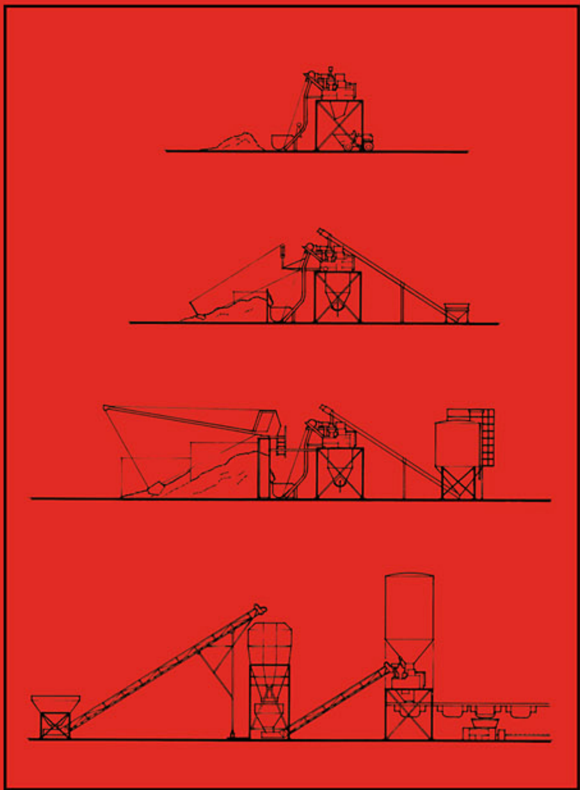
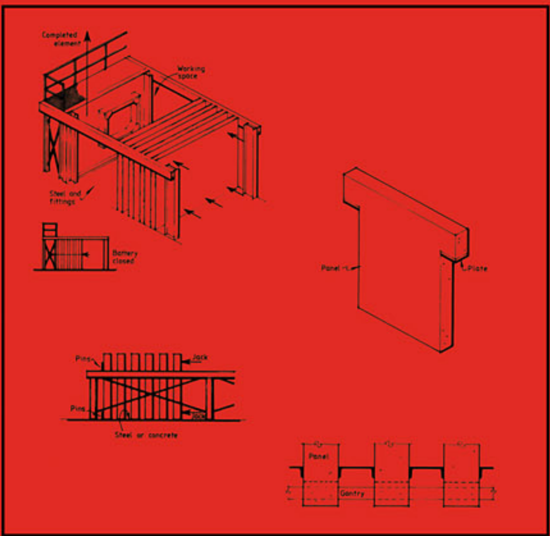
Supervision of concrete construction

VOLUME 2

by

JOHN G RICHARDSON





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Supervision of concrete construction

J.G.Richardson, MIWM, MICT

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Foreword

To the onlooker, concrete construction must appear to be a haphazard and somewhat hazardous process, indeed for many years this was the case. In today's construction industry, however, with all the pressures of time and responsibilities, it is essential that the process should be carried out in a logical, economic and work-manlike manner. Much of the pressure devolves upon the supervisor, be he section engineer, general foreman, clerk of works or trades foreman, and it is with these people in mind that the present work has been prepared. The coverage is such that all the activities of supervision are considered and a vocabulary established to enable the supervisor intelligently to deal with matters outside his normal discipline.

The extent of the detail has determined the length of the work and necessitated publication of the book in two volumes. The author wishes to thank the staff of Palladian Publications Limited and in particular Mandi J Forrest-Holden for all the assistance received in the preparation of the book.

J G Richardson
April 1986

Author's note

Of necessity, a publication such as *Supervision of Concrete Construction,* takes some years to prepare. Where the reader requires to refer to a specific British Standard or Code of Practice, it is advisable to check the status of such information with the BSI Cataloguean annual publication, or by telephoning the British Standards Institution.

The author is indebted to the British Standards Institution for permission to reproduce those parts of Codes used in this publication. Complete copies of Codes can be obtained from BSI at Linford Wood, Milton Keynes, MK14 6LE.

15.
Steel reinforcement

The satisfactory performance of a reinforced concrete structure is, to a large extent, dependent on the accurate placement of carefully detailed reinforcing steel. Many reinforced concrete structures and precast concrete elements are marred by cracking, rust marks and similar problems, directly related to workmanship. Certain defects result from poor design work, the inclusion of details which do not permit application of satisfactory workmanship and faulty dimensioning of such critical details as location and cover to steel. Many defects, however, are caused by factors which are within the control of the supervisor and which could be avoided by discussion prior to the concrete operations and particular care during them.

Steel reinforcement is often purchased from specialist suppliers. In many instances the contract includes site fixing of the reinforcement, although the steel may sometimes simply be delivered precut and bent for fixing by the main contractor. It is essential that the supervisor has an understanding of the physical properties of steel reinforcement, the reasons for its particular location and factors regarding concrete cover. On the job site the supervisor will be concerned with planning and controlling the sequence of operations and he must, therefore, be conversant with the activities and skills of cutting, bending and fixing steel. Methods of site handling and storage of steel are also extremely important. Failure to maintain stocks in good order may result in installation of steel in a substandard condition due to contamination, or worse consequences, such as the omission of the steel from the concrete, with resultant failure of the structure.

Site storage

The steel in lengths or in bundles should be stacked on bearers in such a way to be free of contamination, such as splashes of mud from an adjacent roadway. Concrete sleeper walls with holes for vertical bars will assist in separating sizes. Precast sleepers can be moved as the construction proceeds. Reinforcement must be free of grease, oil, loose mill scale and excessive rust at the time of installation. Where any of these contaminents is present in quantity, it may be necessary to clean the bars using wire brushes—a costly and wasteful process.

Cutting steel

The steel yard should be so arranged that stock lengths can readily be drawn into the cutting shop. The transport of steel will be by winch or tractor. In the case of static equipment, the steel is lifted onto the cutting bench and passed along rollers until the end butts against a previously secured stop, determining the required cutting length. Several bars can be cropped to length at one time, depending upon their diameter, although of course the larger the bars the greater the demands on the cutter. It is usual to cut the longest lengths required from each bar first, leaving the smaller lengths for stirrups and links until last, thus

Steel fabrication for walls proceeding on a reservoir site (South West Water Authority)

reducing off-cuts to a minimum. Time spent breaking down cutting schedules into lists to enable this procedure to be followed yields economies in wasted materials by achieving minimum off-cuts. Cut lengths are labelled for identification and bundled. If no further work, such as bending to shape, is to be carried out, the bundles are transported to the stockyard.

When bending is to be undertaken, the use of modern equipment makes it possible to prejig or programme the machine such that the bends are produced in a predetermined sequence. With such machines, it is essential that due allowance is made in cutting for the losses in bending and draw-in (the way in which the machine draws the bars into the mandrels as bending proceeds). This must be determined by the production and checking of trial bends. On completion of bending operations, bars are labelled and bundled. Labels should clearly indicate mark number and number of bars in the bundle. Where steel is being prepared for precast units, the contract number must be marked on the label as well as the unit number, bar mark and number of pieces. Ideally bundles should contain complete sets of bars as split bundles can result in omission of bars from a unit.

Bending steel

Whilst the cutting operation is essentially a linear process, the activities of bending steel demand a greater area around the machine to accommodate the handling and bending of longer bars in a safe manner. To overcome the requirements of space, some of the automatic link benders have inclined working tables, some of which are almost perpendicular. The type of machine in use on site generally requires a horizontal table to support the steel at the commencement of the bending operation, particularly where large or awkward shapes are to be produced. This basic table can be supplemented by trestles which ensure the truth of the bent bar by supporting it on a constant level plane.

The mandrels on the machine are interchangeable to allow formation of the correct bending radius as recommended by the relevant Codes of Practice. The simplest machine, and one which is used worldwide, consists of a fence, a fixed pin capable of accepting a static mandrel and a lever having a pin mount for the roller which forms the bar against the internal mandrel. For large bars this lever-operated roller is replaced by a more substantial roller worked by hand-driven gears. Of course, more recent bending machines, whilst being essentially similar in principle of operation, utilise adjustable stops in conjunction with limit switches which cut out and reverse the motor in a pre-determined sequence to bend the bars to the required shape. The operator manipulates the steel whilst activating the roller by a foot-operated push switch. Once bent, bars are bundled, labelled, tied and set aside ready for delivery to the work site or for tieing into cages.

