conserving our remarkable past* (undated)
59. URA, Singapore. Conservation of Tanjong Pagar Area. *Jnl of Singapore Institute of Surveyors and Valuers, No. 82/9487, 1.1/87,33–7*
60. URA, Singapore. *Skyline, Jan./Feb., 1989, 10*
61. DOE. *Improving Urban Areas. Good Practice in Urban Regeneration*. HMSO (1988)
62. M. Gloster & N. Smith. *Inner Cities – A Shortage of Sites*. Discussion Paper. RICS (1989)
63. ICE, Infrastructure Policy Group. *Urban Regeneration*. Telford (1988)
64. National Audit Office. *Regenerating the Inner Cities*. HMSO (1990)
65. DOE. *Five Year Review of the Bolton, Middlesbrough and Nottingham Programme Authorities*. HMSO (1990)
66. DOE. *Greening City Sites. Good Practice in Urban Regeneration*. HMSO (1987)
67. Civic Trust. *Urban Wasteland Now* (1988)
68. House Builders Federation. *Private Housebuilding in the Inner Cities* (1988)
69. DOE. *Cost Effective Management of Reclaimed Derelict Sites*. HMSO (1990)
70. Olympia and York. *Canary Wharf* (1990) and Canary Wharf. *Estates Times, 21 Sept. 1990, Supplement*
71. G. Smith. Flying over the Canary. *New Civ. Engr, 8 Nov., 1990, 30–1*
72. L. Mallett. *Building up the nation's prestige. Estates Times, 20 July 1990, 15–20*
73. Director of Development, Swansea City Council. *Swansea Maritime Quarter in Progress* (1988)
74. Welsh Development Agency, Urban Renewal Unit. *Swansea Maritime Quarter, RICS 1988 Inner City Awards: Submission document by Swansea City Council* (1988)
75. Milton Keynes Development Corporation. *Policy Statement, Economic Development Strategy* (1989)
76. D.R. Butler & R.A. McKittrick. Development of Tuen Mun New Town, Hong Kong. *Proc. Instn Civ. Engrs, Part 1, 1989, 86, Aug. 603–25*
77. H. Beck. *The Architecture of Australia's Parliament House*. Watermark Press, Sydney (1988)

8

Water Based Works, Recreational Facilities & Energy Generation

Rising Groundwater and Sea Levels

Groundwater

A CIRIA report in 1989[1] stated that rising groundwater beneath London and other cities will cause severe damage to buildings and tunnels within 20 to 30 years, by the water pressure causing ground movement in the overlying clay in central London, unless action is taken. As a result the DOE, which funded part of the 5-year research project, requested the NRA to undertake an urgent review of the problem and suggest remedial measures. The groundwater level under central London is rising by about a metre per year, because water is no longer being drawn from underground wells, as industry moved out of cities to other locations. Of the 150 km of the London Tube system, 40 km are within the critical zone.

CIRIA believes that the solution is to pump the groundwater into the sewerage system at the rate of about 30m litres/day, involving constructing some 30 wells across London at a cost of £10m to £30m (1989 prices). If the rise continued unabated, numerous large buildings will require expensive repairs resulting from differential ground heave. The British Library in Euston Road already has wells constructed into the specially strengthened foundations for pumping out water.

Sea Levels

Pugh[2] has shown that there was no evidence in 1990 of global sea level increases over and above the 1.0 to 1.5 mm/year, which had been occuring since tide gauge recording began in the early 19th century, although present knowledge cannot even determine the relative importance of the various factors which contribute towards it. He therefore advocated the establishment of comprehensive monitoring systems, both globally and nationally, and of the predictive capability linking global temperature increases and other aspects of climate change to sea level rise, and to take account of the impacts of sea level rise in designing long term coastal facilities.

Sweby Cowan[3] in 1989 believed that it was realistic to assume that over the next century sea level rises will range between 0.5 and 1 m. However, even a relatively small rise could have serious consequences for many of Britain's low lying areas, particularly on the East Coast. Possible problems facing water authorities include erosion of beaches and coastal margins, land use changes, wetland losses, increased frequency and severity of flooding, damage to port facilities, coastal structures and water management systems. As practical illustrations, Anglian Water estimated that the provision of additional flood protection for low lying farmland in East Anglia could cost £5m to £7m, while the British Ports Federation estimated that improved sea defences for one port alone could cost £100m to £200m.

Flood Barriers

A number of impressive flood barriers across tidal rivers have been constructed in the United Kingdom since the 1970s, and four have been selected for a study of their main design and constructional characteristics. They perform a most vital function in preventing the severe flooding of large areas of land and the properties thereon.

Thames Barrier

General Background Extensive studies initiated by the government following the 1953 floods led to the 1972 Barrier Act which empowered the then GLC to construct the Thames Barrier. Rendel Palmer & Tritton (RPT) have described how the area of Greater London at risk before the construction of the Barrier, and the associated downstream embankment raisings along the Essex and Kent coasts, consisted of a densely built up industrial and residential area of 116 km^2.[4]

Navigational interests and shipping requirements resulted in a long gestation period for the final scheme. Progressively, trade moved down the River to new facilities at Tilbury, or away from the River altogether, resulting in the closing of docks which became little used for the handling of cargo. In consequence, it became possible to reduce the navigational opening of 427 m to 61 m, and the airdraft requirement for large liners with fixed masts was rendered obsolete. Gilbert and Horner[5] pointed out how the long delays in the provision of the Barrier could have put London at risk and that it was only saved in the main by temporary bank raising.

In 1967 the GLC assumed responsibility for the project and, at that time, the cost of possible damage to London was estimated at £3b, with the Capital out of action as a communication centre for one year should severe flooding occur. Some 41 possible sites for the barrier were evaluated with Woolwich as the preferred site. In 1971, 18 years after the floods which started the search for a solution to their prevention, RPT was engaged to design the works and supervise their construction. The design surge was to be taken as the 1000 year return flood relevant for conditions operating up until the year 2030. Extensive hydraulic and structural tests amd model studies were carried out during the development of the final design, including 80 boreholes to determine the ground conditions on site and seismic studies to minimise risks from earthquakes.[6]

The Barrier Complex The width of the River at Woolwich is 520 m. The Barrier has ten waterway openings contained between the north and south abutments and nine piers. Six openings are for navigation and have rising sector gates, of which the centre four have 61 m clear openings and the others 31 m openings. A view of the complex, with gates in the flood defence position, is shown in Figure 8.1. The concept of the rising sector gate was that it could lie in the bed of the river under normal conditions, be rotated into a vertical position at times of flood, and be rotated to be completely above the water for maintenance purposes.

The basic layout is shown in Figure 8.2, while a typical arrangement of a rising sector gate and its relationship with the piers and sill is illustrated in Figure 8.3. The gate spans are fixed at one end to the gate arm by a full moment carrying connection and to the other gate arm by a hinge. The gate arms house the cast iron counterweight needed to balance the deadweight of the gate span. The 5000 t load on each gate arm is transmitted to the pier structures through a spherical bearing having a solid lubricant, and the bearings do not require maintenance. Each rising sector gate is moved by the operation of two hydraulic cylinders acting through a triangular shaped rocking beam connected by a link arm to a gate arm.[4]

Operations of the gates, generators and power systems are controlled from control panels in the central control room located near the top of the control building, and electrical power supply is available from three separate sources and there are two separate water supply systems for fire.

Figure 8.1 *Thames Barrier (Source: Rendel Palmer & Tritton)*

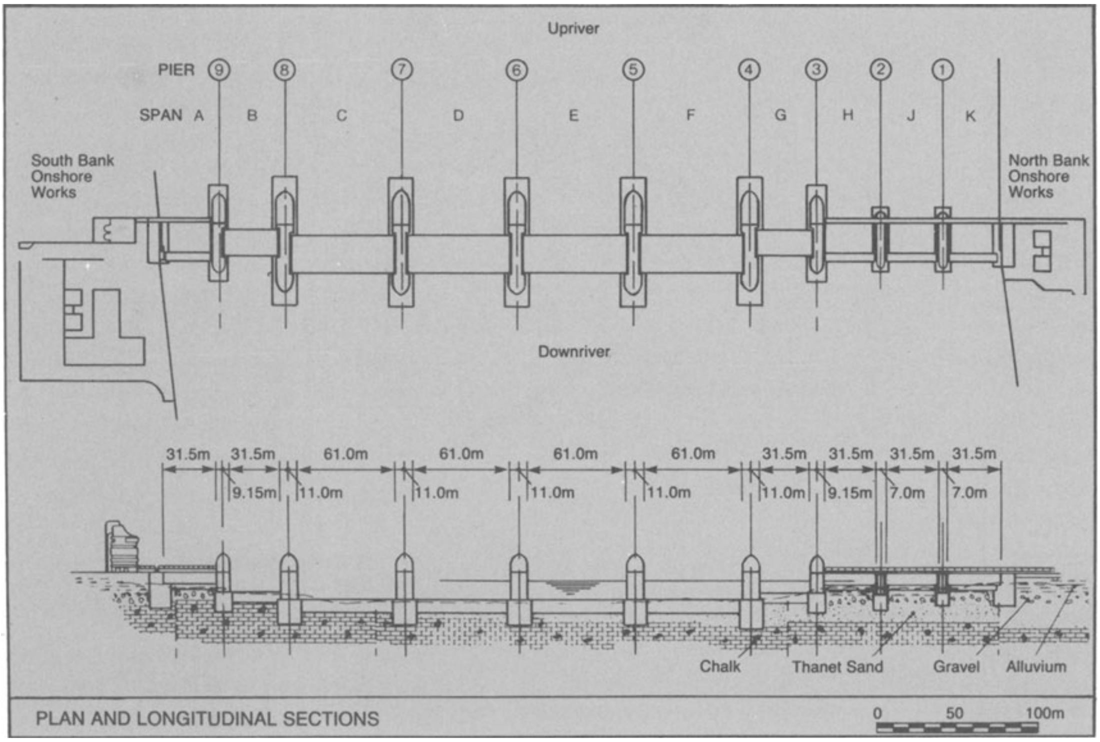


Figure 8.2 *Plan and longitudinal sections, Thames Barrier (Source: Rendel Palmer & Tritton[4])*

fighting. Automatic fire detection, alarm and security systems operate through a central database and computer system. Tidal data from automatic gauges located upstream and downstream from the Barrier, also storm and weather information from main and coastal centres, is transmitted through radio links and land-lines for dissemination into the computer system and display on VDUs in the communication centre adjoining the central control room. River traffic through the Barrier is controlled by navigation lights installed at the upstream and downstream ends of each pier. There is also radar coverage from five stations over a length of 17 km of the river.[4]

Construction There were 25 main contracts of which the largest was for civil engineering works, valued at £38m at 1973 prices. The main work on the south abutment and the four southern piers started in 1975. Concurrently, work commenced on the north bank where a large area was cofferdammed to form a 'dry dock' for the precasting of the six sills for the navigation spans and for the construction in the dry of the north abutment and the two northern piers. When the first four sills had been constructed the 'dry dock' was flooded, the bank was breached and the sills were towed out to be stored afloat. Thereafter the cofferdam was closed again and the remaining two sills were cast.[4]

Construction of the piers in the river was carried out using the traditional method of working inside heavily braced steel sheet pile cofferdams. For the large piers on each side of the main navigation channels, the cofferdams were 75 × 17 m in plan, the piers within them being 65 m long by 11 m wide. To facilitate construction work within the cofferdams, piled jetties were erected along each side of the cofferdams.[4]

The sills for the six rising sector gates were

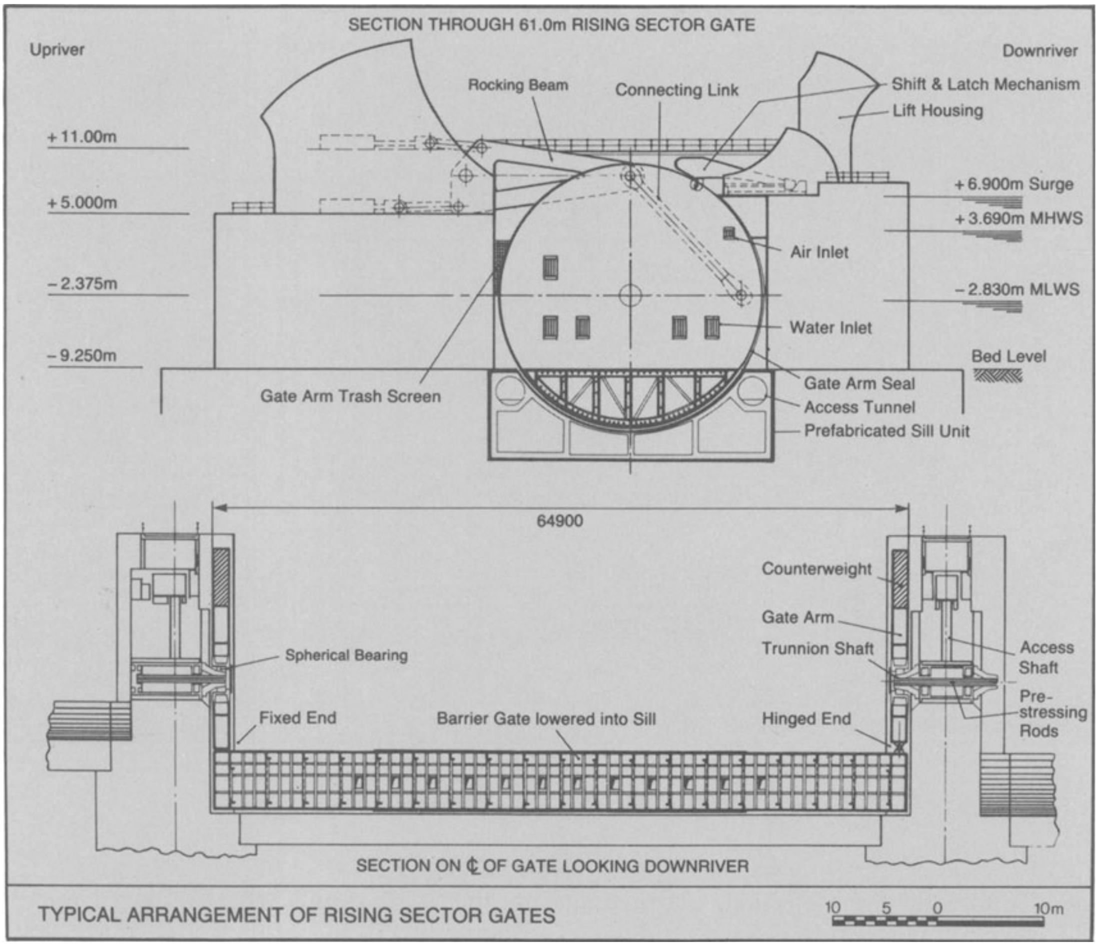


Figure 8.3 *Typical arrangement of rising sector gates, Thames Barrier (Source: Rendel Palmer & Tritton[4])*

prestressed reinforced concrete boxes of cellular construction floated between the piers and sunk into position. Those for the large navigation spans were 60 m long, 27 m wide and 8.5 m deep with a dry weight of 9000 t. The sills were mounted on laminated steel and rubber bearings at each corner, supported on flat jacks grouted up solid. The connections between sills and piers were formed of flexible joints moulded from 32 mm thick nylon reinforced chloroprene rubber. At the peak period of civil construction, the contractor employed 150 divers working in depths up to 30 m and the consulting engineers (RPT) carried out critical tests from a diving bell.[4]

The 61 m gate spans were 65 m long, 19 m wide and 5.3 m deep, with an all-up weight of 1450 t, and the arms were 24.5 m diameter by 1.5 m thick and weighed 1250 t. The 31 m gate spans were 34.5 m long, 13 m wide and 3 m deep, weighing 350 t, and the arms were 16.8 m diameter by 1.0 m thick and weighed 320 t. Each assembled gate unit was brought by barge from Teesside to the Thames and lifted into position by two 800 t capacity floating cranes. More that 50 t of hot applied solvent-free epoxy paint was applied to each 61 m gate span.[4]

Costs and Other Aspects Much has been written about the high cost of the project. When the design was finalised in 1973 the estimated cost was £110m, whereas the final cost in 1984 was £440m. Much of the increase was due to inflation which during the 1970s was in excess of 20% in some years. The next major cause was low productivity and delay resulting from industrial action, while constructional difficulties accounted for some 10% of the increased cost and 5% was attributed to design development.[6]

RPT estimate that the Barrier will be operational well beyond the 60 years theoretical design life. The prestigious and unique nature of the project was duly recognised when, in 1985, RPT was honoured by the award of the Queen's Award for Technological Achievement.

Barking Barrier

This project formed part of Thames Water's contribution to North Thames Tidal Defences and provided a supporting role to the Thames Barrier, previously described. The impressive structure with its drop gate, a navigation channel for shipping and three tidal gates was designed by Binnie and Partners and was constructed in 1979/80. It consists of two concrete towers 60 m high and 38 m apart. The main 300 t steel gate, which is 10.1 m deep, is suspended at the top of the towers under a high level gallery ready to be lowered when required. At other times, shipping can pass freely underneath. To the east of the barrier are two 12 m wide tidal gates which, together with the one to the west, are suspended just above the mean high water level. Details of the project are shown in Figure 8.4, and the work under construction is illustrated in Figure 8.5.[7]

All four barrier gates are electrically operated, and lower at the rate of 900 mm/minute. An emergency generator was installed beneath the control room on a spur next to the west tower. As a final safeguard, all the gates can be lowered manually.

The associated tidal defences include a steel wall from 75 m inside Barking Creek, which continues past the Barrier connecting with the

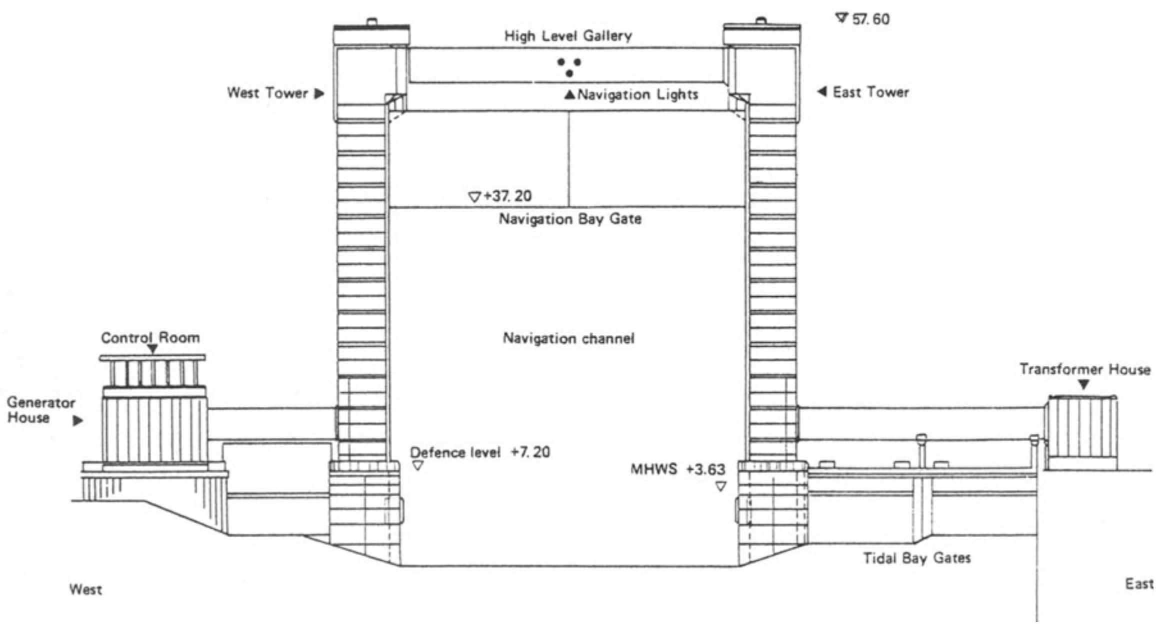


Figure 8.4 *Thames tidal defence: Barking Barrier, south elevation (Source: Thames Water[7])*

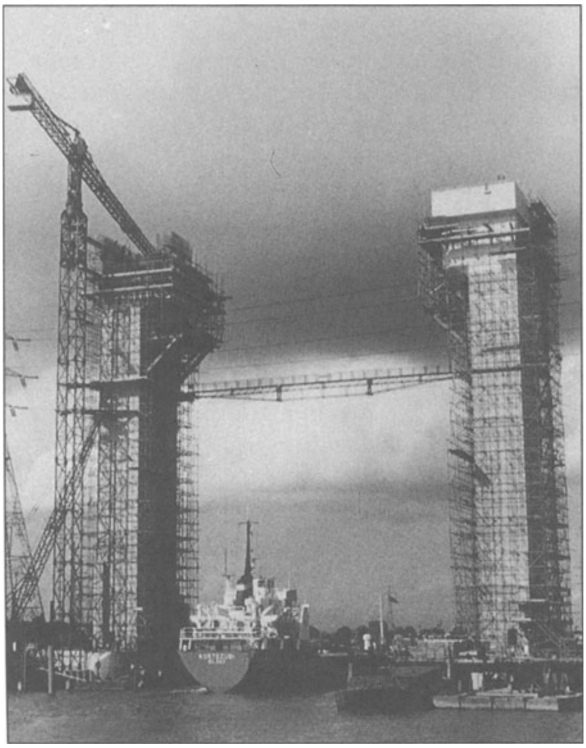


Figure 8.5 *Barking Barrier, under construction (Source: Binnie & Partners)*

Seabright Chemicals wharf defences, and steel piling upstream, which incorporates a vertical lift gate spanning the outfall from Beckton sewage treatment works.[7]

Tidal Surge Barrier, River Hull

This spectacular barrier was constructed by W.A. Dawson Ltd during 1977–80 for Yorkshire Water Authority under the direction of Sir M. MacDonald & Partners, at a cost of £3.7m. The twin monolith foundations were excavated and framed underwater to a depth of 28 m below ground level in piled cofferdams constructed from 34 m Larssen nr 6 piles. The sill was constructed in two halves in the dry using a three-frame cofferdam with 25 m Larssen nr 5 piles. The 32 m high towers were constructed of site batched white concrete with a boarded finish, with attractive steel space frames fabricated from mild steel hot rolled hollow sections supporting the stairs and glazing on the outside face of each tower. There is a similar framed and glazed footbridge above the gate as illustrated in Plate 32.[8]

The gate is 30 m wide, 10.6 m high, weighs 200 t and has a clearance of 22.6 m above high water spring tides when fully raised. The project received a Concrete Society Award in 1981 and a Civic Trust Award in 1982.

River Foss Floodgate, York

The final project in this section of the book comprises the River Foss floodgate which won the ICE Yorkshire Association's Award for Civil Engineering Excellence in 1989. Its construction arose from serious flooding in York in 1978 and 1982. Snow melt caused abnormally high levels in the River Ouse with water backing up the Foss tributary and flooding low lying areas of the city.

The scheme designed by Mott Hay & Anderson (since becoming part of Mott MacDonald) on behalf of Yorkshire Water Authority, comprised a 8.6 m wide by 8.25 m high up and over lift gate across the Foss near its confluence with the Ouse, and a 250 m long associated flood wall, pumphouse and control room. During gate closures, flow in the Foss is maintained by eight vertically mounted electric propellor pumps which transfer the water downstream. As the structure is located close to the centre of the historic city, its appearance was an important aspect and brickwork was used in a skilful and sympathetic manner to link the various components of the scheme together. The judges summed it up as a 'sound, elegant solution' to the perennial flood problem 'carried out with imagination and care for detail'.

Flooding in Bangladesh (Proc. Instn Civ. Engrs, Part 1, 1990, 88, Dec., 1131–35)

In direct contrast to the UK, flood plains occupy 80% of Bangladesh, with the mean rainfall ranging between 1250 and over 5000 mm. Flooding is predominantly by rainwater ponded on the land when the main rivers are at high levels. River-water flooding is generally confined to land within and near the main channels, whereas hill-foot land is subject to flash floods, and unembanked coastal land is affected by high spring tides and, occasionally, by storm surges. Crop damage occurs when floods come earlier, rise higher or more rapidly or peak later, and normal yields can also be reduced by drought or unusually low level floods.

The United Nations Development Programme (UNDP) plan in 1989 recommended a phased programme of embankment construction, associated compartmentalisation, river training and main drainage, preceded by master planning and special studies to confirm technical, economic, social and environmental soundness. These would be supported by non-structural activities, such as flood forecasting, early warning, flood preparedeness and hazard management. Of particular interest is the prospect of training the Brahmaputra River in its braided sections where the river can be as wide as 15 km. Innovative methods of diverting currents away from threatened bank sections would be tried at the same time, with the aim of increasing the hydraulic efficiency of the main channels and of reclaiming land for settlements and agriculture. These trials may provide a more cost-effective way of protecting river bank erosion than the conventional methods of revetments or groynes.

Coastal and River Engineering

Introduction

The term 'coastal engineering' embraces both coast protection and sea defence, and 'river engineering' includes work to the banks of river estuaries.

For hundreds of years the south east of England has been sinking in relation to sea level, and the northern part of the British Isles has been rising, probably partly as a result of land tilt and partly as a result of the continued melting of the polar ice cap.[9]

Coast protection covers the protection of the coastline and coastal land from erosion through the action of sea and weather. In the British Isles it is normally undertaken by maritime district councils who may be grant aided by central government and/or the county council, with powers derived principally from the Coast Protection Act 1949. There are wide variations throughout the country with the soft clay cliffs of the north Kent coast having little natural resistance to north easterly storms, and rapid erosion takes place every year. By contrast, the Romney Marsh area and the Dungeness peninsular continue to grow as shingle and silt are deposited by a receding sea.[10]

On the wider front, coast erosion is a worldwide problem, with about 20% of the world's coastline being of a sandy nature of which over 60% has suffered erosion over the past few decades. In addition, many coastal areas consist of soft cliffs of clay, marl or glacial drift material, which are adversely affected by sea, rain and frost. Such cliffs are subject to sudden slips, in which considerable quantities of soil fall on to the beach where it is broken up by the waves and carried alongshore or offshore, following which erosion of the base of the cliff starts again. To combat this a barrier is required between the sea and the cliff and the cliff face regraded to the natural angle of repose.[11] Another example is provided by the worsening erosion of the coastland of the Gulf of Thailand, where a survey conducted by Prinya Nutalaya on behalf of the Society for the Conservation of National Treasure and Environment, found that between 1969 and 1989, erosion claimed over 7.2 km^2 of land.

'Sea defences' usually refer to the protection of coastal land and buildings against inundation by the sea, thereby avoiding damage to property or danger to life. In the British Isles, this work may be undertaken by a land drainage authority, normally the relevant water company, or by a county or district council, under powers derived principally from the Land Drainage Acts 1930 and 1961. Originally earth walls were thrown up, but as maintenance costs rose and the consequences of a serious breach became more disastrous these walls have been improved, faced

with stable material or replaced by more durable constructions.[10]

History of Sea Defence in the United Kingdom

The most serious storm within living memory to attack the east coast of Britain occurred in January 1953. Many thousands of hectares of land were flooded, thousands of houses and factories were damaged and some 300 lives were lost. It was estimated that some 1200 breaches had to be repaired and countless kilometres of sea defences were made good following extensive overtopping along 2000 km of defences.[12]

As a result, the Waverley Committee[13] was set up to investigate the causes, consider the standard of future defences and the need for a public warning system. Since 1953 a number of storms were experienced which exceeded the intensity of the earlier storm. Most of the reconstructed defences withstood these onslaughts although some older defences suffered and failed in some instances.[12]

Subsequently in 1979, the Flood Protection Research Committee[14] recommended the adoption of an increased defence level arising from the higher storm frequency and magnitude. The recommendation directed that the effects of waves be taken into account together with the worst recorded still levels, thus securing protection against the worst recorded storm tide. The committee recognised that there were many combinations of wave/surge/tide which affected the final level at the defence structure and it recommended that each element should be analysed and combined to determine the overall risk to the protected areas.

Repairs to damaged defences and reconstruction of new defences included a new concrete or steel piled wall, or the reconstruction of a clay embankment having the front face and possibly the crest and back face protected by concrete blockwork or other semi-rigid material, or reconstruction of sand dunes in combination with other works such as groyne fields to stabilise the foreshore. The solid faces to the defences, whether vertical or stepped, generated reflected waves which caused scouring of the foreshore and lowered the beach levels, thereby exposing the toe foundations and endangering the stability of the defences. Hence much has since been done in the construction of works which 'chase the toe downwards'. Furthermore, new defences built in front of sand dunes or similar formations prevent the sea from depositing material needed to enhance the natural littoral drift processes.[12]

Sea Defence Techniques

The various techniques used for sea defence purposes are now examined together with the problems experienced and how they have been overcome.

Sand Dunes Taylor and Marsden[15] have described how in Eastern England, wherever possible, reliance is placed on the natural defences of beach, dunes and shingle banks. In some places restriction of access to the dunes is a feature of the management policy to prevent damage. To stabilise the sand dunes, marram grass and sea buckthorn are often planted on the dunes, and occasionally conifers.

Dune systems fulfil three main functions, namely coast protection, nature conservation and often public recreation. It has been estimated that in England and Wales there are about 400 km of coastline with dunes. They consist primarily of a sufficiently large volume of sand to provide good defence in depth, but are generally not much more than 15 m high. They will erode under storm wave action, but can survive a transient attack, and are often restored by the sea under calmer conditions. They provide a relatively inexpensive method of coast defence.[11]

Embankments In their earliest form they comprised earth walls but are now more often formed of shingle, which may occur naturally on the coastline or in the shallow water nearby, and may contain a clay core to increase impermeability. They may have drainage dykes on the land side to collect any water which overspills the embankment in heavy storms or violent wave action.

Their principal advantage is the simplicity of construction and use of readily available materials. The main disadvantages are the large size with a very wide base, and the vulnerability of the seaward slope to wave erosion which could result in the progessive collapse of the wall. Hence, shingle protection is generally confined to shallow slopes often combined with groynes to help retain the shingle. Another approach is to protect the sea face with stone pitching, masonry, concrete blocks or gabions.

Wakelin[16] has described how earth embankments in one form or another for the protection against tidal flooding of 1400 km out of a total length of 1600 km of Anglia Water's coastline. At one extreme are the shallow silt embankments with extensive marshes or saltings around the Wash with a life measured in hundreds of years. At the other end of the scale are the steep clay embankments in Essex, which dry out in a hot summer exhibiting large fissures, and whose life may be as little as 20 to 25 years.

Revetments These comprise protective facings to resist scour and erosion, are usually set at a slope of less than 1 in 3, and may be smooth, rough or stepped. Common facing materials are stone rip-rap or concrete blocks which may be linked with steel cables or synthetic fibre ropes. Stone pitching keyed by wedge shaped stones on a clay base are often used in *estuaries*, where a simpler approach is to grout the blocks with asphalt or to brush in a weak cement:sand grout. Another suitable form of protection for use on *river banks* are gabions, which are wire cages filled with loose rock or crushed stone.

