Without site investigation ground is a hazard

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SITE INVESTIGATION IN CONSTRUCTION

1 Without site investigation ground is a hazard

Site Investigation Steering Group

Thomas Telford, London

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1. Without site investigation ground is a hazard

2. Planning, procurement and quality management

3. Specification for ground investigation

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Contents

Executive summary

This document has been written for clients and their professional technical advisers in the construction industry. It aims to raise their awareness of the importance of ground, and highlights the consequences of inadequate site investigation in terms of escalating costs and late completions.

Inadequate site investigations can arise from a lack of awareness of the hazards associated with ground, inadequate focus of finance, insufficient time and a lack of geotechnical expertise.

The essential elements of site investigation are herein reviewed briefly, with recommendations to improve practice and obtain better value for money. In this regard, an outline of the scale and nature of the problems indicates that insufficient attention is given to desk studies where valuable information can be obtained at low cost.

Case histories are described to illustrate the consequences of inadequate site investigation and the benefits of adequate site investigation.

It is concluded that a site investigation should be undertaken for every site, since without a properly procured, supervised and interpreted site investigation, hazards which lie in the ground beneath the site cannot be known.

The need for site investigation

Introduction 1 There are hazards associated with ground, and unless these hazards are adequately understood they may jeopardise a project and its environment.

The ground is itself a vital element of all structures which rest on or in the ground. There is no other element of a structure about which less is known, but the properties and behaviour of the ground must be known to achieve a safe and economical structure.

This publication has been produced for construction industry clients and their professional technical advisers. It aims to increase awareness of the risks associated with hazards in the ground and seeks to help professional advisers obtain better long-term value for money when planning site investigations.

Scale of problem 2 Various reports (Institution of Civil Engineers (ICE), 1991a) over the past 25 years have shown that in civil engineering and building projects the largest element of technical and financial risk normally lies in the ground. Ground-related problems have led to late completions and high cost overruns on a national scale.

A review of 5000 industrial building projects by the National Economic Development Office (NEDO, 1983) showed that half of the projects overran by one month or more. 37% of a representative group of 56 case study projects suffered delays due to ground problems. Without exception on redeveloped sites unforeseen ground conditions were met during construction.

In an analysis of 8000 commercial building projects, NEDO stated in 1988 that one-third of the projects overran by more than one month; a further one-third overran by up to one month. 50% of a representative group of 60 case studies suffered delays from unforeseen ground conditions. In 1990 Johnson reported that the National House-Building Council pays out on claims with a total value of £5–11 million each year, and of these over 50% are related to geotechnical problems.

On ten large highway construction projects, Tyrrell reported in 1983 that the final cost was on average 35% greater than the tendered sum. Half of this increase was a result of inadequate planning of ground investigation or poor interpretation of the results.

Following a review of over 200 road and bridge projects where premature remedial costs exceeded £100 000 (1988 prices), in 1989 the National Audit Office expressed concern at the high costs associated with geotechnical problems. Geotechnical problems on eight road and six bridge projects resulted in extra work costing £18 million.

In 1993 the Public Accounts Committee stated that for major road contracts (1988–89) the average cost increase was running at 28%, equivalent to a £200 million increase in cost over tender price. The reason was judged to be the undertaking of larger and more complex schemes which involved greater risks, particularly with ground conditions.

Based on an analysis of 89 underground projects, the US National Committee for Tunnelling Technology in 1984 concluded that in more than 85% of the cases the level of site investigation was too low for adequate characterisation of site conditions, leading to claims and cost overruns.

Nature of problem 3

In the NEDO industrial building survey it was noted that sites often contained buried man-made obstructions such as foundations and services. Information about their nature and location was missing or inaccurate or had not been pursued with sufficient determination. Ground problems included: soft spots in recycled ground and industrial waste which required piling, waterlogged ground, rock in ground, methane pollution, and colliery waste which required deep compaction.

Aside from unforeseen ground being encountered, recorded incidents in the NEDO report on commercial building included: differential settlement leading to foundation problems; old underground chambers, tunnels and shafts encountered; an unknown spring located; site flooding requiring groundwater lowering; necessity of underpinning of adjacent building; rocky ground encountered; undetected ground and groundwater conditions leading to a change in concrete design; and existing massive foundations encountered which could not be removed.

Low-rise buildings, such as domestic houses, are normally founded on relatively simple foundations at shallow depths, where the soil tends to be more compressible than it is at depth. According to the Building Research Establishment, typical problems have included: soft spots under spread footings on clay; growth or removal of vegetation on shrinkable clays; collapse settlements on made ground; floor slab heave on unsuitable fill; foundation failure on very soft subsoil; slope instability; groundwater attack on foundation concrete; reactions to chemical waste; increased depth of footings or piling to overcome soft spots; and need for dewatering.

In underground projects common problems have included: overbreak and cave-ins of blocky and slabby rock, groundwater ingress leading to instability and wash-out of materials, poor tunnel machine performance for anticipated rock, unforeseen difficulties in handling and removing spoil due to lack of durability data, and inappropriate rock support system for the rock mass encountered.

Value for money 4

Expenditure on site investigation as a percentage of total project cost is low, and ranges typically from a mere 0.1 to 0.3% for building projects. Over the past 25 years ground investigation prices have been forced down in real terms and investigation today is often based upon minimum cost and maximum speed. This inevitably increases the risk of poor-quality work. ('There is hardly anything in this world that some man cannot sell a little cheaper and make a little worse. Those who consider price only are this man's lawful prey.' John Ruskin, *Sesame and Lillies).*

Many investigations bought cheaply fail to present an accurate account of the ground or groundwater conditions; it is therefore not surprising that the groundworks designed for the site are often not suited to the actual ground conditions. In such circumstances the costs of remedying wrongly designed works or mobilising alternative construction methods are usually far in excess of the cost of the original site investigation.

The solution to the problem, however, is not just to throw more money into more site investigation. In many cases, greater benefits for the client can be obtained simply by better planning of the investigation using a geotechnical specialist, i.e. a chartered engineer or chartered geologist with appropriate expertise and experience in geotechnics (see Appendix I and the companion volume by the Site Investigation Steering Group (SISG, 1993a).

Valuable information can be obtained from desk studies at low cost, but insufficient attention is given to this preliminary phase of routine site investigation. An investigation of geology, geomorphology, aerial photographs and archival data should be included in any desk study.

Investigations benefit from the use of high-quality equipment handled by skilled operatives. Such 'quality' investigations will not necessarily be more elaborate, or take longer, than one bought at the cheapest price available, but they will provide good quality data.

There is no universal 'yard-stick' that gives the cost of site investigation as a percentage of construction contract cost. Each investigation will bear a price that results from the market value of the skills of the operatives and those who supervise and direct them, the complexity of the ground, the equipment used and the duration of the investigation work. The site investigation report, resulting from the employment of people of appropriate experience and skill, should present an accurate account of the ground and groundwater conditions, and enable appropriate groundworks to be designed and constructed.

Principal technical adviser 5

This adviser, who is often a chartered engineer or architect, is the leading adviser to the client on technical matters. If the principal technical adviser is not suitably qualified and experienced, a geotechnical specialist should be associated with the site investigation from conception to completion. This specialist may come from within the principal technical adviser's own organisation, or may be an independent appointment.

Procurement 6

The use of selective competitive tendering for site investigation work is recommended, since long open tender lists lead generally to wildly fluctuating prices and quality, and inhibit serious bidding by skilled specialist contractors. To ensure fairness, the pre-selection of tenderers should be based on the same criteria for all.

At present this is the exception rather than the rule, and only 16% of site investigations are managed by geotechnical specialists. This situation alone accounts for much of the poor quality of site investigations. In this regard the arrangement whereby the geotechnical specialist procures the site investigation, with separate employment of a contractor for physical work, testing and reporting of factual information, has been available and used successfully for many years. The geotechnical specialist is usually responsible for preparing the interpretative report.

If a client chooses to rely solely upon the all-round abilities of a chartered engineer or architect for the control of small projects, it is the responsibility of that professional to appreciate the risks associated with ground and the value of specialist geotechnical advice, and to seek it, if necessary.

Often site investigations, and subsequent geotechnical design, require input from geotechnical specialists with different skills and expertise, e.g. a geotechnical engineer, an engineering geologist, a groundwater hydrologist etc. Site investigation is an interdisciplinary subject, and the different but complementary roles of such specialists have to be recognised if site investigation is to adequately cover all aspects of a complex site.

Conditions of contract 7 Site investigations are frequently carried out under ICE Conditions of Contract (ICE, 1983, 1991b) but nearly one-third of employers use no formal conditions. Irrespective of the form of contract, clear identification and definition of the responsibilities of each party to the contract is essential. If the contract is based on a performance specification, e.g. for field instrumentation, the investigation contractor is responsible. On the other hand a 'method' approach (in which the manner of doing things is specified) tends to place the responsibility with whoever directs the works. It may be argued that a client would be better served in this case by dealing with one contracting party only, so that there would be no doubt about responsibilities.

Specification 8 In the absence of a clearly defined contract specification, and without adequate enforcement through supervision, the quality of ground investigation will inevitably be variable.

A national Specification for ground investigation (SISG, 1993b), of which this book is a companion, with appropriate notes for guidance has been produced to reduce the potential for inappropriate tenders resulting from the misinterpretation of the many contract documents which abound in the construction industry (virtually every specialist firm and many clients have their own documents). Widespread use of this national specification, with good supervision, will be a major factor in improving the quality of site investigation.

Planning 9 During the planning and design phases of a project, site investigations often suffer from the rush and tumble associated with planning pressures, provision of access, last minute changes in scheme layout and construction deadlines.

Given the importance of site investigation, adequate time should be allowed for its planning, design and execution, which should be directly relevant to the final lines and levels of the project.

Relevance 10 Schemes change due to political and environmental influences, such as those resulting from Public Inquiries, and geotechnical design may come to depend on extrapolation of site investigation data derived for other locations. In situations where roads or tunnels are constructed along different routes, or buildings are repositioned, the original site investigation may no longer be relevant for the project in its new position.

Flexibility 11 It is important to be aware that ground is complex and when strata inconsistencies come to light further investigation should be undertaken.

Site and ground investigations should be conducted as operations of discovery. Investigation should proceed in logical stages and planning should be flexible so that the work can be varied as necessary in the light of fresh information. After each stage of a site investigation, it should be possible to assess the degree of uncertainty that remains in relation to vital aspects of the ground. This observational approach should allow the best engineering strategy to be developed and reduce the risks of unexpected hazards being found during or after construction.

Communication 12 The site exploration team is frequently remote from those responsible for the design and construction of the project. This can result in poor communication between the various disciplines, leading in turn to a lack of awareness or appreciation of each other's requirements.

The importance of links between site investigation, planning, design and construction should be recognised and a continuous thread of responsibility should be maintained for the geotechnical input of a project, starting with the feasibility studies and extending right through to project completion. This responsibility can be held by a geotechnical adviser (Appendix I).

Groundwater 13 Observations of groundwater are often totally inadequate. Greater use of instruments is recommended to identify water levels and pressures and to monitor their changes over a period of time, which takes account of seasonal variations. To put these results into perspective it may also be necessary to consult a hydrogeologist.

Supervision of work 14 The type and degree of supervision required in ground investigation is quite different from that required during a construction project. In the latter case, it is generally sufficient that supervision should detect any defect in the finished work, whereas supervision of ground investigation can be carried out only while the work is in progress. Since exploration procedures can both influence the end product and be influenced by the ground conditions encountered, the supervisor should be able to amend the type and scope of the investigation as it proceeds.

The supervisor of a ground investigation should have geotechnical expertise and experience, as well as practical knowledge of the different techniques.

Interpretation and dissemination of data 15 Boreholes provide a view only of the ground at the specific locations of the boreholes. Interpretation of the ground conditions between boreholes is a matter of judgement based on geotechnical knowledge and experience.

All factual geotechnical data relevant to a project, and whenever available the interpretative report, should be made available to all parties who place reliance on ground data and who are involved in the plannning, design, tendering and construction of the project.

The interpretative report should be prepared by a geotechnical specialist and should describe the ground conditions and groundwater regime, together with a summary of the engineering properties relating to the materials present.