Bending machines are also available which have the facility for mounted accessories, such as coil and ring benders. Accessories consist of serrated drive and one to three rollers which can be set to the required radius and pitch. As with straightforward bending, the product must be suitably supported by benches or trestles to avoid the production of links and so on, which are in wind or out of plane.

Reinforcement

Steel bars

The main grades of steel used as reinforcement in concrete are mild steel and high yield high bond steel bars. Mild steel in plain smooth round bar form is produced at steel mills by hot rolling. High yield steel is made either by hot rolling low alloy steel or by cold working mild steel. Hot rolled low alloy steel exhibits a pattern of ribs (but no spiral). Cold worked mild steel is recognisable by its twisted configuration of ribs. The construction site practice of calling high yield high bond steel *high tensile* is quite incorrect and this term should only be applied to steel in wire, strand or bar form used in prestressing operations or, for example, in connections which are made by tightening nuts or bolts by manual or mechanised means to give a torque reading. Steel for reinforcing purposes must have adequate tensile strength, ductility measured by minimum elongation under a proof load, and may be weldable. It is manufactured in plain, indented and twisted bars as previously described, and the following table indicates the characteristic strengths and minimum elongations:

TABLE 15.1

Type	Characteristic strength N/mm^2	Minimum elongation
Hot rolled mild steel bars to BS 4449	250	22%
Hot rolled high yield steel bars to BS 4449	410	14%
Cold worked high yield steel bars (up to 16 mm) to BS 4461	460	12%
Cold worked high yield steel bars (over 16 mm) to BS 4461	425	14%
Hard drawn steel wire to BS 4482	485	14%

Fabric

For ease and speed of placement, steel fabric or meshes are used in many types of reinforcement concrete construction. Fabrics comprise hard drawn steel wires, electrically spot welded at their intersection points or cold worked bars assembled to BS 4483. The types of mesh available include:

The ideal tie wire reel in use dispensing soft iron tieing wire

Square mesh—where the longitudinal and transverse wires are of the same diameter, forming a 200×200 mm mesh.

Structural mesh—where the longitudinal wires are of a greater diameter than the transverse wires and form rectangles of 100×200 mm.

Long mesh—which is similar to structural mesh as above, but with rectangles of 100×400 mm.

Wrapping fabric—which is similar to square mesh as above, but with 100 or 200 mm squares comprising 2.5 and 2 mm wire respectively.

Non-preferred fabrics can be produced to order where sufficient quantities are required for a given contract, in which case the manufacturer will advise on wire sizes which may be governed by the welding process.

Fabric reinforcement is supplied in standard sheets of 4.8×2.4 m and in rolls 2.4×45 or 72 mm. Where there is sufficient repetition special cut sizes can be supplied in quantity.

Steel for prestressing

Prestressing steel must have a high yield strength in tension and an elongation of not less than 3.5% for strand and not less than 6% for steel bars. Details of the four main types are as follows:

Cold worked high tensile alloy steel—to BS 4461 has a characteristic strength of 1000 N/mm^2

Cold drawn high tensile steel wire—to BS 5896 has a characteristic strength between 1550–2000 N/mm^2

Hot rolled and hot rolled and processed high tensile alloy steel bars—to BS 4486 have a characteristic strength of 1030 and 1230 N/mm^2 respectively

Seven and nineteen wire strand—to BS 4757 and BS 5896 have characteristic strengths of 1600–1850 N/mm^2 and 1500 N/mm^2 respectively.

The stress/strain curve for high tensile steel does not show a definite yield point as is the case with mild steel. So that an indication can be given in a test certificate of the curvature of the stress/strain line, the concept of proof stress is adopted. The proof stress is defined as the stress at which the applied load produces a permanent elongation of a specified percentage of the guage length. For prestressing wire a value of 0.1% elongation is used for the proof stress. As with concrete, the characteristic strength concept (that value below which 5% of the results may be expected to fall) is used in describing the quality of the steel.

Bar marking on drawings

The generally accepted system for bar identification is as follows. The type of steel is indicated by an abbreviation:

R = round mild steel bars, hot rolled bars with a characteristic strength of 250 N/mm^2 and complying with BS 4499

T = type 2 high yield steel bars complying with BS 4449 or BS 4461 with a characteristic strength of 460 N/mm^2 for diameters up to and including 16 mm and 425 N/mm^2 for diameters exceeding 16 mm

X = types not covered by R or T and a full description will be provided

If in doubt, the supervisor should refer to the local specification for the works.

The following example indicates the way in which the bars are referenced on the structural drawings:

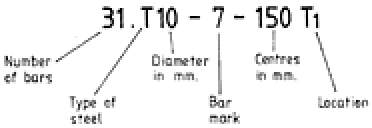
Example: 20T. 3201. 300

when — number of bars=20
type of steel=T
diameter of bars=32 mm
mark number of bar=01
pitch of bars=300 mm

The detailer will include further information on the drawing using some of the following abbreviations as applicable:

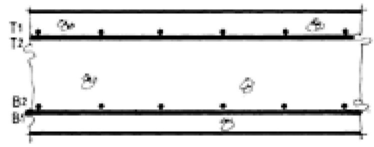
B bars in bottom of slab
BB (in two way slabs) bottom layer of bottom reinforcement
T bars in top of slab
TT (in two way slabs) top layer of top reinforcement
EF bars in each face

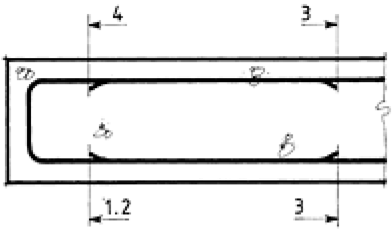
NF bars in near face (as drawn) of column or wall



the notation on a drawing refers to steel schedule and is interpreted as indicated

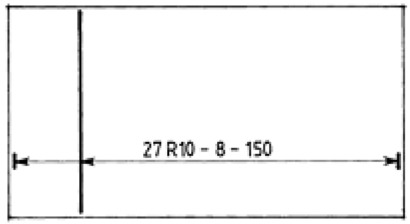
the suffix (T_1, T_2, B_1 B_2) indicates layer counting from face in top or bottom

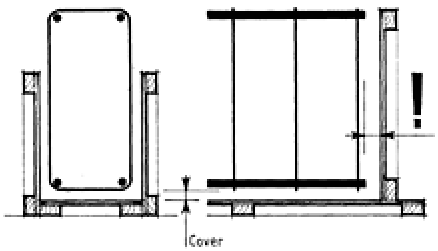




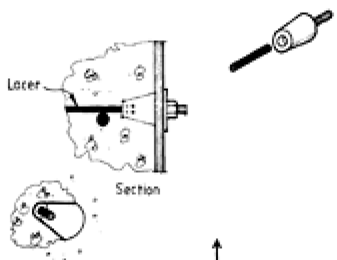
the extent of bars in section (and thus lap) is indicated by bar mark number and convention for termination

the location of bars, stirrups, etc., is indicated by showing extreme bars and indicating bar description and mark

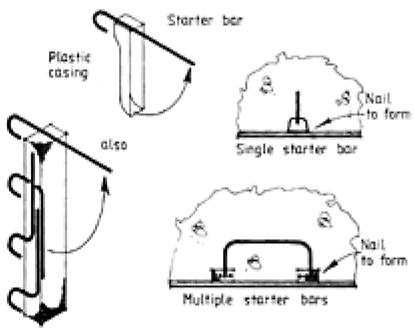




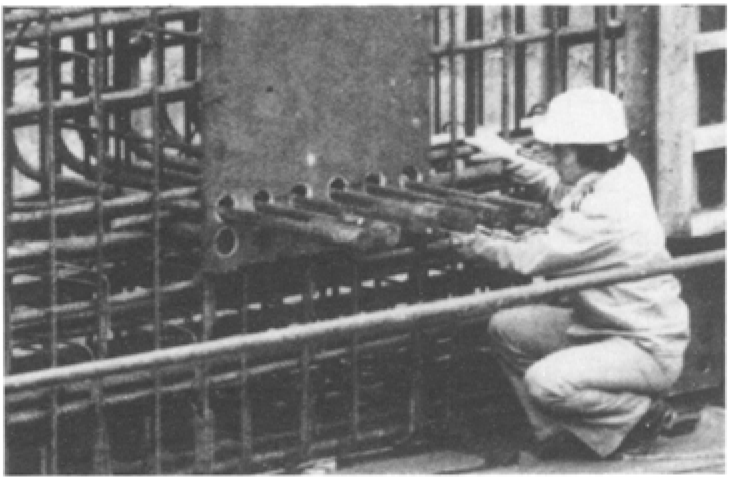
whilst attention focusses on cover at form face, end cover is equally important



ferrules are useful to ensure critical location – a visual check can be made before making good



proprietary starter bar assembly using plastic case—other units are available with bars embedded in a *foamed* plastic for attachment to form