Sea Walls Sea walls consist of porous and non-porous, sloping or vertical structures which are designed to protect against either erosion, flooding or a combination of them. A comprehensive review of the design of sea walls has been undertaken by CIRIA, [17] in which the various types of sea wall in the UK have been identified and illustrated, together with historical information on the damage that has occurred to them. The principal types of damage suffered by sea walls is summarised in table 8.1, which shows toe erosion as the most frequent form of failure.

Table 8.1 *Types of damage to sea walls*

Types of damage	Number of occurrences
Erosion of toe	63
Partial crest failure	26
Collapse/breach	16
Removal of revetment cladding	19
Abrasion	16
Wash-out of fill material behind sea wall	10
Concrete disintegration	9
Structural member failure	5
Landslip	5
Damage to promenade	4
Corrosion	3
Outflanking	3
Uplift of armouring	3
Settlement	2
Spalling of concrete	2
Concrete cracking	2
Total	188

(Source: CIRIA Technical note 125, Table 10 [17])

Probably the most effective and durable form of coastal defence structure incorporates a concrete or masonry wall. Concrete may take the form of *in situ* construction or precast concrete blocks. Masonry is generally limited to the facing of concrete walls, because of the high cost of providing and handling suitable stone. The main advantages of concrete and masonry walls are their durability and relatively low cost of maintenance.[10] Concrete walls may be of mass or reinforced concrete, and the choice will be determined largely by site conditions, foundation design, space available, required height and cost limits. Where differential settlement may be expected, reinforced concrete is likely to be the preferred solution, possibly supported on pile foundations. It is customary to design the seaward face of the wall with a wave return parapet designed to throw back the force of a wave which could otherwise break over the wall. A cross section of a typical concrete sea wall is shown in Figure 8.6.

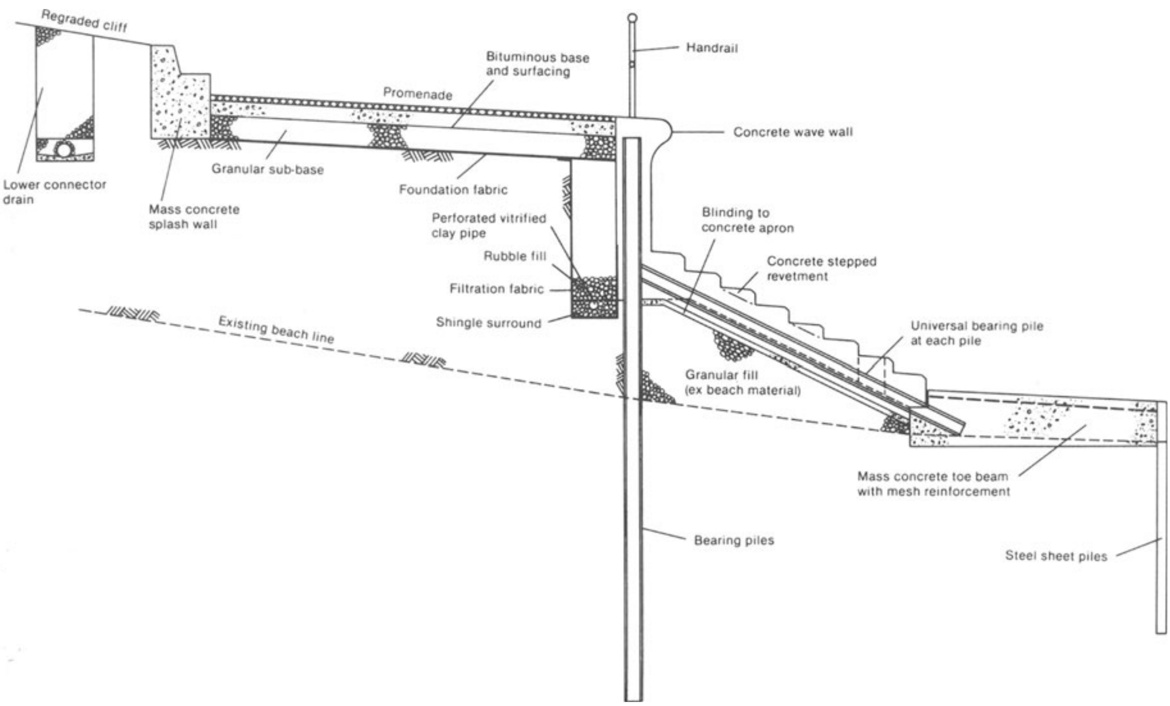


Figure 8.6 *Typical cross section of sea wall (Source: Mun. Engr. 1985 Apr.*[10]*)*

A promenade is often provided in conjunction with a sea wall to give stability against overturning moments, to form part of the load spreading foundations and also to enhance the amenity value of the foreshore. It also provides access for the public, maintenance vehicles, cleansing equipment and emergency services. The position of a promenade in relation to a wave wall is largely influenced by the configuration of the land to be protected. Where low lying land is at risk from flooding, the wall is normally placed at the rear of the promenade, whereas with rising ground subject to erosion the promenade is best located at the back of the wave wall. In the latter instance, it is wise to build a splash wall at the foot of the rising ground as a further protection against erosion from splash water overtopping the wall in extreme conditions, with suitable guard rails incorporated for the safety of pedestrians.[10]

In many cases, particularly where the foreshore consists of shingle or sand, other than a shallow overlay, the foundations of the wall and/or promenade require protective measures to restrict the entry of water through the sub-base and to prevent the erosion of the sub-base. This is normally effected by a line of steel sheet piling driven to a sufficient depth to achieve a stable condition. The piling may form an independent structure, but is more usually linked to the main wall by capping beams which may be tied into the wall structure or form an integral part of it.[10]

Figure 8.7 shows sea defence works under construction at Felixstowe, Suffolk. They comprise a 600 m long stepped reinforced concrete revetment, sloping concrete wave wall and toe steel sheet piling, together with the installation and refurbishment of timber groynes. The project was carried out for Anglian Water in 1985 at a cost of £881 000.

Figure 8.7 *Sea defence work under construction, Felixstowe (Source: W.A. Dawson Ltd)*

Groynes When a beach has been nourished or a naturally formed beach provides an effective coast protection feature, it is often necessary to take action to retain the beach material. There is frequently a tendency for loose beach material to move along the beach parallel to the shoreline as a result of wave action, known as littoral or alongshore drift, denuding one area and adding to another.

A common method of preventing littoral drift is to construct groynes at right angles to the shoreline, which provide barriers interrupting the drift of material along a beach. They are often formed of oak, greenheart or other durable species of timber, but can also be constructed of masonry, concrete or steel sheet piling, particularly in exposed positions. Their height depends on the desired beach level, and their length and spacing are determined by the angle of the most severe tides and the gradient of the beach, which is influenced by the beach material. The gradient may vary between 1 in 40 for sand to 1 in 7 for boulders. Groynes require an effective inspection and maintenance system and adjustable heights are a big advantage. They are relatively simple and inexpensive to design, construct and maintain, but are highly susceptible to storm damage and unattractive in appearance.[10]

Breakwaters Breakwaters are usually substantial structures which cause waves to break upon them or be reflected by them. They exert a significant effect upon waves and currents and, therefore, sediment movements in coastal areas. When used for coastline control, they can be either detached from or linked to the shore and may be totally or partially submerged, and usually form part of a combination of defences as at the Wirral. Breakwaters vary in profile from the vertical to gently sloping, but not flatter than 1 in 10, and can consist of *in situ* or precast concrete, natural stone, asphaltic materials or a combination of them.[11] 'Tetrapods' are quite popular, consisting of large precast concrete units with four legs or spikes, with good interlocking characteristics, high resistance to movement and a capacity to break up the force of waves and absorb energy.[10]

Alternative Methods Some less traditional approaches to protection have been developed, but some which have low initial costs may incur high maintenance expenditure. Examples include the use of bitumen as the main constituent of the revetment protecting an existing sea wall at Porthcawl; the reinforced earth wall at the Mumbles, Swansea Bay; combining rubber tyres and rockfill in a wall at Inverness; and the use of floating breakwaters employing scrap tyres in sheltered waters.[17]

Sheet Piling Sheet piles may be of timber, interlocking steel or reinforced concrete, of which steel sheet piling is the most widely used. Piling is useful in coastal protection schemes to form retaining walls, sometimes in isolation but more frequently in combination with other forms of protection, as in the foundations to coastal defence structures, as described previously.

In *river defences*, they can form both a protection against the river water and, at the same time, holding back the bank against soil pressures. Normally a capping beam along the upper edge of the sheet piling is tied into anchor blocks, piles or beams located in the ground sufficiently clear of the face of the piling to provide undisturbed support. An example of this type of work is shown in Figure 8.8, which illustrates flood defences to the River Nene, Wisbech, carried out in 1985 for Anglian Water by W.A. Dawson Ltd at a cost of £547 000. The project comprised a design and construct contract which included piling from the river in front of sensitive listed buildings. An embankment was provided above the steel sheet wall over part of the length and the remainder consisted of a concrete capping over the piling with ground anchors or tied sheet pile anchors. Protected banks and concrete flood walls were also used on different sections.

Coastal Management Systems

Roberts and McGown[18] have defined the prime purpose of an overall coastal management system as directing limited resources to where they are most required, while ensuring that valuable investments are protected as far as possible and that safety to life and property is given a high priority.

Their experience at Seasalter-Reculver, North Kent, showed that in order to establish an overall management scheme it was necessary to collate

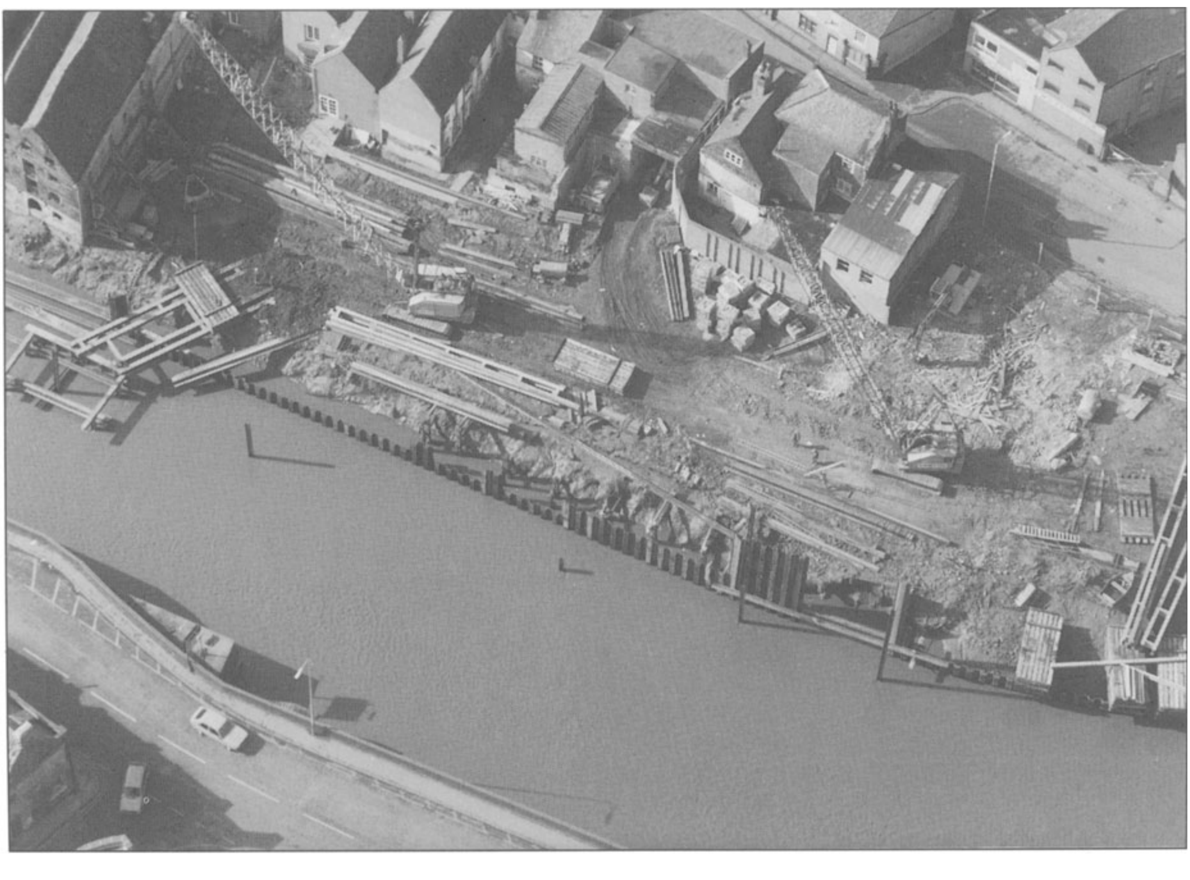
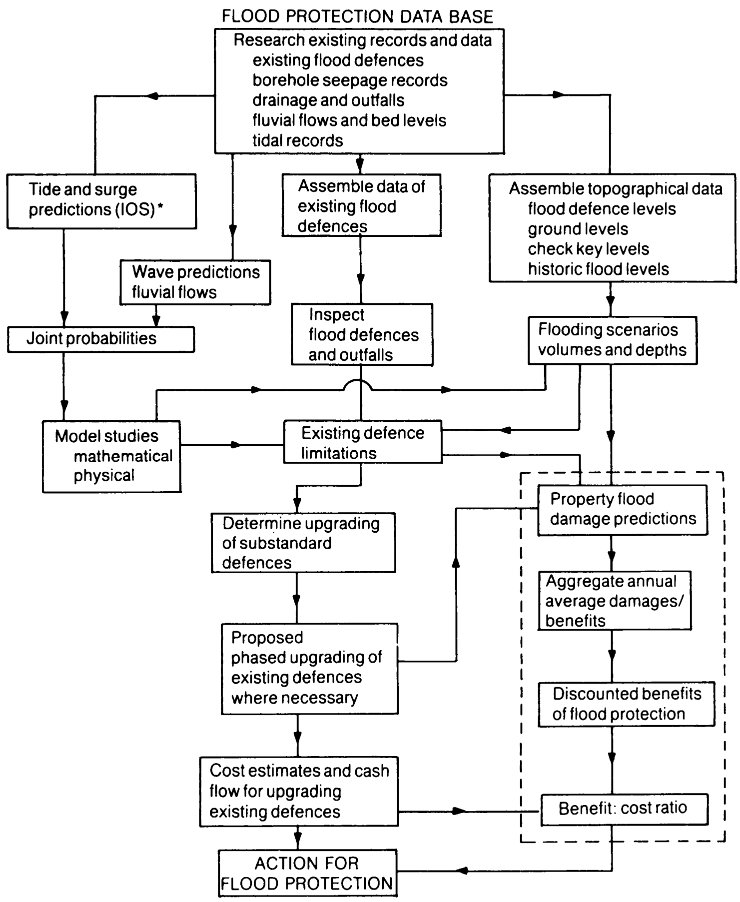


Figure 8.8 *Flood defence work under construction, River Nene, Wisbech (Source: W.A. Dawson Ltd)*

and critically assess the data from investigations within the various components of the coastal process unit. This permitted the formation of databases on which decisions relating to the provision of protection against flooding and coastal erosion could be based. They further suggested that the data inputs required for these databases should be as shown in Figures 8.9 and 8.10.[18]

Having built up the databases, it will then be possible to prepare reports on the offshore zone, intertidal zone, sea walls, flats, slopes and hinterland. From these reports an overall management scheme for flood protection and coastal erosion can be developed. The final outcome will be programmes for capital works, maintenance and monitoring of conditions, including the list of priorities within each of these, together with the implementation of planning controls.

Anglian Coastal Defences Study Following the disaster of 1953, sea defences built along the east coast needed major reinvestment by 1987. Therefore, at that time, Anglian Water commissioned Halcrow to develop a management strategy for this vulnerable coastline at an estimated cost of £220 000, and Halcrow led a consortium to devise a sophisticated management system showing the most effective and environmentally sensitive solutions, commencing with an examination of all relevant existing data.[19]



* Institute of Oceanographic Studies

Figure 8.9 *Flood protection database (Source: Roberts & McGown[18])*

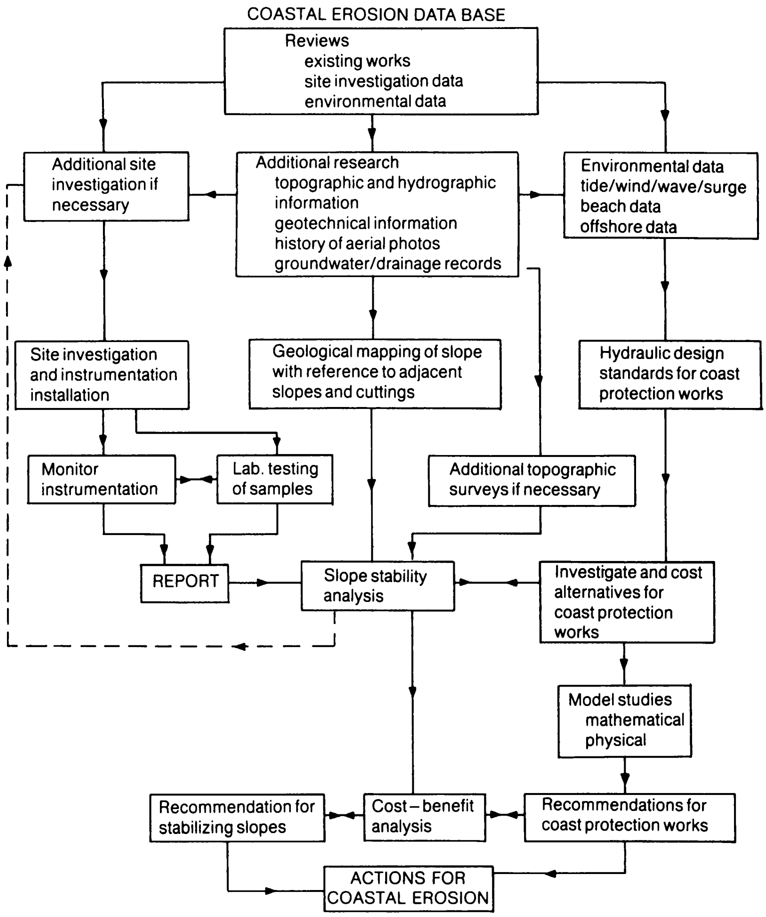


Figure 8.10 *Coastal erosion data base (Source: Roberts & McGown[18])*

Halcrow next collated existing information about the 1000 km of coastline and entered it into a database. Data on 20 primary variables was collected, including wind, wave energy, tides, features of beach material, vegetation and slope of seabed. Supplementary studies provided further information on nearshore wave climate, regional current situation, long term climatic variations and beach profile changes. Aerial photography, historic records and records of shoreline works carried out were also assembled. From this data an atlas of interpretive maps showing the main features and influences on any section of the shoreline was developed. Following further field studies, the relational database was developed and incorporated into an 'expert system'. The coastal management system included various mathematical models and gave Anglian a framework to use when designing vital coast defences.[19]

Port and Harbour Works

General Introduction

Planning for the movement of goods through ports requires co-ordination of a number of transport disciplines including mechanical handling. Sophisticated computer programs are used to simulate berth layout, vessel queueing and priorities, handling plant and delivery and despatch systems.

The behaviour and size of a ship using a harbour are key factors to be considered when designing an approach channel, waterway or turning basin, laying out aids to navigation or determining such features of port operation as the number and size of tugs required. Ship manoeuvrability is affected by the ratio of water depth to draught, the width of a channel or canal, the magnitude and direction of any current or wind and the height and slope of any banks which may form boundaries to the waterway. The ship may also be affected by passing vessels. All of these factors are closely related to both ship and waterway design, thus requiring the expertise of both the naval architect and the civil engineer.[11]

The main aim is to predict accurately berth tenability. Thus the economics of schemes for port extensions and new ports rely on optimising the layout in such a way that construction and maintenance costs are minimised and kept in balance. One important aspect is to provide sheltering that results in minimal 'downtime' so that the running of the port both practically and economically is not impaired.[11]

Aberdeen Harbour Development

Aberdeen has been selected as a large UK harbour which has undergone extensive development and modernisation to accommodate changing needs. RPT were commissioned by Aberdeen Harbour Board to design and supervise the staged development of the existing port, which is

Figure 8.11 *Aberdeen Harbour (Source: Rendel Palmer & Tritton)*

illustrated in Figure 8.11. Developments included deepening and widening the harbour entrance, rehabilitation of quays for use as an oil rig base, a fish quay and general cargo berths. A new roll-on/roll-off terminal operable at all states of the tide was constructed within the existing port. This example illustrates how ports must adapt to survive and how they are particularly susceptible to changes in user requirements and to developments in world trade.

Port of Felixstowe, Suffolk

This is an excellent example of a port which is over 100 years old but where major development has taken place almost continually since 1965 from the original small dock basin. By the early 1980s the roll-on/roll-off services accounted for about 1.2m t, while the annual throughput of containers was approximately 700 000 TEU (6 m long equivalent units) and general cargo was in excess of 400 000 t. A site plan of the port in 1986 showing the available facilities is illustrated in Figure 8.12. The port has changed dramatically from one catering for the short sea trade to Scandinavia and the near Continent to one that now plays a very significant part in UK and international maritime trading.[20]

Umm al Qaiwain Port, United Arab Emirates

W.S. Atkins surveyed, designed and supervised construction of port facilities at Umm al Qaiwain as part of the expansion policy of the Emirate. The work was carried out in three phases:

(1) 800 m long sheet piled wharf, 450 m long stone revetment forming the boundary to a boat and yacht marina and the dredging of a 4 m deep navigation channel.
(2) 400 m long sheet piled wharf with associated dredging of a navigation channel to a depth of 10 m out to open sea. It should be emphasised that reasonably accurate and complete knowledge of the marine environ-

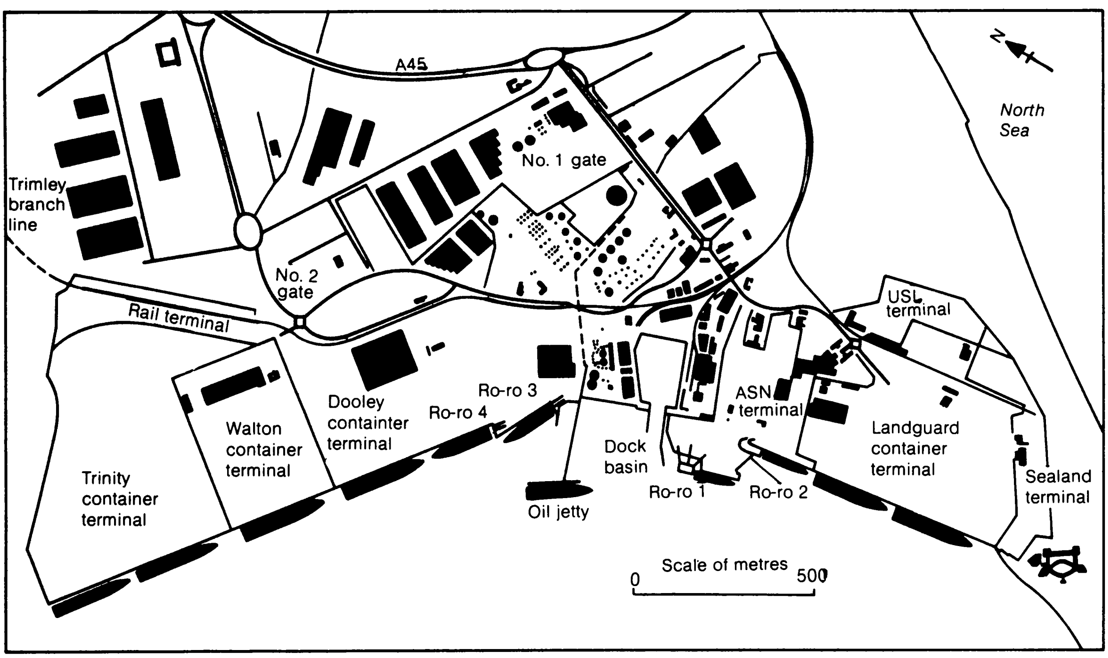


Figure 8.12 *Port of Felixstowe: site plan (Source: J. H. W. Northfield[20])*

ment and ground conditions are essential for the design of any dredging or protection works. The wharf provides berthing facilities for cargo shipping up to 15 000 dwt. Other works included the construction of an offshore island involving the movement of 200 000 m^3 of dredged material. The civil engineering works contracts included steel sheet piling of the main and anchor walls, quay paving, and the provision of navigation aids, services and floodlighting to the quay and storage areas.

(3) Extension of the 4 m dredged channel with associated reclamation.[21]

Kallin Harbour, Grimsay, Hebrides

Robson[22] has described how a new fishing harbour was excavated out of the rocky coastline of the Hebridean Island of Grimsay. The harbour is 25 m wide and 32 m long with a 6 m wide slipway. The works comprised the excavation of 11 000 m^3 of rock, the formation of 1000 m^2 of vertical rockface by specialised blasting techniques, the construction of 90 m of reinforced wall, 8 m high, anchored to the vertical rockfaces by resin anchors, the construction of a 35 m long slipway, and the formation of 1600 m^2 of car park and storage areas. The client was the Highlands and Islands Development Board and the project was undertaken under the direction of Turner & Townsend and the Director of Engineering Services, Western Isles Islands Council, at a cost of £600 000. The contract was completed in 1985 and awarded a Civic Trust Award in 1986.

The harbour incorporating 80 m of sheltered mooring and a minimum of 2.5 m of water at low spring tide with its associated facilities is shown in Figure 8.13. The traditional approach to the brief would be to select a prominent piece of rock on the Kallin coastline and then to build a jetty out into the sea to secure 2.5 m of water at low spring tide. This method would have involved importing many materials and items of plant from the mainland, which would have been expensive. Furthermore, it would be difficult to provide shelter without constructing expensive breakwaters.[22]

The rock box principle which was adopted involved choosing an area on the rocky coastline of Grimsay where the rock profile dived steeply to below low water. A large hole was then carved out of the rock to form a rock box, the front of which was retained to act as a cofferdam while the work inside was completed in the dry. On completion of the excavation and concrete work inside the box, the entrance was blasted away to allow entry of the sea. The remaining work was then completed, this time in the wet. The rock box was oriented so as to provide the maximum shelter for the fishing boats. The reinforced concrete harbour walls are 8 m high and anchored to the rock mass by means of rock anchors at approximately 2 m centres, as shown in Figure 8.14. The wall and the rock mass together are designed to act as effectively as a 5 m thick mass wall.[22]

Blacksness Harbour, Scalloway, Shetland Islands

This Scottish example comprises an entirely different type of project to Kallin, entailing the reclamation of land and a new quay wall. It was undertaken in 1982/83 by W.A. Dawson Ltd for the Shetland Islands Council at a cost of £1.25m, and the work under construction is illustrated in Plate 33. The works included 4150 m^2 of Larssen 4/20 steel sheet piles, 160 t of walings and tie rods, 56 800 m^3 of rockfill, 185 m of concrete capping, 3000 m^2 of concrete paving, 8400 m^2 of sub-base and 990 m of services including 27 manholes and drawpits.[23]

Container Terminals

Design Aspects Coode[24] contrasted the different planning methodology used in Mina Sulman, Bahrain, with that adopted at Surabaya, Indonesia, and postulated that there is no single, simple container terminal design which can be implemented in any port. Hence each design has to be individually prepared and based on local

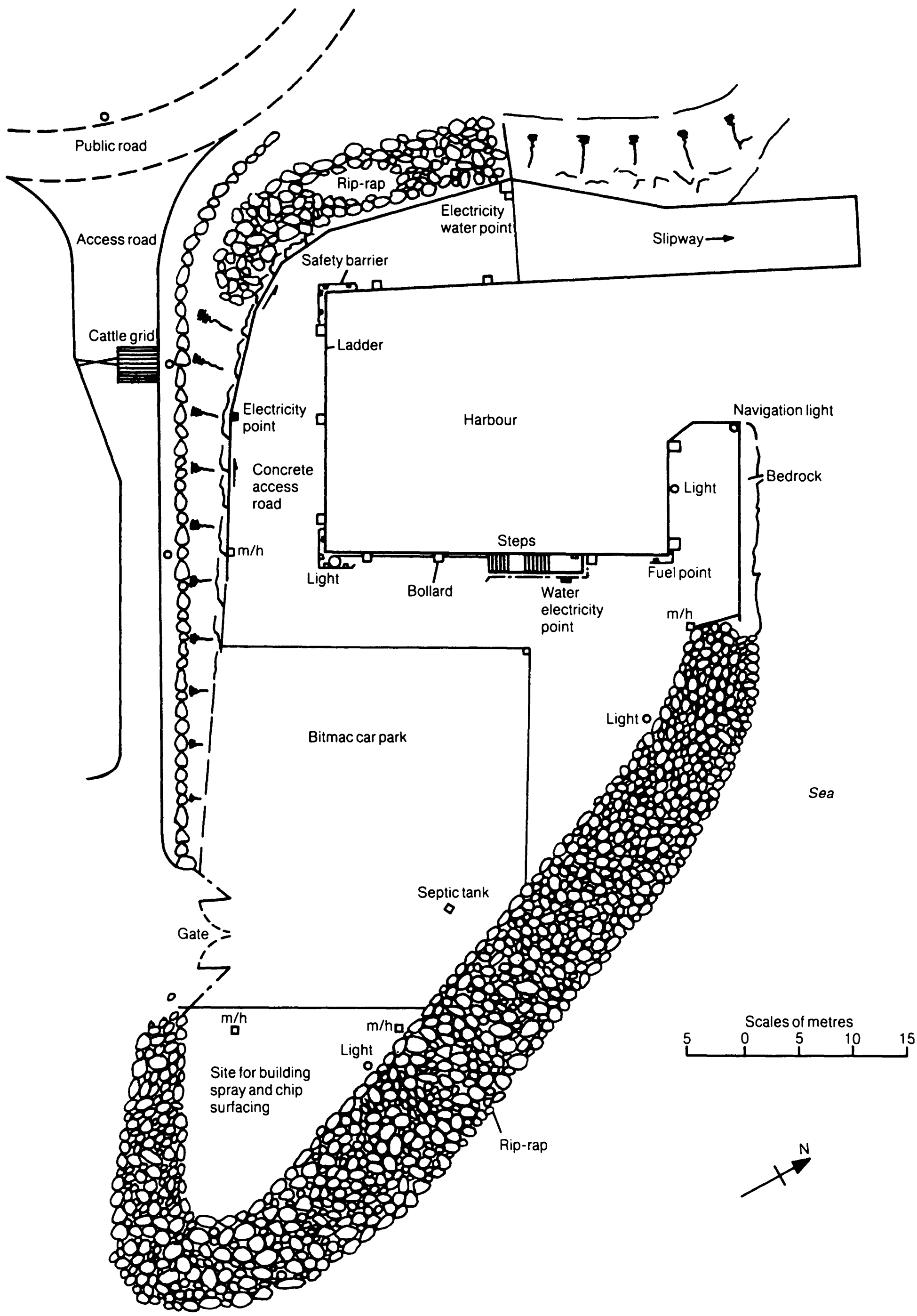


Figure 8.13 *Plan of Kallin Harbour (Source: A. M. Robson[22])*

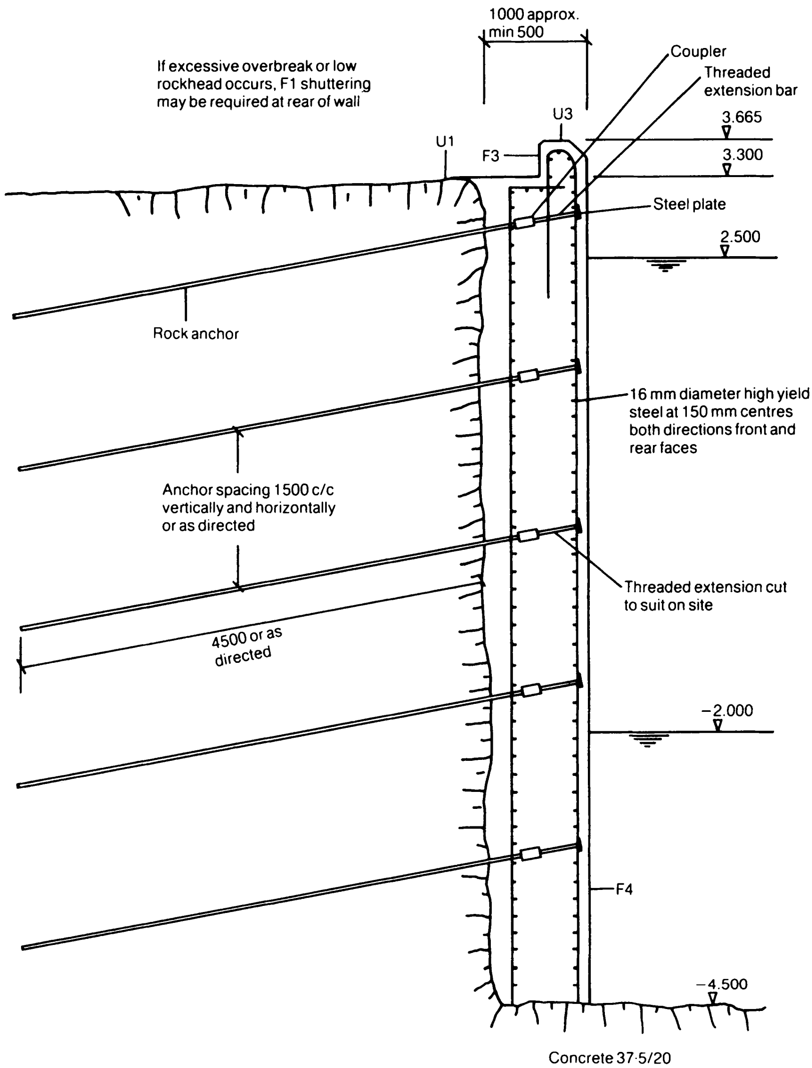


Figure 8.14 *Kallin Harbour: section through wall showing general arrangement of anchors (Source: A. M. Robson[22])*

factors, such as how much control the terminal operator will have over the movement of boxes to the land side and whether the land side moves will be primarily road-rail or container freight station oriented. However, there must be ample space available for both current and future needs.