Quality management 16 One way to test that site investigation procedures are properly implemented is to subject them to a quality management system. Such a system involves everyone, from client to driller, and should be part of the quality plan for the whole project, so that site investigation is not divorced from the design and construction phases of a project.

Financial risk 17 It is not realistic to expect a site investigation to reveal ground conditions in their entirety, but provided the data are analysed and interpreted correctly, investigation can reduce the residual risk associated with unforeseen conditions to a level which is recognised as being tolerable within the project budget.

Most construction activities involving the ground are sufficiently close to the critical path for any delay to those activities to affect the whole project. For example, ground works and foundations for new buildings can absorb up to one-third of the construction time, although amounting to only 10% of the project cost.

Although the consequences of inadequate site investigation are often serious for the design and construction phases of a project, the effects can be even more severe when continued into full-life costing.

The principal technical adviser should inform the client of the financial risks at all stages from project conception to completion.

Claims 18 As claims for unforeseen ground conditions currently form the largest proportion of contractual claims, it is recommended that geotechnical specialists are involved at the earliest opportunity when ground problems arise to ensure that

(a) appropriate safety and remedial measures are taken
(b) design changes are made or site procedures amended
(c) accurate records are obtained of the ground actually encountered
(d) supplementary investigation which could help to mitigate the problems is considered.

Inadequate site investigation 19 In summary, inadequate site investigations can arise from a lack of awareness of the importance of ground, inadequate amount or focus of finance, insufficient time and a lack of geotechnical expertise.

These shortcomings lead routinely to the following problems in site investigation practice which result in additional delays and costs, often far in excess of the price of the original site investigation

(a) poor planning and design
(b) poor execution
(c) poor interpretation
(d) poor communication

Now, and in the future, it is vital that financial decision makers appreciate that you pay for a site investigation whether you have one or not, and you are likely to pay considerably more if you do not.

Conclusions 20 A site investigation should be undertaken for every site. Without a properly procured, supervised and interpreted site investigation, hazards which lie in the ground beneath the site cannot be known.

*   *   *

The following case histories illustrate the consequences of inadequate site investigation and the benefits of adequate site investigation.

Inadequate investigations start with inadequate instructions

Typical examples of enquiries from professional technical advisers are given below. In each case the requests quoted comprise the entire text presented to the tenderers.

Example A Please quote for carrying out a conventional borehole site investigation plus testing for contaminants. Six boreholes should be sunk, four number 14 metres deep and two number 4 metres deep.

Observation What is a conventional borehole site investigation?
What is the purpose of the site investigation?
What are the likely contaminants?

Example B Please find enclosed one copy of an Architect's drawing of the site survey showing location of a proposed hotel. Could you please quote for carrying out the necessary site investigation, together with providing recommendations for foundations, ground slab and car parking. We understand the location is about half a mile from Junction X on Motorway Y.

Observation The 'necessary site investigation' is defined by the requirements for foundations, etc., but no drawing or description of the proposed structure is included, so the size of the necessary site investigation cannot be judged. In which direction is the site located from the junction?

Example C We have been appointed as consulting engineers for the development at the above site, which comprises a three-storey domestic construction, and have been asked to obtain three quotations for the soils investigation. This should include an interpretative report of your findings. A site layout and location plan is attached. We will take your advice as to whether a trial hole or borehole survey is the most suitable. Your response to our enquiry by the 21st December is requested (letter dated 14th December).

Observation Since the lowest quote is invariably selected, conscientious tenderers who visit the site or who undertake a desk study to establish the geology and previous uses of the site, to enable them to decide whether the investigation should be by trial hole (trial pit) or borehole, are penalised when they seek to recover such costs through the investigation programme and associated bid.

Cost-effective tunnelling

Description

A 1984 study by the US National Research Council of 89 underground projects has been conducted with particular emphasis on: the site investigation practice and procedures that had been adopted, and the problems, if any, that had been encountered during construction which resulted in claims, delays and project cost increases.

The first illustration shows that for a level of exploration greater than 0.6 metre of borehole per metre of tunnel length, the convergence of the contractor's bid with as-completed cost is excellent.

Claims were examined and related to the engineer's estimate, the contractor's bid and the amount of site investigation work (see the second illustration). When exploration effort was low the incidence of claims increased. Overall, claims averaged 29% of the engineer's original cost estimate for the project. As exploration exceeds 0.6 m of borehole per metre of tunnel length there is a pronounced reduction in the cost of claims, and the claims continue to reduce in cost as exploration effort increases.

Observation

Although site investigations cannot predict every problem that is likely to be encountered on site, increasing the effort and funding for exploration has demonstrable cost-effective benefits. The amount of site investigation does influence and can moderate the occurrence and cost of claims. Furthermore, when investigation effort is increased, both bids and completed costs tend to fall more in line with original estimates.

(Courtesy of New Civil Engineer)

TBM shut down after just two months' work

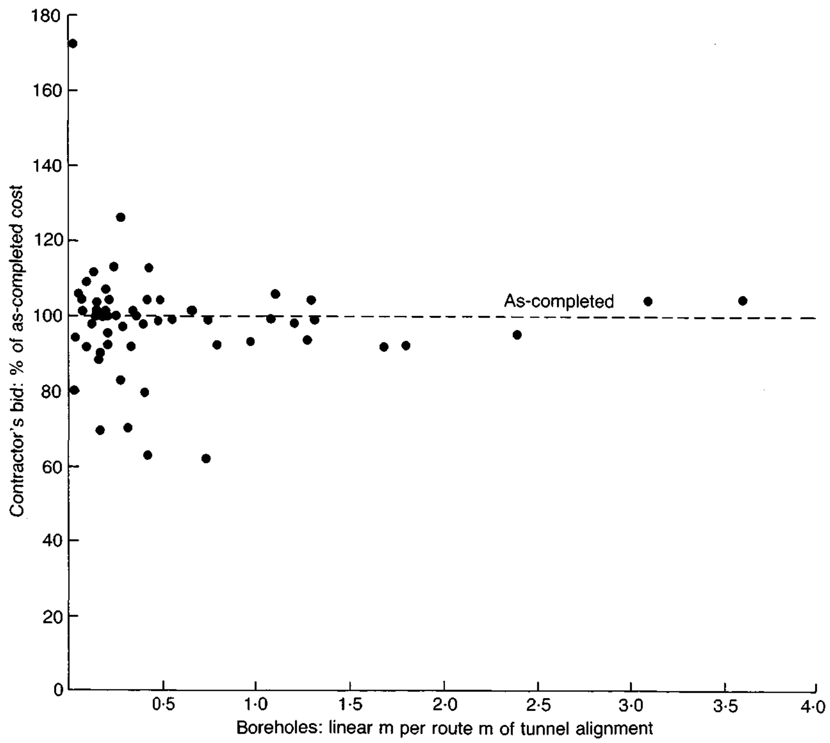
ONE OF the world's largest tunnel boring machines is being mothballed after moving just 15 m in two months.

The 200 m long, 950 tonne Atlas Copco machine was being used by Swedish construction group Kraftsbyggarna on a £300 million, 6.8 km tunnel for the Malmo-Gothenburg railway.

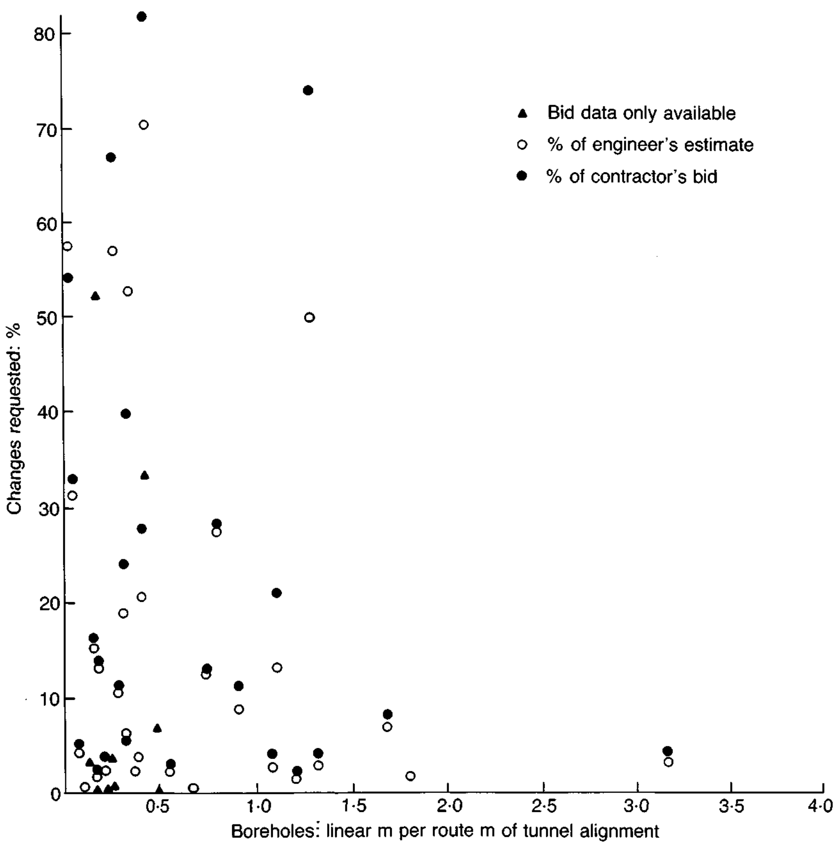
The £7 million machine was unveiled in May amid claims that it would carve through the Halland Ridge at 100 m a week. But the machine has been dogged by poor ground conditions.

Kraftsbyggarna did not carry out a a full geological survey because of cost. The firm believed that the TBM would hit rock soon after it started work. But so far the only material to be uncovered is montmorillonite, a soft clay which has rendered the TBM ineffective.

On Monday excavators replaced the TBM, which will be repositioned when rock is found.



Contractor's bid: % of as-completed cost
Boreholes: linear m per route m of tunnel alignment
As-completed



Changes requested: %
Boreholes: linear m per route m of tunnel alignment
Bid data only available
% of engineer's estimate
% of contractor's bid

Ground improvement for a viaduct

Description

The photograph shows a four-carriageway viaduct in an urban area, and the underlying ground conditions have been illustrated. All the coal seams had probably been mined in the late 18th and early 19th centuries by pillar and room working. No records were available but it was known from earlier investigations that the workings had not completely collapsed, i.e. cavities remained, as they were overlain by a 'bridging' stratum of massive sandstone some 10 m thick.

Observation

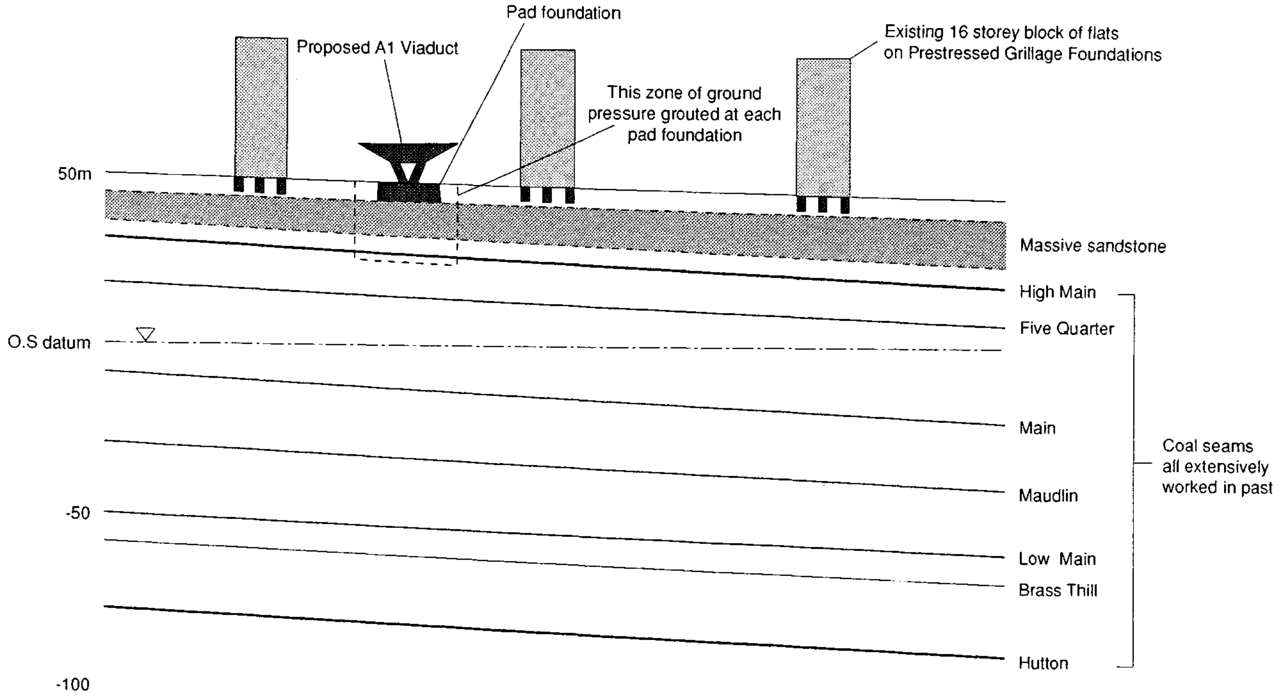
Designers of earlier tower blocks in the area had introduced deep foundation beams to ensure even distribution of the building loads on to the sandstone, relying in turn on the rock to distribute the loads to remnant coal pillars.