Screwed couplers being installed to accommodate starter bars. The couplers eliminate expensive cutting of forms and provision of support to projecting steel (CCL Systems Limited)

FF bars in far face (as drawn) of column or wall
AP bars alternately placed
AR bars alternately reversed
AS bars alternately staggered
UB "U" bars
LB "L" bars

The standard radius of bends is:

(a) 2×diameter of bar, internal radius for mild steel
(b) 3×diameter of bar, internal radius for high yield steel up to and including 20 mm
(c) 4×diameter of bar, internal radius for high yield steel bars sizes 25 mm and over

The radius of bend is required to be greater than these standards in certain locations within the structure, as for example end column and wall connections to a beam or slab, in cantilever walls, where the bar changes direction from the horizontal to the vertical, in corbels and in bottom bars for simple pile caps—these bars will come under the heading "other shapes" rather than the preferred shapes defined in BS 4466:1981.

Drawing interpretation

Whilst the steelfixer and his supervisor work from drawings and schedules in caging up steel and locating it onto or into the formwork, it is necessary for the concrete supervisor to be able to interpret the schedules and drawings and himself check the installation of the reinforcement prior to concrete placement. Practice is, of course, essential, although the methods adopted as standard for steel drawings, details and schedules are reasonably straightforward and use a standardised vocabulary of symbols and abbreviations.

The supervisor is likely to become involved in drawn detail in the event of discrepancies, steel which cannot be fitted into a form or around an opening for example. In this case, he must have sufficient knowledge of the way in which reinforcement detail is presented to be able to discuss the problem sensibly with the detailer or the engineer. In such discussions it is essential that the drawing dates and issue are checked to ensure that the latest and most up-to-date revision is in use. It is helpful if the critical detail is sketched out from the information given, ideally where beam sections, scarf jointing or corbel detail is concerned the profile should be set out on a piece of ply when the actual links or stirrups can be set into place and checked for fit. Poor or difficult fits, loss of cover and so on, can be identified and trial pieces dropped into place for checking purposes.

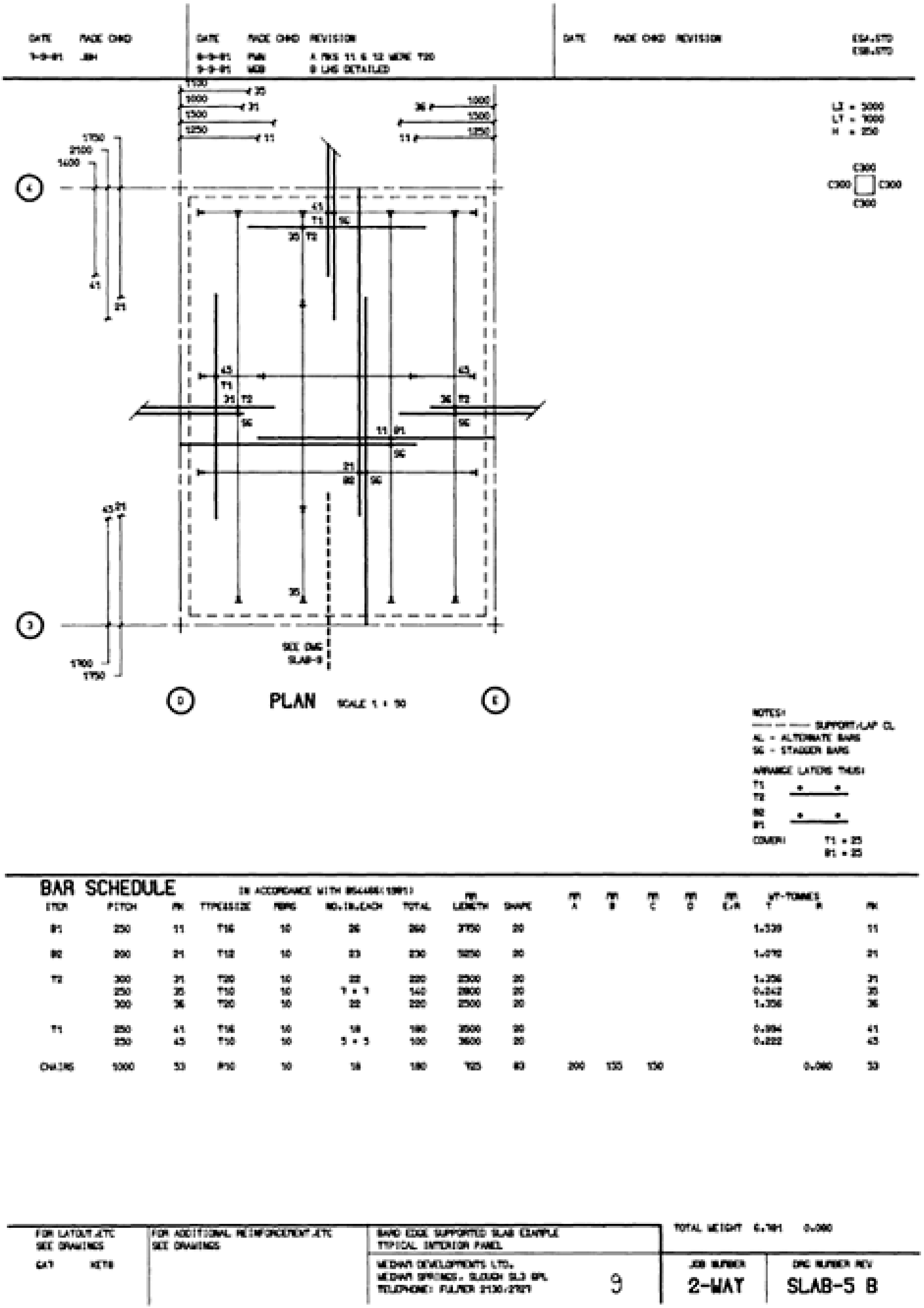
Apart from the bars included in a particular lift or bay, the supervisor must identify bars which project from the bay to provide continuity for further work. These will need to be passed through stopends or to project from the top of a bay if of considerable length, and may upset successive operations and at least, will require support to avoid damage to the concrete— coning in its fresh state or cracking in the hardened form.

Discussion early in the course of the contract can result in simplification of steel detail and introduction of joints in the bars at points in the structure which best suit the eventual location of construction and day joints, determined by the casting method. An example of this arises in shafts and in linear type construction where the laps in steel can be so arranged that only a portion of the total steel has to be fixed in any one lift or bay. Arrangements of this nature allow for better continuity of work for all trades.

The quantity of projecting, repetitive continuity steel is important in decisions regarding formwork quantities in slab and floor construction, sufficient formwork being required to allow continuity of form, steelfixing and concreting operations whilst also allowing for supporting and striking operations to continue uninterrupted. Where work is of a complex nature, the supervisor should press for the adoption of open stirrups and links which allow ease of adjustment of cages to maintain the required cover. At this stage it is worth considering the fabrication of jigs and templates which can be used for assembly and for ensuring the accuracy of the steel cage in this connection. Where there is any considerable amount of repetitive work or where the requirements of accuracy are particularly stringent, then it is worthwhile setting up in the steel area a part of the formwork or a template representing the form into which the steel can be assembled, both for fabrication and checking purposes.