The container terminal at Mina Sulman consists of a marginal quay equipped with container cranes and a stacking area. A marginal quay is one built either along, or parallel to, the shoreline, as opposed to a jetty which is built perpendicular to the shoreline. The stacking area is located immediately behind the quay and is occupied by a stack laid out in blocks for straddle carrier operation. This pattern is the more common in container terminals.[24]

By contrast, the container terminal layout at Tanjung Perak, Surabaya, as shown in Figure 8.15, is completely different. It has two berths on a piled island some 2 km from the shore, with very little emergency stacking area on the berths within the backreach of the gantry cranes, and is

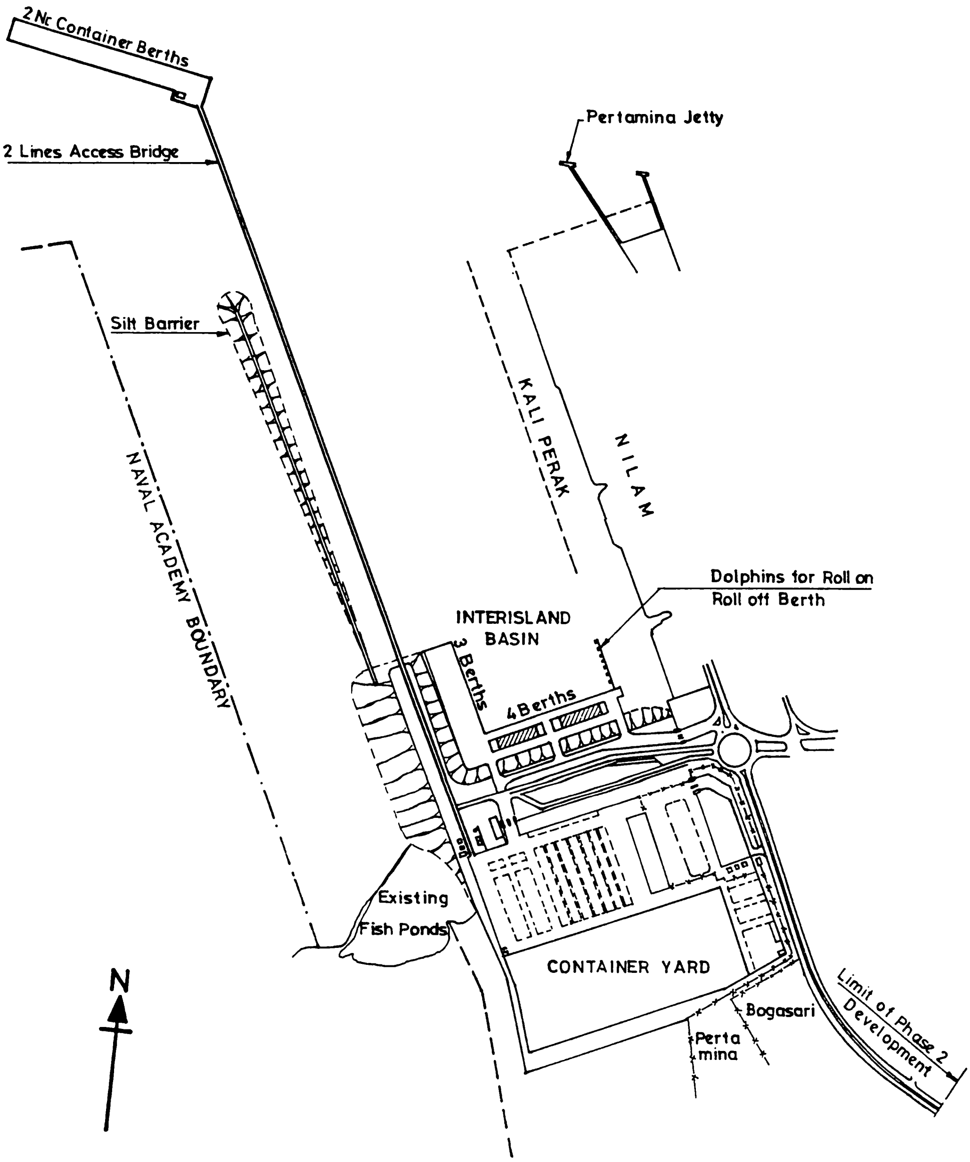


Figure 8.15 *Container berth, Tanjung Perak, Surabaya, Indonesia (Source: D. Coode (RPT)[25])*

connected by a long causeway to a remote stacking area on the shore. This design helped the engineers (RPT) to overcome site limitations arising from a combination of:

1. the limited areas available adjoining the existing port for new facilities;
2. the magnitude of capital and recurring costs resulting from initial and maintenance dredging adjoining or leading to container berths constructed marginally along the shore, and the siltation rates were abnormally high;
3. the need to locate the berths in deeper water and oriented parallel to the existing seabed contours and direction of current, thereby reducing present and future dredging costs, and making navigation to other port facilities easier;
4. the extremely poor soil conditions for construction purposes, which precluded land reclamation being carried out in the vicinity of the existing berths.[24]

Siting a Sea Terminal Siting is an important consideration when designing a container terminal, which should ideally be as close to as many major sea routes as possible to minimise ship diversions. The site also needs to be sheltered and sufficiently tide-free and deep to provide 24 h/d vessel access, with sufficient space for all forseeable needs and ready access to major road and rail networks. These are the principal and most critical factors affecting the choice of site. It has been suggested that a terminal of 10 ha could handle some 100 000 6 m long containers per year.[25]

General Characteristics of Containerisation The effect of containerisation was to replace the non-standard packages of general cargo with large units of up to 12 m long, 2.5 m wide and 2.9 m high and weighing 30 t, which are easily handled by mechanical plant. Some containers are 6 m and 9 m long but all are of standard design. Hence container ships are much larger than the cargo ships that they replaced, yielding significant economies of scale. In consequence, the 15 m or more of water required to float a large container ship, or indeed a bulk carrier or medium sized tanker, is rarely available next to dry land. If storage space is required, the following three options are available:

1. deep water can be created by dredging;
2. dry land can be created by reclamation;
3. a long jetty can be installed, connecting the storage area to the deepwater berth, usually with a 'T' head and carrying a road or walkway and pipes.

That the use of a remote stacking area can generate large savings in capital costs was shown at Surabaya.[25]

Coode[25] has shown that the key to container mobility is the nature of the equipment used to transfer containers between the quay or shipboard crane and the stacking area. There has been continuing disagreement about the relative merits of the various container handling systems, and particularly of the two most popular systems, namely straddle carriers and rubber tyred gantry cranes. Rubber-tyred gantry cranes, as illustrated in Figure 8.16, have proved popular in a variety of situations. Coode[25] believes that straddle carriers are slow and ungainly and unsuitable for use over the extended distances encountered in a container terminal with a remote stack, as at Surabaya. Rubber tyred gantry cranes can straddle a number of rows of containers, often six as shown in Figure 8.16, plus a roadway and it works exclusively on the stack, transferring con-

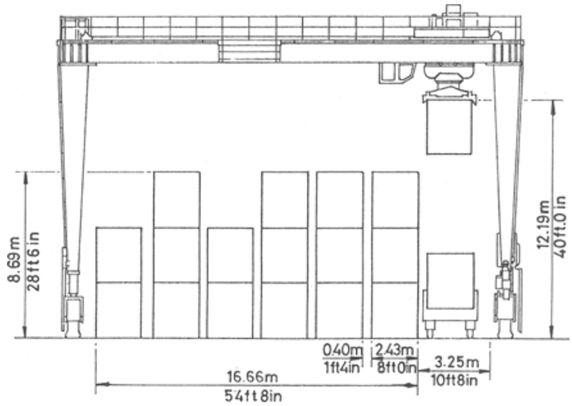


Figure 8.16 *Rubber tyred gantry crane (Source: D. Coode (RPT)[25])*

tainers between the stack and road vehicles or tractor trailer units.

Plate 34 gives an aerial view of the Kwai Chung Container Port alongside the new town of Tsuen Wan, Hong Kong. This has now become the busiest container port in the world, with the development of three new terminals in the 1980s on reclaimed land.

Land Reclamation

This section is concerned with the reclamation of land from the sea as opposed to the reclamation of derelict land in the UK which was considered in chapter 7, and embraced areas such as London Docklands and the derelict and deteriorating areas of inner cities and former industrial sites. The case studies centre on Singapore and Hong Kong where some remarkable reclamation projects have been carried out to augment their acute shortage of land.

Land Reclamation in Singapore

General Background

In the early 1960s Singapore started experiencing rapid population growth. The increasing pressures on the scarce land resources of the island arising from demands for industrial and housing development were the main reasons for the initiation of various major reclamation projects. These works were carried out by three statutory boards as agents for the government, namely the Housing and Development Board (HDB), the Port of Singapore Authority (PSA) and the Jurong Town Corporation (JTC), who together had reclaimed some 58 km^2 of land by 1989. The HDB alone accounted for about 26 km^2 of the reclaimed land, which is equivalent to about 4% of Singapore's land area.

The largest project was the East Coast Reclamation Scheme which was carried out in seven phases between 1966 and 1985. The latter stages, combined with earlier work, provided 660 ha of new land for the Republic's proposed city of the future, at a project cost of S$385m and a unit cost of approximately S$107/m^2. The North Eastern Coast Reclamation Scheme involved the reclamation of 685 ha of land, to be implemented in four phases with the first starting in 1985 and the last is expected to commence in 1994. Tables 8.2 and 8.3 give a summary of the reclamation works carried out or planned by HDB, which illustrate clearly their extensive scope, costs and new land uses.

Reclamation Methods

Reclamation projects involve massive earth-moving operations, using various techniques for excavating, transporting and depositing large quantities of earth. For instance, in the earlier phases of the East Coast Reclamation Scheme, earth was excavated by bucketwheel excavators, transported by belt conveyors and deposited into the sea using a tripper travelling along a dump conveyor working jointly with a large spreader. Bulldozers levelled the deposited earth and provided initial compaction to the newly filled ground. This method proved to be very efficient and minimised noise and dust pollution.

In the last two phases of this scheme excavation was carried out by two large bucketwheel excavators and the earth was transported about 7 km by belt conveyors to a loading jetty, from which barges were loaded with fill material for transportation by sea for a distance of 12 km to the fill sites, as shown in Figure 8.17. Each bucketwheel excavator had a rated output of 2000 t/h, the conveyor system could handle up to 5000 t/h and the barges had capacities ranging from 4000 to 10 000 t.

The first stage of the construction entailed dredging of a trench to the designed profiles followed by filling it with sand. Stone bund was then constructed over the sand filled trench followed by temporary works of silt barricade. Once a substantial portion of stone bund and silt barricade were completed, the reclamation filling commenced. Excavating, transporting and filling were carried out round-the-clock involving about 60 000 t/d. Filling, grading and compaction to the final levels were performed with a combination of conveyor system and conventional equipment. Both gabion and riprap headland breakwaters were used on various phases of the work for shore protection.

Table 8.2 *Completed Land Reclamation Projects Since 1959*
Singapore Housing and Development Board

Period	Reclamation scheme (ha) (location)	Project cost (S$m)	Unit cost S$/$m^2$	Uses
1964–76	Kallang Basin reclam (199) (Kallang Basin)	26.44	13.29	Housing Roads Industrial
1966–70	East Coast reclam Ph I (405) (From Bedok to Singapore Swimming Club)	45.00	11.11	Housing Roads Park
1970–71	East Coast reclam Ph II (53) (From Singapore Swimming Club to tip of TG.Rhu)	10.00	18.87	Roads Park
1971–75	East Coast reclam Ph III (67) (Nicoll Highway between Kallang and Singapore Rivers)	23.00	34.33	Roads Commercial Parks
1971–76	East Coast reclam Ph IV (486) (From Bedok to Tanah Merah Besar)	44.00	9.05	Changi Airport Roads Parks
1974–77	East Coast reclam Ph V (154) (Telok Ayer Basin)	106.00	68.83	Commercial Roads Parks
1975–77	West Coast reclam (86) (West Coast)	6.42	7.47	Housing Roads Parks
1978–79	Pasir Ris reclam (44) (Pasir Ris)	5.20	11.82	Parks
1979–84	East Coast reclam Ph VI & VII (360) (At TG.Rhu and Telok Ayer Basin)	385.00	106.94	Commercial Roads Parks
1980–81	Pasir Panjang reclam (4.7) (Pasir Panjang)	3.73	79.40	Wholesale Centre
1983–87	Ponggol reclam (276) (Pasir Ris to Ponggol)	77.00	27.90	Housing Parks Roads Industrial
1985–88	NE Coast reclam Ph I (79) (Pasir Ris)	34.00	43.04	Roads Parks Industrial Agricultural
Total	2,213.7	765.79		

Table 8.3 *Latest Land Reclamation Projects Singapore Housing and Development Board*

Period	Reclamation scheme (ha) (location)	Project cost (S$m)	Unit cost S$/m^2	Uses
1986–90	NE Coast reclam Ph II (385) (Seletar)	248	64.42	Roads Housing Parks
1988–90	NE Coast reclam Ph III (83) (East of SG Punggol)	67	80.72	Roads Housing Parks
1994–96	NE Coast reclam Ph IV (145) (Pulau Serangoon and Punggol)	130	89.65	Roads Housing Parks
Total	613	445		

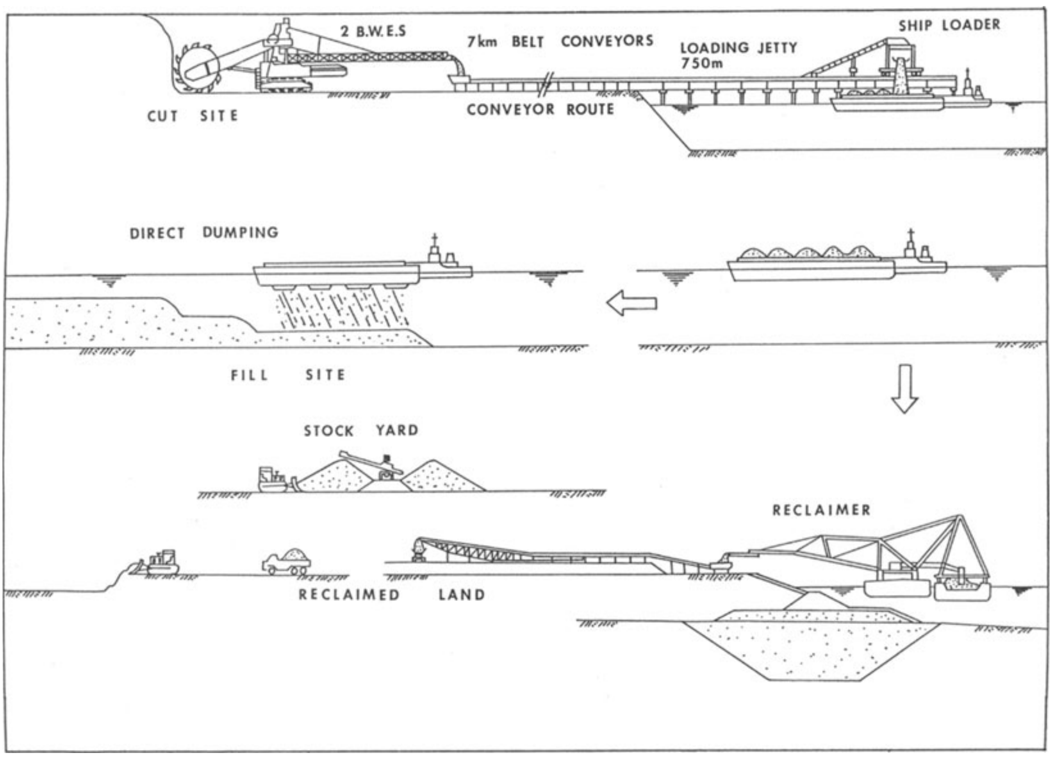


Figure 8.17 *Land reclamation methods, East Coast Singapore: phases 6 and 7 (Source: HDB, Singapore)*

The first two phases of the North Eastern Coast Reclamation Scheme were carried out in the manner illustrated in Figures 8.18 and 8.19. The work comprised sand key dredging by grab dredgers, sand key filling by hopper barge, perimeter bund formation by reclaimer, sand blanket laying by sand spreader, main reclamation by direct pumping and compaction and shore protection works. The third phase incorporated sand compaction piles, using columns of sand forced into the soft clay of the seabed to achieve soil improvement partly by replacement and partly by drainage.

Main Uses of Reclaimed Land

The reclaimed land uses include Bedok New Town (240 000 population), Tampines New Town (225 000 population), reservoir development, the 19 km East Coast Parkway (expressway), Changi Airport, the East Coast Park (325 ha) and a new city centre (690 ha). The reader is referred to tables 8.2 and 8.3 for more detailed information.

Land Reclamation in Hong Kong

Sea reclamation minimises land acquisition costs in the mountainous New Territories, and has been used extensively. Before the land to be reclaimed can be built upon, it must be made safe. Firstly, sea walls or rockbunds are constructed to prevent the new land washing away. The underlying mud can then be covered with fill material, or if this layer is particularly deep, it may be dredged and removed to special marine dumps. Alternatively, a deep mud layer can be covered with a sand drainage blanket containing a series of vertical drains and the water is drawn up through these by pressure from fill material, so accelerating the normal compaction process. The new filling material is then spread into layers, and rolled and compacted to provide firm solid land.[26]

Six examples of large new towns in the New Territories built principally on land reclaimed from the sea are now briefly described to show the great importance of this process in the development of Hong Kong:

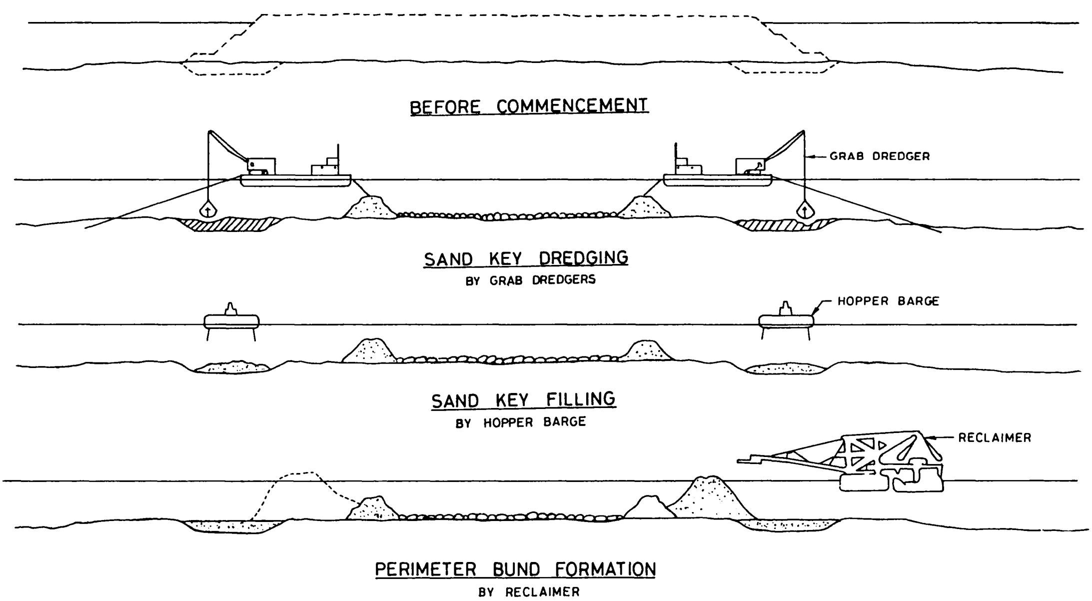


Figure 8.18 *Land reclamation methods, North Eastern Coast Singapore: phases 1 and 2 (earlier stages) (Source: HDB, Singapore)*

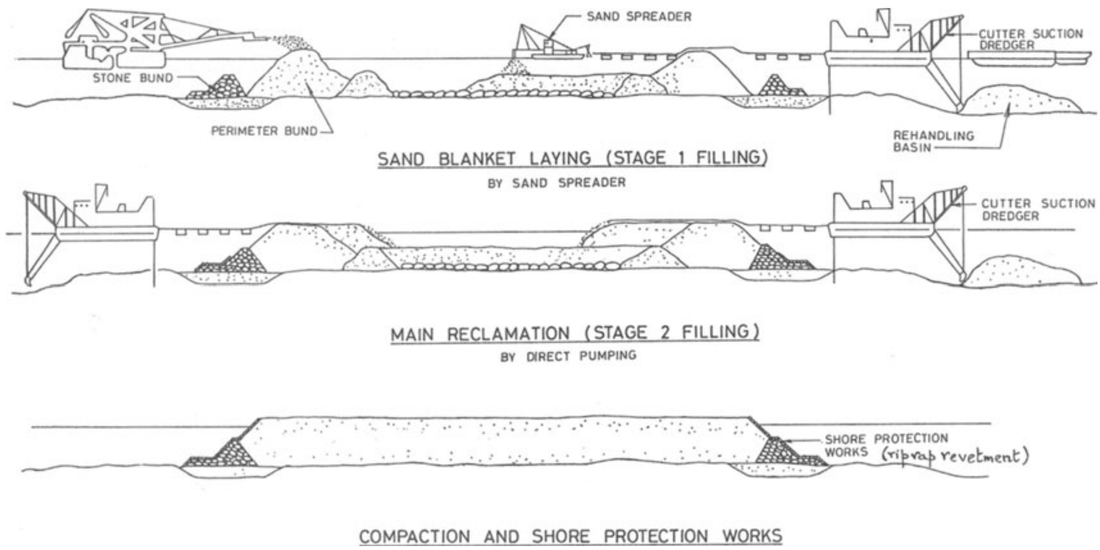


Figure 8.19 *Land reclamation methods, North Eastern Coast Singapore: phases 1 and 2 (later stages) (Source: HDB, Singapore)*

(1) Tsuen Wan New Town, planned to house up to 800 000 people by the mid-1990s, is centred on two main sea reclamation schemes at Kwai Chung and Tsuen Wan, together with the development of Tsing Yi Island.
(2) Sha Tin New Town with the extension at Ma On Shan, which is expected to increase to 700 000 population by the mid-1990s, has moved increasingly to sea reclamation as shown in Plate 35.
(3) Tuen Mun New Town's population is scheduled to increase to 500 000 by the mid-1990s, and the growth will comprise continued development of public and private housing on land reclaimed from Castle Peak Bay and in the adjacent Tuen Mun Valley.
(4) Tai Po New Town will approach its target population of nearly 300 000 by the late 1990s, taking advantage of the impressive coastal setting and background cresent of mountains. Much of its development has been facilitated by sea reclamation.
(5) Extensive sea reclamation was required in the construction of Junk Bay New Town (Tseung Kwan), which is illustrated in Plate 19, and has a projected population of 440 000.
(6) Tin Shui Wai New Town is situated around a large expanse of fish ponds in the North West New Territories. Using dredged marine fill materials from Deep Bay has provided the base for the first phase of development with a target population of 146 000. This project is a joint venture between the government and private enterprise, with the first intake of residents scheduled for 1991.[25]

Offshore Works

General Introduction

1989 marked the 25th anniversary of oil and gas exploration in the North Sea and the oil companies and their employees operating on the UK Continental Shelf (UKCS) have shown enormous commitment despite the hazardous conditions and the nation has benefited tremendously. The tragedy of Piper Alpha in 1988, when 167 men lost their lives, bears witness to the great dangers involved and the need for the highest safety standards to be operated. By 1989, over 2000 exploration and appraisal wells had been drilled and 200 significant oil and gas discoveries made. There were 62 offshore fields in production – 36 oil and 26 gas, with a further 21 fields under development. There were 150 installations and around 5630 km of pipeline in the UK North Sea. Cumulative production amounted to approximately 1.2b t of oil and over 660b m^3 of gas, with a total expenditure of £64b by the industry (1988 prices) and UK Government revenues exceeded £65b. The UK is expected to be self-sufficient in oil well into the 1990s and a significant producer into the next century.[27]

Oil companies always endeavour to minimise the commercial risk by carrying out extensive geophysical surveys, as they did in the most promising parts of the North Sea, but even the most attractive subterranean strata can turn out to be dry or produce no more than water trapped under pressure. In worldwide exploration operations, companies normally expect only one well in ten to find oil and gas and even fewer to be commercial, and the northern North Sea was no exception. However, in the 1970s, BPs Forties field and the Shell/Esso Brent discovery showed that enough oil could be recovered from those two reservoirs alone to meet total UK demand for nearly five years.[27]

The main oil fields were found at locations where the depth ranged from about 90 m off the Scottish coast to more than 180 m in a very successful drilling zone north east of the Shetland Islands. This entailed designing some of the tallest offshore structures ever built with the strength to withstand not only North Sea storms, but also with the load bearing capacity to support the massive processing equipment required to develop these large oil fields. Because most of the fields were 160 km or more from shore, the production platforms had to be designed as self-contained units with their own power supplies and accommodation for operational and maintenance staff, requiring great skill with companies drawing on experience gained throughout the world.

In particular, the planning of North Sea oil fields was helped considerably by the development of techniques for directional drilling which allows wells to deviate at angles from the vertical. Thus companies were able to plan clusters of wells reaching out from each production platform and tapping the remoter areas of reservoirs. But for some of the largest fields, it was still necessary to install two to four platforms to develop these fields fully.[27]

Plant installed on some of the large platforms required as much power as a city the size of Bristol. In addition to operating drilling equipment, power was needed for the processing units treating output from the wells to remove water content and separate gas from oil before being delivered ashore. At many offshore fields, gas is used to fuel the power generation plant, with the surplus carried by pipeline to the mainland or another platform as an additional energy source rather than being flared. Subsea pipelines to shore terminals offered the best method for exporting oil from large fields with prolific flows. The subsea pipelines led to some very impressive shore terminals, such as Sullom Voe in Shetland, Flotta in Orkney, and St Fergus, Teesside, Easington, Theddlethorpe and Bacton on the east coasts of Scotland and England. Because of the complexities of operating offshore in deep locations, projects became very expensive. For example, the development of the Brent complex and its associated pipelines and terminals cost over £3b.[27]

Apart from the use of ports by supply boats, the most visible spin-off from the North Sea development is seen at the fabrication yards set up to construct the huge production platform jackets and the equipment packages, known as modules, which are installed on them.