In considering the viaduct foundations the above approach was rejected because high concentrated loads occurred at each pier and any local weakness in the sandstone might have created excessive settlement. Furthermore, for economy and elegance a continuous supported prestressed concrete viaduct had been chosen which could only tolerate small settlements at the piers.

This example illustrates the need for a geotechnical model coupled with an understanding of the structural engineering requirements in order to provide an appropriate foundation.

Four-carriageway viaduct

Underlying ground conditions



Solution The cavities of the main coal seams were filled with a cheap fly ash-cement grout beneath and immediately beyond the foundation of each viaduct pier and abutment to ensure that collapse of the workings some distance away could not cause settlement or rotation of the foundations.

Supplementary investigation for bridge

Description

A single carriageway surface route across a steep-sided narrow valley was to be replaced by a bridge to provide a dual carriageway. The local Highway Authority had investigated the ground beneath the proposed route by several boreholes, some extended by rotary drilling to take rock samples across the valley.

The consulting engineers appointed for the bridge design observed that the underlying ground comprised strata of the Coal Measures Series with the mined High Main Seam reported at a depth of 200 m. British Coal records showed a group of seams some 150 m higher which were sufficiently thick in some localities to have been mined.

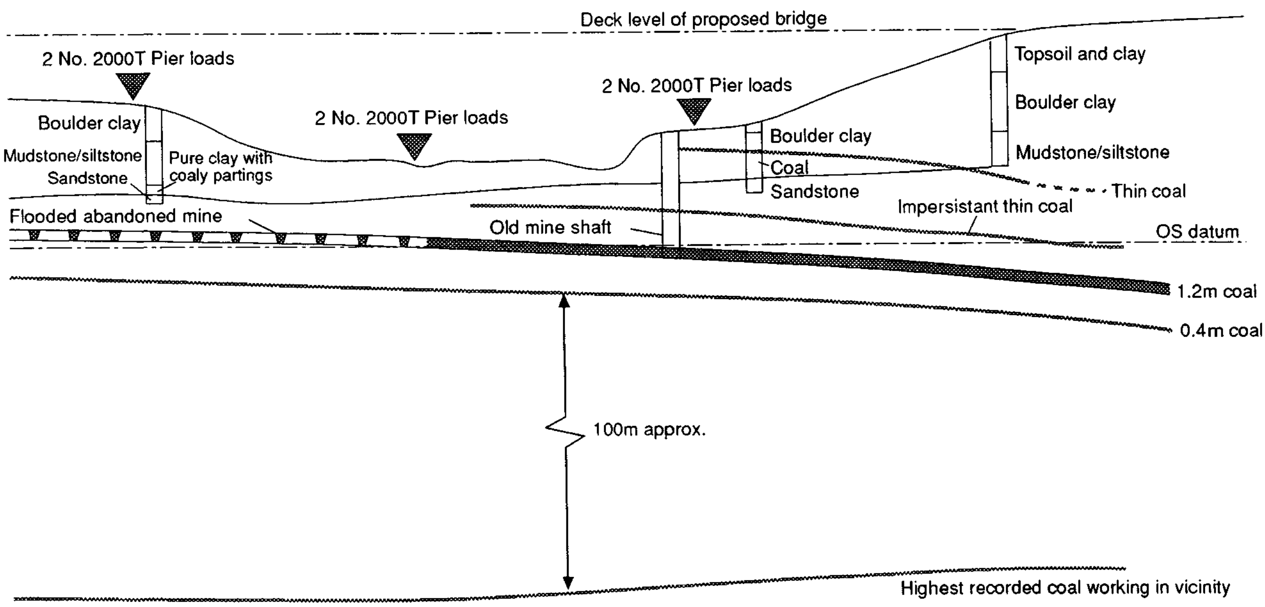
The consulting engineers implemented a more thorough ground investigation, comprising a 60 m deep rotary cored borehole to obtain the nature of the rock at each of the positions proposed for the bridge piers.

The borelogs confirmed that mining had been extensive and also located a shaft for which no records existed.

Observation

This example highlights the need for an overall understanding of the nature of the ground (the geotechnical model) in planning a site investigation.

Coal seams



Faults in factory building

Description

Within three months of completion, a light industrial factory building developed severe structural faults (see the photographs) due to differential settlement which eventually led to reconstruction of the building. The site formed part of a tip with 4 to 5 m depth of refuse material, underlain by a soft clay layer overlying sand and gravel. This information was revealed by six boreholes taken to depths of 9.5 to 12.5 m.

The steel frame of the structure was built on 10 m deep piles whereas the external cladding and internal walls were founded on strip footings in 1 m deep by 1 m wide trenches overlying tip material. The tip material was believed to have been placed 18 years earlier and was therefore capable of accepting low bearing pressures without excessive settlement.

Solution

As part of the investigation into the cause of the faults a 2 day desk study by a geotechnical specialist revealed that a nearby boring in 1898 had proved peat at depths of 12.6 and 15.8 m. In addition, aerial photographs (£50 cost) confirmed the history of the tip development and illustrated the presence of recent refuse on the site of the building together with a less compressible access road.

A supplementary ground investigation with boreholes to 20 m confirmed an absence of peat and the building was reconstructed on a completely piled foundation to a depth of 10 m.

Observation

A desk study should form the preliminary phase of any site investigation.

Completed factory building

Crack developed in wall

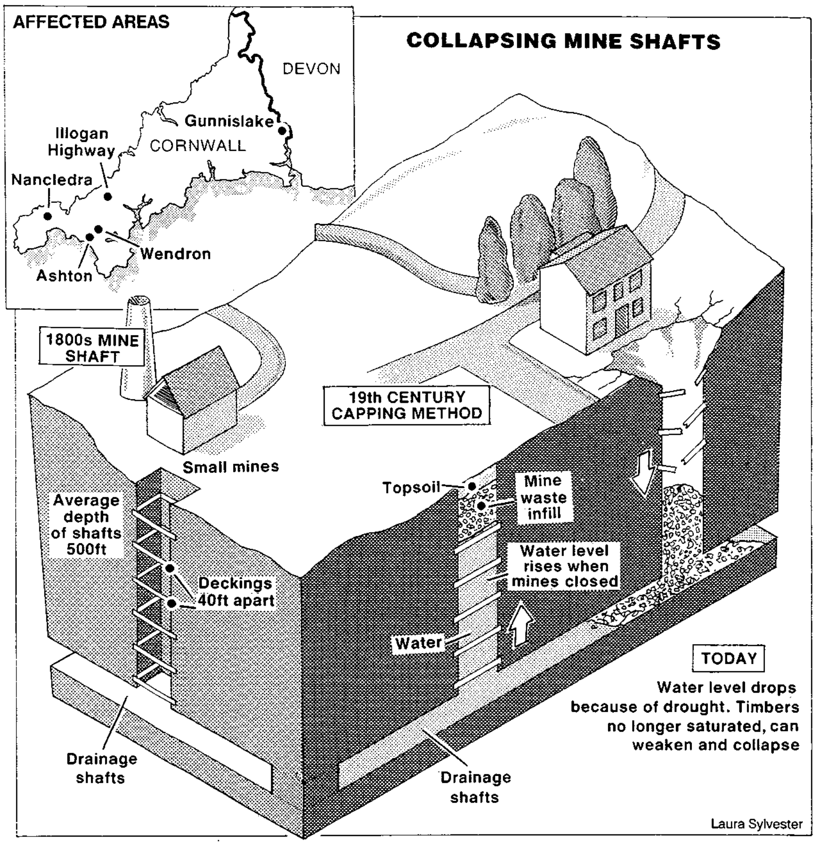
Mine collapse makes homes unsaleable

Description Before the estate was developed five trial pits were excavated where the houses were to be built. The extent of the trial pits was contained within the perimeter of the houses and inspections were carried out to make sure that the buildings were put on ground suitable for the imposed load.

Problem Collapse of an old mine shaft leading to a surface 'crown' hole brought into question the surface stability across the whole housing estate.

Gunnislake garden hole

Collapsing mine shafts (courtesy of Times Newspapers)



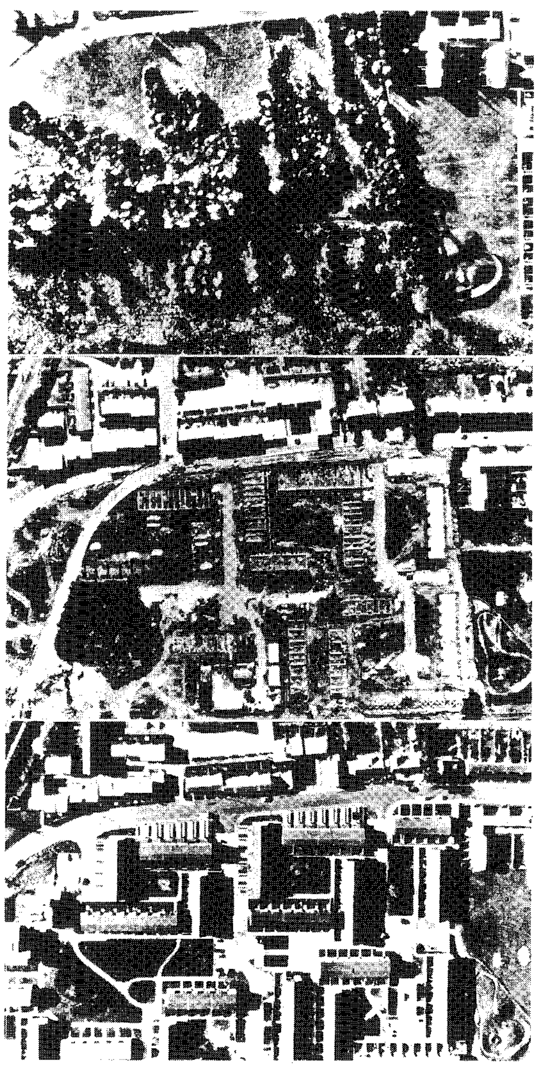
Observation A desk study would have highlighted a regional authority warning not to build on the site, and investigation of the local mining history using old maps and aerial photographs would have indicated the presence of three abandoned shafts in the area.

Cracking in terraced housing

Description Following construction some of the terraced houses suffered serious cracking and investigations showed that parts of the structures were heaving.

Problem The geological map of the area shows that the site is underlain by London Clay which is known to be a shrinkable clay. The photograph shows that before construction one part of the site was densely wooded whereas other areas appear to have been grassland. Large differential movements and damage occurred as long structures crossed from one area to another, as a result of differential heave due to tree removal.

Observation Air photographs as part of a desk study can provide records of the size and position of trees and other vegetation removed some years before the housing development was envisaged. Coupled with a geotechnical classification of the underlying soil such photographs can provide warnings of the need for precautionary measures in foundation design and housing layout.