When using reinforcement detail, the information sought is as follows (emphasis depending upon whether the location of steel is in question, the method of trimming an opening, or the interaction between the reinforcement and some cast in fitting such as a lift control box, for example):

drawing scale, date and latest revision;
schedule date and latest revision;
location of the structural element;
sections and where taken;
cover to steel (from drawing notes or from specification clause);
type of steel;
shape (particularly shapes other than those "preferred");
spacing;
laps and curtailment;
arrangement of steel (staggered, top or bottom, near or far face);
cover (considerable attention focusses on face cover, end cover is just as critical and sometimes more difficult to maintain);



Steel reinforcement detail and bar schedule produced by computer and plotter using commercially available software (Wexham Developments Limited)

additional steel and trimming steel at openings; relationship between reinforcing steel and cast in

components, dowel bars, anchor plates, bearing plates and so on;
location of chairs and "U" bars intended to space the various layers of reinforcement.

In general terms considerable attention has focussed upon the importance of maintenance of standard methods of detailing. The advent of computer aids to design and detail has reduced the number of drawing errors and inconsistencies between schedule and drawing. The main problems which now arise are those where the line on the drawing misleads, radius and thickness combine in some instances with the result that some bars cannot be fitted within the allocated space in the form, as the main bar diameter is rarely twice that of the stirrup, that main bar cannot be accurately located "as drawing". At column beam connections there is often a considerable amount of steel crammed into a restricted space and main beam and main column bars may clash. Where tapered work, work of reducing height, balconies splayed on plan and non-standard tapering floor bays are being detailed, the range of bar lengths can be reduced by grouping bars in set lengths and varying the lap to achieve the required changes in overall dimension.

It may be necessary for the concrete supervisor to approach the designer/detailer to obtain permission to divert steel to allow the continuous casting of a wall or to allow the insertion of a poker vibrator into a congested part of the structure. Where there are continuous cast in channels or sizeable inclusions in the concrete, in the form of box outs, bearing plates and anchor plates, etc., then the steel and inclusion details should be combined on one detail to avoid the need for excessive adjustment to cages at the time of installation into the formwork.

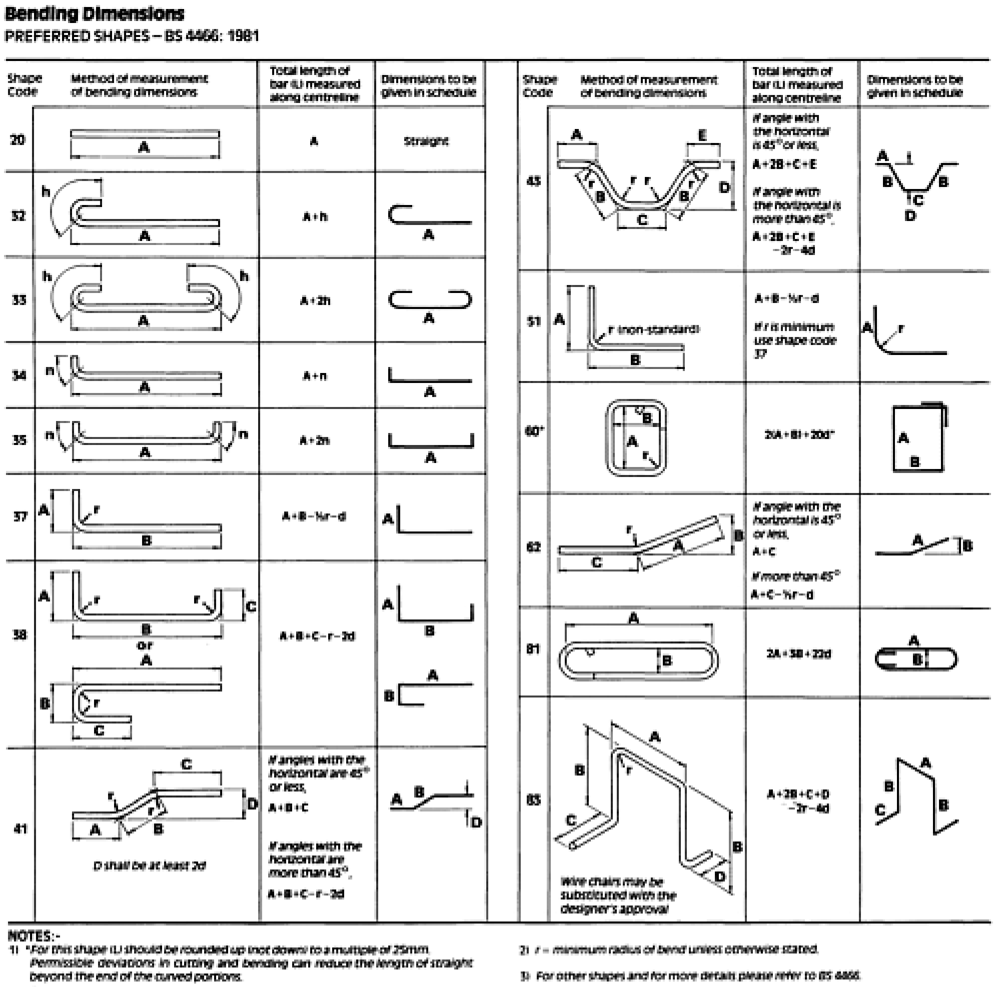
Tieing reinforcement

Reinforcement may either be located and tied in situ or prepared into cages ready for installation onto or into the form work. Whilst tieing is normally carried out using soft iron wire, there are occasions when stainless steel wire is used. As well as avoiding corrosion in the finished product, stainless steel wire is also by far the better for the operative, being free from black scale. The tieing wire is obtained in coils and most operatives work from a coil hung near the steel they are tieing. Small dispensers are also available which can be worn on the belt ensuring a supply of wire wherever the operative works.

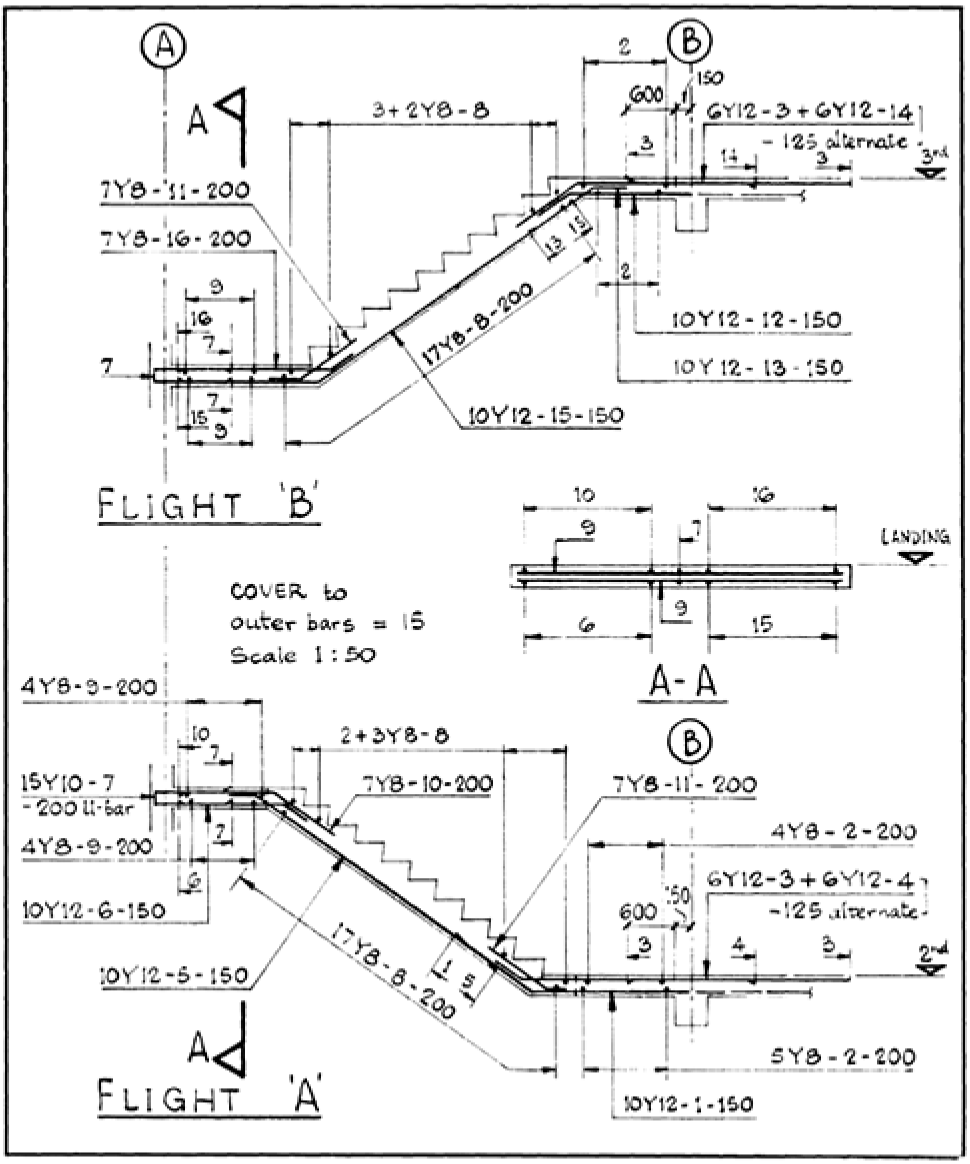
A number of tie arrangements can be used, each of which has been developed over the years to deal with particular situations. They are mainly designed to secure the steel prior to and during concrete placement without allowing slip or displacement, but the ties are not intended to contribute to the action of the steel in reinforcing the concrete. Forces imposed on the ties can be quite substantial, particularly where they must resist the impact of concrete being shot from the skip into a wall form. Special clips can be used to fasten steel and indeed preformed ties, which depend upon the use of a tool for their application, provided they tie the steel firmly and are not allowed to encroach into the concrete cover over the steel, are useful as they simplify and speed the work. These ties are purely for steel location and restraint during the casting process. The ties illustrated have been tried and tested. There is a current tendency toward the use of diagonal or "slash" ties which are often used by subcontractors for infill ties, intermediate fixings and so on, the hairpin tie and the crown tie providing a more positive fixing and the ring slash tie preventing sideways movement, as does the ring hairpin.