THE MAGNUS OIL FIELD

Introduction

The Magnus Field operated by BP has been selected as one of the most impressive of the large oil fields. It lies 160 km north east of the Shetland

Islands and is 16.5 km long and up to 3.5 km wide. The Magnus reservoir is estimated to have contained 1.6b barrels of oil, of which 665m or 40% are expected to be recovered. The first exploration well was drilled in 1974, appraisal drilling in 1976, approval of development plans obtained in 1978, main oil export line laid in 1981, emplacement of jackets undertaken and modules and main gas export line laid in 1982, first gas export and oil production in 1984, and production plateau raised in 1988.[28]

Because of the deep water, hostile weather conditions and high cost of development, one central fixed platform was installed with subsea wells at the northern and southern extremities, linked by individual flowlines to the platform, and to export Magnus oil through the BP operated Ninian pipeline. The system comprised:

(1) A single combined drilling and production platform of conventional steel structure with four legs, self-floating at float-out and standing in 186 m of water.
(2) Seven subsea producing wells, capable of being converted to water injection and each with a remotely controlled wellhead.
(3) A 600 mm crude oil pipeline from the Magnus field to the Ninian Central platform. Gas from Magnus was combined with that from the Thistle and Murchison fields through a joint pipeline to St Fergus in Aberdeenshire.[28]

Construction and Installation

The Magnus jacket was in 1980 the largest single piece steel structure to be designed and constructed for the North Sea, and was fabricated in a dry dock in the Cromarty Firth. The huge structure, measuring 85 × 85 m at its base and 56 × 62 m at the top and 212 m high, used 31 000 t of British and Japanese structural steel and weighed a total of 34 400 t at float-out. It was constructed lying horizontally to a self-floating design which eliminated the need for a launching barge, and also enabled the flotation legs to be used for the storage of water and diesel once the platform was operating. The principal statistics of the platform and associated works are listed in table 8.4.[28]

The jacket was swung into the vertical position by controlled flooding of the buoyancy legs, and the platform was anchored to the sea bed by means of a cluster of nine piles around each of its four legs. While the jacket was under construction, the topside modules were being fabricated at one European and four British yards. Nineteen main modules were designed to house all the drilling, production, utilities, control and accommodation facilities needed for an isolated North Sea production unit with a workforce of about 200, and they were subcontracted in packages. The completed modules were loaded on to barges, transported to the Magnus site and lifted into position by the 3000 t Heerema sub-submersible crane vessel (SSCV).[28]

The 91 km main oil export line crossed three pipelines and the crossings of two oil pipelines were trenched over 1 m deep, protected with bitumen mattresses and retrenched. While a bridging structure was provided to carry the gas pipeline over the oil export line and all three crossings were protected with gravel cover. The Magnus pipeline was laid in 1982 using a semi-submersible pipelaying barge. The 12 m lengths of pipe, complete with protective and concrete weight coatings, were welded and inspected on the barge before being passed over the stern to the sea bed.[28]

The Control Room

A major part of the central control is the automatic shutdown system called Unit Control Logic (UCL), made up of 45 units each of which is able to detect any abmormality in its section and initiate its immediate shutdown. The UCLs are connected by a master control system – the Process Control Logic – enabling them to shut down plant automatically in response to a shutdown in a related section. The Central Monitoring System (CMS), a computer based telemetry system with four visual display units (VDUs) in the Control room, constantly monitors all variables on the platform.[28]

Table 8.4 *Magnus Statistics*

Platform	
Jacket section	
Weight at float out (excluding piles)	34,400 tonnes
Weight at float out (with 14 piles included)	40,400 tonnes
All piles and conductors	12,000 tonnes
Dimensions of jacket base	85 m x 85 m
Dimensions of jacket top	62 m x 56 m
Height of jacket	212 m
Outside diameter of legs	2 of 10.5 m 2 of 2.6 m at top 2 of 9.6 m at bottom
Weight of weld metal	145 tonnes
Quantity of paint used	800 tonnes
Topsides	
Total weight of modules and equipment	31,000 tonnes
Number of modules	19
Largest single lift	2,450 tonnes
Dimensions of main modules	Approx 14 m x 16 m x 30 m
Overall deck dimensions	66 m x 70.5 m
Number of levels	8
Clearance of lowest deck above mean sea level	26 m
Piling	
Total number of piles	36
Number of piles around each leg	9
Maximum depth of piles	90 m
Diameter of piles	2.1 m
Length of piles	110 m
Subsea wells	
Height of wellhead	7.6 m
Distance of furthest subsea well	7 km
Diameter of flowlines to subsea wells	150 mm
General	
Total height of platform from seabed to top of flarestack	312 m
Accommodation	194
Drilled depth of wells	Drilled depth up to 5,200 m in deviated holes
Directional drilling maximum deviation (platform wells)	55°
Radius covered from platform	3 km
Maximum design wave height	100-yr storm: 31 m with 15–20 second period
Number of terminations in Central Control Room	750,000
Total length of electrical cable installed	1,680 km

(Source: BP[28])

Maintenance, Inspection and Safety

Microprocessors and digital equipment bring information instantly to hand for maintenance planning and construction work involving shutdowns. In the summer months all painting, subsea inspection and work on the flare towers, cranes and structures takes place, and the only time that a complete shutdown of production is necessary is when work is being carried out on the flares. The use of advanced materials in plant construction, such as titanium and nickel alloys, requires special monitoring for the effects of severe conditions. In addition to visual checks, ultrasonic testing is used to check pipework, and fibre optics to scan the inside of vessels, pipelines and machinery. A diving system commissioned in 1985 enables inspection and maintenance to be carried out from the platform by air divers and remotely operated vehicles (ROV), being a safer and less weather-dependent method than conducting operations from a support vessel.[28]

A structural monitoring system was installed to record data from accelerometers, strain gauges, a wave sensor and current meters, the object being to determine how well the jacket is performing throughout its life. A similar programme was set up for foundation monitoring, measuring movement at the tops of groups of piles, the load entering the groups and the strain on individual piles.[28]

Safety is built into the design of every component and process, with constant computer monitoring of all areas to minimise the risk of faults going undetected. Equipment includes a fire and gas monitoring system, fully equipped lifeboats and other life saving equipment, and a purpose built 2700 t safety and support vessel on permanent standby for evacuation or the provision of first line fire fighting cover at the rate of 80 000 l/min of water over a distance of 160 m, and it carries dispersants and boom equipment to deal with accidental oil spillage. The International Safety Rating System (ISRS) is used to audit safety and health management performance.[28]

OTHER NORTH SEA PROJECTS

Five other unusual and interesting projects from the civil engineering viewpoint are now briefly described, although the reader can refer to the publications listed for further information.

South-East Forties Project Livett[29] has described the unusual Forties Echo (FE), normally unmanned, extension to the BP Forties oil field, constructed between 1984 and 1987, some 175 km ENE of Aberdeen. The platform has 14 production wells, all pre-drilled by a semi-submersible rig through a subsea drilling template. After the installation of the jacket and topsides, the subsea wells were tied back to the topsides facilities with tieback conductors. This concept avoided the need for full drilling facilities on the platform, thus simplifying the arrangement of the wellbay module, minimising the topsides weight and permitting an early start and rapid build up to full production.

Ravenspurn Platform In 1989, the North Sea's smallest concrete platform, designed by Ove Arup & Partners, was floated out to the Ravenspurn North gas field, in 40 m of water off Humberside. The £15m concrete jacket consisted of three 38 m high concrete legs mounted on a 54 m × 62 m hollow base, which was split into a series of cells which acted as buoyancy tanks to allow controlled installation and removal of the structure. Using concrete showed a 25% saving in cost compared to the traditional two platform steel structure, and the 10 000 t steel topside was added after installation of the concrete jacket.[30]

Ula Platforms In Norway RPT[6] carried out extensive work in BP's Ula field, including independent design verification of jackets and deck structures for production, drilling and quarters platforms, as illustrated in Figure 8.20.

Steel Jacket Design Laver *et al.*[31] have described the conceptual and detailed design of two steel jackets; one in 36 m of water (Leman F), and the other (Leman G) in 20 m. Both platforms were required for further development of the Leman gas field in the southern North Sea. The authors make useful comparisons between the designs of the two jackets which, although only 2.7 km apart, required different analytical and design requirements.

Piled Foundations for Britoil's Clyde Platform Tilston and Gilchrist[32] have described the design and installation of the piled foundations to Britoil's platform, located 400 km east of Dundee in 81 m of water, where oil and gas reserves are developed from a fixed steel platform. The platform's oil and gas drilling and production topside facilities are supported by a single eight legged tubular steel jacket, whose foundations consist of twenty six 2134 mm diameter tubular steel piles. The authors aptly describe the development of the foundation design through the major phases of the project as soil and loading information was modified and refined, and taking account of the steadily advancing equipment and methods.

Irrigation

Irrigation Methods

Irrigation is desirable where natural rainfall does not meet plant water requirements for all or part of the year. Irrigation is essential for agriculture in the desert but even in areas like northern Europe it can improve the yield of crops

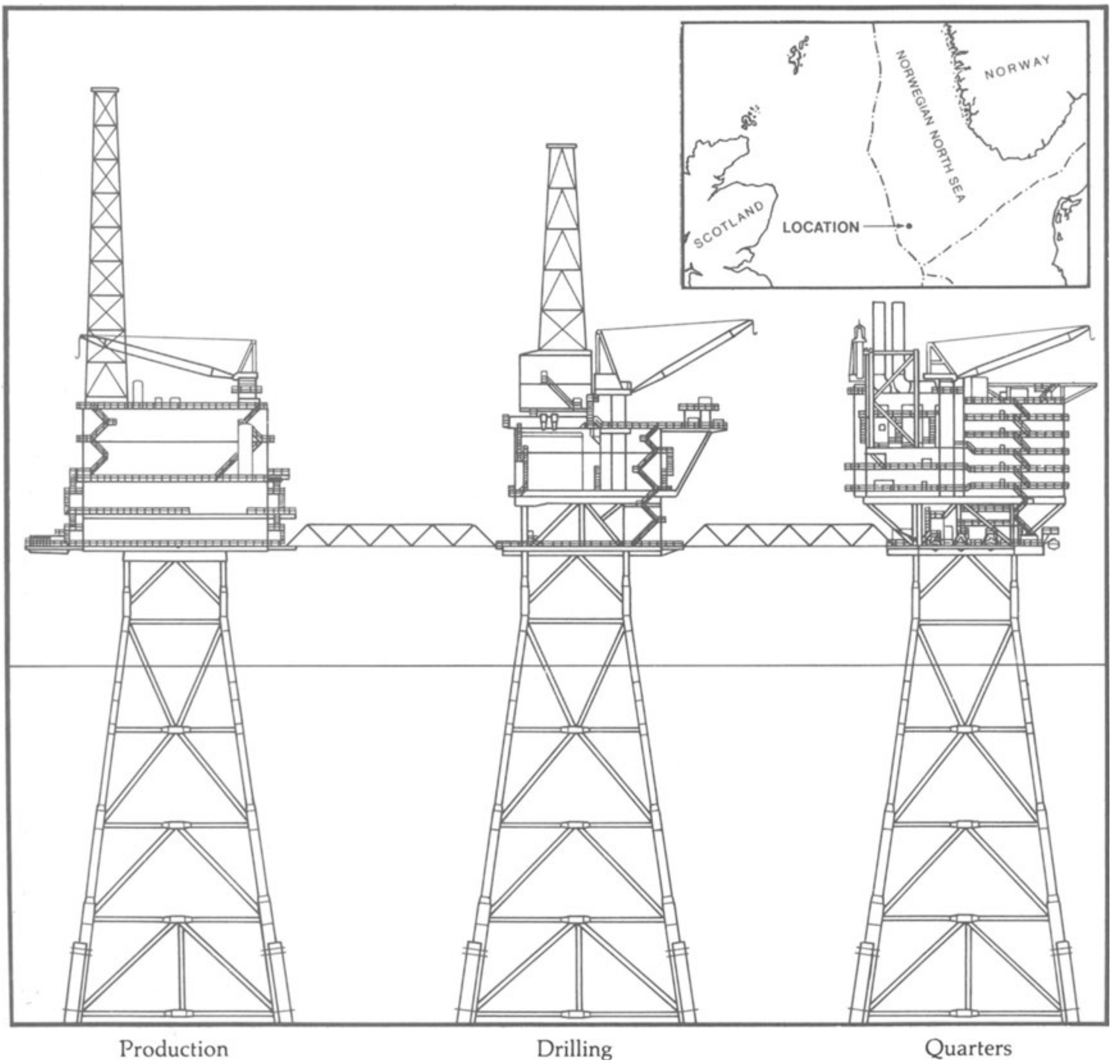


Figure 8.20 *Design audit: Ula field development project (Source: Rendel Palmer & Tritton)*

normally grown under rainfall conditions only.

Pemberton and Rickard[33] have classified irrigation work into four main methods:

(1) Surface: this is the most common and is suitable for most soils with an infiltration rate of less than 150 mm/h and an overall slope of less than 3%. This can also be subdivided into four main types, namely basin irrigation with large basins supplied by small canals and surrounded by earth bunds; border strip irrigation with water running down sloping strips separated by earth bunds; furrow irrigation with crops on beds between furrows; and corrugation irrigation with small furrows on medium soils.

(2) Sprinkler: individual sprinklers provide a cone of precipitation so that an overlap of sprinkler patterns is needed to provide a uniform application.

(3) Trickle: providing irrigation water to individual plants normally using a plastic pipe containing orifices or using an emitter.
(4) Sub-irrigation: this is only suitable for specific soil conditions.

Melby[34] has described in considerable detail the design, installation and operation of sprinkler and drip (trickle) irrigation systems.

Howard Humphreys have rightly described how irrigation practices appropriate to prevailing conditions are based on estimates of crop water use and water losses, consideration of irrigation methods, (surface, drip, overhead and sub-irrigation) and field distribution design. The type of tenure, such as tenant, smallholder, co-operative or state farm, should also be taken into account in system design. For instance, one of the objectives of irrigation work in Thailand is to help small farmers to increase rice yields and plant a second crop each year. Water control structures, which can vary from large cross regulating weirs to small in-field works, associated with either gravity flow or pumped irrigation systems are designed for both surface and overhead distribution.

Computer aided design and simulation is used extensively to achieve the most efficient and cost effective distribution system both in construction and operation. Systems designed by Howard Humphreys have included the design of canals and pipe conveyors in earth and rock as well as lined canals where site conditions so dictate. Bramley[35] has described how poor distribution of irrigation water to the farm turn-out is often a key problem in the rehabilitation of an irrigation scheme, and that different rehabilitation tasks require different engineering approaches. For example, hydraulic and structural upgrading of a 50 m^3/s irrigation canal is a major civil engineering project, whereas renovation of a 0.1 m^3/s watercourse is best handled by local labour as an extension to normal maintenance. Careful consideration is required of the farmer's needs for irrigation (depth, flow rate, duration, time of day and frequency) and the equitable operation (control and monitoring of flow). In many developing countries it is essential to provide an installation which is very cost effective and simple to operate.

Practical Applications

Three entirely different irrigation schemes are now examined to show the wide variations that can occur in both scope and the techniques involved.

Madeira In Madeira there is an ingenious network of irrigation channels or watercourses which mainly follow the contours, called 'levadas' (a Portugese term), varying in construction from clay to stone and concrete. The first levada was started in 1836 and some which served only small isolated areas no longer carry water. The levadas were skilfully and laboriously built along cliff faces and around obstacles, and carry mountain spring water down to fields which would otherwise be parched. Many years of audacious engineering work have preserved the water to green the terraces at all altitudes, instead of allowing it to flow uselessly out to sea. Beside many of the levadas are paths which have high recreational value. About 90% of the levadas are owned by the Madeira government who charge landowners on a scale based on size of farm and type of crops. The flows are regulated by government officials to secure a fair distribution through the side channels.

Southern and Central Africa In these areas 'dambos' are used extensively for small scale irrigation. Dambos were small valley wetlands where groundwater is near to the surface and they formed a reliable source of water for dry season irrigation and there is an indigenous tradition in Africa of dambo garden cultivation. The irrigation technology involved is both simple and low in cost (under \$3000/ha in 1987). However, their agricultural use in some African countries such as Zimbabwe was limited because of fear of erosion and their importance in providing base flow to streams.

West Nubariya Reclamation and Settlement Project Halcrow and VLG Consultants Ltd investigated the potential for settlement of smallholders and agricultural development of some 40 000 ha of desert land to the west of the Nile Delta for the Egyptian Government in 1979–84. The master plan for the area provided for a combination of surface and sprinkler irrigation, including village, town and agro-industrial development, low cost housing and the infrastructure of roads, water, electricity and associated services. The work undertaken included detailed soil studies, crop trials, social and economic studies, public health and agro-industrial development studies and cost benefit analysis. The capital cost of the scheme was US$95m.[36]

A mathematical model was developed for the operational regime of the 85 km long El Nasr Canal which supplied the water for the project, with five pumping stations along its length and numerous offtakes to other irrigation schemes. The model covered summer and winter flow conditions, variable obstructions and pumping conditions, and it examined the fluctuations of water in the canal and the need for regulating structures.[36]

Reuse of Sewage Effluent

Pescod and Alka[37] have emphasised that effluent reuse is not a new concept and that controlled wastewater irrigation has been practised on sewage treatment works in Europe, America and Australia since the beginning of the 20th century, and the value of wastewater for crop irrigation is becoming increasingly recognised in arid and semi-arid countries. The prime water quality objective in any reuse scheme is to prevent the spread of waterborne diseases. For example, Californian standards[38] require that reclaimed water for irrigating food crops must be adequately disinfected and filtered, with a median coliform count of no more than 2.2/100 ml. WHO[39] recommended that crops eaten raw should be irrigated only with biologically treated effluent that has been disinfected to achieve a coliform level of not more than 100/100 ml in 80% of the samples.

Cowan and Johnson[40] have highlighted the importance of selecting the most suitable sewage treatment process and cite those provided in the Middle East, comprising percolating filters, stabilisation ponds and activated sludge and extended aeration plants. In broad terms, the organic quality is monitored by the Biological Oxygen Demand (BOD) and the physical properties by the Suspended Solids (SS). When effluent is diluted by discharge to a river after treatment, the standards have traditionally been 20 mg/l BOD and 30 mg/l SS. In the absence of subsequent dilution, additional tertiary treatment is necessary and the standard is typically 10 mg/l BOD and SS, with disinfection by chlorination as a primary health safeguard.

Typical Examples of Sewage Effluent Reuse for Irrigation

Kuwait The objective was to make Kuwait self-sufficient in several products, principally milk, potatoes, onions and garlic by the year 2010, involving the bulk transfer of tertiary treated sewage from three treatment plants to a central distribution centre and then to an existing farm and a newly created agricultural area. In 1985 over 10m m^3/a of effluent was being used rising to the very ambitious level of 125m m^3/a by the year 2010.[40]

Abu Dhabi The first phase of the scheme was substantially completed in 1985 and included a treatment works serving a population of 330 000, treating some 100 000 m^3/d of effluent to tertiary standards. This was distributed for amenity use in central reservations, parks and afforestation schemes. Manual and drip feed application are the principal methods of irrigation.[40]

Qatar By 1985 drip feed irrigation was used fed from a new sewage works incorporating tertiary treatment (60 000 m^3/d capacity), with some 15 000 m^3/d used mainly for amenity and afforestation, with the surplus being pumped to an evaporation lagoon in a remote desert region where it also provides groundwater recharge.[40]

Dubai (UAE) Reuse of sewage effluent started on a small scale in 1971, but this has since been extended to incorporate drip and sprinkler irrigation of 27 000 m^3/d of effluent on reservations and verges, with the ultimate aim of achieving

8% of green area throughout the city, including 62 km of road reservations and the 60 ha Saffa Park. One of the most impressive elevated towers containing reused effluent for irrigation, the Jumeirah tower, is illustrated in Plate 18.

Recreational Facilities

Introduction

This section of the chapter is concerned with a variety of recreational facilities and their provision, ranging from water based activities to sports stadia, national and country parks and other leisure facilities.

Recreational facilities, particularly outdoor ones, are extremely diverse in their nature and scope and often involve large areas of land or water which are frequently in short supply. Furthermore, leisure is becoming an increasingly important part of people's lives, and more free time and greater prosperity enable people to extend their free time activities. An increasing population which is better educated, generally more prosperous and more mobile places a heavy demand on many recreational facilities.[41]

There is a pressing need to make realistic assessments of probable demand for the whole range of recreational resources, taking into account past trends, future population structure, and the other factors influencing demand. The demand has to be converted into areas of resource in suitable locations, with full regard to desirable capacity standards and multiple use arrangements. These resources have to be planned and properly interrelated since the fortuitous provision of facilities, as past experience has shown, is rarely satisfactory. In addition, it is necessary to cost alternative proposals to determine which will give the greatest social benefit, and this involves the difficult task of quantifying and evaluating a whole host of direct and indirect costs and benefits.[41]

Recreation in the UK in the early part of the twentieth century was given little consideration except by some benevolent landowners. The very unsatisfactory underlying factors were clearly and eloquently identified by Bryant [42] in 1970 when he wrote 'Nearly all the social troubles and divisions from which we suffer today stem from that fatal social division, that appalling neglect of and blindness to human well-being which the land and its use should serve'. He had in mind the intolerable housing and working conditions for many people and the scant regard for people's well-being and recreational needs in the nineteenth and early twentieth centuries. Fortunately, considerable advances have been made between 1970 and 1990 in the provision of a wide range of recreational facilities, as will be illustrated in this chapter.

MARINAS

Marina Design

Kalis[43] has identified the main criteria for the siting of marinas as obtaining a safe harbour of refuge close to a population centre. Different geographical locations give rise to varying degrees of engineering complexity and cost. Moody[44] has distinguished between those requiring little development and others which need dredging, bulkheading, and, perhaps, a breakwater. There are large and small tidal ranges which may need to be accommodated by dredging or by the provision of locks, tidal gates or sills. Some sites are suitable for fixed piers and many require floating walkways or pontoons. Dredging costs, siltation problems and capital investment are all important factors. Methods of achieving adequate finance have included building houses around the new development and funding the marina from the enhanced building prices, prior to the downturn in the property market in 1988–91, and raising money by debentures such as selling berths in a marina before it was built.

Kalis[43] has described how the geometry of the berthing arrangements is a function of boat size and proportion. The ratio of boat width to boat length was changing with modern designs resulting in variations in the width between finger jetties. A system of laterally mobile jetties helped to overcome this problem. The larger the boat, the proportionately greater area of marina water was required for manoeuvring. Where water space is limited, boats in the 6 to 9 m length range are the most profitable for marina operators.

Specifying a lock for entry into a marina is difficult as the variables of water differential, boat length and width, amount of use and time for lockage all have to be considered. For dredging in marinas, a small cutter section dredger was often the ideal machine, although problems could arise in finding large areas for disposal of the dredged material. Problems were also encountered when using backhoe or grab dredgers in the confined spaces of a marina and the dredged material had to be transported to barges at the marina entrance. Alternative methods including the use of concrete pumps and augers have been tried with varying degrees of success.[43]

Pontoons of different makes and types are available for the marina operator, with concrete, galvanised steel and aluminium alloy being used extensively, with floats varying from concrete covered polystyrene, plain polystyrene and glass fibre. It is important to make the correct choice for the specific location; for example, concrete pontoons help to break up waves. Decking for the pontoon system was traditionally good quality keruing but this is now in short supply and tanalized softwood and pallet systems are often used. The pontoons often consist of 2.0 m or 2.5 m wide walkways and 1 m wide cantilevered fingers. Necessary associated features include guide piles, safety ladders, fire and life saving appliances, refuse bins, lighting, and electricity and water supplies to boats within the marina.

The Walcon 2000 pontoon system is illustrated in Figure 8.21 and this has been used at Torquay and Swansea marinas and for the first major marina rebuild at Port Hamble, which is described later in the chapter. The standard range comprises walkway units (WS) 7.5 m and 11.5 m long and 2.0 m and 2.5 m wide, with cantilever finger units (SS) to give individual berths, 4.5, 6.0, 7.5, 9.0, 10.5 and 12.0 m long with a minimum width of 720 mm and a minimum length of 75% of the length of the boat. Walkways may be fitted with continous ducts along both sides to provide direct and easy access to services. The structure consists of welded aluminium alloy braced frame and the decking is ex 100 × 25 mm hardwood boards, planed, grooved and fixed with stainless steel self-tapping screws. All main connections are made with through-bolts of stainless steel with rubber bushes, and floats are constructed of fibre concrete protected expanded polystyrene.[45]

The provision of car parks, boat storage areas, boatyard premises and shops can require about

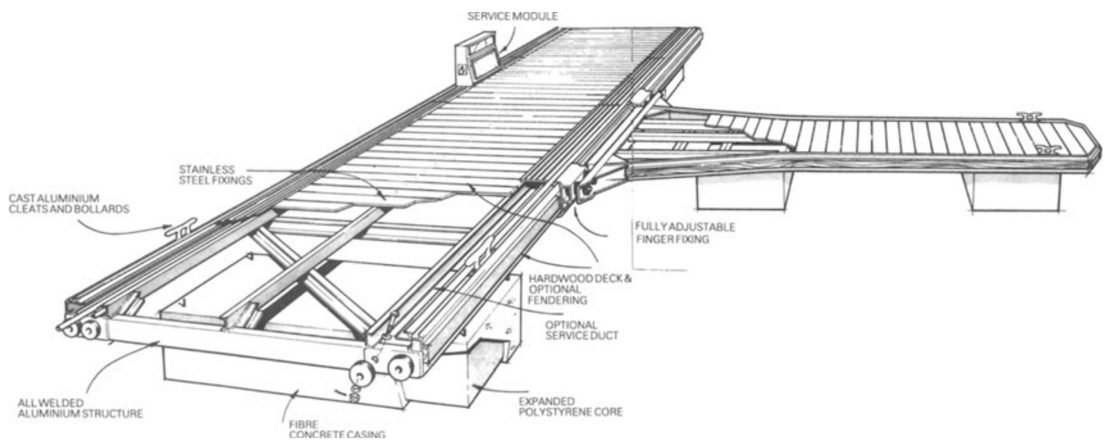


Figure 8.21 *Walcon system 2000 pontoon units (Source: Walcon Marine Ltd)*

the same area of useable land as water space, and almost all of this ground has at some time been reclaimed. For example, at Hamble the water/land interface has been sheet piled and the foreshore used as hardstanding. [44]

Marinas and Planning Policy in the Solent

Bell[46] has identified the Solent as one of the most popular and important yachting centres in the world and is host to many international events, including the Admiral's Cup. The total coastline accessible by boat, at least at high tide, is about 320 km. Futhermore, a yacht leaving any Solent harbour has a choice of 17 destinations within the area which can be reached on a single tide. There are large expanses of deep water, the Isle of Wight provides shelter in most weather conditions and the area is readily accessible to a large population in Southern England.

Planning permission was granted for the first marina in the Solent area at Port Hamble in 1964 and, at that time, there were about 10 000 moorings in the Solent, mostly swinging moorings. By 1989 the total had risen to almost 28 000 moorings, of which over a quarter were in marinas, as listed in table 8.5.[46]

Bell[46] has described how the planning authorities were extremely wary of the early marina proposals and were slow to appreciate the large expansion of the boating industry, and feared that the marina might be a means by which developers would obtain permission for other more lucrative projects which could adversely affect the character of the area. Consequently, marina developments were restricted to support services, such as shower and toilet blocks, chandleries, boatyard facilities and car parks. After a lull in marina development during the latter part

Table 8.5 *Moorings in the Solent Area*

	1974			1976			1989		
Harbour	Marinas	Other	Total	Marinas	Other	Total	Marinas	Other	Total
Keyhaven				–	312	312	–	578	578
Lymington				713	571	1284	1040	713	1753
Beaulieu				103	328	431	110	300	410
Southampton Water				101	2152	2253	1220	3091	4311
Hamble				964	904	1868	1530	1816	3356
Hill Head				–	36	36	–	36	36
Portsmouth Harbour				581	1763	2344	1086	2814	4000
Langstone Harbour				–	1036	1036	316	1121	1437
Chichester Harbour				1530	5648	7178	1670	5826	7496
Mainland total				3992	12750	16742	6972	16395	23367
Yarmouth				–	808	808	–	865	865
Newtown				–	150	150	–	240	240
Cowes				262	816	1078	537	1637	2174
Wootton				–	135	135	–	211	211
Bembridge				–	221	221	120	891	1011
Isle of Wight total				262	2130	2392	657	3844	4501
Solent total	4750	11496	16246	4254	14880	19134	7629	20239	27868

N.B. 1. The figures exclude craft stored ashore.
2. The 1989 figures are based on a survey in 1985, updated by adding recent developments.

Source: P. Bell [46]

of the 1970s, the 1980s saw a second wave of marina proposals in which the marina was the centre piece of a development package, including in particular attractive waterside housing.

Two of the second wave sites would not have been feasible without the use of lock gates. In addition to increasing the number of site opportunities, locks offer visual advantages arising from the maintenance of a constant water level within the marina. By 1989, developers were formulating further proposals, some of which involved substantial engineering works to provide adequate shelter, following the pioneering approach adopted at Brighton and described later in the chapter. Many of the second wave marina developments were attractive schemes and have done much to revitalise neglected and semi-derelict urban waterfronts, as at Southampton.[46] There are further excellent examples of this type of development at Liverpool and South Quays Marinas in North West England.

The success of the second wave marinas gave rise to a third wave, comprising the redevelopment of the first wave sites with a broader range of facilities, including housing, and were meeting considerable opposition from the planning authorities. Table 8.5 and Figure 8.22 show moorings in the Solent area suitably classified. The following points are worthy of note:

(1) The number of moorings increased by 60% between 1974 and 1989, and about one-third of the growth was in marinas.
(2) In 1989 there were 23 marinas in the area.
(3) There were, in 1989, outstanding requirements for approximately 1700 further marina berths.
(4) In 1989, the last six marinas were of the second wave variety in urban locations and two had locked entrances.[46]

Bell[46] believed that constraints to further marina development were likely to intensify for the following reasons:

(1) There will be fewer acceptable sites in land use planning terms, particularly having

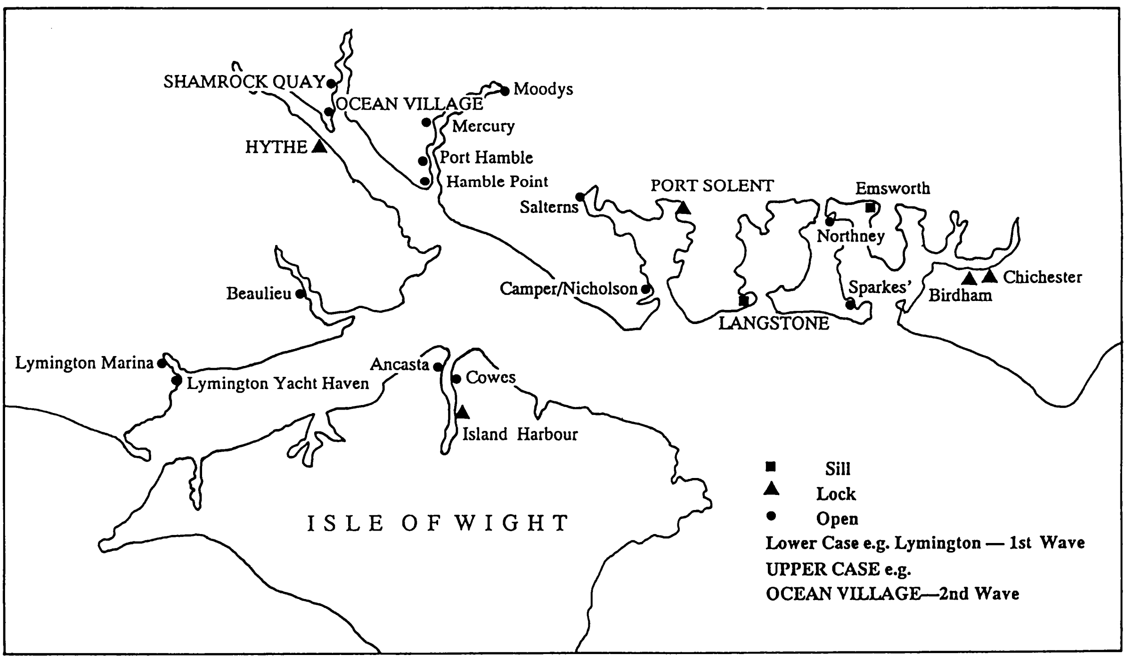


Figure 8.22 *Marinas in the Solent (Source: P. Bell[46])*

regard to landscape and nature conservation and the capacity of the approach roads.

(2) Navigational capacity could be stretched to the limit involving safety hazards.