Critical move of a tanker mooring buoy

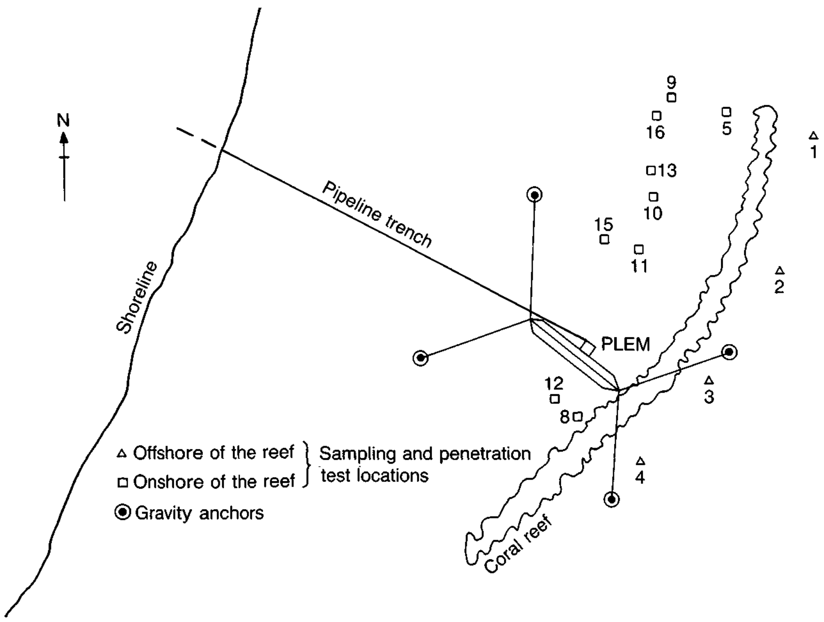
Description The client's site investigation consisted mainly of seabed examinations by a diver and the collection of ten bulk disturbed samples for wet sieving to provide particle size distributions. The contract document described the offshore conditions as sand and coral limestone.

The location of the mooring buoy and its anchor blocks was moved 200 metres further out to sea without a supplementary site investigation (see the map).

Problem The contractor's programme was based on sand dredging using air lift, and blasting in the coral limestone. At the location of two of the anchor blocks the seabed was clayey, and neither excavation method was successful.

Claims related to unforeseen ground conditions added $5 million to a $6 million lump sum contract.

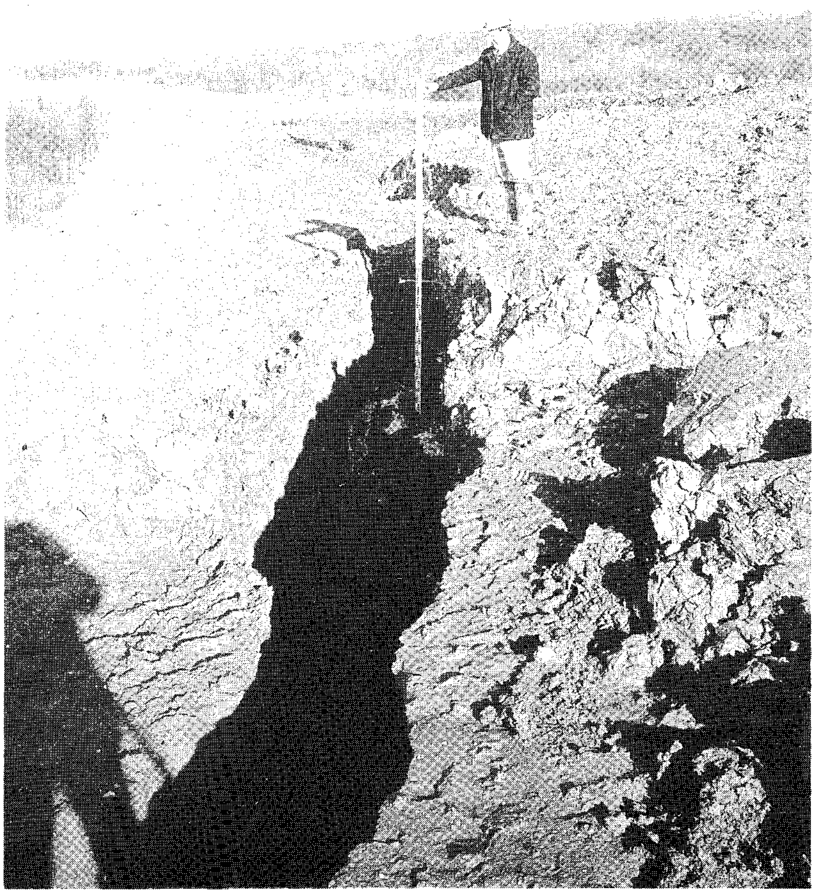
Observation The site investigation may have given a meaningful account of the ground at the original location but this was not appropriate for the buoy's new position.



Instability of highway embankments

Description

Several highway embankments built over stiff-fissured clay strata, e.g. London Clay and the Lias, were found to suffer instability, usually during their construction or, in some cases, post-construction (see the photograph). The associated ground slopes were sometimes as low as 3 degrees. The instability was due to the presence of shear surfaces in the founding strata, associated with small-scale shallow natural failures of the slopes. These were commonly a result of periglacial solifluction. In some, but not all cases, these features had a clear geomorphological expression. The shear surfaces had not been detected by the initial site investigations for the schemes, but were observed in trial pits put down as part of the remedial works. The initial site investigations comprised shell and auger boreholes and a limited amount of trial pitting, coupled with some laboratory testing of small, unrepresentative samples to measure shear strength.



Triggering of large old landslides by highway cuts

Description

A motorway running along the foot of an ancient scarp, composed principally of stiff-fissured clay, was to be constructed in cutting. During excavation of the cuttings, large landslides affecting most of the scarp were triggered, temporarily closing the road trace. Subsequent investigations showed that the slides were re-activations of old landslides mantling the old scarp and were brought about by the removal of their toe support by the excavation for the cuttings. The initial site investigation comprised boreholes and some trial pits, but had not led to a proper appreciation of the geological and geomorphological setting of the proposed works or of the geomorphological signs of former landsliding which existed on the old scarp.

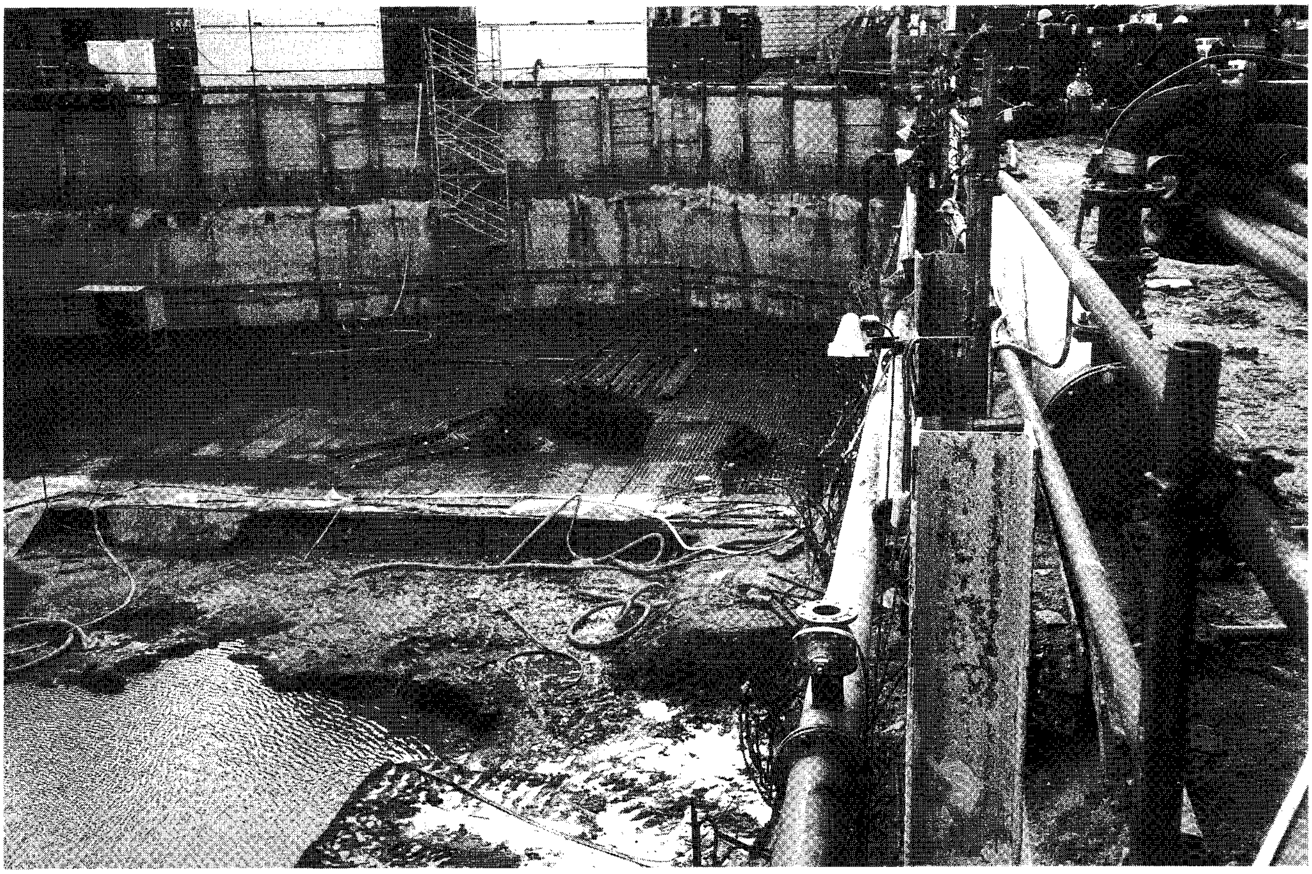
Observation

As a result of such, all too frequent experiences, it is now recommended practice to make, with the aid of aerial photographs, a geomorphological map of the site as an early part of the site investigation programme, to ascertain whether old natural landslips, or other disturbances such as solution collapse features, are present. Where instability is detected, or suspected from such studies, well-supported trial pits are excavated, commonly to 3 to 5 metres below ground level, to permit the detailed examination of the near-surface ground conditions by geotechnical specialists. On the basis of this mapping and pitting, the deeper sub-surface investigation, comprising boreholes, sampling and testing and instrumentation, is designed and executed.

Groundwater blow out drowns basement

Floodwater surged up and filled 2.5 m of the 8.5 m deep pit when a specialist contractor was digging a further metre for a lift shaft (see the photograph). It was observed that excavators had punctured a layer of slaty marl beneath silty ground.

The Architect blamed the inundation on unforeseen ground conditions.



(Courtesy of New Civil Engineer)

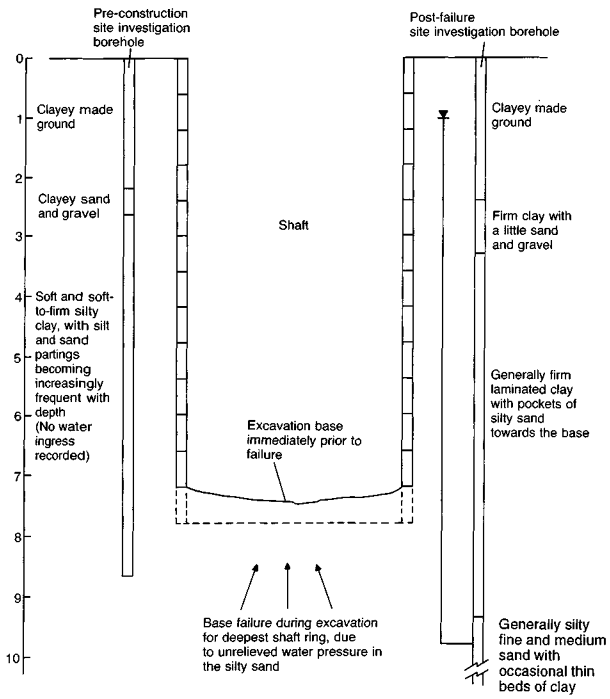
Shaft abandoned due to base failure

Description The site for a 3.7 m diameter, 7.8 m deep shaft was located within a flat-bottomed valley, infilled by a variable sequence of alluvial and glacial cohesive soils overlying water bearing granular material.