It is usual to set up the steel at the benches using slash or double slash ties, using a double tieing wire. The assembly is then completed using crown ties or some more rigid tie appropriate to the manner of the intersection being fixed. A great deal of steel is fabri cated into cages by welding. Welded cages are rigid and easier to locate in many instances than a similarly tied cage, although care must be taken to ensure that the welding process does not change the characteristics of the steel. Bars manufactured to BS 4449 and BS

Bending dimensions: preferred shapes: BS 4466:1981



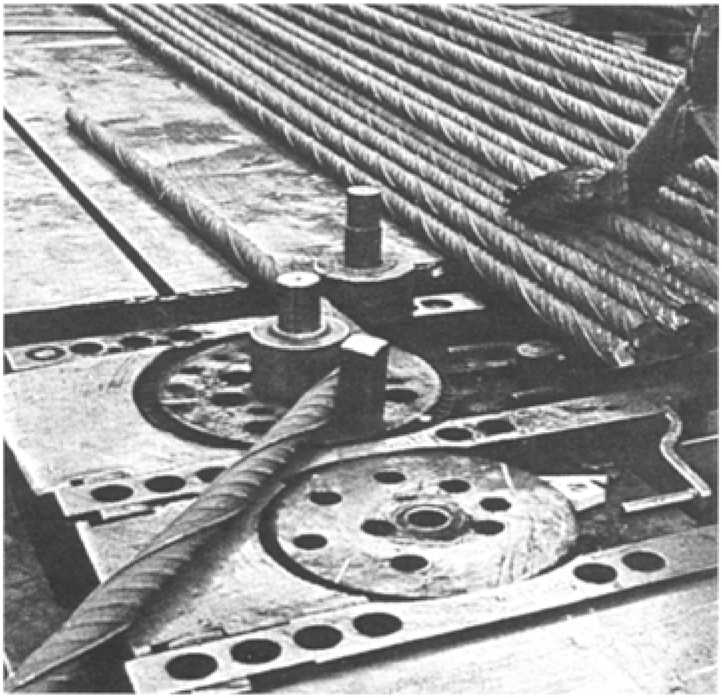
4461, including cold worked bars, may be joined by full strength welding under controlled conditions and using certificated welders. Tack welding for assembly and welding which is carried out without express instructions from the designer can be dangerous, may cause failure and should be avoided. The steel should be placed into jigs prior to the welding operation. Should any distortion exist in the cage it is virtually impossible, once welded, to achieve accurate placement and maintenance of cover. Mesh reinforcement can be used in the fabrication of cages for beams and particularly where repetitious work is concerned such as in the mass production of precast elements. Manufacturers produce what is known as “tartan” mesh, where the mesh is fabricated in such a way that when folded the bars are correctly located in the structural member. Of course, this is really an extension of the techniques used in reinforcing pipe and similar products, where the bars are fed through a combined folding or rolling jig and welding machine.



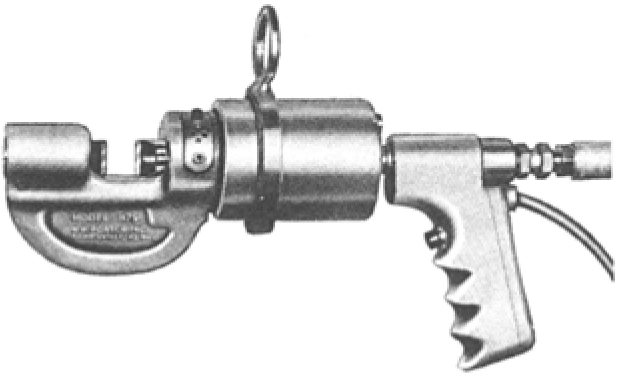
Typical detail for stair flights and landings (note convention for h.y.h.b. steel is now T not Y) (Cement and Concrete Association)

The tieing operation may be carried out with the steel in its working position within or against the form, in which case the main bars are tied to starters projecting from the kickers or from previously cast bays of concrete. Stirrups and links are then added in bundles, finally being tied in locations chalked on the main bars using the appropriate tie. The supervisor must ensure that the forms are properly cleaned of tieing wire clippings by blowing out.

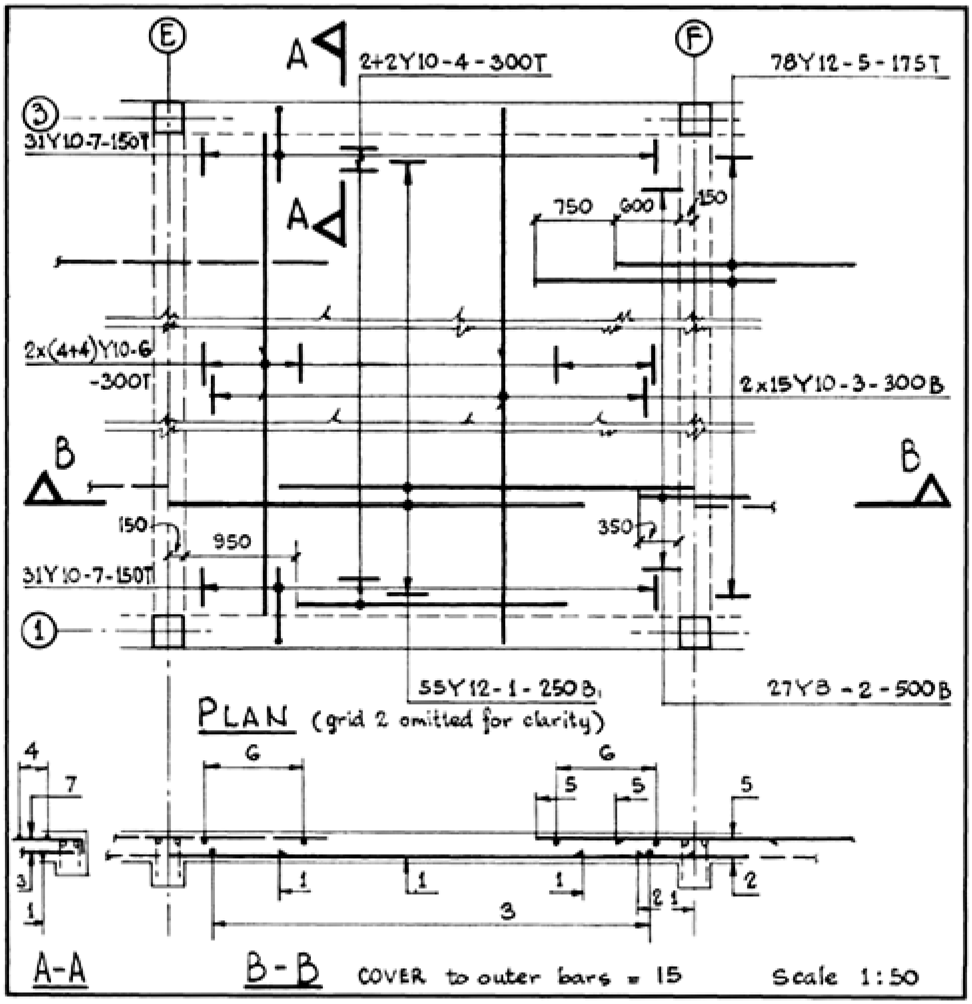
Bending T steel—machine can be preset to produce bars to a variety of shape codes