(3) A growing public demand for an overall limit on the number of moorings in the Solent area, indicating the desirability of a sound planning strategy to maintain a satisfactory balance between competing land uses.

Port Hamble

Port Hamble is situated on the River Hamble which leads into the Solent and its location is shown in Figure 8.22. It has the distinction of being the UK's first modern operational marina and has been periodically updated by Marina Developments Ltd (MDL).

The facilities and services provided comprise 369 alongside deep water berths, with fresh water and 13 amp 240 V electricity supply; diesel and petrol fuel supply jetty; tarmacadamed car parking area; toilet, changing and shower facilities; continuous manning of the marina; large repair yard with slipway and lifting facilities for boats up to 100 t displacement; open and covered boat storage; paint spraying and scrubbing pads; full chandlery, sailmaking and electronic services; yacht brokerage, new boat sales and showrooms; underwater divers; boat salvage; towing launch; and licensed members' club.[47]

Brighton Marina

This scheme was chosen because of its large scale and high civil engineering works content. Although the selected site was very convenient for Brighton, initially there was no land available above high water level necessitating extensive reclaiming of land from the sea and it is situated on an exposed coastline open to onshore winds and waves. The following investigations were carried out prior to designing the works:

(1) installation of long and short wave recorders

(2) hydrographic surveys and site investigations

(3) hydraulic model investigations covering storm waves, long waves, performance of a cellular breakwater, and overtopping forces and moments and distribution of pressure on the breakwater

(4) foundation investigations.[48]

Preliminary works started in 1971 to provide temporary access to the site, comprising a sea wall, access road and alternative pedestrian access. This was followed by the breakwaters, shown in Figure 8.23 and Plate 36, and consisting of cellular concrete cylindrical caissons placed by a special crane, as they required no advance preparation of the sea bed, the concrete finish could be accurately controlled, allowed good progress with less vulnerability to storm damage, and the circular shape was structurally and hydraulically more efficient. There are two breakwaters each with mass concrete roots; the west breakwater contained 35 caissons and was 628 m long and the east breakwater contained 75 caissons and was 1214 m long.

The caissons, weighing 470 to 635 t each, were designed to withstand a maximum horizontal force of 8.4 MN and a maximum overturning moment of 61 MN/m, being a 1 in 1000 year condition. The wave pressures on the shell were based on a 1 in 100 year condition and were derived from model tests and subsequent data analysis and reached in places a peak value of 650 kN/m^2. A 1 in 100 year condition giving a design wave height of 4.5 m was adopted for overtopping, the superstructure being designed to limit the regenerated wave height in the inner harbour to 450 mm. Extensive temporary works included a 1200 t crane, retaining wall and land reclamation to accommodate the casting yard, crane transfer track and turntable, and slip form shuttering.[48]

The next major contract comprised the construction of the north wall, dividing the harbour into a tidal area and a locked basin, and forming the southern wall of the spine reclamation area preparatory to further development. It was constructed of mass concrete 7 to 8 m wide within

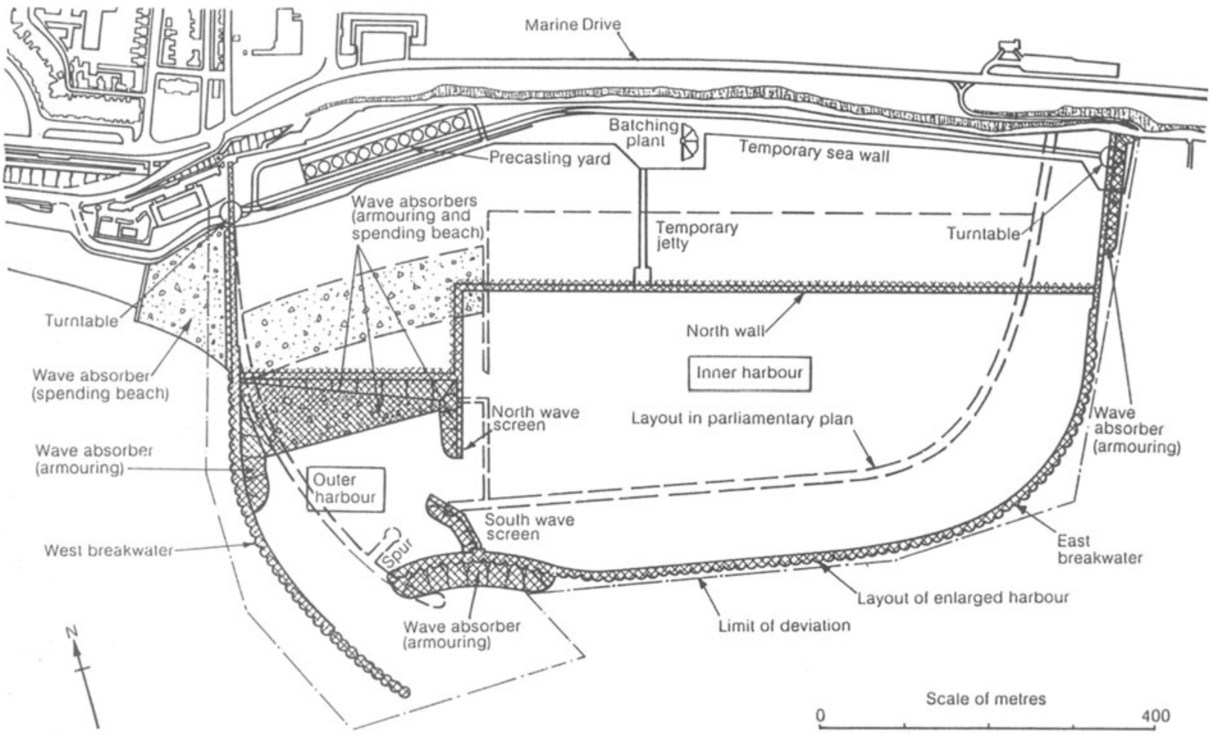


Figure 8.23 *Harbour works at Brighton Marina (Source: Terrett, Ganly & Stubbs[48])*

steel sheet piled cells. Piling frames which cantilevered forward from the previously constructed cells of the wall were used to support the steel sheet piling, before it was filled with concrete. The temporary wave screen gave protection to the work behind the north wall before the breakwaters were completed.[49]

The further harbour works consisted of the east breakwater superstructure; the outer harbour spending beach to dissipate wave energy and provide acceptable conditions for boats in the inner harbour; the south wave screen to reduce the entrance width and improve conditions in the inner harbour; the armouring and scour protection to reduce wave reflections and prevent undermining of the caisson foundations; dredging by pontoon mounted excavator and cutter suction dredger to secure adequate depth for boats in the marina; gunite revetment to protect the toe of the undercliff walk retaining wall; the necessary handrailing and staircases; and concrete pontoons, steel frame fingers and anchorages in the locked and tidal basins for some 2000 berths.[50]

The constructional work was carried out between 1971 and 1979 at a total cost of £22.5m made up of breakwaters: £12.5m, north wall: £2.5m, other harbour works, including dredging: £5.5m, and moorings: £2.0m.[50]

Brighton Marina Village is being developed beside the harbour on 7 ha of land of which over 2 ha was reclaimed. As well as extensive high quality housing accommodation in the form of apartments and pontoon housing, as shown in Plate 36 the development includes an international standard hotel, health and sports centre with water theme park, supermarket, shopping and restaurant terraces and extensive car parking. One hundred and seventy dwellings were completed by mid-1989.[51]

WATER-BASED RECREATION

General Background

In inland areas of the UK it has become increasingly necessary to use every suitable stretch of water for recreational purposes to satisfy the rising demand for water-based recreation of all kinds. Resources encompass the whole gamut of rivers, canals, lakes, wet gravel pits and reservoirs. With wet gravel pits it is important that the form of recreational use is planned before the pits are excavated in order that the over-burden from the excavation can be suitably tipped in readiness for the future use. Similarly, reservoirs also need planning and constructing with the recreational use in mind, even to the extent of comparing differing scales of investment and probable monetary returns stemming from varying patterns of recreational provision. With canals, the economics of refilling, conversion to water channels, or complete restoration to navigable canals (cruiseways) have to be compared. The principal water-based recreational pursuits encompass motor boating and cruising, sailing, canoeing, rowing, water skiing, powered boat racing, sub-aqua activities, angling, walking and rambling, nature study and swimming.[41]

British Waterways (BW)[52] own, or are the navigation authority for, a network of canals, rivers and reservoirs, extending to 3220 km of waterway and 90 reservoirs, as described in chapter 2, which provide a rich natural habitat for plants and wildlife and support a variety of leisure activities, including angling, boating, walking and nature study. The enjoyment and tranquillity of the canal scene is evidenced in Plate 37, illustrating a colourful narrow boat at Cowley Lock, Uxbridge on the Grand Union Canal, with the lock keeper's house and a typical humped back bridge in the background. BW are aware of the great leisure potential on inland waterways, subject to their capacity not being exceeded and/or the environmental attractiveness destroyed, and this is indicated in table 8.6.

Table 8.6 *Main Leisure Activities on UK Inland Waterways*

Activity	Adults 1986	Av. adult user days 1986	Market potential 1986: million adults*
Walking/informal recreation	4 830 000	96.1	1.29
Angling	770 000	16.2	1.14
Trip boats	500 000	1.0	4.20
Private boating	400 000	1.8	3.13
Unpowered boating	400 000	2.8	1. 53
Hire boating	140 000	1.2	9. 26

* Number who had not undertaken activity but had seriously considered it.
Source: National Opinion Polls.[52]

Rutland Water

This reservoir has been selected as it is the largest man-made reservoir in the UK and as a lake it is second only in size to Windermere. The total area of the site is 1880 ha with a top water area of 1360 ha and recreation and amenity area of 530 ha. The prime function of the reservoir is to supply water but the extensive recreational uses include angling, sailing and bird watching. The Water Authority provided picnic sites with associated car parks, toilets and refreshment kiosks; sailing facilities; trout fishing; and a nature reservoir.

Car parking for 3000 cars is of three types: high density on a tarmac base, medium density on a gravel base, and low density staggered parking on grass and under trees. Some picnic furniture is provided and the picnic sites are landscaped with extensive tree and shrub planting.

Chelmer Lakes

In 1986 Travers Morgan designed an attractive and exciting scheme for the proposed Chelmer Lakes water sports and conservation park at Manor Farm near Chelmsford. The 65 ha farmland site was prone to flooding and it was planned to extract 2m tonnes of gravel from the site in a phased programme spread over six years, prior to development of the site. The scheme entailed the diversion of a variety of services crossing the site and taking measures to prevent polluted water from nearby rivers entering the lakes.

Extensive surveys identified a significant demand from the public for improved water facilities. Sailing, wind surfing, water skiing and rowing are all sports which gained in popularity in the 1980s, and demand in the Chelmsford area was higher than the national average. The scheme included four major water sports lakes, a marina and a conservation area. The proposed main expanse of water is a 500 m long lake for conventional water skiing using modern gas powered boats which avoid noise and pollution. The course will also be used for sprint canoeing and rowing. A second 7.5 ha lake provides adequate space for 40 racing dinghies or more than 100 training boats. Of the two smaller lakes, one is set aside for board sailing and canoeing and the other contains a 350 m long cable tow, silently powered by electric motors, which can carry up to eight skiers simultaneously at speeds varying from the 'beginning' to 'challenging'. Provision is also made for a clubhouse and refreshment building, with changing rooms and other facilities, 400 car parking spaces, dinghy parking, mooring and launching jetties.[53]

The nature conservation area will be shielded from the remainder with an attractive landscape of shallow lakes, willows, alders, and reed-fringed marshland, and over 125 000 trees will be planted. A system of footpaths, footbridges and boardwalks allow controlled access, while inaccessible islands will become wildfowl breeding sites, banks will be covered with native trees and shrubs, and the water's edge planted to provide food for waders.[53]

If it materialises the project will provide valuable guidelines for the future restoration of gravel workings, in addition to being a great asset for many residents of this region.

HOLME PIERREPONT NATIONAL WATER SPORTS CENTRE

General Characteristics

Holme Pierrepont National Water Sports Centre is situated in 110 ha of parkland alongside the River Trent, 6.5 km from the centre of Nottingham, and was Britain's first purpose built, multi-water sports centre. The centre is one of the most comprehensive water sports facilities in the world with its exceptional 2000 m regatta lake, unique slalom course and water ski lake and ski tow, with supporting residential, catering and conference facilities. The water sports centre and country park are managed as a joint venture between Nottinghamshire County Council and the Sports Council. Its primary objective was to meet the national and international requirements of rowing, canoeing and water skiing, and its success in meeting these objectives is evidenced by the holding of world championships at the centre in rowing, canoeing and power boating, and numerous major competitive events. The centre also offers considerable scope for dinghy and board sailing, power boating and hydroplaning, slalom for all grades, water ski tow and angling.[54, 55]

The centre was officially opened in 1973 following a 2½ year construction period at a cost of £1.2m (1970 prices), and was sited on former gravel workings. The standards adopted were almost identical to those implemented at Munich in 1972 for the Olympics course. The course is 2215 m long and 135 m wide at water line and is 3.5 m deep over the rowing and canoeing lanes. This width allows six rowing lanes 13.5 m wide or alternatively nine canoeing lanes 9 m wide, with a circulation lane 27 m wide at each side of the course. The water ski course is 1.25 m deep and is 550 m long between centres of radii of 50 m, with an overall width at water line of 70 m. The side slopes of the rowing course are 1 in 8 which is designed to break the waves reaching the banks, and the banks were subsequently enlarged in the light of experience. The general layout of the centre is illustrated in Figure 8.24 and an aerial view in Plate 38, which also shows the extensive viewing banks for spectators.

Special features of the main course are the starting platforms at 2000 m adjustable to boats of all lengths, with adjustable intermediate start positions at 1500, 1000 and 500 m, together with timing and commentary boxes, starter's tower, judging and course control tower, electronic information and scoreboard measuring 29 m long by 1.3 m wide and weighing 14 t and containing 5150 lamps and 144 display modules, photo-finish and electronic timing equipment.[54]

The construction entailed 1.2m cubic metres of excavation with all the surplus soil used on the site for landscaping purposes. Basic course facilities included a control weir and outfall to produce relatively still conditions, a water inlet for emergency use, four launching jetties each 20 m long × 6 m wide with a freeboard of 150 m, two landing stages 40 m long × 4 m wide and 20 m long × 6 m wide. All jetties and landing stages are of reinforced concrete construction comprising flat slabs on circular columns and the jetties have circular ends to prevent backwash. Reinforced concrete casings were constructed to house floating pontoons as permanent starting arrangements at 2000 m, adjustable to suit all lengths of craft. Approximately 5 km of roads and cycle tracks, together with car parks, were constructed around the course.[54]

The administration block comprises a reinforced concrete frame supported along the course side by a 4.6 m retaining wall, with cantilever viewing platforms provided at all levels along the front elevation of the building. The hostel and changing blocks are of traditional load bearing brick and slab construction, while the six level finish tower, connecting bridge and external access staircase to the roof are fabricated in fully welded exposed steelwork. Extensive spectator viewing ramps and platforms are of mass and reinforced concrete, while the boathouse consists of reinforced concrete perimeter retaining walls and beam and slab construction, with the roof providing spectator viewing and occasional light craft exhibitions. Large areas of exposed concrete were given a special 'elephant hide' finish to contrast with the bronze coloured bricks and tinted glazing of the administration block.[54]

Artificial Canoe Slalom Course

This course was opened at Holme Pierrepont in 1986 and funded by the Sports Council, Nottinghamshire County Council and the British Canoe Union at a cost of £2.2m, to provide the first

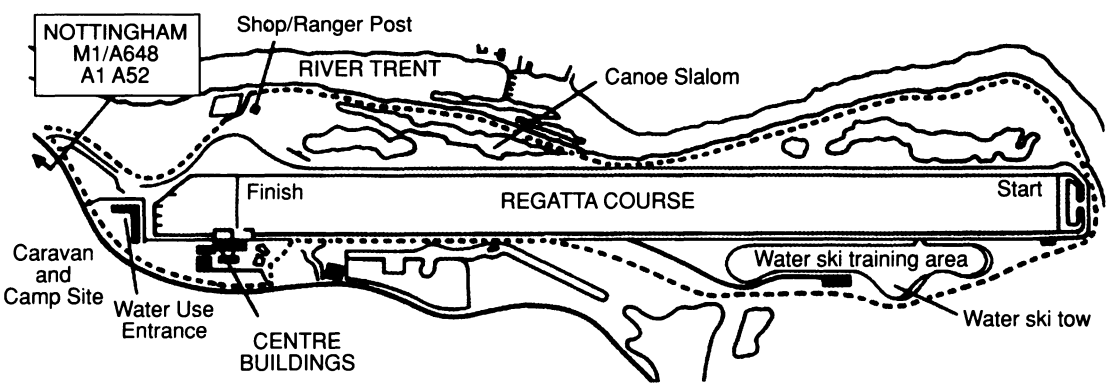


Figure 8.24 *Layout of National Water Sports Centre, Holme Pierrepont, Nottingham (Source: Sports Council)*

purpose-built international standard artificial canoe slalom facility in the UK. Extensive use was made of hydraulic models in the design of the course which takes the form of stepped pools connected by horizontal trapezoidal channels, as shown in Figure 8.25. [56]

The course is constructed as a bypass to Holme Sluices and has an overall length of 700 m, and comprises three sections: an 80 m tapered inlet channel, a 440 m concrete-lined, irregular channel forming the main competition course and a 180 m rectangular section outlet channel. The course has a maximum design discharge of 28 m^3/s with a differential water level of 3.5 m, giving a maximum water velocity of 4.4 m/s. The design discharge represents approximately 50% of the mean summer flow of the river. Much of the course is flanked by shallow sloping beaches to provide easy escape from areas of heavy water and to prevent undesirable edge of stream effects and wave reflection. The degree of difficulty of conditions in the course can be varied by raising a canoeable variable height inverted V weir gate at the start of the course to suit varying levels of expertise.[56]

Peters[56] described how it was decided at an early stage to use the MOSS digital terrain modelling computer system to translate the complex arrangement of the course hydraulic model into construction drawings and setting out information. Several forms of lining were investigated, including spray concrete faced reinforced earth and concrete filled mattresses, which were rejected in favour of traditional reinforced concrete, in order to achieve the required dimensional accuracy, smoothness of finish and durability. To avoid the need for a thick uplift resisting base the main channel was perforated with a large number of pressure relief tubes. A 200 mm deep graded stone drainage layer and permeable geofabric filter membrane were installed beneath the 250 mm thick concrete base slab. The proximity of the river and the regatta course necessitated the use of steel sheet piled walls to reduce the width of excavation in the outlet channel.

The intake control gate consists of a 6 m wide × 2.5 m deep bottom-pivoted front plate activated by a hydraulic ram driving a transverse torsion shaft. The gate apron is hinged to the top edge of the front plate and its lower edge is supported on rails cast into the channel invert. The gate control unit provides full operator control of the course discharge when river conditions permit. Water level information is obtained by pressure transducers installed in stilling wells located upstream

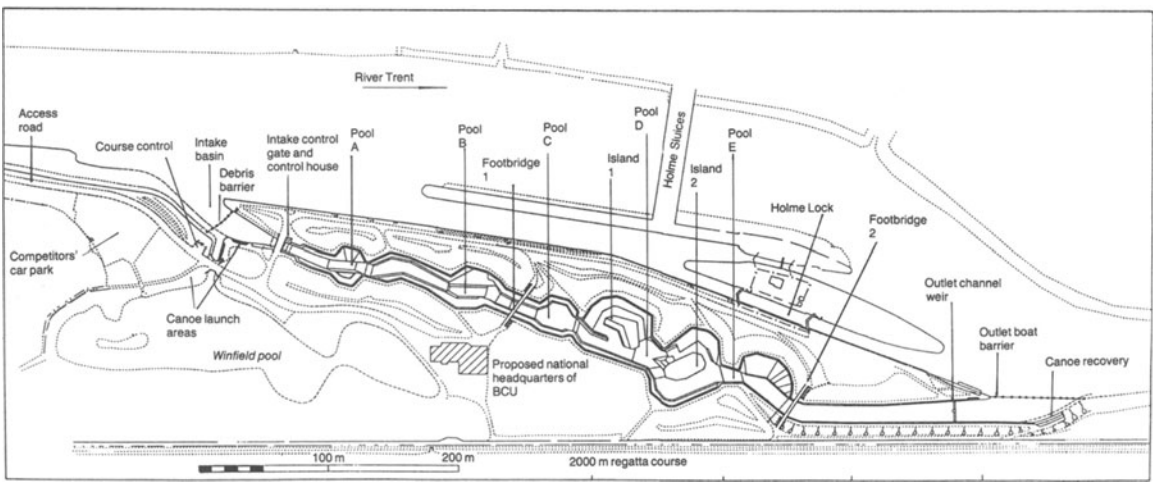


Figure 8.25 *Layout of the Artificial Canoe Slalom Course, Holme Pierrepont, Nottingham (Source: J. R. Peters[56])*

of the gate on the river bank. The gate automatically closes if the upstream river falls to a level at which full operation of the course would endanger the navigational retention level. The control system may also be set to maintain a constant preset discharge when river levels fluctuate.[56]

Peters[56] has described how the land-form design maximised the reuse of excavated materials with mounding on either side of the course, giving gorge-like natural river topography and elevated spectator viewing areas. The two, three span footbridges were constructed in timber to be in keeping with the wooded country park setting.

On completion, calibration measurements were made of discharge, water velocity and surface level at various flow rates. These generally corresponded favourably with data recorded from the hydraulic design model, and are shown in Figure 8.26. Reports from commissioning trials and initial competitive events indicated that the course had met all the prescribed criteria. Canoeing conditions are considered to be more akin to those of a natural river than have been achieved with any previous artificial course. The wide pools and islands which permit continuous practice on the roughest sections of the course provide a unique facility for training and instruction.[56]

Valuable information and advice on the form and use of the slalom course are contained in *Holme Pierrepont Artificial Slalom Course: A Users' Guide*.[57]

SWIMMING POOLS

General Background

The number of indoor swimming pools in the UK is estimated to have increased from about 500 in 1970 to approaching 2500 in 1990, many provided by local authorities as an important component of modern leisure centres. In the 1980s, the design and layout of the pools and their associated buildings and equipment underwent significant changes. Large leisure centres with free-formed

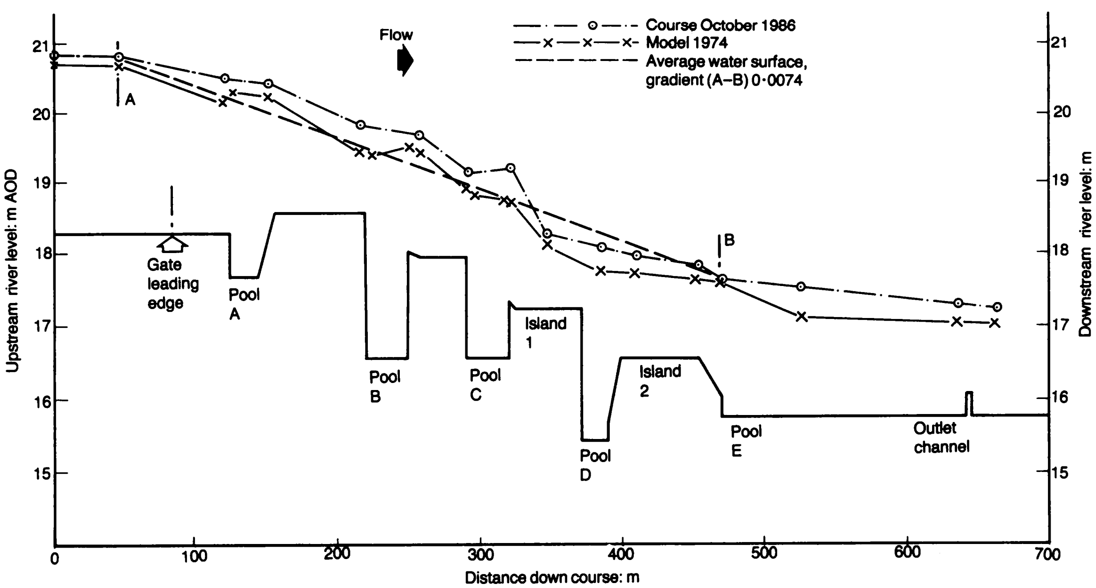


Figure 8.26 *Comparison of model and course water surface profiles, Artificial Canoe Slalom Course, Holme Pierrepont (Source: J. R. Peters[56])*

pools complete with wave making machines, subtropical vegetation and heat energy saving equipment have been incorporated in many schemes throughout the country, and ozone has largely replaced chlorine as the main disinfecting agent for swimming pool water in new pools and the refurbishment of existing pools. Local authorities have increasingly used package deal contracts for the provision of new pools, sometimes with disappointing results.[58]

Swimming Pool Design

Perkins[58] has listed the following basic requirements for the design of swimming pools:

(1) The pool must be structurally sound, and this aspect is considered in more detail later.
(2) The pool must be watertight against loss of water when it is full, and, if constructed below ground, against infiltration of groundwater when empty.
(3) It must be finished with an attractive, smooth, impermeable surface.
(4) The water must be maintained at a satisfactory standard of clarity and purity, and Thames Water[59] have emphasised the importance of maintaining the correct physico-chemical quality of water to enhance swimming enjoyment and prevent microbiological problems.
(5) A diving board should be provided only when the minimum depth of water and the dimensions of the water area comply with the recommendations of the Amateur Swimming Association (ASA).
(6) A walkway, of adequate width and with a non-slip surface, should be provided around the pool.
(7) The provision of a safety step or ledge on the walls where the water depth exceeds about 900 mm is beneficial for all pools used by young children.

Readers requiring detailed information on the planning, layout, construction, finishes, fittings, engineering services and maintenance of swimming pools are referred to *Swimming Pools*.[58]

Main Structural Defects

BRE have advised that the internal atmosphere in a heated indoor swimming pool can result in severe condensation with damaging consequences for roofs. The experience of BRE as described in Digest 336[60] suggests that only two forms of roof construction can be relied upon for heated indoor swimming pools; namely the pressurised roof and the warm-deck roof, both of which are detailed in the digest.

Stainless steel has been used for a variety of fixtures and fittings in swimming pools, such as ducts, louvres, handrails and a variety of suspension systems, and, towards the end of 1988, BRE received reports of unexpected failures of stainless steel components at some swimming pools and leisure centres.[61]

The BRE diagnoses and recommendations are contained in *Corrosion of metals in swimming pool buildings*.[61] For instance, suspended ceilings are best supported by hangers of coated galvanised carbon steel or coated aluminium alloys, or non-metallic materials such as polypropylene or glass reinforced plastics. Ferrous metals adjacent to the pool and in play areas require durable methods of corrosion protection, and poolside equipment requires regular washing or the use of coated galvanised steel where cleaning is impracticable. While for building services equipment, coated carbon steel components seem to offer the most trouble free solution.

Leisure Pool, Blackburn

This swimming pool has been selected as the case study covering a modern pool built to high standards of design and construction and including all the latest features. It is situated on a difficult, sloping town centre site to form a prominent and impressive town centre amenity. The project was aided by the government's Inner Area Programme, which enabled Blackburn to be the first town in North West England to have this kind of amenity. It was constructed by Shepherd Construction Ltd under the direction of Faulkner Browns at a cost of £2.8m on a 25 month contract period.[62]

The dual objectives of spectacular appearance and low maintenance entailed the use of finishes such as special non-slip mosaic tiling, high impact coloured glass changing cubicles, shot blasted fairfaced brickwork and special aluminium plank ceilings. The two storey building's sloping site was fully exploited to provide a most attractive facility. The main features are a 490 m^2 irregularly shaped leisure pool and an elaborate 65 m long flume which runs outside the building's curtain walls for part of its length, and these are well illustrated in Plate 39. The leisure pool also required exacting service installations as the specification included an ozone water filtration system, wave machine, whirlpool bath, geysers and flume water circulation.[62]

SPORTS STADIA AND ARENAS

General Introduction

Arenas and stadia are becoming an important part of the UK leisure scene. The Sports Council has defined an arena as an indoor facility with a minimum free-activity (floor) space of 36 m × 20 m, with permanent seating on at least two sides of the floor, and with adequate car parking, security, catering facilities and other related services. A covered stadium is an indoor facility with an activity space greater than 110 m × 55 m and is designed mainly for pitch sports, such as hockey and American football.

The United States is the leader in arena/-stadium development, and the Houston Astrodome, opened in 1965, was the first domed stadium with full air conditioning. It was designed for baseball and had seating for 45 000 spectators. American football and baseball events command a huge following and hence the vast US superbowls. The largest indoor stadium is the US$173m, 83.3 m tall, superdome in New Orleans, Louisiana, with a maximum seating capacity of 97 300 for conventions.

In 1989, the Sports Council[63] was encouraging the growth of arenas on American lines in the UK. As a rule the floor needs to provide a surface for sports and non-sports use and requires fixings for equipment. The arena roof has to carry the weight of snow and take the load of suspended heavy facilities such as a scoreboard. The Sports Council's latest strategy is to tailor arenas to different sized towns, for example, Birmingham has a scale 1 £47m national indoor arena, and a scale 2 arena was built in Sheffield for the World Student Games in 1991, while smaller regional arenas seating about 3000 people could serve towns with populations of 50 000 to 200 000.

Football Grounds in the United Kingdom

Of the 92 League clubs in England and Wales in 1990, only four had grounds built since the Second World War. However, many clubs have rebuilt or refurbished most of their stands and terraces, some to a very high standard. Financial problems arose out of the implementation of the Taylor Report in 1990 into the Hillsborough disaster in April 1989, in which 95 Liverpool fans died. Hillsborough was regarded as one of the finest, safest grounds in Britain, yet it only took an unforeseen set of circumstances and some poor crowd control to expose serious design flaws. This situation stemmed in part from lack of funds for ground improvements but partly also because of lack of imagination on the part of club directors towards ground relocation and, probably more importantly, ground sharing between neighbouring clubs. The Taylor report brought forth the same reaction from football clubs as did the Popplewell report on the 1985 Bradford fire, about the catastrophic effect of implementation on the smaller clubs.[64]

The most demanding and controversial element of the Taylor report concerned the phasing out of all terraces for standing spectators. It required all English first and second division grounds and those in the Scottish premier division to convert their grounds to all-seated by August 1994 (with a phased reduction in standing capacity of 20% each year). All other division grounds had until August 1999 to make the transition. The provision of seats, roofs over terraces, altering the rake of terraces to suit the different sightlines, widening gangways, and providing other necessary facilities, was estimated to cost £350m. Furthermore, the international football association (FIFA) decided that there should be no standing spectators at World Cup matches from 1993 onwards, and UEFA applied the same rule for European competitions from 1991 onwards.[64]

In 1990, DOE urged football clubs to contact their local authorities at an early stage, whatever their plans. Clubs contemplating a move should work closely with the local authority in identifying suitable sites. Millwall's plans to build a new ground to replace the Den, its home since 1910, exemplifies this approach. The new site was made available by the local authority, and the £15m ground will include community sports facilities and squash courts.