The pre-construction site investigation comprised two boreholes to 8.45 m and 8.65 m, respectively, but the site investigation contractor was not made aware of the proposed construction works. Below made ground the boreholes revealed soft clay containing silt and sand partings which became more frequent with depth (see the illustration). No water strikes were recorded and no piezometers were installed. From the level of a nearby river and local topography the site investigation concluded that the standing groundwater level was probably between ground level and 2 m depth.

Problem Shaft sinking was undertaken without any groundwater control measures, other than sump pumping from the shaft bottom. Base failure occurred with a massive ingress of water during excavation of the deepest shaft ring. The resulting damage led to the abandonment of the original shaft, and the redesign and construction of a replacement.

Observation Post-failure boreholes confirmed the expected ground conditions down to shaft base level, but also revealed that a significant thickness of silty fine and medium sand underlay the soft clay about 1.6 m below base level. It is clear that base failure occurred because of unrelieved water pressure in the sand, due to a lack of appropriate groundwater control measures stemming from an inadequate pre-construction investigation. For the estimated groundwater level an investigation depth of 14 to 15 m would have been appropriate, but the client did not involve a geotechnical specialist.



Flexible planning for underground power station

Description

For an underground power station and 4.5 km of tunnels, an outline design was prepared after a geological reconnaissance but before the start of drilling (see the map). It was assumed that the underground works would be constructed in two types of strong igneous rock, gabbro and overlying agglomerate.

The ground investigation revealed that the whole area had been affected by cliff recession on a massive scale. What was originally assumed to be an in situ agglomerate rock was found to be a 'colluvial' mass containing individual blocks up to 100 m in diameter.

The lowest tender for the civil works was twice the estimate made prior to the site investigation and the project was not considered economically viable.

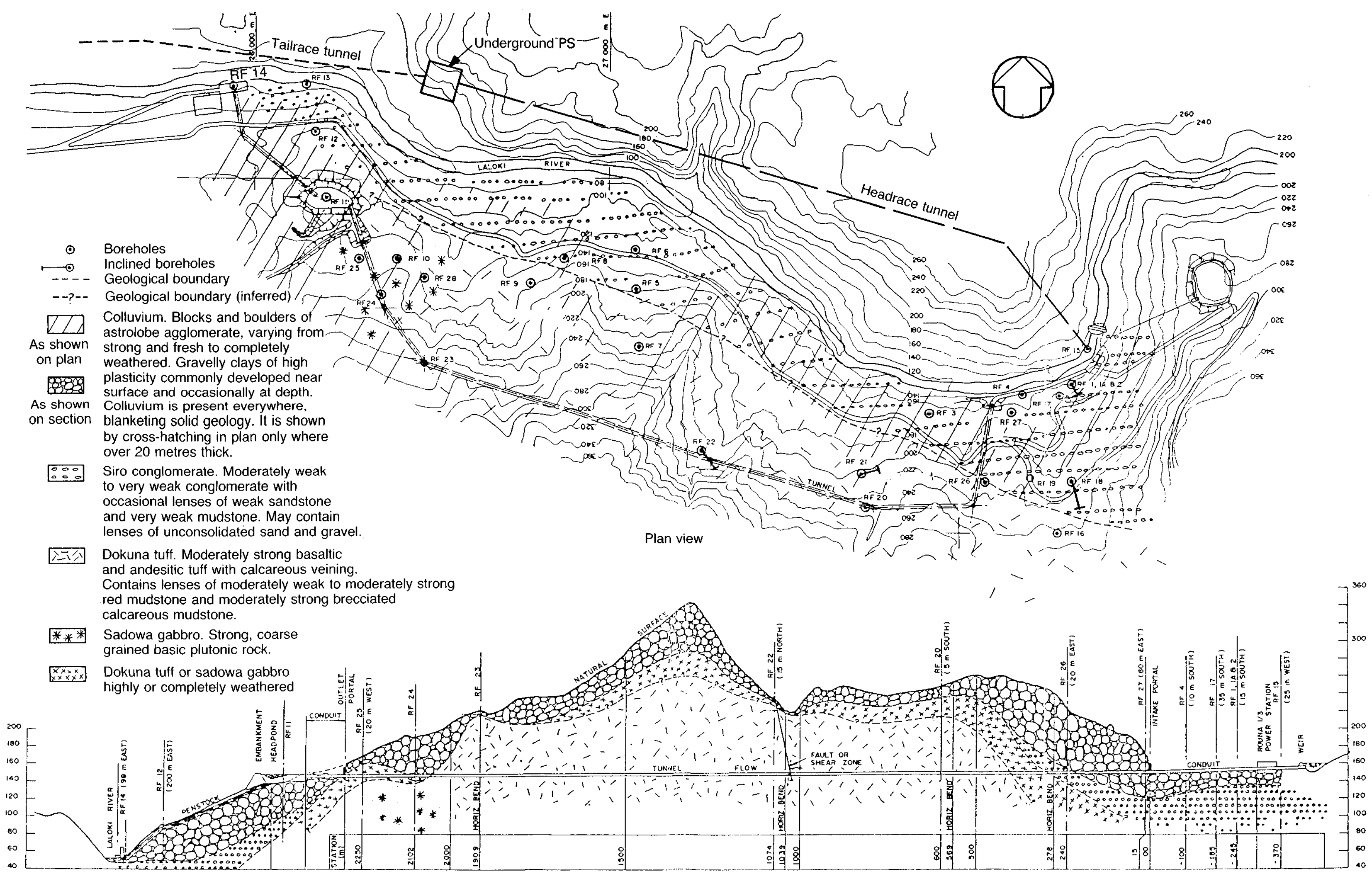
Solution

An alternative scheme was then proposed on the opposite river bank. Again many of the findings of the investigation were unexpected, some were favourable and others not. Each new discovery led to a revision of the concept of the scheme, and in turn changes in the conceptual design rapidly altered the investigation programme.

Six alternative layouts of the water conveyance system were considered within four months and boreholes were drilled to investigate the critical aspects of each variant. The design of the scheme was optimised with respect to the favourable ground conditions, and all tenders received were below the preliminary estimate made prior to any ground investigation work.

Observation

An open-ended and flexible approach to site investigation led to a successful outcome.



Plan view

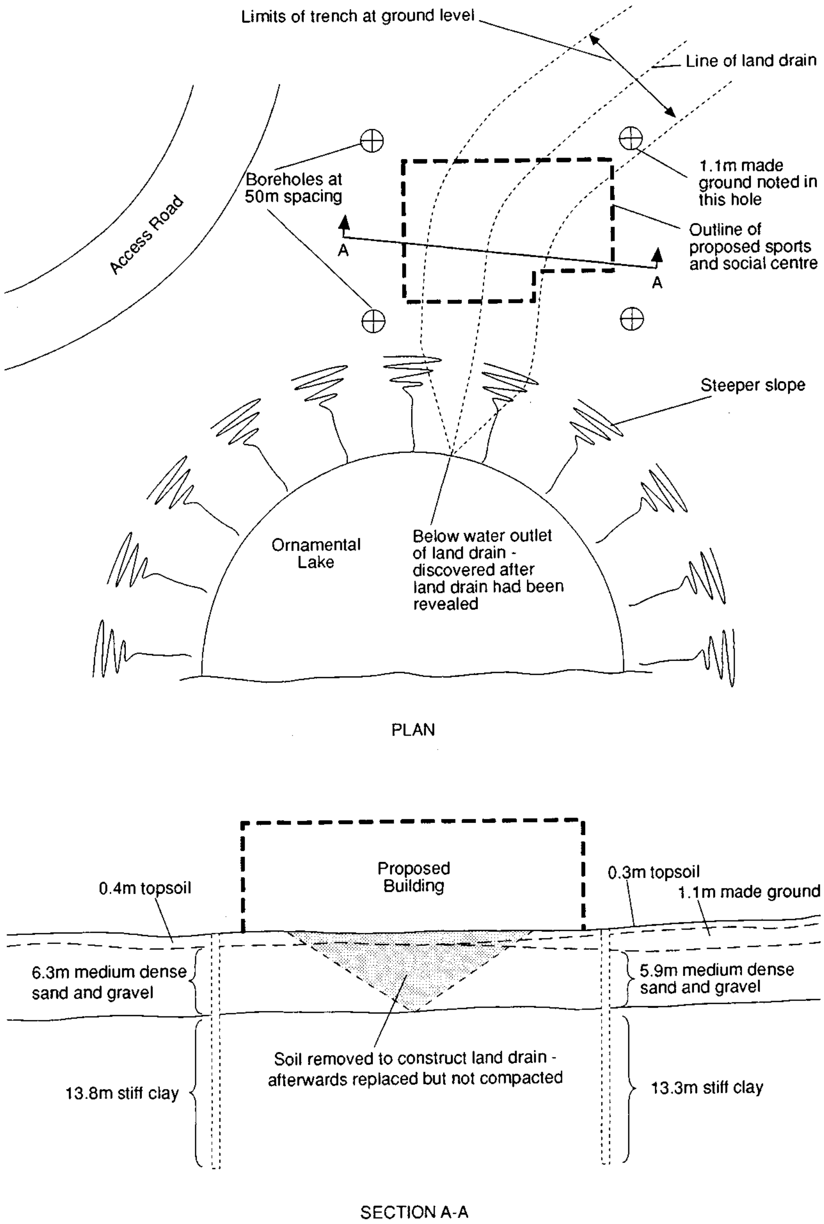
Longitudinal section through tunnel

Missing ground detail at college development

Description

The development comprised several departmental buildings and a sports and social centre on a large campus. Few records were available on existing ground conditions, and a comprehensive study and investigation were made of the site for the new developments, including existing foundations, building services and site drainage. Since the site was large, most of the boreholes were located on a square grid pattern at quite large centres of 50 m, about the same as the extent of the buildings. The remaining boreholes were located to provide additional information on the strata and groundwater conditions at locations such as steep slopes between existing terraces (see the illustration). The ground conditions were medium-dense sandy gravel overlying a stiff clay. Pad foundations bearing on gravel were recommended for the majority of buildings on the higher ground. Buildings

Site details showing position of boreholes



on the lower ground where the gravel layer was thin, and those buildings 'stepping down' existing terraces, were to have piled foundations.

Problem

All foundation work progressed routinely until construction commenced for the sports and social centre which was on the high ground and designed with pad foundations. About one-third of the foundations had been completed when it became evident that at the excavation level the ground conditions were variable and in places very poor.

Solution

A series of trenches across the site location of the building revealed an unrecorded land drain at the bottom of a deep trench some 20 m wide at the surface where the trench had been loosely backfilled. Owing to landscaping and planting the trench was not apparent on aerial photographs. The remedy was piled foundations throughout the building.

Observation

Boreholes at 25 m centres throughout would have located the backfilled land drain trench but would have provided no additional information to influence foundation design at the other college buildings. However, the cost of the remedial works at the sports and social centre was far larger than the cost would have been for boreholes at 25 m spacing for every building.

In this example the need for a ground investigation beneath each building is highlighted, together with the potential risk associated with widely spaced boreholes. Where ground data were extrapolated on this development account should have been taken of the likely significance and cost of the absence of gravel in areas remote from boreholes.

Heave of stabilised capping layer for motorway

Description

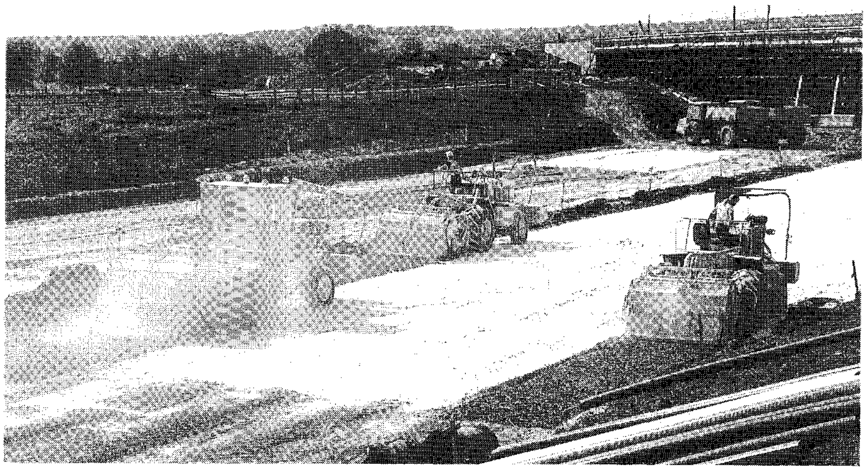
Lime stabilisation has been used in pavement construction since the 1960s, although the application in major highway work in the UK has been limited. Further research in the late 1970s and early 1980s culminated in the inclusion of lime stabilised capping layers in the 1986 DoT specification. After undulations were observed in the partly completed carriageway of a new motorway, trench excavation showed that the 250 mm thick lime stabilised capping layer had increased in thickness to 400 mm in places with accompanying softening.