Hydraulically powered cutter can be taken to the steel location at site



Where vertical steel is used in long lengths, battens or lacers are required to support the steel during fabrication. Heavy or angled bars may require the provision of scaffold support to maintain the correct position. Care is needed in flooring and walling construction that chairs, bent from reinforcing bars, are inserted and tied to each layer of steel in such a way that they are correctly positioned. The use of chairs coupled with the use of plastic or concrete spacers will locate the steel satisfactorily, provided that care is taken to avoid exceptional loads being applied to the steel. In the case of floors, construction loads such as

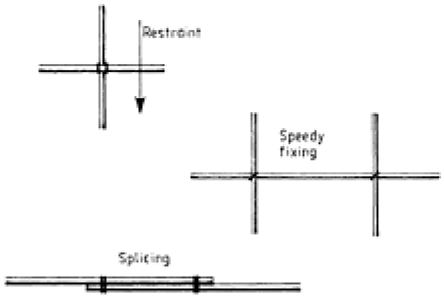


Typical steel detail for bay of floor (note convention for h.y.h.b is now T not Y) (Cement and Concrete Association)

runways and working platforms must not be allowed to bear on the steel reinforcement. In other locations loads such as forms or skips striking the projecting bars must be avoided.

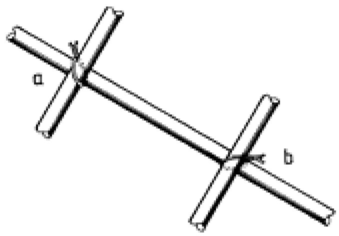
Cages are generally prefabricated on trestles arranged to provide a convenient working height. The main bars are rested on the trestle. Links and stirrups threaded onto the bars in bulk are then spaced and tied into their correct positions onto the top steel or lacers. The bottom steel is then dropped into its correct position and tied to retain correct spacing and location. In the case of deep cages, where there is no diagonal steel incorporated in the cage proper, additional temporary bars will be tied into place to avoid distortion during handling. Cages are handled using spreader bars or, at the very least, a substantial steel or timber section to support the weight of steel between lifting points.

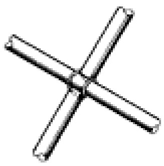
Again the cages must be marked by clear labelling with unit or location number, floor level and so on. A well tied steel cage speeds the construction process, whereas a distorted cage results in loss of cover, possible damage to form faces and wasted effort. Completed cages must be stored in such a manner that



ties have various purposes – restraint of key bars, speedy location of infill, positive connection of splices – during construction but they are redundant after concrete is placed

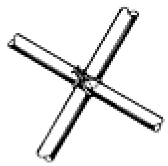
slash ties are used for infill ties (a) slash tie (b) slash tie reversed

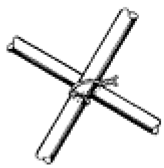




hairpin tie – excellent for key connections

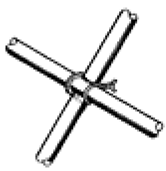
crown tie for setting-up and springy bars

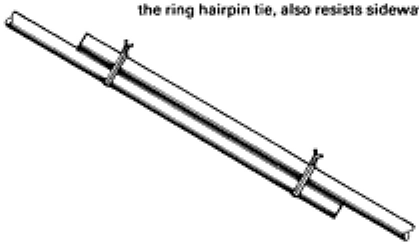




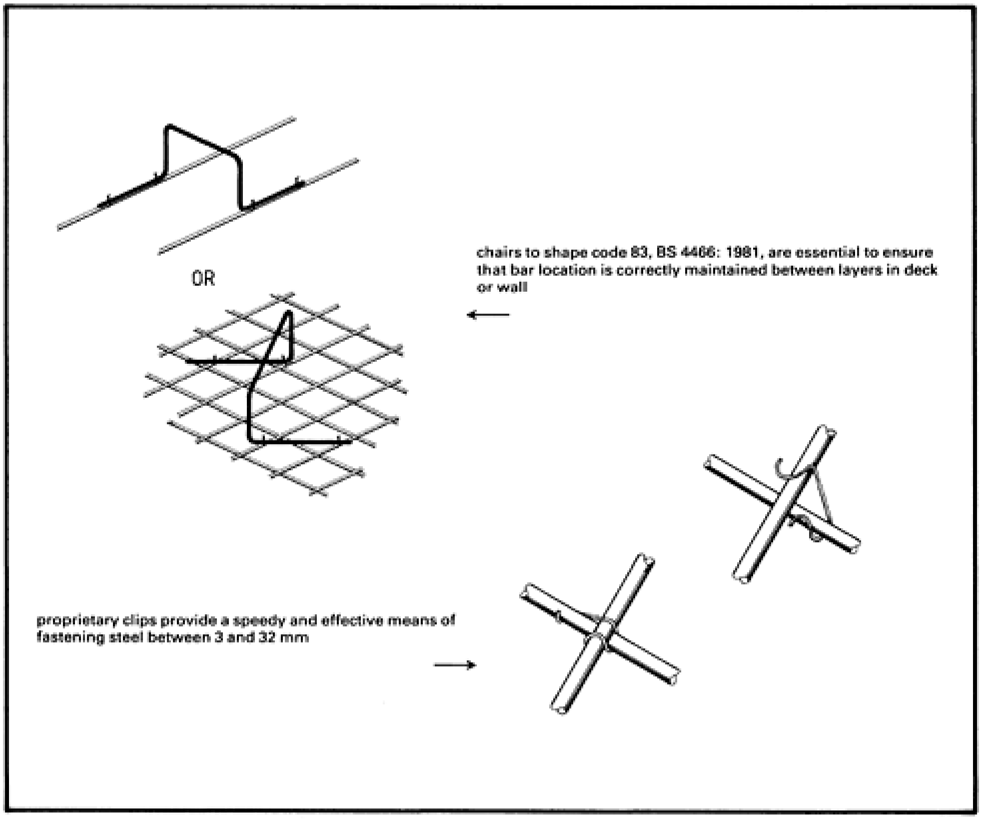
ring slash tie – an infill tie which prevents sideways displacement of the bar

the ring hairpin tie, also resists sideways movement





splice ties secure bars at laps – at least two are required per splice



they are not distorted by stacking and are not contaminated during storage. Where steel is being prepared for any mass production item such as precast elements, cross wall reinforcement, or large numbers of beams or columns, time spent in preparing jigs will prove economic in the long run. Jigs ensure accuracy, reduce tieing time, ease installation at the form or mould and allow the use of more simply skilled labour. The simplest jigs are timber framed with battens marked or notched at stirrup or link centres, used to space the steel during the tieing operation. More complicated jigs can be fabricated from steel or concrete, having a lug or notch to position both the main and the secondary steel. In the case of battery casting, for example, dummy panels cast from the moulds which are to be used hundreds of times can be used as jigs onto which the steel can be placed, tied and/or welded.

Steel cut and bent off site

The purchase of steel ready cut and bent can provide some economy. Provided that deliveries are called off from the supplier, either the contractors yard or proprietary supplier to the industry, in the correct sequence, there are savings to be made in supervisory time, skills and space on site. The order must be placed with a supplier capable of cutting and bending to the specification. For absolute economy, delivery should be phased to meet site requirements and to avoid expensive double handling. There must, of course, be good communications as to quantities, delivery dates and point of delivery. It is also important that bundles are made up into weights which can be handled by the equipment available on site. Deliveries must be arranged during working hours to avoid possible dumping of steel on site and consequent extra handling. Bundles must be checked against delivery notes and the bars themselves should be checked for compliance with schedules prior to the time of use.