In 1990, debt-laden Brighton and Hove Albion football club was planning a joint venture with a local developer for a new £18m stadium and leisure complex on an edge of town site for completion in 1994. Funding for the scheme will come partly from the sale of the existing club ground, valued at between £7m and £10m. The new scheme will include an athletics track, bowling alley, restaurants and cinema, on the premise that an £18m stadium cannot exist on its own.

Another interesting development was the construction of a new £2.5m football grandstand by Dorchester Town football club in 1990 on a new site adjoining the rugby pitch, to replace the old stand which was in a state of collapse. The Duchy of Cornwall, as freeholder of the site, paid the building costs and the impressive design of the new stand was approved at all major stages by HRH the Prince of Wales. The stand is built in the classical style with pediments, reconstructed Portland stone, hand made bricks and unobstructive circular steel columns with a pitched steel sheet roof.[65]

At the other extreme, a new £30m, 25 000 seated stadium was erected at Sheffield to serve the 1991 World Student Games, which fielded some 6000 competitors from over 130 countries. The main structure was of tubular steel with roof canopies of glass fibre cloth coated with a German made PTPE polymer. Precast and *in situ* concrete were used in the structure and seating terraces, with uplighters fixed to the tubular frame to enable events to be held at night.

Italian Football World Cup Developments

Twelve Italian stadia were built, converted or enlarged for the World Cup which was staged in Italy in 1990. These developmemts included what is probably one of the world's most handsome and comfortable sports stadia – the San Nicola elliptical shaped stadium at Bari. Situated at the centre of a low, artificial hill the bottom tier of seats are set at a 30% rake around the edge of the shallow crater enclosing the pitch. Built into the bank below the seats are changing rooms, gyms, medical and physiotherapy rooms, offices, and a service road which encircles the stadium.[66]

Above, and virtually a separate structure, is the upper tier of seats raked at 45%, supported on sets of four reinforced concrete columns placed on each side of 26 open vertical slots. At the top is a ring of 52 box steel cantilever arms supporting a translucent membrane roof, and there are no internal columns to obstruct the view from any part of the terraces. The roof provides a sense of enclosure and a degree of shade. At the same time the open sky above, the continuous open space between the two tiers of seats, and the open slots which break up the upper zone of the top tier into 26 seating areas, give the stadium an air of lightness and elegance. Yet the stadium possesses a dramatic, closed in effect. The stadium had to be designed to withstand class two seismic movement.[66]

The 270 m long, 210 m wide and 45 m high stadium has 60 000 seats and cost £58m (£37m for the structure and £21m for the new roads and international press facilities). The city contributed £33m and the government £25m. There are parking spaces for 9000 cars and 150 coaches.

Only about one quarter of the seats are covered in the warm climate, unlike Britain where they would all have to be covered to give protection from rain, hail and snow. Armoured clear glass is used for most of the enclosure fencing. Except for Wembley, which has been converted to an all seated stadium holding 81 500 spectators and Ibrox Park in Glasgow, there were in 1990 no grounds in Britain built or proposed which approached the standard of Bari.[66]

Toronto's Sky Dome

Toronto's Sky Dome completed in 1989 at a cost of £214m, and containing a 55 000 seat sports arena, was the first major stadium to use a fully retractable roof. The 86 m high roof comprises four interconnected 4.4 m deep, 200 m wide steel parabolic arched lattice trusses supporting a white PVC covered acoustic and thermal insulated corrugated steel roof. Three of the trusses are designed to ride on railed tracks on top of the reinforced concrete stadium walls. The fourth section is of the same construction but remains fixed at one end of the structure. Into this the three moving panels will retract leaving 100% of the playing area and 91% of the stadium seating open to the sky. Panel four also provides shade for the 35 m by 10 m 'Jumbotron', claimed to be the largest electronic scoreboard in the world. It takes 20 minutes to open or close the sliding roof which encloses 3.2 ha and spans 205 m at its widest point.[67]

The roof panels are supported by square steel members of 200 to 300 mm^2 csa and run on 54 bogies driven by a series of electric miniature eight wheeled trucks. The bogies weigh between 20 and 40 t and support roof sections each weighing up to 20 000 t. When in a closed position the gap between the roof panels and the concrete ring beam on which they ride will be filled by inflatable seals and flaps.[67]

The 275 m diameter stadium also has a 364 bed hotel cantilevered off it, with 70 rooms overlooking the playing area, and two parallel wings. The walls, floors and seating tiers are in precast concrete and the wings consist of massive cast *in situ* A frames containing over 100 000 m^3 of concrete and 20 000 t of steel reinforcement. The playing area is formed of artificial astroturf and can thus be used as an indoor facility for what are normally considered outdoor sports. The Sky Dome is expected to accommodate events for over 300 days a year, including various sports, rock concerts, conventions and trade shows.

Two 'Shell Domes', with four fabric leaves fanning across a baseball stadium and an entertainment complex was planned to be built by 1992 at Fakuoka on the island of Kyushu. The Takenaka Corporation of Tokyo had designed what it considered to be a lighter and cheaper alternative to Sky Dome.

Sydney Football Stadium

This impressive stadium was selected largely because of its unique sweeping saddle form of roof designed to reduce the bulk of the building in relation to adjoining residential areas, as illustrated in Figure 8.27. The stadium provides seating for 40 000 spectators for rugby and football, and its exposed lightweight tension structure provides uninterrupted views for spectators. Spectator viewing is maximised about the halfway line by the use of curved seating tiers within the optimum viewing circle. A continuous pedestrian concourse is provided around the stadium at entrance level. Between the concourse level and the playing surface, which is depressed about 5 m below grade, is a continuous bowl of uncovered terraced seating supported by *in situ* reinforced concrete laid on compacted fill.[68]

The seated upper terraces are supported by L-shaped precast concrete units spanning on to support frames, which comprise raking fabricated structural steel girders over a reinforced concrete beam slab and column framework housing the stadium amenities. The roof has lightweight metal upper and lower surfaces supported on purlins spanning between radial universal roof beams, with a maximum cantilever span of 30 m. For the longer cantilevers, universal beams are supported by a tension/ compression framework rising above the roof surface. Forces from these frameworks are transferred into the seating support frames by a space truss at the rear of the roof.[68]

An aerodynamic slot is provided at the roof leading edge to reduce peak pressures and roof flutter. The slot is decked with open mesh and forms the service walkway to the stadium flood lighting system. The complex is supported on Frankipiles except the west grandstand which has Hercules precast driven piles. The scheme secured the winning Award in the IEAust Sydney Division, Building and Civil Engineering Design 1988, and the ISE Special Award for the aesthetic form and technical excellence 1988.[68]

Mound Stand Redevelopment, Lord's Cricket Ground, London

Lord's Cricket Ground is well known by cricketers and cricket supporters as the home of English cricket and the headquarters of the TCCB, the world cricket authority. Redevelopment of the famous Victorian Mound Stand in 1985–87, in two phases to avoid interference with the intervening cricket season, at a cost of about £5m, secured a necessary increase in seating capacity of 4600 seats. The late nineteenth century design by Frank Verity had included the support of a short length of the back of the seating on brick arches. The six original arches were extended to 27 and became the module for the geometry of the new construction.[69]

The steel superstructure is based on a spine beam supported by six columns at 18.3 m centres, with rib beams at 3.66 m centres cantilevered to front and back from the spine. The lower promenade is suspended from the spine and rib beams, with the centre of gravity slightly to the front of the columns with stability assured by rear tie-downs. The 1380 m^2 fabric roof, curved on plan, is of PVC-coated woven polyester fibre tensioned to galvanised steel cables and central pick up rings. Roof cones, each the width of two of Verity's arches, wrap around each of six main masts. Between each pair of masts is hung a large cone, the width of three of Verity's arches, as illustrated in Figure 8.28.

The scheme won a Civic Trust Award in 1989 and a RIBA Architecture Award in 1988. HRH the Prince of Wales aptly described the development in *A Vision of Britain*[70], when he wrote 'You can't get anywhere much more traditional than Lord's Cricket Ground. But they commissioned Michael Hopkins, one of our most innovative architects, to design the new stand. It seems to me to catch the spirit of Lord's, giving a suggestion of marquee tents and Edwardian summer days. There are high-tech elements, with new materials blending in with the old.'

Sydney Tower, Centrepoint

In the late 1970s the 50 000 t Centrepoint Building in central Sydney was used as the base for the 4000 t tower, 324.8 m high and creating the tallest building in Australia. The shaft was made of 46 separate prefabricated barrel units 6.7 m diameter constructed from a high weathering steel known locally as Austen 50, with a total weight of 1828.8 t. These units, weighing 27 t each, could not be transported in one piece and were brought on to the site in seven pieces and welded together in a jig, stacked on the office block roof and erected by gantry frame. Each barrel unit was fully completed with lift rails, stair walls and hydraulic riser before hoisting. The shaft contained two sets of fire stairs, fire, electrical and pumping ducts in one half and three high speed double decker lift shafts in the remainder, which each have a capacity of 24 persons and an elevator speed of 426 m/minute.

The turret was constructed of reinforced concrete with a steel frame and weighed 2239 t with nine levels with a gold exterior. The bottom four levels are for public use and consist of restaurants/bars and observations decks, while the top five levels are for mechanical, electrical and service equipment, surmounted by a complex communications system with a tall while spire. A system of hydraulic jacks was used to hoist the turret up the shaft. The outside steel frame of the turret (perimeter curtain wall frame) was assembled prior to hoisting, excluding the glass to reduce the wind pressure.

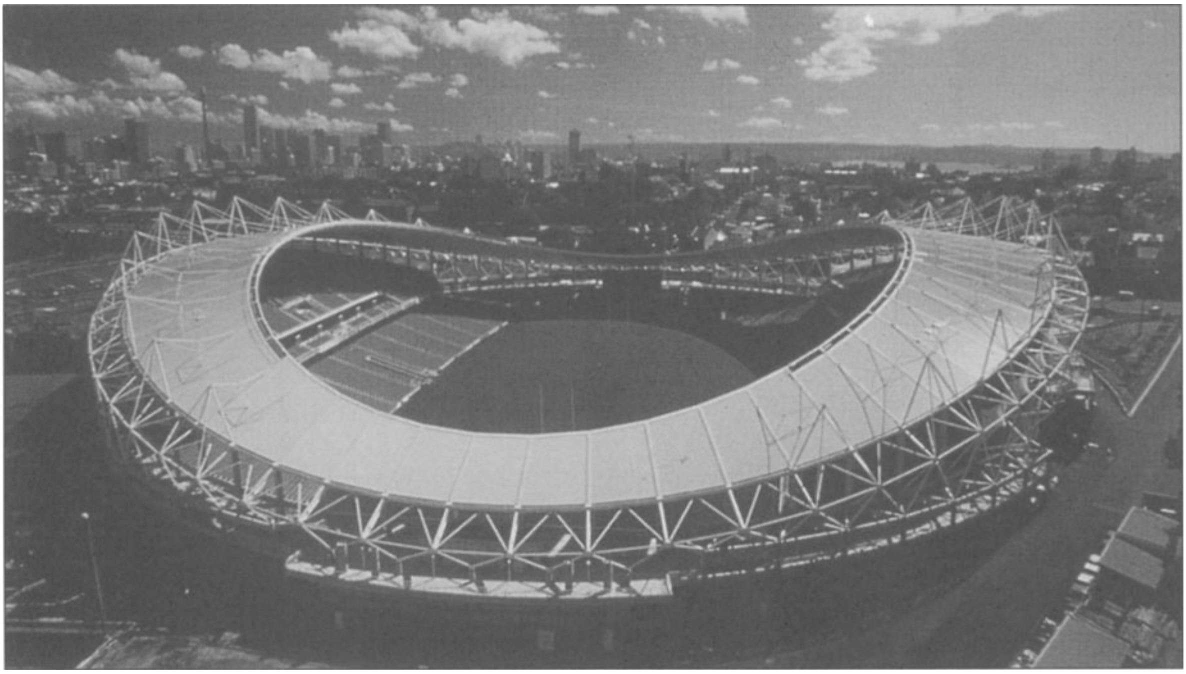


Figure 8.27 *Sydney Football Stadium (Source: Ove Arup & Partners)*

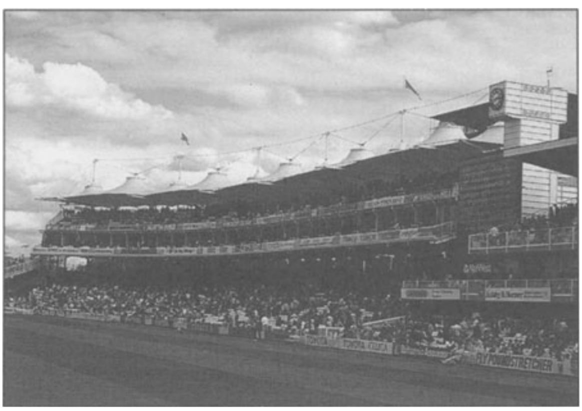


Figure 8.28 *Mound Stand Redevelopment, Lord's Cricket Ground, London (Source: Ove Arup & Partners)*

The cables on the outside of the shaft consisted of heavy galvanised steel as follows: first stage – 56 cables of 114 mm diameter comprising 235 strands of 7 mm diameter wire, each weighing 7 t, from the 1.22 m thick concrete roof slab to the intermediate anchorage ring; second stage – 56 cables of 64 mm diameter comprising 55 strands of 7 mm diameter wire from the anchorage ring to the turret.

SYDNEY OPERA HOUSE

General Background

The book would be incomplete without the inclusion of this uniquely designed building which has virtually become a national symbol of Australia. It is technically fascinating because roof vaults of such size and curvatures have not been built before, and because the soaring roof sails were prefabricated. The Opera House has added enormously to the cultural life of Australia, although the title is misleading because of the wide range of activities carried on within the building. The Opera House has water on three sides with the greenery of the Royal Botanical Gardens and Government House grounds on the fourth side.[71]

The Opera House consists of a huge concrete base or Podium upon which three sets of roof systems have been erected. One set of roofs covers the Concert Hall, another the Opera Theatre and the third and smaller set, the Bennelong Restaurant. In both the Concert Hall and the Opera Theatre, there are four shells in a row, forming both roof and walls of a large covered area, while the Bennelong Restaurant consists of two main shells. These are well illustrated in Figure 8.29, and Figure 8.30 shows axial sections through both the Concert Hall and the Opera Theatre.

The Danish Architect, Jørn Utzon won the design competition for the Opera House in 1957 and construction proceeded in three stages from 1959 to 1973. The original design was so boldly conceived that it proved structurally impossible to build. After four years of research Utzon altered his design and gave the roofs a defined spherical geometry, which enabled the roofs to be constructed in precast form, thereby greatly reducing the construction time and cost. Utzon resigned in 1966, as stage II (roof vaults) was nearing completion, because of changes made to his plans, and a team of Australian architects took over and, after an extensive review of the proposed functions of the building, proceeded to the completion of stage III. Ove Arup and Partners (consultant structural engineers) were intimately involved in all stages of construction.

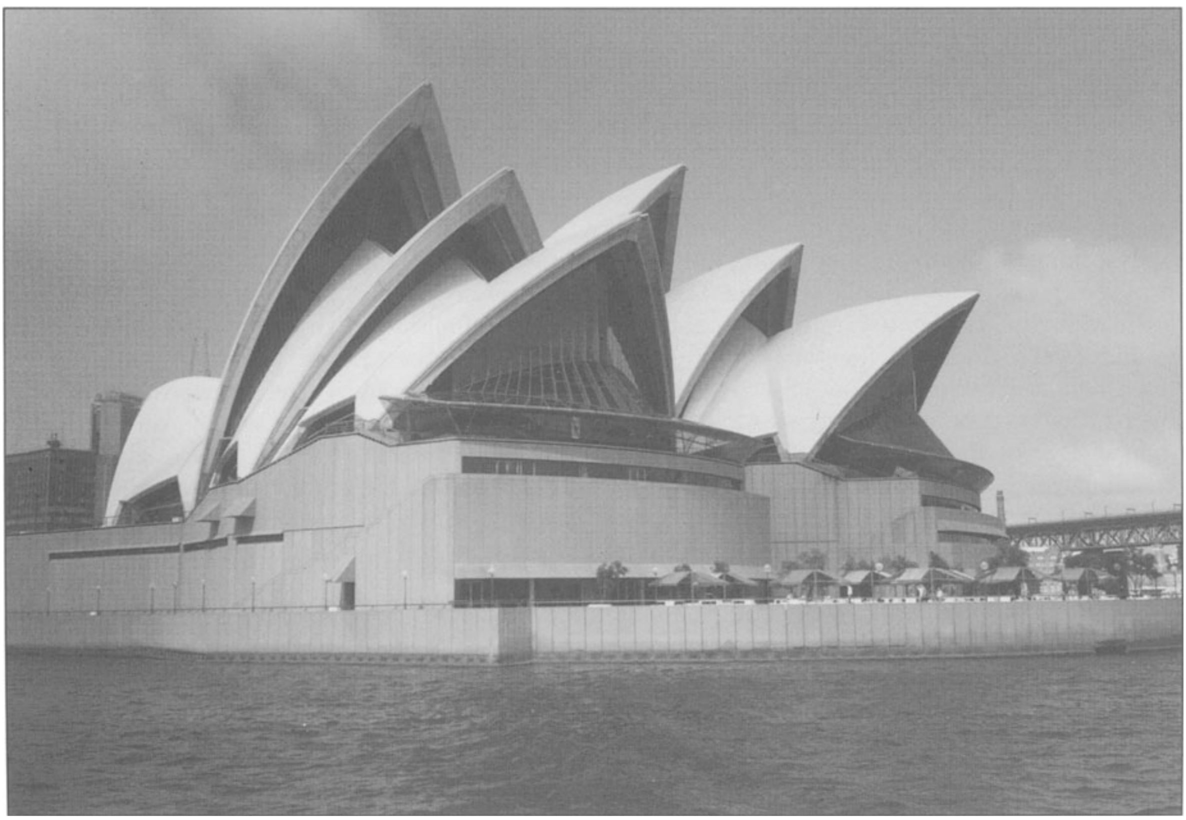


Figure 8.29 *Sydney Opera House (Source: Author)*

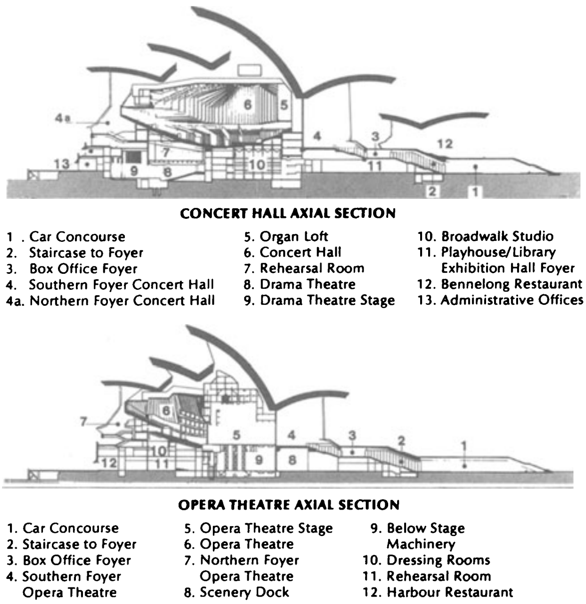


Figure 8.30 *Sections through Sydney Opera House (Source: Sydney Opera House Trust)*

Construction

The building covers about 1.8 ha of its 2.2 ha site and contains about 4.5 ha of usable floor space. It is approximately 185 m long and 120 wide at its widest point, while the highest roof vault above the Concert Hall is 67 m above sea level. The roofs are made up of 2194 precast sections, weighing up to 15.5 t each, and held together by 350 km of tensioned steel cable. The roofs are covered with over 1 056 000 tiles in 4253 precast trays and the total weight of the roofs is 27 230 t. The entire building weighs 161 000 t and is supported on 580 concrete 1 m diameter piles sunk up to 25 m below sea level, while the roofs are supported on 32 concrete columns up to 2.5 m square. The exterior and interior walls, stairs and floors are faced with pink aggregate granite from Tarana in NSW, while interior decorative woods were brush box and white birch plywood, both cut in northern NSW. French glass amounting to 6225 m^2 filled in the mouths of roofs and other areas of the building, in two layers – one plain and the other demi-topaz tinted, in about 2000 panes of 700 different sizes. There are 645 km of electric cable and 26 plant rooms supplying more than 28 500 m^3/minute of air through 19.5 km of ducting.

The precast prestressed reinforced concrete spherical shaped ribs, to a radius of 76.3 m, form both the roofs and walls of the chambers and, because they are placed so close together, it was possible to connect them with a concrete joint and cover them externally with a light continuous skin of ceramic tiles. Each rib was made of segments placed one on top of another with the help of three tower cranes, 77.5 m high with an operating radius of approximately 51 m, with the segments glued together with epoxy resin. The segments were made by pouring concrete into moulds of 25 mm plywood on steel frames in the casting yard on the site.[71]

Batches of tiles were laid face downwards on a firm base and concrete was poured over their backs to form a tray. When the concrete had set, the tray was hoisted by crane and bolted to the roof with phosphor-bronze bolts through aluminium bronze brackets. The largest trays measure 10 m by 2.5 m and weigh 4.8 t. Considerable difficulties were encountered during the tile laying and were eventually overcome using surveying techniques involving computerised calculations.[71]

As installed, the glass panes ranged in size from about 1.24 m square to approximately 4 m high by 2.5 m wide. Most glass panes are 18.8 mm thick and all have two layers of glass, one plain and one amber, joined together with a sound insulating interlayer. The glass walls are supported by steel mullions which run the whole height of the shell mouths. Bronze glazing bars are attached to the mullions to carry the panes of glass, bedded in a silicone putty to take up expansion and contraction. Ove Arup worked with the architect to calculate mathematically the exact size of each pane and, with the help of a computer, they produced data sheets showing the relevant dimensions.[71]

Accommodation and Uses

The Opera House contains nearly 1000 rooms, including the five main auditoria: the Concert

Hall (2690 seats), the Opera Theatre (1547 seats), the Drama Theatre (544 seats), the Playhouse (398 seats) and the Broadwalk Studio (288 seats). There is also a reception hall, exhibition hall, five rehearsal studios, three restaurants, six theatre bars, 60 dressing rooms and suites, library and other facilities. Since its opening performance in 1973, the Opera House has accommodated over 3000 events each year with audiences totalling more than two million. In addition, 200 000 people take a guided tour of the complex every year.

Maintenance

In 1989 a maintenance programme was formulated costing \$60m spread over seven years and the principal item was roof sealant leaks, coupled with problems of access. Other defects included leaks to windows and louvre walls where shells overlap, and water staining and corrosion problems. This cost was not, however, considered excessive when compared with the 1989 valuation of the project at \$450m.

NATIONAL PARKS AND ACCESS TO THE COUNTRYSIDE

In urban areas recreational facilities mainly comprise town parks, neighbourhood parks, playing fields and children's playgrounds, as described and illustrated in chapter 7. Urban dwellers are, however, increasingly seeking leisure facilities in the countryside as they become more mobile, and a variety of facilities are available in the form of national parks, country parks, areas of outstanding natural beauty, nature reserves and a variety of other resources. The major facilities are now briefly described.

National Parks These are extensive tracts of countryside designated as national parks, with a view to preserving and enhancing the natural beauty of the area and to promoting its enjoyment by the public. It must be an area which affords opportunities of open air recreation by reason of its character and position in relation to centres of population. The agricultural and forestry uses of the land in the park will continue, but the local planning authority may provide facilities for public enjoyment, such as camping sites and parking areas, and will maintain strict control of development. In 1990 there were ten national parks in England and Wales occupying a total of 13 600 km^2, equivalent to 9% of the total land area of England and Wales.[72] By comparison, national parks in Australia occupy 20% of the land surface.

Country Parks Country parks differ radically from national parks being sites laid out as parks or pleasure grounds by local authorities. In practice they take a variety of forms from the reuse of gravel workings to the acquisition of country houses and their adjoining grounds. A local authority has the power to purchase land, lay out the site, provide buildings and such other facilities as refreshments, toilets, car parks, and angling and sailing on waterways.[72]

Areas of Outstanding Natural Beauty These are areas of outstanding natural beauty which are considered unsuitable for designation as national parks, either because they are too small or for some other reason. Once so designated by the Countryside Commission, the local planning authority can take action to preserve and enhance the natural beauty of the area and special grants are available for this purpose, but there is no power to provide facilities for public enjoyment as in a national park.[72]

Nature Reserves These are normally established by the Nature Conservancy Council, and are concerned with the study of and research into fauna and flora and their preservation.

Other facilities include areas where a local planning authority secures public access to land for open air recreation by entering into an access agreement with the owner of land, or by making an access order, or by compulsorily purchasing the land. In 1989 there were also over 4000 sites of special scientific interest in England and Wales, occupying more than 8700 km^2, designated by the Nature Conservancy Council. There are also designated long distance footpaths for use by the more energetic members of the public and numerous rights of way. Other facilities are available in the form of common land, national forests, picnic areas, and land and property administered by the National Trust and English Heritage.

SENTOSA ISLAND, SINGAPORE

Sentosa has been chosen for inclusion as a rapidly developing, unusual and attractive multi-purpose leisure facility, situated ½ km south of mainland Singapore, and originally a British military base. In 1968 the Singapore Government decided to develop the island into a holiday resort for both local visitors and tourists, and renamed the island Sentosa, a Malay word meaning 'peace and tranquillity'. A master plan for the development of Sentosa was approved by the Singapore Government in 1970 and a statutory board, the Sentosa Development Corporation (SDC), was set up in 1972 and has implemented most of the major recommended projects suitably modified as necessary.[73]

In 1986, SDC embarked on a new marketing strategy based on product enhancement and the establishment of a more active programme of special events and promotions. Conceptually, the island is divided into four worlds – sun, fun, nature and history, each area having its own distinctive character and attractions. The island which is 4.2 km long with an average width of 1 km and an area of 375.5 ha, has natural attractions with its tropical flora and wide stetches of sandy beaches. Outdoor activities include cycling, roller skating, jogging, swimming, canoeing and windsurfing. Access to the island is by cable car or ferry, with a causeway scheduled for completion in 1992.

The impressive three storey terminal building is illustrated in Plate 40, which also shows the fountain gardens and musical fountain in the background. The terminal building houses the SDC offices, restaurant and other facilities, and has viewing galleries overlooking the harbour and the fountain gardens.

The fountain gardens cost S$4.2m and contain 2.55 ha of formal gardens with three fountains, including a circular fountain 16 m diameter with a jet height of 7 m, and two canals each 39 m long and 4 m wide, where water effects of different patterns and heights can be created. The gardens contain over 25 600 plants comprising 105 different plant species. There is an extensive network of footpaths, four pavilions, two gazebos and an open air stage or amphitheatre with a sophisticated sound system.[73]

A musical fountain, costing S$4.2m was built on reclaimed land in 1982, covering an area of 1.3 ha and consisting of a main pool, a swan-shaped pool, two terrace pools, a rockwall waterfall and a viewing gallery for 5000 people. The fountain measures 103 m in length, 60 m in width and the waterjets can rise to a maximum height of 22 m.[73]

The transport network on the island comprises mainly the monorail and buses. The monorail was introduced in 1982 at a cost of S$16m and comprises a loop layout 6.1 km in length serving six stations. The colourful electric trains travel 3 to 6 m above the ground at a speed of about 13.7 km/h, and one is illustrated in Figure 8.31. There are 13 trains in use, each comprising 15 cabins, capable of carrying 90 persons per train. A wide range of impressive views of landscape and seascape are obtained from the train and the stations are conveniently located in relation to many of the island's main attractions.[73]

Other attractions are as follows:

(1) swimming lagoon on the southern coastline with facilities for swimming, picnicing and various watersports
(2) boating lagoon mainly used for windsurfing and canoeing and some angling
(3) 8000 m^2 campsite
(4) youth hostel with 130 beds
(5) canoe centre
(6) beach 1500 m long with beach huts and changing rooms
(7) food centre serving Chinese, Southern Indian, Malay and Peranakan dishes
(8) 60 'Pasar Malam' stalls with rustic roofs (night market)
(9) outdoor roller skating rink built in 1976 at a cost of S$0.9m with an area of 12 000 m^2, and comprising a main rink, beginners' rink and spectators' gallery, and reputed to be the largest in South East Asia
(10) two golf courses, each 18-hole par 72 championship courses
(11) magic grove of Tembusu, with a wishing well and two whirlpools
(12) coralarium, a S$2.5m project opened in 1974 with an area of 1.7 ha and housing unusual

Figure 8.31 *Sentosa monorail, Singapore (Source: author)*

and colourful live corals, marine life and a collection of 2000 shells from all parts of the world
(13) reef world, showing how coral reefs feed and grow
(14) coral cave, turtle pond and hands-on rock pool
(15) plant nursery
(16) nature walk
(17) remains of Mount Imbiah battery
(18) secondary jungles in varying stages of growth and exciting fauna, including monkeys, squirrels, geckos and more than 20 species of birds
(19) rare stone museum believed to be the only one of its kind in the world, with a collection of 4000 rare and unique stones
(20) butterfly park and world insectarium costing S$800 000 for the exhibition, habitat and breeding of butterflies, and including 4000 mounted butterflies and insects
(21) Fort Siloso, being Singapore's only preserved fort which guarded the Western approaches to Singapore Harbour in the 1880s, and the only existing monument of British coastal fortifications in Singapore
(22) maritime museum covering modern maritime activities, primitive craft and fishing artefacts
(23) pioneers of Singapore exhibition and surrender chamber wax museum, with audiovisuals and filmlets of the war years in Singapore, much enhanced in 1985 by STPB at a cost of S$8.4m
(24) art centre containing work by many leading local artists
(25) other projects completed in 1989/91 included a S$30m lagoon and beach improvement, waterfront promenade, S$8m plaza, cycle track, reclamation work and underwater world comprising a 100 m transparent tunnel and moving walkway,
(26) a private 265 room hotel, conference and leisure complex and village were under construction in 1990.

The popularity of the resort was evidenced in the year 1987/88 when over two million people visited the island (40% overseas and 60% local visitors).[74]

Garden Festivals

Garden festivals originated in Germany in the 1950s and the first in the UK was the Liverpool International Garden Festival in 1984. Prior to approval the DOE required satisfying that there were significant planning benefits and a minimum of 40 ha of urban land in poor condition, mainly neglected or derelict, and close to a large population. The site at Liverpool adjoined the Mersey Estuary, while in 1986 the Stoke National Garden Festival was on the site of a former steelworks. These were followed by Glasgow on the Clyde in 1988, Gateshead in 1990 and Swansea in 1992.