Scanning electron microscope photomicrographs of lime stabilised samples from the trench showed the presence of ettringite crystals, whose formation is accompanied by expansion. Based on research studies, the complex conditions which appear to be necessary for ettringite to form include high alkalinity, a sufficient clay mineral content giving an adequate supply of alumina, silica and carbonates, the presence of suphates, the correct temperature conditions, and availability of sufficient water.

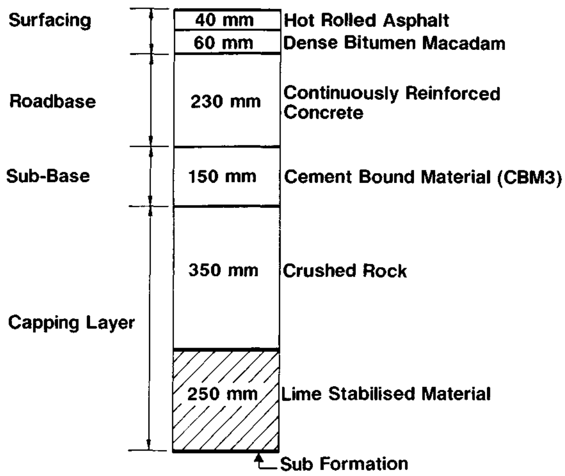
Observation

The unexpected heave emphasises the need for appropriate chemical and laboratory studies of both the soils and groundwater in any project where the use of lime stabilisation is contemplated.

Lime stabilisation in progress on motorway



Contract pavement construction lime stabilised



Incorrect piles for multi-storey office block

Description

A site investigation comprising two boreholes was carried out by the developer, an international contractor. The borelogs (see the illustrations) indicated very little water seepage during boring, but no time was allowed for water to seep out of the ground and prove the 'rest' level.

Bored cast-in-place piles of 500 tonne capacity taken to the underlying mudstone were agreed, and a trial pile was arranged to prove the piling construction method and verify the load-carrying capacity.

Problem

During pile boring close to one of the boreholes, water poured out of the sandy strata into the pile hole, and within minutes the surrounding soil started to collapse.

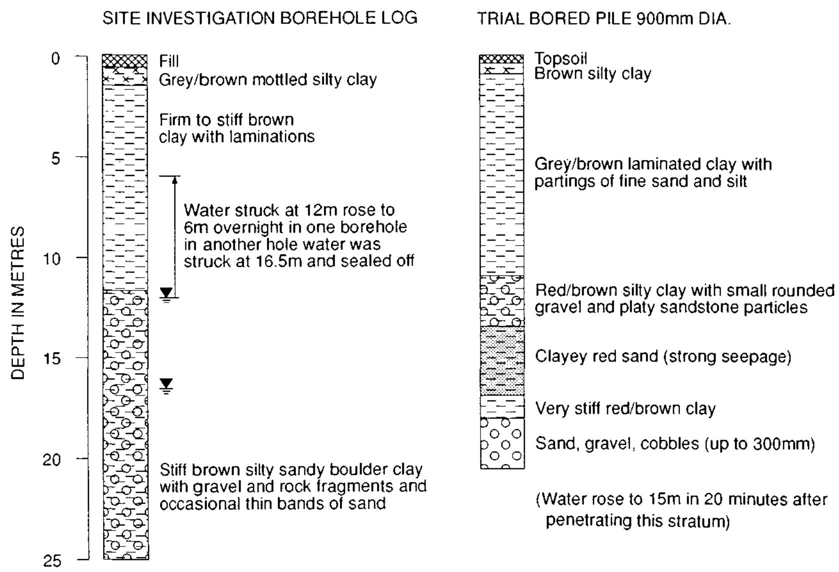
Solution

As a result of these findings the original piling contract was cancelled, and an alternative auger-bored pile system adopted at additional expense to the developer.

Observation

From a comparison of ground logs it was concluded that the original ground investigation borings had been carried out too rapidly, and the overlying clayey material had been dragged down by the boring tools and smeared the exposed surfaces of the sandy strata. Over the short period each borehole was open, the clayey smear resisted major seepage and no collapse occurred. More careful execution of the boring, including close supervision and interpretation of the results by a geotechnical specialist could have avoided this problem.

Borelogs



Conflicting design data for foundation of large office

Description The illustration shows the average penetration resistance of the soil, as measured by the number of blows N of a standard drop-weight hammer, during two ground investigations of the same site. The water level was 5.5 m below the ground surface.

In both investigations the boreholes were sunk by a drill and case method, whereby as the hole advances it is sealed from the surrounding ground and groundwater by the steel tube casing which follows.

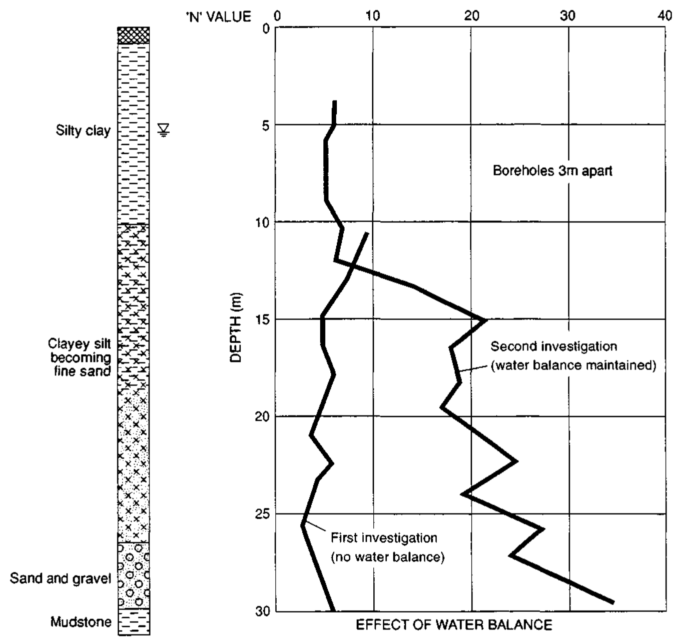
In the second investigation water was poured into the casing to maintain a level inside the steel tube casing at or slightly above the water level in the ground, to provide a balance of water pressure at the base of the borehole.

In the first investigation no water was added and the imbalance of high water pressure outside the casing and no head of water within caused the silty and sandy soil, to be lifted out of place and become loose as the groundwater rushed into the bottom of the casing.

Solution With the correct use of the site investigation N values by a geotechnical specialist, the foundation was based on driven cast-in-place piles founded in sand at a depth of 18 m.

Observation Each penetration test is carried out just below the end of the casing so the first investigation recorded inaccurate and much lower N values. Such values can give rise to conservative and expensive foundation design, e.g. piles to the mudstone, and underestimate the nature of the ground through which the piles will be constructed. This example highlights the importance of using the correct field test procedure and the need for close supervision during execution of the work.

Penetration resistance of soil



Inadequate management of investigations leads to development problems

Description

The site was surrounded by housing and a hospital and had a history of coal mining.

The basic geology was well understood and investigation data were available from an adjoining site owned by the same employer. This led to an unwillingness by the financial controllers to accept proposals drawn up by a geotechnical specialist.

Site investigation work did proceed but was managed by non-specialists and awarded piecemeal. The client's money was poorly directed and in spite of a substantial investigation the precise depth and condition of workings underlying the site were not proven. The site investigators had no ongoing involvement with the design or construction stages.

Problem

During foundation construction a dispute arose with the Building Inspectors as to the depth and nature of the old workings. Work was halted to allow further patterns of probe drilling to be carried out giving rise to unplanned expenditure and delay.

Observation

Lack of geotechnical expertise in the planning, management and control of the site investigation left important questions unanswered, and resulted in an inadequate investigation with expensive consequences.

Adequate investigations lead to successful development

Description

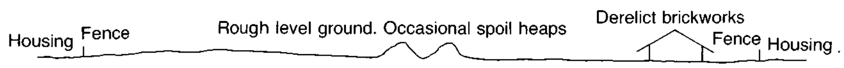
The site, surrounded by houses and a school, had a long and complex history of underground and surface mining of clay and coal as well as on-site clay product manufacturing (see the top illustration). The complexity and potential problems of developing the site were fully recognised and a phased site investigation was implemented.

This phased investigation comprised an initial desk study to obtain old maps and plans of workings and enabled an understanding of the site to be established prior to the planning of the ground investigation. The large-scale but carefully supervised investigation looked at the location and condition of the underground workings, shafts, compaction and settlement of quarry backfills, gas and other contaminants.

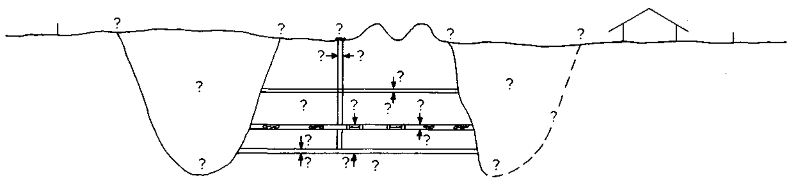
Observation

The field results enabled the site to be zoned by geotechnical specialists in terms of magnitude of hazard to development and cost of ground treatment, which permitted the developer to make sound judgements on housing layout acceptable to the planning authority (see the bottom illustration). The cost of the site investigation on this complex ground was equivalent to £700 per house.

Information available: (a) before desk study; (b) after desk study



(a)



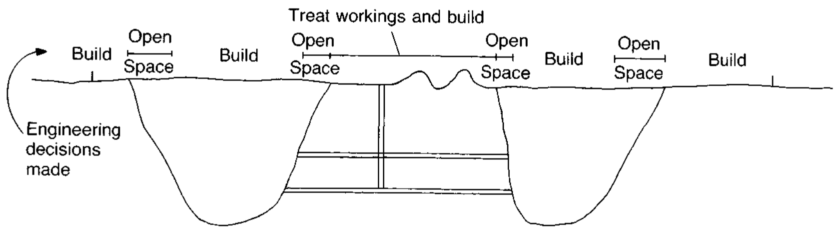
Quarries: Approximate location known
Type and quality of backfill unknown
Potential for settlement and gases unknown

Underground workings: Approximate location and depth known
Current condition unknown
Potential for collapse settlement unknown

Shafts: Approximate location known
Current state of backfill or capping unknown

(b)

Information available after field investigation



Quarries: Location, extent, geometry well known
Type and quality of backfill known
Potential for settlement and gas hazard known

Underground workings: Location and depth well known
Current condition known
Feasibility and costs of infilling identified

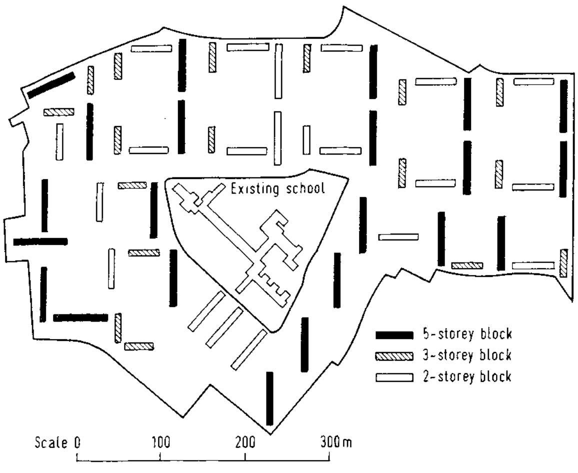
Shafts: Location and current condition known

Safe developments in mining regions

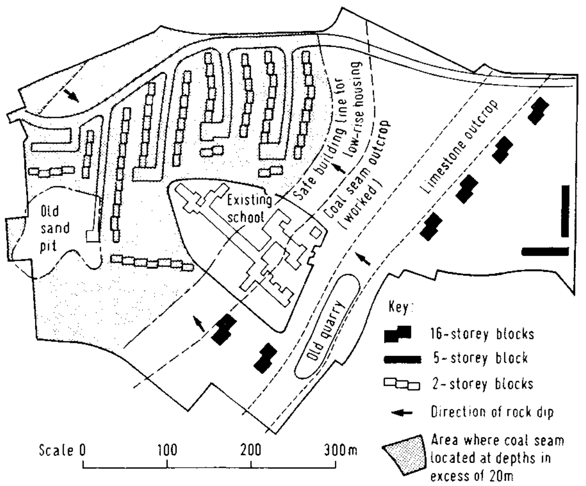
In planning new developments in areas that may be underlain by old mine workings, it is often desirable to investigate the possibility of reorganising the proposed building layout and type of structure, and thereby avoid high costs for the consolidation of the old workings.