Receipt of steel on site

Arrangements must be made for the acceptance of steel whether made up in cages, cut and bent or simply delivered in bundles of stock length. It is important as with all materials that the individual items are checked against a delivery note and only when each item has been identified should the delivery ticket be signed. The danger of signing for an unchecked delivery is that particular items become more likely to be omitted from the eventual structure. Where steel is called off in bays, by block, floor or beam, then it is probable that the bundles will be delivered to a place on site adjacent to the eventual point of use. This introduces the likelihood of bundles being thrown off the vehicle or unloaded onto the ground with the risk of contamination. Where steel is unloaded from the vehicle onto formwork or falsework, care must be taken to avoid introduction of undue double handling or overloading of the temporary works.

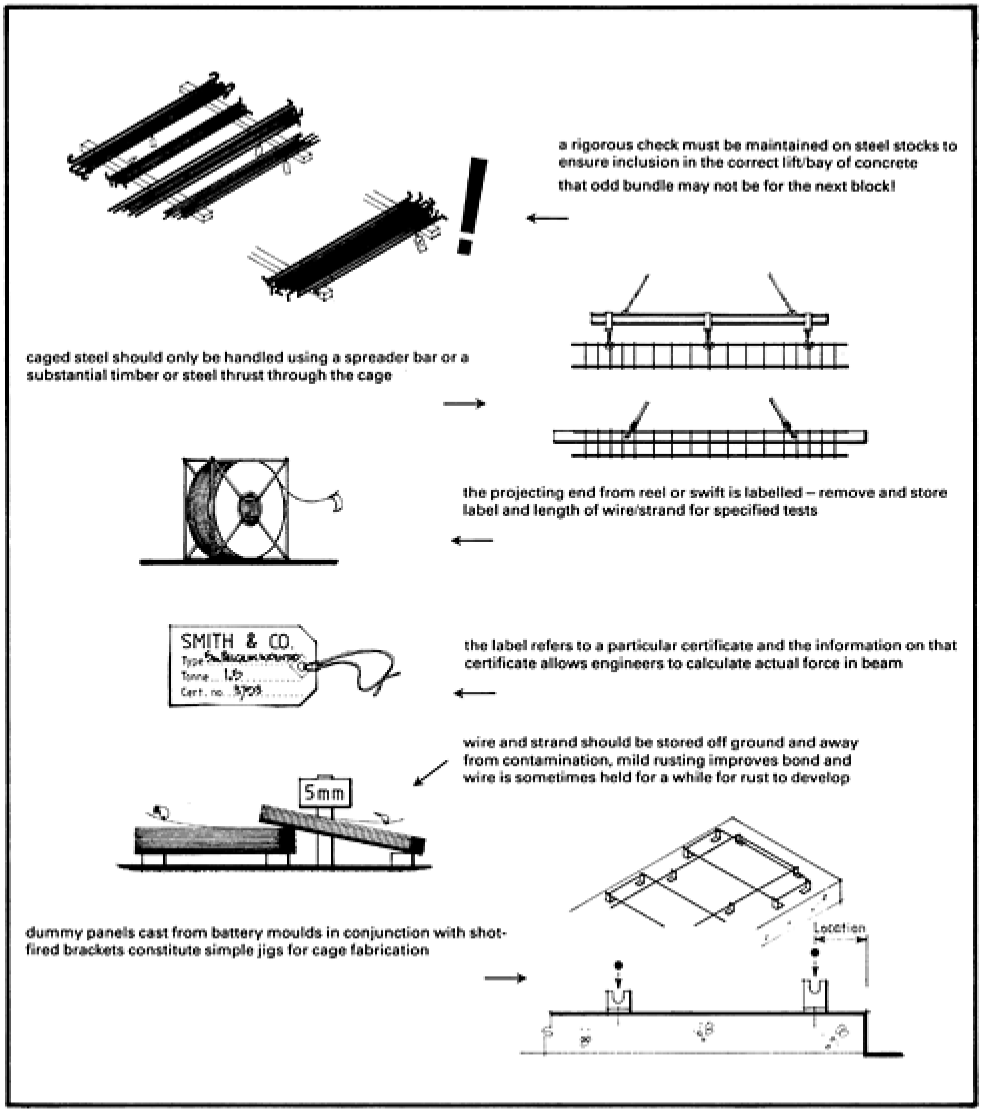
Handling steel

The bundles as delivered can be handled using slings or chairs—a spreader with several points of attachment will avoid kinking of bundles. Bundles should not be set down in a twisted manner as it is otherwise difficult to draw out the required number of bars. Once caged, the steel should be handled in such a way as to avoid distortion, which will make it difficult to maintain cover. Spreader bars, or at least timber plates or lengths of tubes passed through a cage lengthwise, will prevent unnecessary damage. Cages should be stacked by type on battens sufficient to maintain their shape. Cage labels should indicate beam or cage number, block and floor, and it is helpful if the schedule number is indicated to facilitate checks on installation. Labels should be of the indelible type and ideally can remain on the cage when it is installed. In the case of precast elements it may be helpful to leave the label projecting from the unit so that it can be checked after casting and when the unit is in stock.

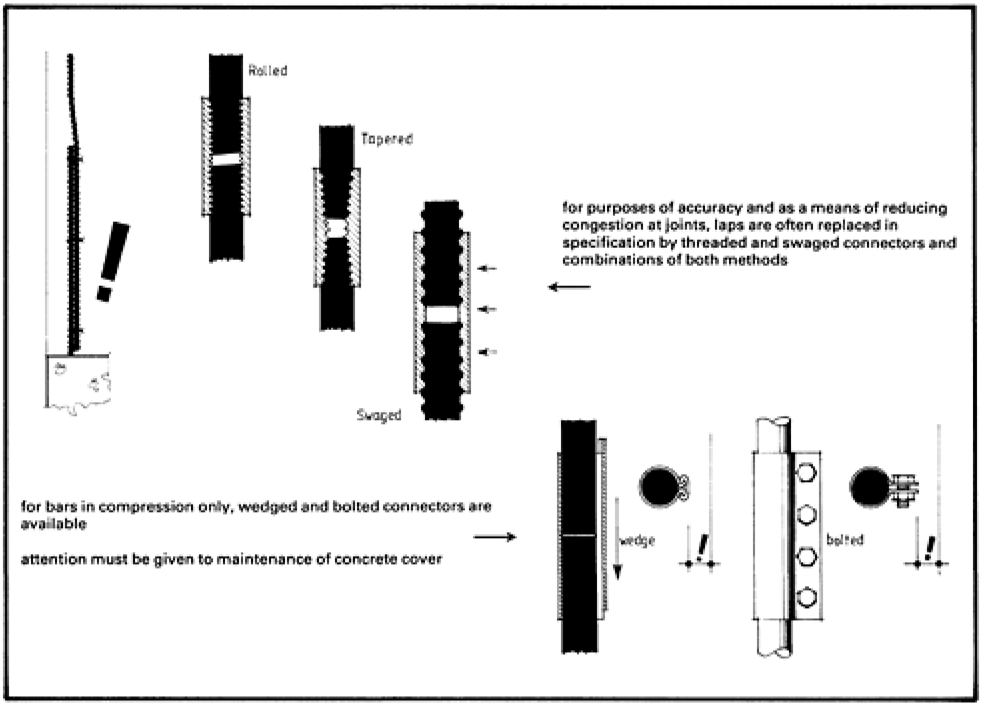
Steelyard and storage areas

These areas are generally located under a tower crane on a building site, within a dead part of the area covered by the crane—also adjacent to the main site access road. Steel is delivered in 12 m lengths normally, although 18 m lengths can be supplied on special order. Care is needed to avoid twisting and distorting the steel whilst unloading and absolute care must be taken to stack and segregate the materials on site. Clean, dry storage on steel racks, concrete sleepers or similar means of storage will avoid formation of excessive rust and scale. The use of long brothers or spreader bars, and avoidance of "barring-off" of steel from the delivery vehicle will ensure that the steel is kept in a condition suitable for inclusion in reinforced concrete. Fabric must be stored flat to avoid expensive work in attempting to straighten sheets at the time of use. Few contracts are of such duration that steel can become so corroded during storage as to be unusable. In the precast works, however, it is quite likely that due to bulk purchase for reasons of economy, some sizes stay in storage for a long time and thus may need brushing and cleaning prior to use.