Energy Generation

POWER STATIONS

Introduction

Oil and gas provided 60% of the world's energy in 1990 but known reserves could be exhausted in

30 years for oil and 50 to 60 years for gas. The supply of oil will, however, probably be augmented by new sources but the costs of supply are likely to increase substantially. The British Geological Survey estimated that there is sufficient coal in the UK to supply energy needs for the next 50 to 100 years. However, its effects on the atmosphere by emitting acid rain are frightening and the cost of removing the relevant gases is very high, while the carbon dioxide emissions are a major contributor to the greenhouse effect.[75]

The options include a variety of renewables in the form of solar, wave, wind, tidal, hydropower, geothermal and waste incineration, all of which do not produce waste and are not exhaustable. Renewables have an increasing role to play in energy generation but their individual inputs are restricted. Another option is a much increased nuclear programme, which was already producing about one third of Europe's electricity in 1990. There are large supplies of uranium available with 1 t of uranium being equivalent to 20 000 t of coal in a modern reactor, and Grimston[75] asserts that the economics of energy production using nuclear reactors compares favourably with that of fossil fuels without the waste problems. This form of producing electricity will be considered in more detail later in the chapter.

Power Station Design and Construction

Plant Layout McKie[76] has described how in the UK in the 1980s it became normal practice to install 660 MW turbo-generators in both fossil fuel and nuclear power stations. The fossil fuel stations had between two and six machines and the nuclear stations two machines. In the former type of station the boiler house and turbine house are parallel to each other and separated by a mechanical annexe. On the far side of the turbine house to the boilers are the generator transformers and the control room, while beyond the boiler and bunker bays the flue gases pass through precipitators to the chimney serving the boilers. Oil fired stations are almost identical except that there is no bunker bay and the boiler is slightly smaller. Each boiler serves one generator and the turbo-generators may be arranged longitudinally, transversely or diagonally in the turbine house. A turbine house is served by at least two overhead travelling cranes which must be capable of lifting the heaviest item of plant, which is usually the stator weighing about 300 t for a 660 MW machine.

Either the turbine house operating floor or the basement floor should be at the same level as the permanent roads around the station. Various services, ducts and tunnels, other than circulating water culverts, can advantageously be accommodated in a sub-basement up to about 3 m in depth.[76]

The power station site should be reasonably accessible to a river or the sea for operation of the cooling water system. The optimum site would have no adverse amenity effects, have low capital cost, low fuel cost, and low transmission cost. Difficult foundation conditions may be acceptable if outweighed by other factors.[76]

Steelwork Grieve[77] has described how in a 2000 MW station with four 500 MW boiler and turbo-generator units, each boiler measures about 24 × 46 m in plan and is suspended from girders about 60 m above ground level. The boiler is surrounded by access floors at about 10 m vertical intervals usually supported by steel members. The turbine house framework may be of concrete or steel but, since the adjoining boiler house is invariably of steel, the turbine house is most likely to be steel framed. The turbo-generators are supported by concrete or steel structures (turbo-blocks) and not the turbine house framework.

Superstructure *Roofs* are generally flat roofs having a drainage slope not exceeding 5°, often built of reinforced concrete or possibly metal deck construction for lightly trafficked roofs.

External walls of turbine and boiler houses are usually constructed of precast panels, with profiled metal sheeting above, fixed to sheeting rails, and comprising steel sheet finished with a plastics coating or aluminium sheet with a mill finish or coated with plastics. Glazing is generally incorporated to give natural lighting and to provide an architectural feature.

Floors normally consist of open grid for the stairways, galleries and much of the general flooring, except where the imposed loadings require solid suspended floors.[78]

Natural-draught cooling towers are a prominent feature of most power stations as at Drax Power Station shown in Figure 8.32. They consist of large reinforced concrete shells into which air is admitted around the base and this mixes with and cools a falling stream of water which has been heated in passing through the turbine condensers. The water is distributed evenly across the area of the shell by a sprinkler system, supported at about 14 m above ground level. Packing is provided below the sprinkler system to increase the specific surface of the water stream to secure maximum heat transfer. The cooled water is collected in a concrete pond at the base for recirculation to the condensers. Two cooling towers about 90 m diameter and 115 m high are required for a 500 MW unit.[79]

Chimneys discharge flue gases to the atmosphere at a sufficient height and velocity to ensure that the concentration of pollutants, such as sulphur dioxide, at ground level is kept within acceptable limits. Brickwork is suitable for free standing chimneys up to 60 m high, but for taller chimneys reinforced concrete is better able to withstand the overturning moment arising from the increased windload. The chimney shafts are usually lined with free standing, acid resisting brickwork, half a brick thick, supported by corbels at 10 m intervals. A 50 mm cavity is provided between the concrete shaft and the brick lining, which may be filled with an insulant or left as an air gap.[79] It is also necessary to provide adequate aircraft warning lights, access and lightning protection.

The disposal of pulverised fuel ash (PFA) is a major problem associated with coal fired power stations. RPT were responsible for the design and implementation of the very successful Gale Common scheme, being the largest of its kind in the UK, and it disposes of the ash from the two large power stations at Eggborough and Ferrybridge on the Yorkshire/Humberside border, and is illustrated in Plate 41. It was started in the mid-1960s and is planned to continue until the year 2020. The scheme provides for lagooning 1m tonnes of fuel ash each year. The ash, pumped as slurry, is stored in two main lagoons covering an area of 21.5 ha, encircled by 8 km of embankments composed of fuel ash and quarry shale. On completion, the lagoons will form a landscaped artificial hill 49 m high, containing 15m cubic metres of ash.[6]

Figure 8.32 *Drax Power Station (Source: Ove Arup & Partners)*

Flue Gas Desulphurisation (FGD)

In 1990, the UK Government was committed to reducing sulphur dioxide emissions which contribute to acid rain by providing scrubbers to power stations producing 12 GW, about a quarter of the national generating capacity. The EC is requiring member states to cut their emissions by a fifth by 1993, two fifths by 1998 and three fifths by 2003. The world's largest FGD plant was under construction in 1990 at Drax Power Station, the largest coal-fired power station in Western Europe, at a cost of £700m. Ove Arup conducted a detailed engineering assessment of alternative methods of disposing of the resultant large quantities of potentially surplus high quality gypsum. This power station is illustrated in

Figure 8.32 and also contains one of the UK's major land reclamation schemes, where millions of tonnes of PFA are being used to create over 120 ha of grass, water and woodland habitats and a working farm.

Unfortunately, a byproduct of desulphurisation is water high in chlorides. Hence the National Rivers Authority (NRA) objected to two FGD schemes in 1990 at Ferrybridge on the River Aire in West Yorkshire and Ratcliffe on Soar on the River Trent in Nottinghamshire, because the waste would be diverted into rivers threatening fish and public water supplies. NRA requested that the plants be transferred to other power stations sited below public water supply inlets.

However, in late 1990 Powergen secured planning permission and awarded a contract for the installation of their first scrubber at Ratcliffe on Soar, a 2000 MW power station at a cost of £200m on a five year contract, and occupying about 12.5 ha of site behind the power station. The gases from the power station will be sprayed with a mixture of crushed limestone and water which reacts chemically with 90% of the sulphur dioxide to produce gypsum, which may be used in the production of plasterboard.

Nuclear Power Stations

Jones[80] believes that nuclear stations are needed because they can supply electricity more cheaply, offer diversity and greater security of supply. Public opinion has been influenced by the Chernobyl disaster, despite the fact that the graphite moderated, water cooled design is unique to the USSR and would almost certainly have been rejected on safety grounds anywhere in Western Europe. Nevertheless, the British Government in 1990 halted the further construction of nuclear stations beyond Sizewell B, pending a government review in 1994, although three similar schemes were originally planned. This action coupled with high inflation caused the estimated cost of building Sizewell B to rise to £2.4b, with consequently higher electricity production costs.

The cost of decommissioning eight Magnox and five advanced gas-cooled reactors (AGR) was in 1990 estimated at £10b, although about half of these stations will continue to operate into the next century. The Sizewell B station is the first of a new category of pressurised water reactors (PWR) and has great potential, although the method of disposal of nuclear waste had still to be resolved, whether by deep land or sub-sea burial.

Readers requiring information on the design and construction of nuclear reactors and reactor buildings are referred to Eggleton.[81]

Case Studies

Two case studies have been selected to illustrate the civil engineering works associated with these major projects, with details kindly supplied by the two firms of consulting civil engineers.

Shajiao 'B' Power Station, Guangdong Province, China

This coal-fired power station, comprising two 350 MW units, was constructed for a joint venture between Hopewell Power (China) Ltd of Hong Kong and the Shenzhen Special Economic Zone Power Development. Ove Arup & Partners carried out the civil, structural, maritime and architectural detailed design for the civil works contractor. The power station is illustrated in Figure 8.33.

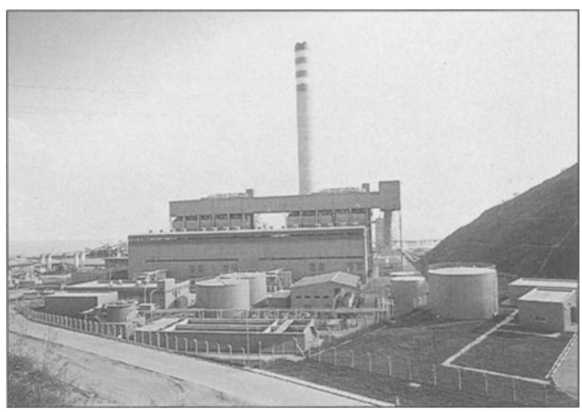


Figure 8.33 *Shajiao 'B' Power Station, China (Source: Ove Arup & Partners)*

The station is some 80 km from Hong Kong on the Pearl River estuary. Excavation of over 1m cubic metres from a hillside created a rock platform suitable for the founding of the turbine generator and boiler structures. The excavated material was used to reclaim some 23 ha of shoreline area to form the remainder of the site.[82]

The two turbine generators are housed in a steel framed, metal clad power house 135 m long × 33 m wide × 30 m high, and required some 2500 t of structural steelwork. A 210 m high chimney serves the boilers and consists of a slipformed concrete windshield with two internal brick flues. The windshield diameter varies from 21.5 m to 15.2 m. There are two ash silos, each of 2200 m^3 capacity and over 30 m high. Two separate water treatment plants are also provided, one to produce some 1200 t/d of demineralised raw water and the other to deal with waste water.[82]

Delivery of coal for the station is by bulk cargo vessels to an off-loading jetty. The jetty head is 260 m long × 25 m wide and located 800 m offshore. The 11 m wide jetty access arm provides a roadway and support for the conveyor system which transports the coal to the storage yard. The jetty is founded on precast prestressed concrete piles for the access section and steel pipe piles for the jetty head. The superstructures of both consist of reinforced concrete, where a mixture of *in situ* and precast allowed the minimum construction period.[82]

An offshore intake 800 m long provides over 1800 m^3/min of cooling water through precast double 3.5 m × 3.5 m cell boxes in a dredged trench. The onshore culvert system is of *in situ* concrete with an outfall to an open channel. The whole power station area is serviced by a network of roads constructed to cope with future settlement of the reclaimed land.[82]

Excavation to formation level was completed in mid 1985. The completion date for the first 350 MW unit was April 1987 after only 22 months of construction and commissioning, and the second unit followed three months later.[82]

Castle Peak 'A' Power Station, Hong Kong

Formation of the Castle Peak site by the mass excavation of Tap Shek Kok headland and the reclamation of the area of the adjacent foreshore which had begun in 1978 was followed in 1979 by the construction of Castle Peak 'A' Power Station, with Mouchell carrying out the planning and design of all the civil engineering work. The station occupies almost half of the site. The main building of the station, housing the four 350 MW turbine generators, the coal/oil fired boilers and their auxillary plant, is 225 m long and consists of a 27 000 t structural steel framework on reinforced concrete foundations on bedrock. The turbine house is clad in coloured lightweight moulded sheeting, but the boiler houses are open sided.[83]

Within the main building foundations are reinforced concrete pressure culverts carrying the cooling water to the turbine generator condensers. This cooling water is drawn from the deep water at the southern boundary of the site through a low level intake to the cooling water pumphouse sited on the original shoreline. From here it is pumped through the pressure culverts and discharged over a weir into the shallow water to the north west of the site. The deepwater jetty can accommodate two colliers or oil tankers of up to 120 000 t deadweight and serves both the 'A' and 'B' stations. This jetty is one of the largest of its type in the world with the 545 m long jetty head and 200 m approach beyond the sea wall, constructed of reinforced concrete supported on 790 tubular steel piles, each 1.2 m in diameter in lengths up to 55 m. The sea wall has twin layer granite block armouring to a 1:2 slope on the seaward face designed to withstand 1 in 50 year typhoon storms.[83–85]

Substations (132 kV and 400 kV) were designed to serve both power stations. The chimney which discharges the boiler flue gases after they have passed through the electrostatic precipitators where the fine ash is removed, is sited on the reclaimed area close to the original shoreline and is 210 m high, and constructed of a slip-formed reinforced concrete windshield enclosing four steel flues. The four 60 MW gas turbine units were installed and commissioned ahead of the main generators to enable their power to be available in 1980/81. As the formation of the remainder of the site was proceeding con-

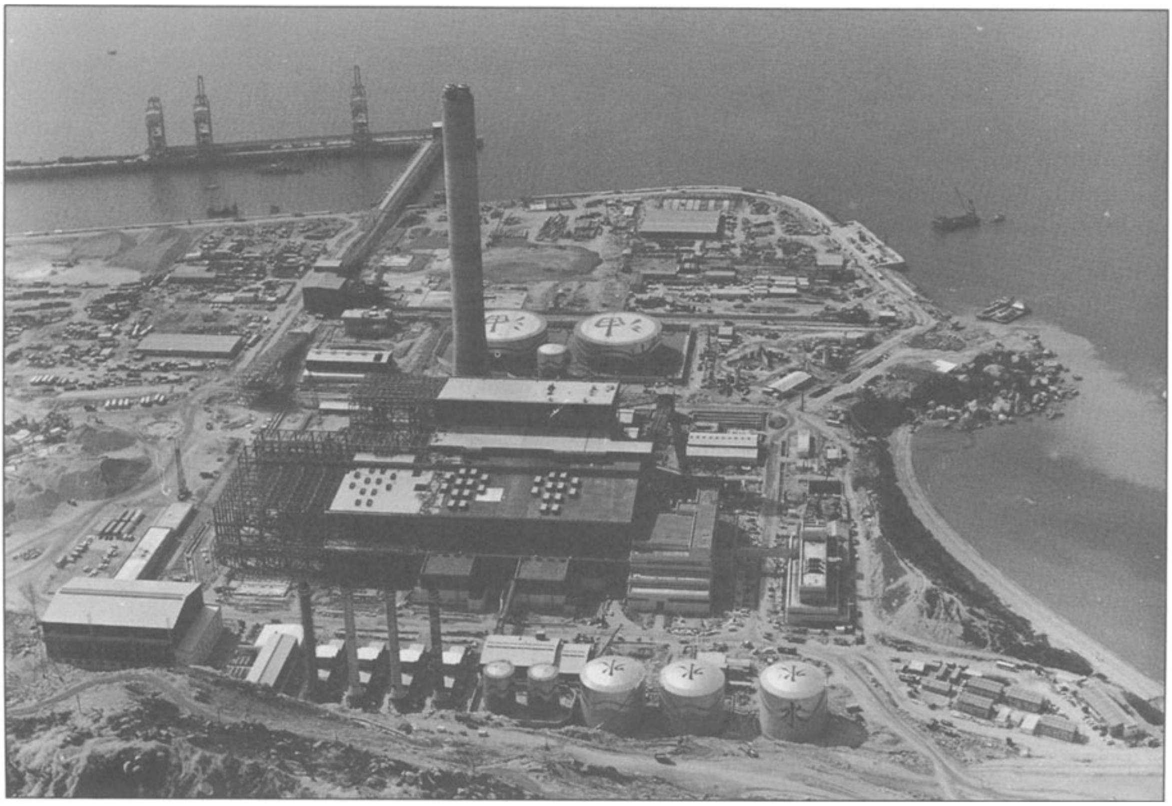


Figure 8.34 *Castle Peak 'A' Power Station, Hong Kong (Source: L.G. Mouchel & Partners)*

currently with the construction of the 'A' station, working space was restricted and the work had to be carefully programmed. Figure 8.34 shows the 'A' power station with the deepwater jetty in the background.

The 'B' station was commenced in 1982 and its four 660 MW units were commissioned in 1986 to 1990. It is of similar construction to the 'A' station, but the main building is 320 m long and the chimney is 250 m high, making it the tallest structure in South East Asia at the time of construction.[86]

HYDROELECTRIC SCHEMES

Introduction

Hydropower involves generating power by using water as the energy producing agent. Water flows from a higher to a lower level through a turbine where the potential energy of the water is converted into kinetic energy and the turbine rotates a generator to produce electricity. Hydropower generation is non-wasting, self-replenishing and non-polluting. A useful text on the subject has been written by Jog.[87]

Hydroelectric schemes are often developed as combined systems with alternative forms of energy generation each playing a part. For example, pumped storage can be used to relieve peak loads on thermal power stations. Binnie & Partners have described how computer models simulating power generation of complex schemes enable the best output to be achieved. The remainder of this section of the last chapter covers three case studies to show how the schemes have been developed in practice.

Batang Padang Hydroelectric Scheme, Malaysia

This project was sited below the tailrace of the Sultan Yussuf power station of the Cameron Highlands scheme in Malaysia, with an installed capacity of 154 MW. Binnie & Partners were the consulting engineers for the civil engineering works which cost over £13m. The project was partly financed by a loan from the World Bank and was completed in 1968.

Woh Power Station is an underground station, 275 m below ground level, and is illustrated in Plate 42 and Figure 8.35. The machine hall, transformer hall and lower valve chamber were all excavated out of solid granite. Because of the soundness of the rock, reinforced concrete roof supports were not considered necessary but, as a precautionary measure, the roof and walls of these underground caverns were secured by pattern rock bolting, wire mesh and gunite. Access to the underground power station is through a tunnel which slopes downwards from the portal at a gradient of 1 in 7 for a distance of about 0.80 km. The three turbines are vertical shaft Francis turbines, running at a speed of 600 rev/min. Their static head is 420 m, which was among the highest heads in the world for this type of turbine at the time of installation. The turbines are directly coupled to vertical shaft alternators, each capable of delivering 50 MW at 0.9 pF.

Mrica Hydroelectric Project, Java

Halcrow was involved in a joint Swedish/British/Indonesian venture among the volcanoes and rice terraces of central Java to harness the waters of the Serayu River for the generation of 580m kWh per year of electricity in the 1990s for homes, public services and businesses across Indonesia, at a cost of £320m. This large hydroelectric scheme comprised a 105 m high rockfill dam, 6.5 km of additional clay embankments, tunnels, a power station, intake tower, spillways and all the necessary electrical transmission facilities. The large intake tower, under construction, is illustrated in Plate 43, and the giant spillway in Figure 8.36.

The construction contract for the 180 MW project was let on the basis of a feasibility study, leaving the preparation of detailed designs to proceed concurrently with construction, probably saving two to three years on the project schedule. Work began on site in 1983 with the arrival of some £25m of construction plant from Europe, as almost 9.5m cubic metres of material had to be excavated for the power station, spillway, diversion tunnels and dam. The 650 m long main dam (rockfilled with inclined clay core) reaches a height of over 100 m in the Serayu Gorge, using an earthquake-resistant design in the seismic area. Twin 9 m diameter diversion tunnels, each 550 m long, were driven on eight faces in order to meet the crucial date for the river diversion, and one of the tunnels became the power tunnel with a 7.5 m steel liner[88].

The very large intake tower, illustrated in Plate 43, is linked at deck level with a more slender tower for the drawdown culvert maintenance gate, allowing a single gantry crane to serve both structures. The 250 m^3 capacity drawdown culvert has a spectacular ski jump and plunge pool and will be used for reservoir drawdown and sediment flushing. A gated spillway of approximately 5000 m^3/s capacity is equipped with four hydraulically operated radial gates, and in addition to the structure's role in power generation, provision has been made for a 15 m^3/s capacity irrigation outlet.[88]

Kiambere Hydroelectric Project, Kenya

The 140 MW project, commissioned in 1988, represented an important phase in the development of Kenya's hydroelectric power resources. Built at a cost of £109m (1984 prices), and illustrated in Figure 8.37, the main components of the scheme were:

(1) the main embankment dam with a crest height over foundation level of 112 m, impounding a gross storage of 585×10^6 m^3
(2) 10 km of tunnel works, with the headrace tunnel of 6.1 m diameter

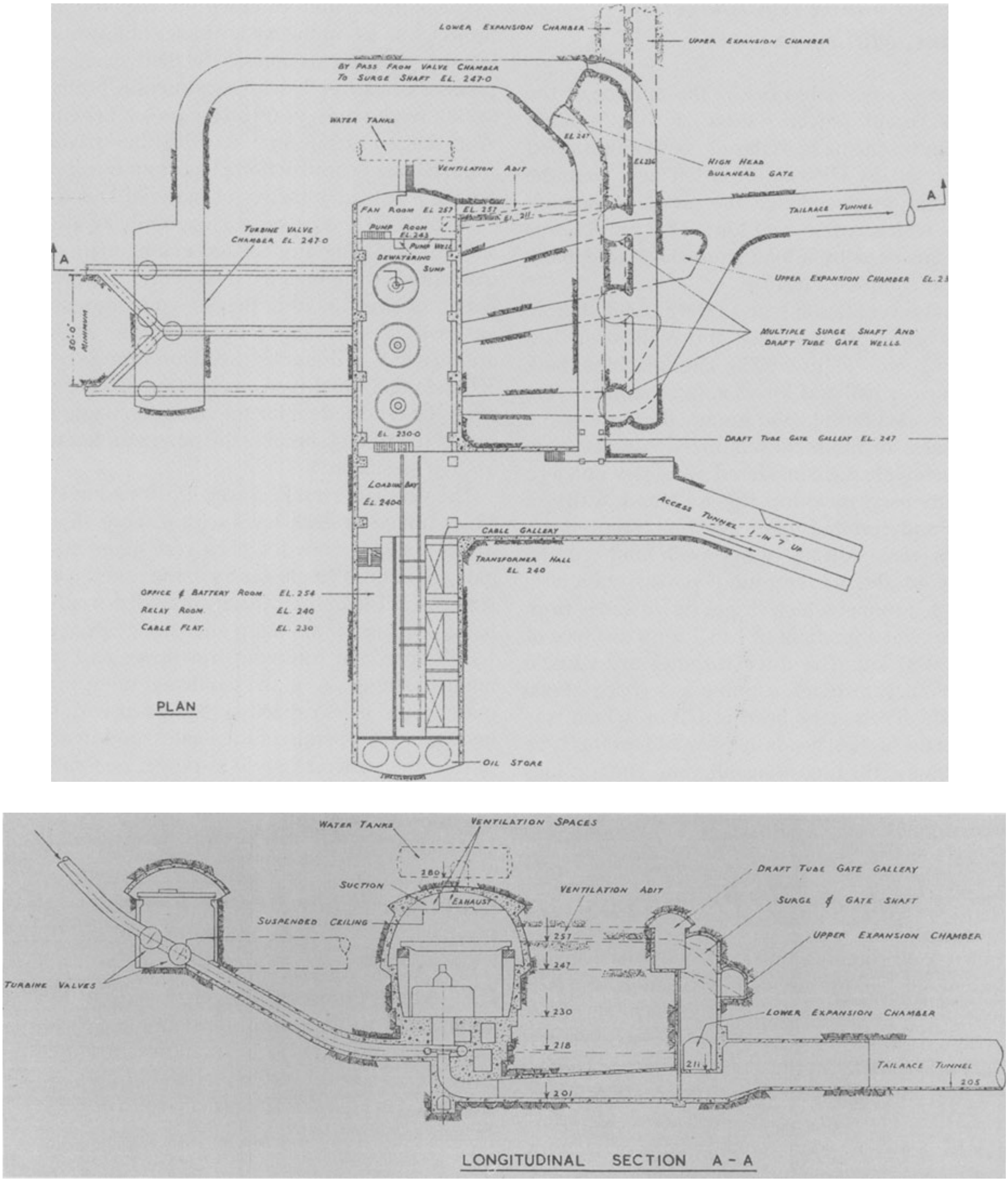


Figure 8.35 *Woh Power Station, Batang Padang Hydroelectric Scheme, Malaysia (Source: Binnie & Partners)*

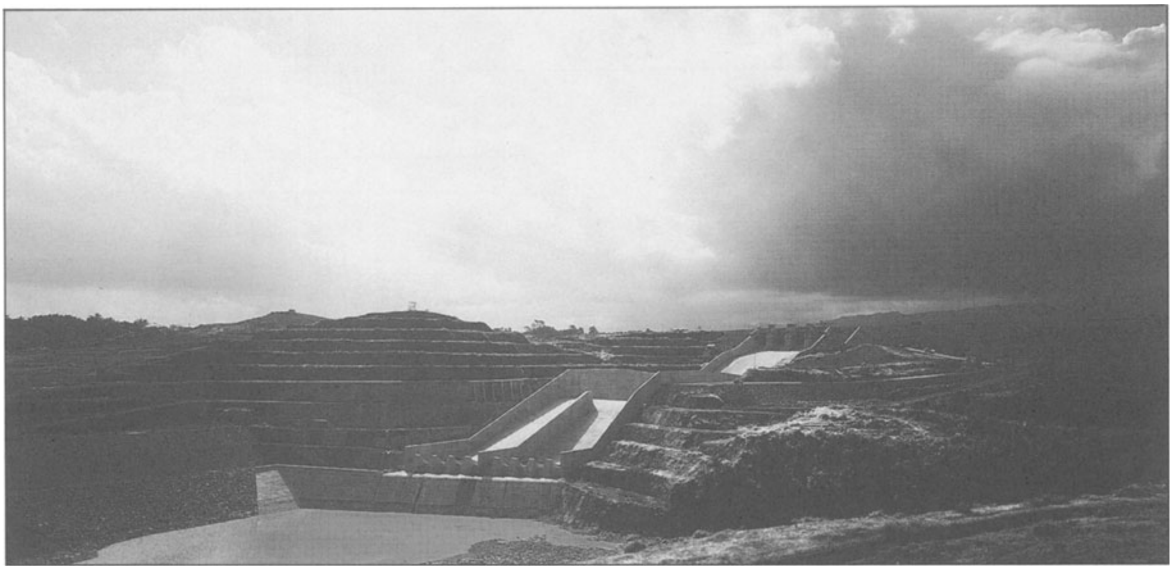


Figure 8.36 *Mrica Hydroelectric Scheme, Java: spillways (Source: Sir W. Halcrow & Partners)*

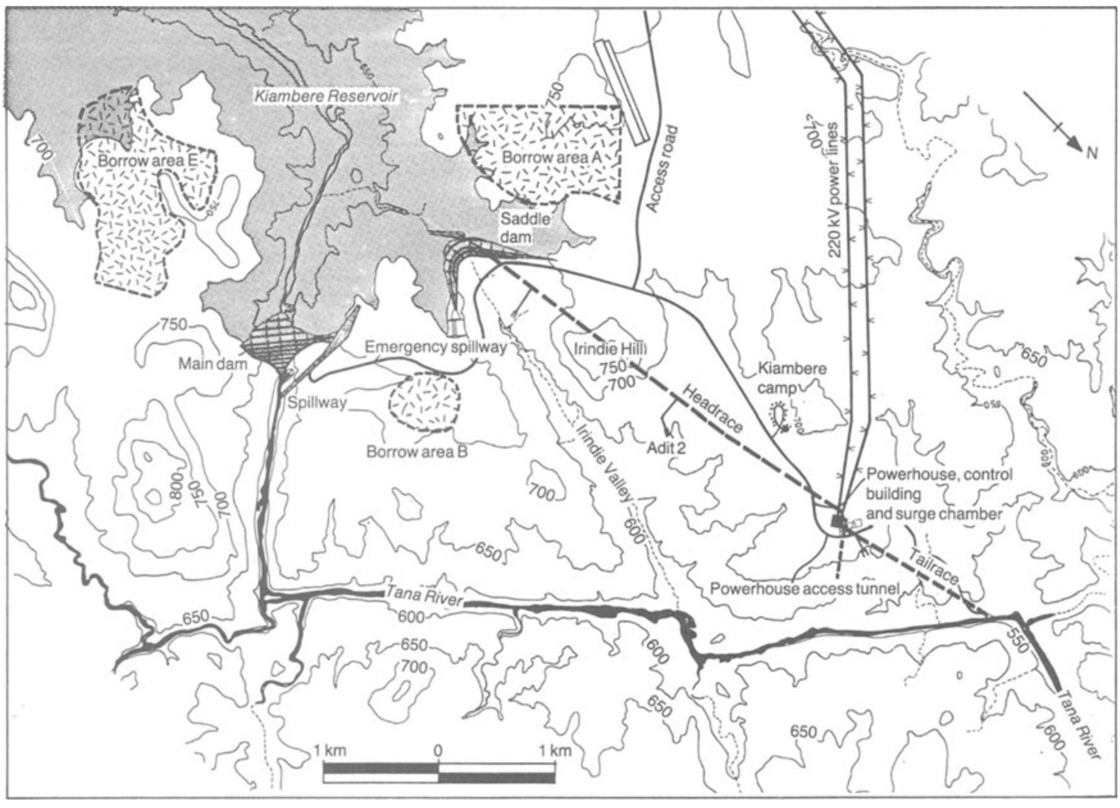


Figure 8.37 *Layout of the scheme: Kiambere Hydroelectric Project, Kenya (Source: Miller & Gill[89])*

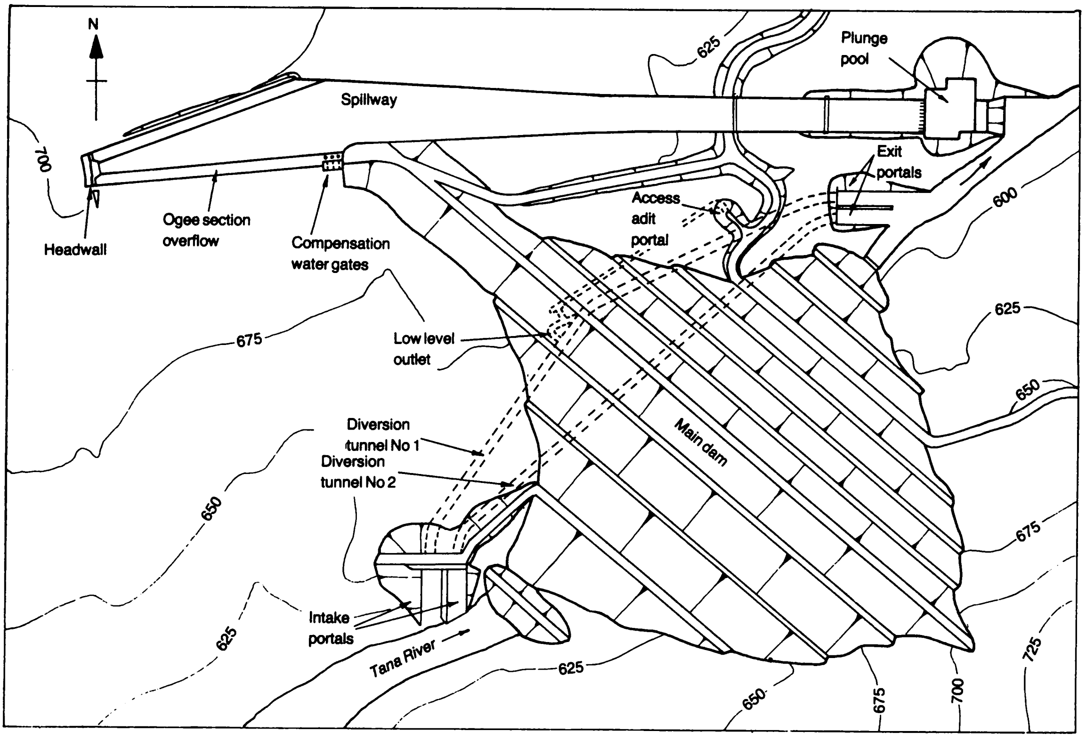


Figure 8.38 *Plan view of the main dam: Kiambere Hydroelectric Project, Kenya (Source: Miller & Gill[89])*

(3) an underground powerhouse with an excavated volume of 22 000 m^3 and a principal span of 20 m
(4) two 72 MW/158 m gross head Francis turbines with associated generators, transformers, switchgear and transmission.[89]

The main civil engineering works are now briefly described and illustrated.