The illustration shows how a proposed development was redesigned to accommodate an undermined area defined by the site investigation. By careful interpretation of the ground data the new site layout avoided the hazards from dipping mined coal and limestone strata, and yet provided a similar number of dwellings.

Example of redesign of a proposed development to avoid mining hazard (Price 1968)



Proposed layout of structures before site investigations



Reappraisal of site layout to avoid problems from old mine workings

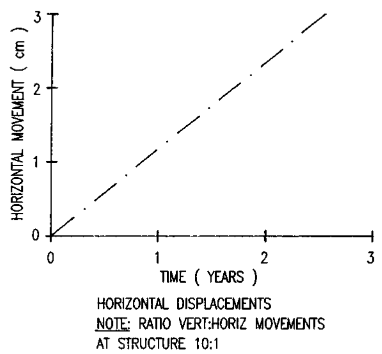
Problems with private housing developments

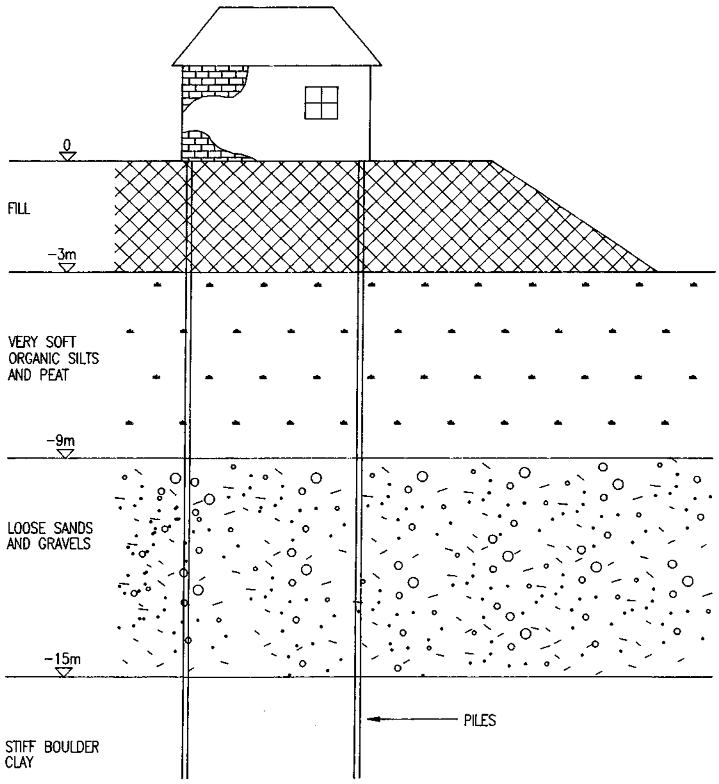
Description The existence of peats and very soft clays overlying glacial deposits was known from an earlier site investigation. Nevertheless, significant depths of fill were placed on the soft deposits and buildings were constructed on piled foundations close to the crest of the fill.

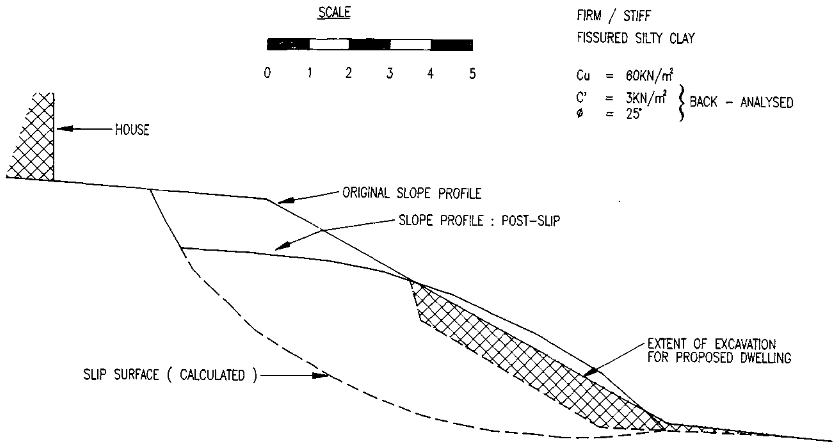
Problem Significant lateral displacements in addition to vertical settlements have led to the demolition of one structure, and to the others being closely monitored.

Observation Although adequate site data were available no geotechnical specialist was involved to identify and employ the relevant parameters to produce satisfactory foundations.

Ground movements in very soft organic deposits







Description To develop a housing estate on a hillside, terraces were cut into a fissured boulder clay.

The site investigation established groundwater levels and undrained shear strengths of the soils.

Problem Slope instability occurred within a few months of excavation.

Observation In the absence of a geotechnical specialist no consideration was given to the long term stability of the cut slopes at the design stage.

Misinterpreted bedrock at river crossing

Description

A proposed river crossing for a new water trunk main was to be created by thrust boring between two shafts.

From the published geological map, a geological boundary was indicated at the site with the sequences recent alluvium overlying sandstone bedrock on one side, and recent alluvium, flood plain gravel and sandstone on the other side. The ground investigation comprised one borehole on either river bank.

The boreholes indicated that the ground consisted of a thin layer of cohesive soil overlying very dense sandy gravel (see the illustration). Particle size distribution tests confirmed the described grading of the material. No chiselling times were given for the cable percussive boreholes.

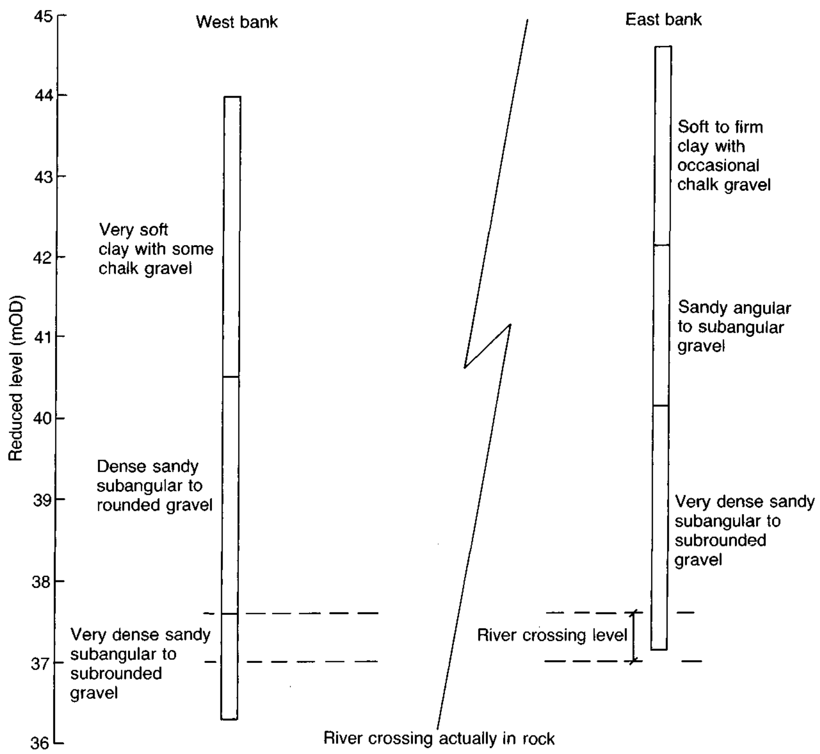
Problem

The successful contractor based his tender on an auger boring machine suitable for work in sandy gravels. During shaft sinking sandstone was encountered below a thin layer of cohesive soil. The unforeseen rock led to significant delays and additional costs.

Observation

The cable percussive boring was able to penetrate the weakly cemented sandstone, but the arisings, comprising sand and gravel-sized rock fragments, were not recognised as rock. The borelogs should have described the horizon as weakly cemented sandstone recovered as sandy gravel fragments.

The ground investigation contractor failed to provide competent and experienced staff to ensure that the borelogs described the in situ material and not the recovered samples.



Landfill gas explosion

Description

The photograph shows a house that was completely destroyed by a methane gas explosion, badly injuring the three occupants. Subsequently at a Public Inquiry, the sequence of events leading up to the incident was established and evidence produced to ascertain the origin of the methane. During the proceedings it became apparent that signs of ground heating had been detected approximately 100 metres beyond the boundary of a nearby infill some years before the explosion but that the phenomenon had been misinterpreted as a shallow burning coal seam.

Observation

Had the geology of the area and the geochemistry of methane been known to the investigators at that time, it is possible that the landfill would have been identified as the source of the methane and the area protected from the dangers of uncontrolled gas migration.

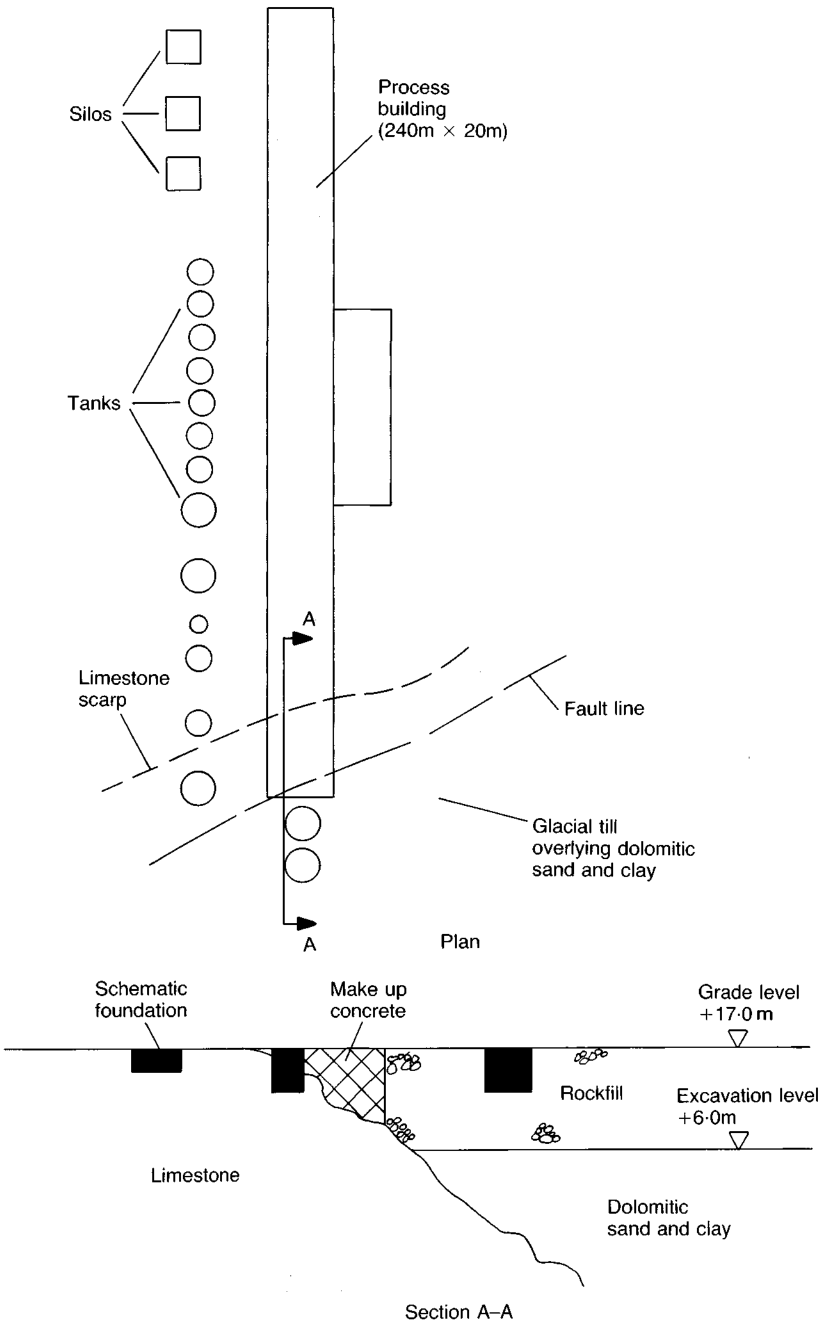
(Courtesy of Derby Evening Telegraph)

Rejection of advice for industrial development

Description

A major industrial complex including some linear processing plant was planned in an area of limestone hills and outcrops with a history of glacial action. It was envisaged that the hills would be removed to provide a series of level platforms for site development.