The *dams* consist of a relatively thick inclined impervious core zone encased between granular shoulder zones. The side-channel spillway to the main dam is shown in Figure 8.38 and has an overall length of 980 m, including the 260 m long ogee crest, and its width varies from 90 m at the control section to 36 m at the chute.

In the *power system* about 6 km of underground water passages were required to develop the gross head of 158 m at the site. The layout of the underground waterway system, comprising a single headrace tunnel, surge chamber, twin steel lined penstock shafts and tailrace tunnels, is shown in Figure 8.39. The headrace and tailrace tunnels were optimised at 6.1 and 8 m diameter which, at the maximum discharge of 111 m^3/s, gave water velocities of 3.8 and 2.2 m/s for the headrace and tailrace respectively and a total tunnel friction loss, including penstock losses of 8 m, or about 5% of the available gross head. Water for power generation is drawn from the reservoir through the intake adjoining the saddle dam. The free-standing reinforced concrete intake structure was designed to permit 36 m drawdown of the headpond, to obtain some 80% of the gross reservoir storage.[89]

Access to the *underground powerhouse* cavern is provided by the inclined main access tunnel, from which adits were driven to gain entry to the roof heading and the gate gallery. Concrete crane beams were secured to the cavern walls using

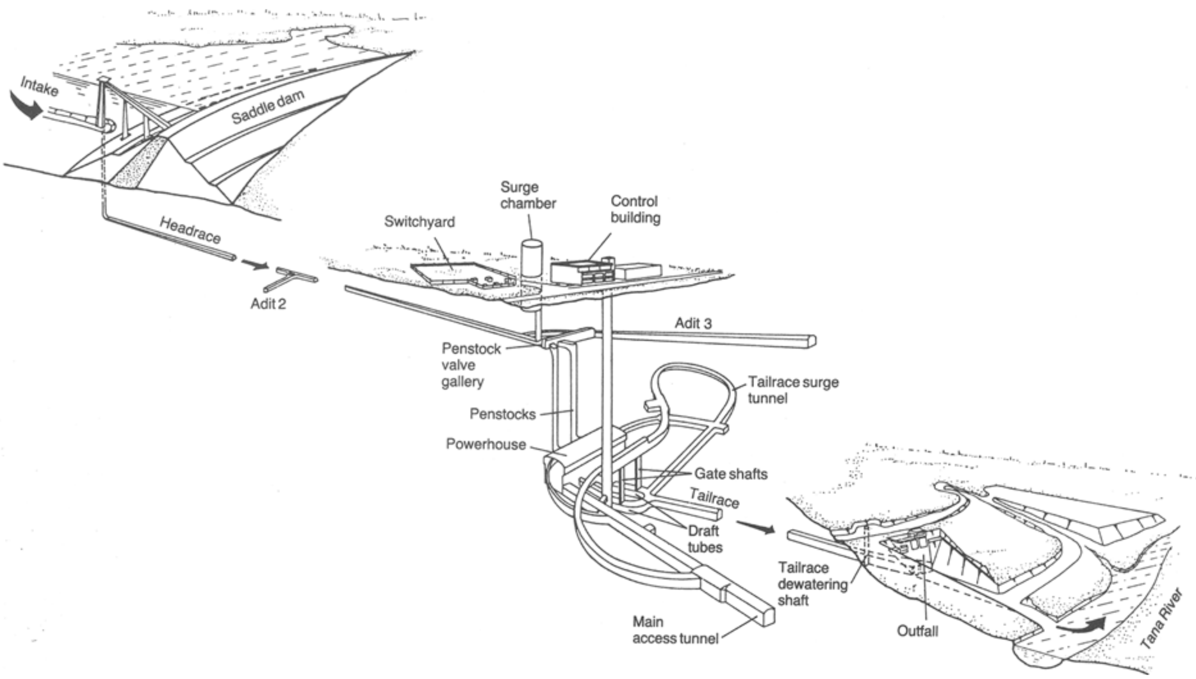


Figure 8.39 *The power scheme: Kiambere Hydroelectric Project, Kenya (Source: Miller & Gill[89])*

tensioned ground anchors with double corrosion protection. The rock roof to the cavern was sound but a light steel ceiling was provided mainly to improve the aesthetics and lighting to the cavern. Situated directly above the powerhouse cavern, the concrete framed control building houses control and relay rooms, offices, workshops, stores and ventilation plant for the powerhouse cavern.[89]

Readers requiring information on the construction of the Kiambere project are referred to the paper by Tattersfield and Bennett.[90]

TIDAL BARRAGE SCHEMES

Most of the development work on tidal barrages in the UK has been concerned with the proposals for the Severn and the Mersey. In general, the barrage alignment and layout depends mainly on the availability of deep water in which to locate turbines and sluices, on provision of a safe navigation route for shipping and on the adequacy of the seabed materials to support the barrage structures. In order to extract a substantial proportion of the potential tidal energy, a powerhouse of at least 3 km long in water depths of about 30 m is needed.[91] As has been shown by the Severn and Mersey schemes, it is also necessary to find satisfactory solutions to the many environmental problems.

Severn Tidal Barrage

A report by the Severn Tidal Power Group (STPG) in 1989[92] indicated that a 16 km long electricity generating tidal barrage was feasible with current technology, and it was considered that environmental problems could be overcome. The project was estimated to cost £8280m at 1988 prices and generate 8640 MW, equivalent to 7% of the 1989 electricity demand in England and Wales, with the turbines functioning about 50% of the time.

The tidal barrage would include 216 turbine generators, each of 9 m diameter, generating 40 MW and occupying 4.3 km in total length. There

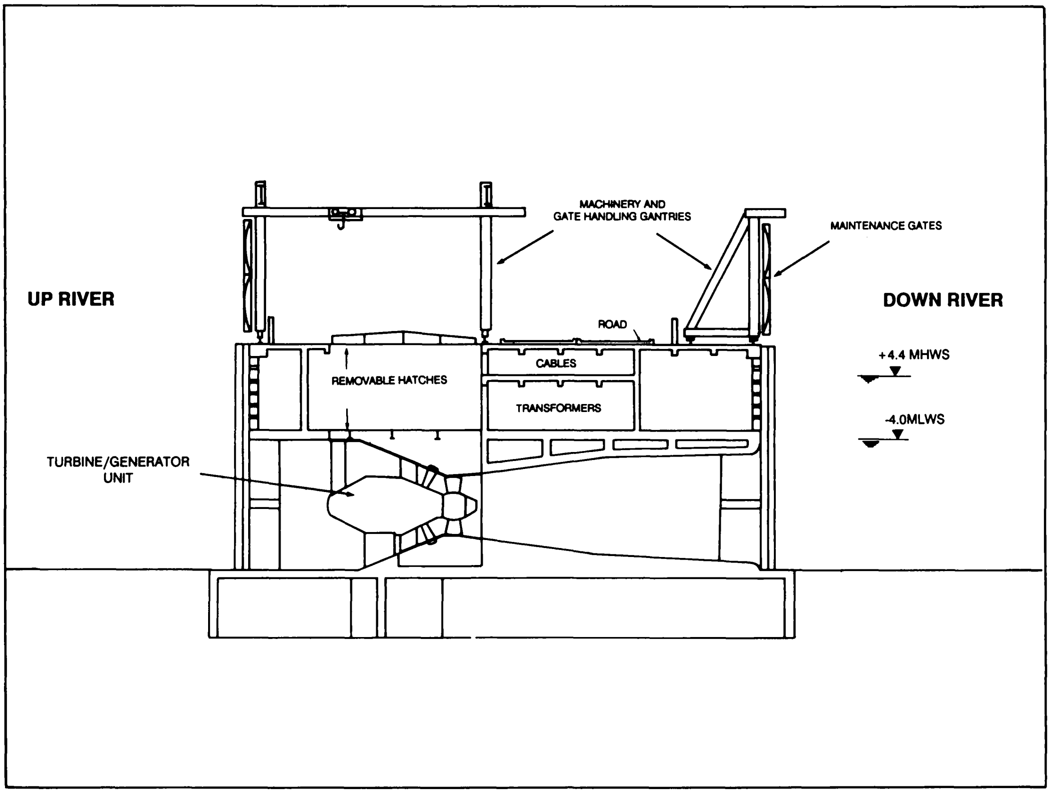


Figure 8.40 *Mersey Barrage, turbine caisson (Source: Rendel Palmer & Tritton).*

would also be caissons containing 166 sluices together occupying 4.1 km, twin locks capable of taking ships of 70 000 t, and small locks on both sides to take leisure and other small craft. Precast concrete turbine, sluice and plain caissons, of 80 to 90 m nominal length, would be built on several shore locations to avoid overloading facilities at any one site. They would be brought in by barge and sunk into position once the site had been dredged and filled with crushed rock foundations.[92]

The embankment would include a breakwater with a rock core on the seaward side, faced with precast concrete armour units, and riprap stone behind. The bulk of the material would be hydraulic sand fill behind the breakwater, supporting an elevated twin lane dual carriageway. Course rock materials would probably need to be imported, while finer ones could probably be obtained from local quarries. Sand could be used from dredgings during construction. It was anticipated that the project could be carried out in stages over a period of about eight years.[92]

STPG was, in 1990, able to estimate the costs and benefits of the non-energy aspects of the barrage, although a further four years' work, costing up to £20m, was required to obtain definitive answers on several aspects. Much would hinge on the new dynamic regime following the construction of the barrage, because this affected directly water quality, salinity and sediment movements in the estuary, which in turn affected both the natural and human environments.

Mersey Tidal Barrage

Since 1984, Rendel–Parkman have been responsible for the co-ordination of a wide range of studies related to this project. They have included engineering, economic, hydraulic, sedimentation, environmental, navigational and socio-industrial investigations. The scheme would generate between 480 and 750 MW depending on the final location, and would make a major impact on the potential for the economic and social regeneration of the Liverpool area. Second stage studies were completed in 1990.[6]

In 1989, civil design work was in progress for the barrage and related works for a range of construction methods and plant options and including locations at New Brighton and Rock Ferry. Each project was conceived as an ebb generation tide scheme with ship lock(s) to permit the estuary to function as a navigable waterway, with a probable barrage length of about 1.8 km incorporating over twenty turbine generators.[93] Figure 8.40 illustrates a Mersey Barrage turbine caisson.

Towner[94] conceded that a barrage would have a major effect on the physical character of the Mersey Estuary. These major physical changes will have significant implications for the chemical and ecological features of the estuary. With regard to the key issue of concern, effects on birdlife, it was believed that the impacts would be negative, but some positive effects, such as increased sediment invertebrate densities, could help offset impacts.

WIND ENERGY SYSTEMS

Development of the vertical axis wind turbine (VAWT) dates from 1926 when a Frenchman, Darrieus, first patented a curved bladed wind turbine to the UK development of a straight bladed VAWT in the 1980s. In 1989, the Department of Energy was interested in developing large multi-megawatt turbines for supply of electricity to the grid from wind farms possibly sited offshore.[95]

An experimental 25 m diameter VAWT was commissioned at Carmarthen Bay in 1986, on a 25 m high prestressed concrete tower, with a computerised control and monitoring system. In addition, a 17 m diameter, 100 kW commercial demonstration unit was installed on the Isles of Scilly in 1987. It has been shown that wind turbines on land in wind farms at good wind speed sites can produce electricity at competitive prices, but there remains some objections on visual and noise grounds.[95] Readers requiring more information on this approach to energy generation are referred to an overview of EC demonstration projects on autonomous and wind-diesel systems.[96]

References

1. CIRIA. *Special Publication 69: The engineering implications of rising ground levels in the deep aquifer beneath London* (1989)
2. D.T. Pugh. Is there a sea-level problem. *Proc. Instn Civ. Engrs, Part 1, 1990, 88, June, 347–66*
3. Sweby Cowan Research Services. *The greenhouse effect: its relevance to the surveying profession* (1989)
4. Rendel Palmer & Tritton. *The Thames Barrier* (undated)
5. S. Gilbert and R. Horner. *The Thames Barrier.* Telford (1984)
6. M.R. Lane. *The Rendel Connection: A dynasty of engineers*. Quiller Press (1989)
7. Thames Water, North London Division. *North London Tidal Defences* (undated)
8. W.A. Dawson Ltd. *Tidal Surge Barrier, River Hull* (undated)
9. R. Berkeley Thorn and A.G. Roberts. *Sea Defence and Coast Protection Works*. Telford (1981)
10. IME. Coastal protection: state of the art. *Mun. Engr, 1985, 2, Apr., 97–112*
11. ICE, Maritime Engineering Group. *Coastal Engineering Research*. Telford (1985)
12. I.R. Whittle. Technical overview. *Coastal Management*. ICE. Telford (1989)
13. *Report of the Departmental Committee on Flooding*. HMSO (1954)
14. Flood Protection Research Committee. *Quinquennial Report 1974–79*. Ministry of Agriculture, Fisheries & Food (1980)
15. H.R. Taylor and A.E. Marsden. Some defence works in Eastern England. *Shoreline Protection*. Telford (1983)
16. M.J. Wakelin. The deterioration of a coastline. *Coastal Management*. ICE. Telford (1989)

17. CIRIA. *Technical Note 125: Sea walls: Survey of performance and design practice* (1986)
18. A.G. Roberts and A. McGown. A coastal area management system as developed for Seasalter-Reculver, North Kent. *Proc. Instn Civ. Engrs, Part 1, 1987, 82, Aug., 777–97*
19. Sir W. Halcrow & Partners. *Project sheet: No. 1 Anglian Coastal Defences Study* (1988)
20. J.H.W. Northfield. Port management and operations at Felixstowe. *Port Engineering and Operation.* ICE Conference. Telford (1985)
21. W.S. Atkins. *Umm Al Qaiwain Port, United Arab Emirates. 80129.8* (undated)
22. A.M. Robson. Kallin Harbour – design and construction. *Mun. Engr, 1987, 4, Oct., 243–55*
23. W.A. Dawson Ltd. *Blacksness Harbour, Scalloway, Shetland Islands* (undated)
24. D. Coode (RPT) Options in the design and operation of container terminals. *The Journal of World Port Design. Dredging + Port Construction. March 1987, Vol. XIV, No. 3, 19–23*
25. D. Goode (RPT). *Container Terminals: Options in Layout and Operation* (undated)
26. Hong Kong Government, Lands and Works Branch. *Hong Kong: The Development Challenge* (1989)
27. UK Offshore Operators Association Ltd. *The North Sea Achievement* (1989)
28. BP Exploration, Public Affairs Department. *The Magnus Oilfield* (1989)
29. I.G. Livett. South-East Forties Project. *Proc. Instn Civ. Engrs, Part 1, 1989, 86, June, 445–59*
30. H. Jones. Throwing away the rule book. *New Civ. Engr, 27 July 1989, 28–30*
31. W.G. Laver and N.D.P. Barltrop. Offshore platforms: design of two southern North Sea jackets. *Proc. Instn Civ. Engrs, Part 1, 1988, 84, Feb., 21–41*
32. C.G. Tilston and J.M. Gilchrist. Design and installation of the piled foundations for Britoil's Clyde platform. *Proc. Instn Civ. Engrs, Part 1, 1988, 84, Aug., 713–36*
33. W. Pemberton and C.E. Rickard. Irrigation, drainage and river engineering. *Civil Engineer's Reference Book.* Butterworths (1989)
34. P. Melby. *Simplified Irrigation Design.* Van Nostrand Reinhold (1988)
35. M.E. Bramley. *Improving Irrigation Conveyance and Distribution Systems.* Seminar on Rehabilitation of Irrigation Schemes. ICE. International Commission on Irrigation and Drainage, British Section. (1987)
36. Sir W. Halcrow & Partners. *West Nubariya Reclamation and Settlement Project* (undated)
37. M.B. Pescod and U. Alka. Urban effluent reuse for agriculture in arid and semi-arid zones. *Reuse of Sewage Effluent.* ICE. Telford (1985)
38. Camp Dresser and McKee. *Guidelines for Water Reuse.* US Environmental Protection Agency, Contract No. 68–03–2686 (1980)
39. WHO. *Health aspects of treated sewage reuse.* Euro reports and studies 42 (1980)
40. J.P. Cowan and P.R. Johnson. Reuse of effluent for agriculture in the Middle East. *Reuse of Sewage Effluent.* ICE. Telford (1985)
41. I.H. Seeley. *Outdoor Recreation and the Urban Environment.* Macmillan (1973)
42. A. Bryant. The best use of our land. *Chart. Surv., 103.3 (1970)*
43. D.H. Kalis. Problems in marinas. *Proc. Instn Civ. Engrs, Part 1, 1987, 82, Apr., 487–9*
44. A. Moody. The hidden costs in running a marina: from the private side. *Leisure Harbours in the 80s.* National Yacht Harbour Association (1981)
45. Walcon Marine. *System 2000* (1985)
46. P. Bell. *Marinas and Planning Policy in the Solent: Conference on Marinas, Southampton* (1989)
47. Marine Developments Ltd. *Port Hamble Marina, River Hamble* (undated)
48. F.L Terrett, P. Ganly and S.B. Stubbs. Harbour works at Brighton Marina: investigations and design. *Proc. Instn Civ. Engrs, Part 1, 1979, 66, May, 191–208*
49. T.J. Llewellyn and W.T. Murray. Harbour works at Brighton Marina: design. *Proc. Instn Civ. Engrs, Part 1, 1979, 66, May, 209–26*
50. Brighton Marina Co Ltd. *Brighton Marina: Harbour construction and moorings contracts* (1979)
51. Brent Walker Group. *Brighton Marina Village: a fresh outlook on living* (undated)
52. British Waterways. *Leisure on the Inland Waterways* (1989)
53. Travers Morgan. Pooled resources: planning proposals for the Chelmer Lakes. *The Travers Morgan World, Issue Two* (1986)
54. Nottinghamshire County Council. *Holme Pierrepont National Water Sports Centre* (undated)
55. Sports Council. *Holme Pierrepont National Water Sports Centre: fact sheet* (undated)
56. J.R. Peters. The design and construction of an artificial canoe slalom course at Holme Pierrepont, Nottingham. *Mun. Engr, 1987, 4, Dec., 317–30*
57. F. Goodman and G. Parr. *Holme Pierrepont Slalom Course: A User's Guide.* Canoe Products, Colwick, Nottingham (1986)

58. P.H. Perkins. *Swimming Pools*. Elsevier (1988)
59. Thames Water. Make sure your pool is safe. *The Water Standard, Autumn, 1990*
60. BRE. *Digest 336*. Swimming pool roofs: minimising the risk of condensation using warm-deck roofing (Sept. 1988)
61. J.F.A. Moore and R.N. Cox. *Corrosion of metals in swimming pool buildings*. BRE (1989)
62. Shepherd Construction. *Leisure pool sets new standards* (undated)
63. Sports Council. *Arenas – a planning, design and management guide* (1989)
64. S. Inglis. Grounds for complaint. *New Civ. Engr, 7 June 1990*
65. M. Evamy. Grandstand. *New Builder, 10 May, 1990*
66. G.H. Stanton. Grandstand. *New Civ. Engr, 7 June, 1990*
67. B. Dumbleton. Raising the roof. *New Civ. Engr, 26 Jan. 1989*
68. Ove Arup & Partners. *Sydney Football Stadium. 864* (undated)
69. Ove Arup & Partners. *Mound Stand Redevelopment, Lord's Cricket Ground, London. 864* (undated)
70. HRH The Prince of Wales. *A Vision of Britain*. Doubleday (1989)
71. J. Yoemans. *A Guide to the Sydney Opera House*. Sydney Opera House Trust (undated)
72. A.E. Telling. *Planning Law and Procedure*. Butterworths (1990)
73. Singapore Development Corporation. *Sentosa, Singapore's discovery island* (1989)
74. Singapore Development Corporation. *Sentosa 87/88 Annual Report*
75. M. Grimston. Energy and nuclear power: a view in perspective. *Building Technology and Management, Apl./May 1989, 22–7*
76. D.L. McKie. Plant layout, buildings layout and station siting. *Civil Engineer's Reference Book*. Butterworths (1989)
77. N.M. Grieve. Power house steelwork. *Civil Engineer's Reference Book*. Butterworths (1989)
78. V.F. Harman. Roofs, walls, floors and ventilation. *Civil Engineer's Reference Book*. Butterworths (1989)
79. K.P. Grubb. Natural-draught cooling towers and chimneys. *Civil Engineer's Reference Book*. Butterworths (1989)
80. P. Jones. The UK energy scene. *Proc. Instn Civ. Engrs, Part 1, 1987, 82, Apr., 397–402*
81. N.G. Eggleton. Nuclear reactors and reactor buildings. *Civil Engineer's Reference Book*. Butterworths (1989)
82. Ove Arup & Partners. *Shajiao 'B' Power Station, Guandong Province, China* (1989)
83. Mouchel. *Castle Peak 'A' Power Station, Hong Kong. 050–483* (undated)
84. Mouchel. *Castle Peak Power Stations – Jetty, Hong Kong. 059–184* (undated)
85. Mouchel. *Castle Peak Power Stations – Sea Wall, Hong Kong. 092–384* (undated)
86. Mouchel. *Castle Peak 'B' Power Station, Hong Kong. 080–284* (undated)
87. M.G. Jog. *Hydro-electric and pumped storage plants*. Wiley (1989)
88. Sir W. Halcrow & Partners. *Project Sheet: No. 30. Mrica Hydroelectric Project: 0696E* (1988)
89. A.B. Miller and R.D. Gill. Kiambere Hydroelectric Project, Kenya, Part 2: design. *Proc. Instn Civ. Engrs, Part 1, 1989, 86, Aug., 787–812*
90. J. Tattersfield and J.C. Bennett. Kiambere Hydroelectric Project, Kenya, Part 3: finance and construction. *Proc. Instn Civ. Engrs, Part 1, 1989, 86, Aug., 813–41*
91. D. Kerr, B.F. Wareham and D. Coursey. Severn barrage: site investigation and barrage layout. ICE. *Developments in Tidal Energy*. Telford (1990)
92. Severn Tidal Water Group. *Tidal Power from the Severn Report*. STPG (1989)
93. N. Reilly and B.I. Jones. Progress on civil engineering and planning of a Mersey tidal project. ICE. *Developments in Tidal Energy*. Telford (1990)
94. J. Towner. Environmental aspects of a Mersey tidal project. ICE. *Developments in Tidal Energy*. Telford (1990)
95. R. Clare and I.D. Mays. Development of vertical axis wind turbine. *Proc. Instn Civ. Engrs, Part 1, 1989, 86, Oct., 857–78*
96. H. Nacfaire (Ed.) *Wind diesel and wind autonomous energy systems*. Elsevier (1989)

Appendix: List of Abbreviations

AADF	Average annual daily flows
AASHTO	American Association of State Highway Officials
ACE	Association of Consulting Engineers
ACN	Aircraft classification number
AGNIS	Advanced azimuth guidance nose-in systems
AGR	Advanced gas-cooled reactors
ALA	Association of Local Authorities
AMA	Association of Metropolitan Authorities
AME	Association of Municipal Engineers
AMS	Austenitic manganese steel
ASA	Amateur Swimming Association
ASR	Alkali silica reaction
ATP	Automatic train protection
ATO	Automatic train operation
BA	British Airways
BAA	British Airports Authority
BEC	Building Employers Confederation
BNF	British Nuclear Fuels
BOD	Biological oxygen demand
BP	British Petroleum
BPF	British Property Federation
BR	British Rail
BRE	Building Research Establishment
BREEAM	BRE environmental research method
BRF	British Road Federation
BSI	British Standards Institution
BW	British Waterways
BWL	Bottom water level
CBA	Cost benefit analysis
CBD	Central business district
CBI	Confederation of British Industry
CBR	California bearing ratio
CEN	Comité Européen de Normalisation
CENWAG	Centralised Intersystem Wagon Transit (Australia)
CESMM	Civil Engineering Standard Method of Measurement
CFC	Chlorofluorocarbon
CHART	Computerised highway assessment of ratings and treatment
CIE	Commission Internationale de l'Eclairage
CIPFA	Chartered Institute of Public Finance and Accounting
CIRIA	Construction Industry Research and Information Association
CMS	Central monitoring system
COD	Chemical oxygen demand
CPRE	Council for the Protection of Rural England
csa	Cross sectional area
CTG	Anglo-French Tunnel Group
CV	Calorific value
CWR	Continuously welded rail
DLG	Derelict Land Grant
DLO	Direct labour organisation
DLR	Docklands light railway
DOE	Department of the Environment
DPTSP	Docklands Public Transport Strategic Plan
DTI	Department of Trade and Industry
DTp	Department of Transport
DTS	Dynamic track stabiliser
DWF	Dry weather flow
DWT	Dead weight tonnes
EC	European Community
EFTA	European Free Trade Association
EIA	Environmental impact assessment
EJ	European Journal
ERDF	European Regional Development Fund
ETSU	Energy Technology Support Unit (Department of Energy)

FCEC Federation of Civil Engineering Contractors
FGD Fuel gas desulphurisation
FIDIC International Federation of Consulting Engineers
FIFA Federation of International Football Associations
FM France Manche
FTA Freight Transport Association
FTU Formazin turbidity unit

GCWW Greater Cairo Wastewater
GLC Greater London Council
GRP Glass reinforced polyester

HAC High alumina cement
h/d Hours per day
HDB Housing and Development Board (Singapore)
HDPE High density polyethylene
HGV Heavy goods vehicle
HK Hong Kong
HMIP Her Majesty's Inspectorate of Pollution
HOS House ownership scheme (HK)
HRM High speed road monitor
HRS Hydraulic Research Station
HST High speed trains

IAEA International Atomic Energy Agency
ICAO International Civil Aviation Organisation
ICE Institution of Civil Engineers
IEAus Institute of Engineers of Australia
IME Institution of Municipal Engineers
IOH Institute of Housing
IPD ICE Infrastructure Planning Group
ISO International Organisation for Standardisation
ISRS International safety rating system
IStructE (ISE) Institution of Structural Engineers
INTRANS Railways of Australia Intersystem Transport Operating Plan

JAL Japan Airline
JNWC Jersey New Waterworks Company
JTU Jackson turbidity unit

LAMSAC Local Authority Management Services and Computer Committee
LCC London County Council
lcd Litres per capita per day
LDDC London Docklands Development Corporation
LCG Load classification groups
LCN Land classification numbers
LGORU Local Government Operational Research Unit
LRT Light rail transit *or* London Regional Transport
LSC Line supervisory control
LWRA London Waste Regulation Authority

MARCH Maintenance assessment rating and costing of highways
MCE Maximum credible earthquake
MDC Merseyside Development Corporation
MDPE Medium density polyethylene
MHLG Ministry of Housing and Local Government
Mld Million litres per day
MLSS Mixed liquor suspended solids
MRT Mass rapid transit (Singapore)
MRTC Mass Rapid Transport Corporation (Singapore)
MSC Manpower Services Commission
MSF Module support frame
MTRC Mass Transit Railway Corporation (Hong Kong)

NAWDC National Association of Waste Disposal Contractors
NCC National Conservation Council
NEDC National Economic Development Council
NERC National Environmental Research Council
NLWA North London Waste Authority
NRA National Rivers Authority
NSW New South Wales

OD Ordnance Datum
ODN Ordnance Datum Newlyn

OECD	Organisation for Economic Co-operation and Development
OFWAT	Office of Water Services
OPC	Ordinary Portland Cement
OS	Ordnance Survey
PAPA	Parallel assisted parking aids
PB	Polybutylene
PCBs	Polychlorinated biphenyls
PCN	Pavement classification number
PD	Public datum
PE	Polyethylene
PFA	Pulverised fuel ash
PLA	Port of London Authority
PMF	Probable maximum flood
PMP	Probable maximum precipitation
PMS	Pavement management system
PP	Polypropylene
PSA	Property Services Agency
PSPS	Private sector participation scheme (Hong Kong)
PTE	Passenger Transport Executive
PQC	Pavement quality concrete
PV	Permanganate value
PVC	Polyvinylchloride
PWD	Public Works Department
PWR	Pressurised water reactor
QA	Quality assurance
RBC	Rotating biological contactor
RC	Reinforced concrete
RIBA	Royal Institute of British Architects
RICS	Royal Institution of Chartered Surveyors
ROV	Remotely operated vehicles
RPT	Rendel Palmer & Tritton
SBR	Sequencing batch reactor
SDC	Sentosa Development Corporation (Singapore)
SERPLAN	London and South East Regional Planning Conference
SETEC	Société d'Etudes Techniques et Economiques
SHC	Spring hoop clip
SIA	Singapore International Airline
SIMBIDS	Simplified bidirectional signalling
SNCF	French Railways
SPZ	Simplified planning zone
SS	Settleable solids *or* suspended solids
SSCV	Semi-submersible crane vessel
STPB	Singapore Tourist Promotion Board
STPG	Severn Tidal Power Group
STW	Severn Trent Water
TBM	Tunnel boring machine
TCCB	Test and County Cricket Board
TCPA	Town and Country Planning Association
TEU	Transit equivalent unit
TGV	Train à Grande Vitesse
TML	Transmanche-Link
TOD	Total oxygen demand
TRADA	Timber Research and Development Association
TRRL	Transport and Road Research Laboratory
TSR	Temporary speed restriction
TWA	Thames Water Authority
TWL	Top water level
UAE	United Arab Emirates
UB	Universal beam
UCL	Unit control logic
UDA	Urban Development Area
UEFA	Union of European Football Associations
UKCS	United Kingdom Continental Shelf
UNCRD	United Nations Centre for Regional Development
UNDP	United Nations Development Programme
UP	Urban Programme
uPVC	Unplasticised polyvinyl chloride
URA	Urban Redevelopment Authority (Singapore)
VAWT	Vertical axis wind turbine
VDU	Visual display unit
WDF	Waste derived fuel
WHO	World Health Organisation
WRc	Water Research Centre
YDG	Yorkshire Development Group

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