The site investigation was commissioned with a broad remit to undertake a desk study, walk over study, initial exploratory field work, a detailed scope of works and a contingency for supplementary investigations.



The desk and walk over studies both suggested the possibility of a buried valley trending diagonally across the site. Exploratory boreholes confirmed in places poorly sorted and compacted glacial till exceeding a depth of 65 m.

At one location where 35 m of glacial till had been proved a linear process structure was scheduled to be built. Given the sensitivity of this structure to differential settlement, it was proposed by the geotechnical specialist that the structure should be moved onto a sounder stratum.

Problem

The linear processing plant was not moved and across the buried valley it was necessary to replace a significant depth of poor material with rock fill and pad foundations. At the edge of the valley each foundation had to be excavated separately to ensure a sound bearing in the buried sloping rock face. Extensive temporary works were required and the construction was inevitably slow and costly.

Observation

The geotechnical specialist's recommendation would have resulted in economical foundations, hence showing the benefit of an adequate site investigation. Given the additional time and expense incurred founding across the buried valley, the value of the site investigation was severely eroded.

Cost-effective foundations for high rise buildings

Two apartment buildings built on different ground

Description

Two similar apartment buildings were constructed in close proximity. One building was founded onto bedrock through concrete caissons, and the second was placed on a simple concrete raft bearing on glacial soil overlying the rock.

Observation

The foundations were constructed routinely and the difference in designs was dictated by differences in the subsurface geology revealed by an accurate site investigation with appropriate interpretation of the ground data.

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Appendix I: Definitions of geotechnical personnel

Geotechnical Specialist

A Chartered Engineer or a Chartered Geologist with a postgraduate qualification in geotechnical engineering or engineering geology, equivalent at least to an MSc and with three years of post-Charter practice in geotechnics;

or a Chartered Engineer or Chartered Geologist with five years of post-Charter practice in geotechnics.

The Geotechnical Specialist will generally be a Geotechnical Engineer or an Engineering Geologist. The graduate with general experience requires five years of post-Charter practice in geotechnics to compensate for a lack of formal education and training in geotechnics.

A non-graduate with 15 years of practice in geotechnics is encouraged to become chartered by a mature candidate route.

Geotechnical Adviser

A Chartered Engineer or a Chartered Geologist with five years of practice as a Geotechnical Specialist.

This individual, who may be a named person in an organisation, advises the Client or his Professional Technical Adviser of the geotechnical requirements of the project, and upon instruction arranges the procurement and interpretation of the necessary information and its validation during construction.

Geotechnical Engineer

A Chartered Engineer with at least one year of postgraduate experience in geotechnics and a postgraduate qualification in geotechnical engineering or engineering geology, equivalent at least to an MSc;

or a Chartered Engineer with at least three years of postgraduate experience in geotechnics.

Engineering Geologist

A Chartered Geologist with at least one year of postgraduate experience in geotechnics and a postgraduate qualification in geotechnical engineering or engineering geology, equivalent at least to an MSc;

or a Chartered Geologist with at least three years of postgraduate experience in geotechnics.

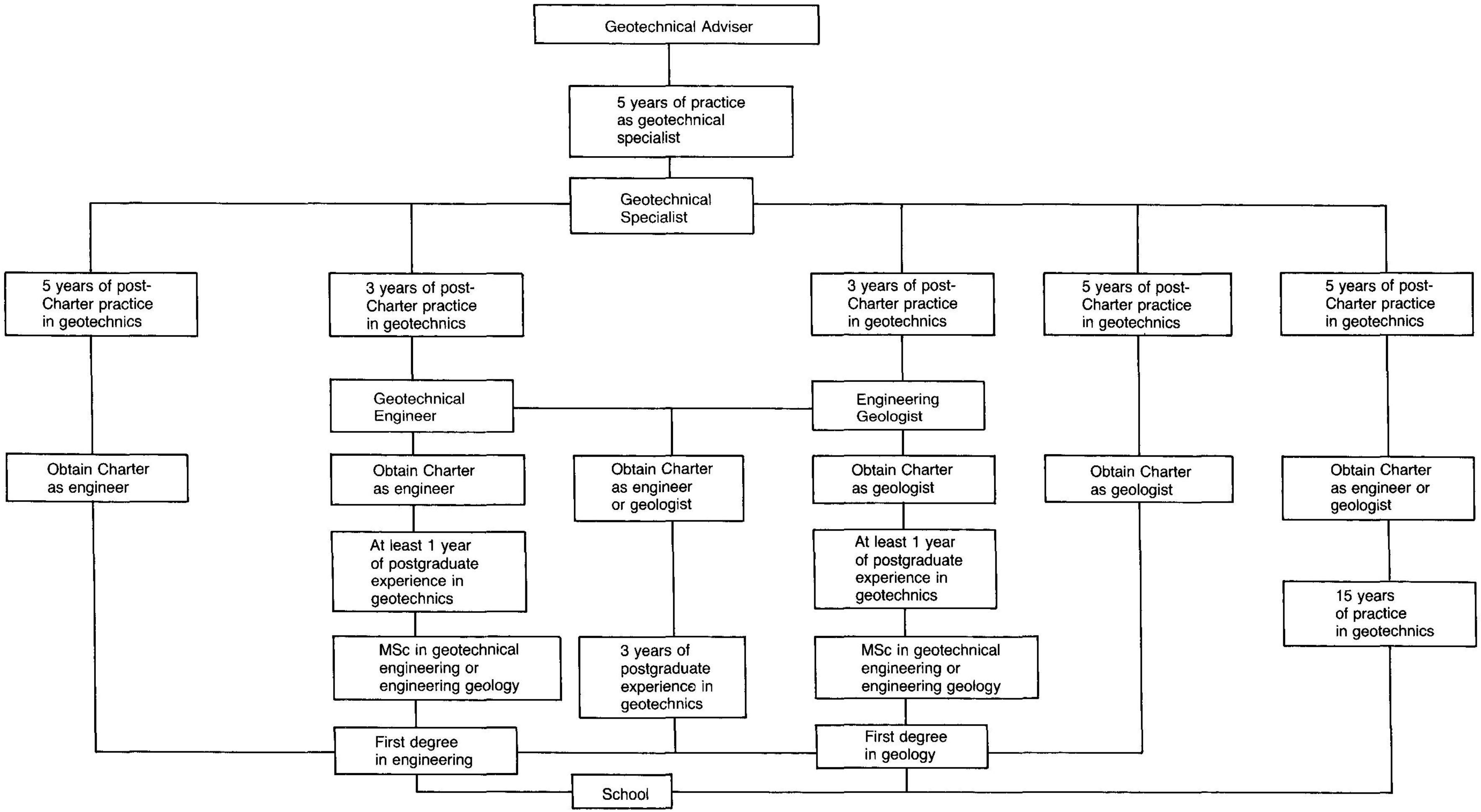
The definitions of Geotechnical Engineer and Engineering Geologist recognise the different but complementary roles they can impart through their knowledge, and the skills that the Geotechnical Adviser requires for successful ground engineering.

Geotechnician

An individual with specific training and experience in the use of specialist equipment and procedures for sampling, testing and monitoring.

Such a person should be supervised by a Geotechnical Specialist, Geotechnical Engineer or an Engineering Geologist. Further refinements could include limits of expertise, e.g. field or laboratory testing and years of experience.

The names of professional geotechnical personnel and organisations can be found in references contained in the companion publication (Site Investigation Steering Group, 1993a).



The MSc courses in geotechnical engineering and engineering geology have as core subjects geology, geomorphology, hydrogeology, rock mechanics, soil mechanics and foundation engineering.
Prior to the attainment of chartered status as an engineer or geologist, prefix terms such as graduate or assistant may be appropriate.
To accommodate the above routes and associated definitions for geotechnical personnel, a five year transitional period (ending 12/98) is considered necessary.
Geologists may date their chartered status as commencing from the time of their validation as MIGeol. Enquiries should be directed to the Chairman of the Engineering Group of the Geological Society.

Routes to becoming a Geotechnical Adviser

Appendix II: Membership of Site Investigation Steering Group and working panels

Site Investigation Steering Group

Professor G.S. Littlejohn, BSc, PhD, FEng, FICE, FIStructE, FGS, University of Bradford (Chairman)
Mr. R. Cater, BSc, CEng, MICE, CGeol, FGS, Hampshire County Council
Professor C.R.I. Clayton, BSc, MSc, DIC, PhD, CEng, MICE, University of Surrey
Mr. K.W. Cole, BSc, MSc, CEng, FICE, Arup Geotechnics
Mr. G.P. Dean, BSc, CEng, MICE, Oscar Faber Consulting Engineers
Dr. M.H. de Freitas, PhD, CGeol, FGS, Imperial College of Science, Technology and Medicine
Mr.R.M.C. Driscoll, BSc, MSc, CEng, FICE, Building Research Establishment
Mr. J.D. Findlay, MSc, CEng, MICE, FGS, Stent Foundations Ltd.
Mr. P.A. Gee, BSc, CEng, FICE, Soil Mechanics Ltd.
Dr. D.A. Greenwood, BSc, PhD, CEng, FICE, FGS, Cementation Piling and Foundations Ltd.
Mr. J.R. Greenwood, BSc, MEng, MICE, MIHT, FGS, Travers Morgan
Mr. B.S. Hookins, CEng, MICE, Messrs. Scott-White & Hookins
Mr. F.M. Jardine, MSc(Eng), Construction Industry Research and Information Association
Mr. R.W. Johnson, CEng, FIStructE, National House-Building Council
Mr. T.M. Leon, BSc, FRICS, MIQA, Consultant
Dr. J.A. Lord, MA(Cantab), CEng, MICE, Arup Geotechnics
Dr. D.M. McCann, B.Sc, MSc(Eng), PhD, CGeol, FGS, British Geological Survey
Dr. T.W. Mellors, BSc(Eng), MSc, DIC, PhD, CEng, MICE, MIMM, FGS, Consultant
Mr. W.H. Pearce, London and Edinburgh Insurance
Mr. A. Smith, DArch(Hons), BSc, RIBA, AFAS, ACIArb, Bickerdike Allen and Partners
Mr. B.E. Spark, CEng, MICE, MIWEM, Anglian Water Services Ltd.
Mr. S.B. Tietz, BSc(Eng), CEng, FICE, S.B. Tietz and Partners
Mr. J.R. Wilson, BSc, CEng, MICE, Federation of Civil Engineering Contractors
Mr. P.E. Wilson, BSc, CEng, MICE, Department of Transport

Working Panel 1: Geotechnical Awareness Programme

Professor G.S. Littlejohn, BSc, PhD, FEng, FICE, FIStructE, FGS, University of Bradford (Chairman)
Mr. K.W. Cole, BSc, MSc, CEng, FICE, Arup Geotechnics
Dr. T.W. Mellors, BSc(Eng), MSc, DIC, PhD, CEng, MICE, MIMM, FGS, Consultant

Working Panel 2: Specification for Ground Investigation

Mr. J.R. Greenwood, BSc, MEng, CEng, MICE, MIHT, FGS,Travers Morgan (Chairman)
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