Steel bars for prestressing can be ordered in lengths appropriate to unit size—long lengths will be fabricated using special couplers. Wire and strand is delivered in reels and cheeses weighing up to one



tonne, and for certain of the systems, multi-wire or multistrand tendons are delivered ready made, possibly assembled into ducting with anchor block incorporated, specially wound and crated. Care should be taken to avoid rust, corrosion and contamination and special care taken to avoid damage by dropping weld metal or spelter and molten metal from burning and cutting operations onto the wire or strand in stock, as this would result in loss of the characteristics of the high tensile steel which make it desirable for the purposes of prestressing. Where tendons are threaded, particular care must be taken to preserve these threads, although they will be greased and wrapped by the manufacturer. Where wire and strand is used for pre-tensioned production, some small amount of rust may be acceptable, although any pitting would obviously reduce the sectional area of the tendon with the possibility of failure when the tendon was stressed.



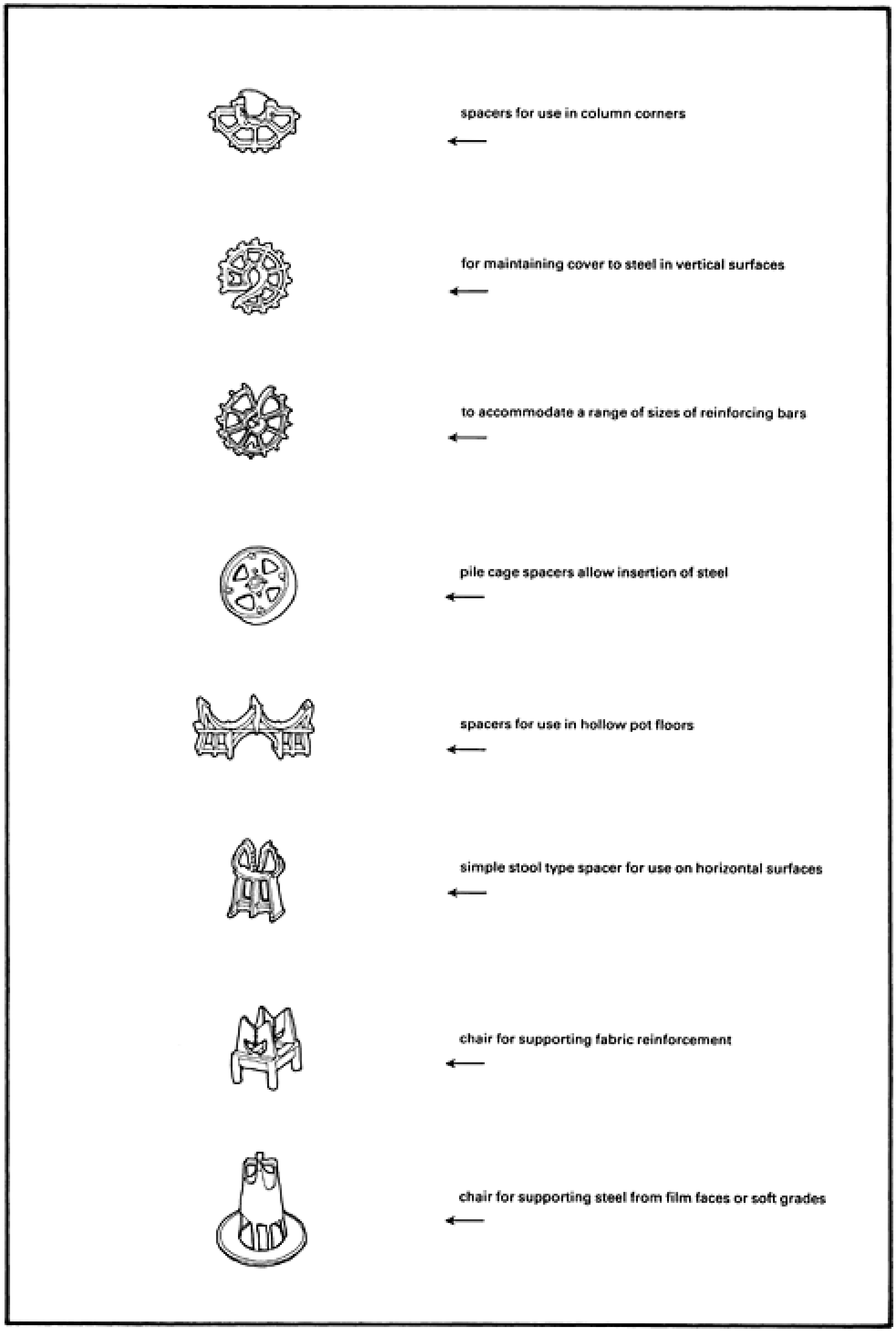
Where the scale of operations demands a steel fabrication yard, this will include equipment for cutting and bending steel as well as tieing and fabrication of cages—perhaps where it is permissible the equipment may also be provided for the welding of cages and folding of mesh. Essential in these areas are clear and clean conditions underfoot and cover for use in inclement weather. Machines must be installed by suitably qualified tradesmen, electricians and engineers, and the installation inspected and approved by a Chartered Engineer. Particular attention is required where machines use high voltage supplies and these supplies must be installed in properly fixed and armoured cables, each machine being equipped with an isolating switch as well as a clearly visible emergency switch and a shrouded "on" switch. It is obviously essential that the ground be prepared by blinding or similar means to provide satisfactory underfoot conditions.

Practical aspects of steel design and location

The Concrete Society Technical Report: *Standard reinforced concrete details,* prepared by a working party of specialists, makes useful recommendations regarding the placement of reinforcement and the way in which reinforcement may be detailed to aid those who must fix it on site. Emphasis is placed on the need to provide adequate space between stirrups to allow access for concrete and for the insertion of poker vibrators to achieve compaction. Some points of detail of particular interest to the supervisor will be:

The recommendation regarding the use of open stirrups in beams to facilitate insertion of main reinforcement;

The considerations regarding the radius of bend and its effect on displacement of the main reinforcing steel;


spacers for use in column corners
for maintaining cover to steel in vertical surfaces
to accommodate a range of sizes of reinforcing bars
pile cage spacers allow insertion of steel
spacers for use in hollow pot floors
simple stool type spacer for use on horizontal surfaces
chair for supporting fabric reinforcement
chair for supporting steel from film faces or soft grades

The point that links should be located at the upper offset point in the cranked bar in a column to resist the horizontal component of the force in the inclined part of the bar.

Reference is made to the use of mechanical splices in bars in compression as a means of reducing steel congestion, although the recommendations underline the need for square cut bar ends in this instance. Whilst the various recommendations regarding insertion of lacing bars and similar means of caging and supporting steel are aimed at the structural detailer, they make sound sense and assist in the construction task.

The supervisor should be aware that the detailer at the drawing board may find it difficult to visualise the full implications of the three-dimensional form of reinforcement. The lines on a drawing do not convey the actual space taken by a bar which is prepared in accordance with the standard shapes given in BS 4466: *Bending dimensions and scheduling of bars for the reinforcement of concrete.* The most likely time and place for problems to arise is when the formwork is closed about the steel just prior to concreting or when the steel in a reinforced precast concrete unit is mated to the mould, once again just prior to concreting. The supervisor, in conjunction with the steel fixer foreman, should look carefully to ensure the correct cover can be maintained as well as space for concrete placement and compaction. Important aspects of reinforcement which the supervisor should check are:

Where, for some reason of construction, bars have been diverted, bent into and along the form face or omitted for later insertion. Failure to ensure that these bars are properly reinstated can have dire results;

Where openings are formed in a slab, possibly in accordance with revised detail. It is important to ensure that additional bars required to trim the opening are installed as detailed—a point which may easily be overlooked in the course of changing or inserting formers onto or into the formwork.

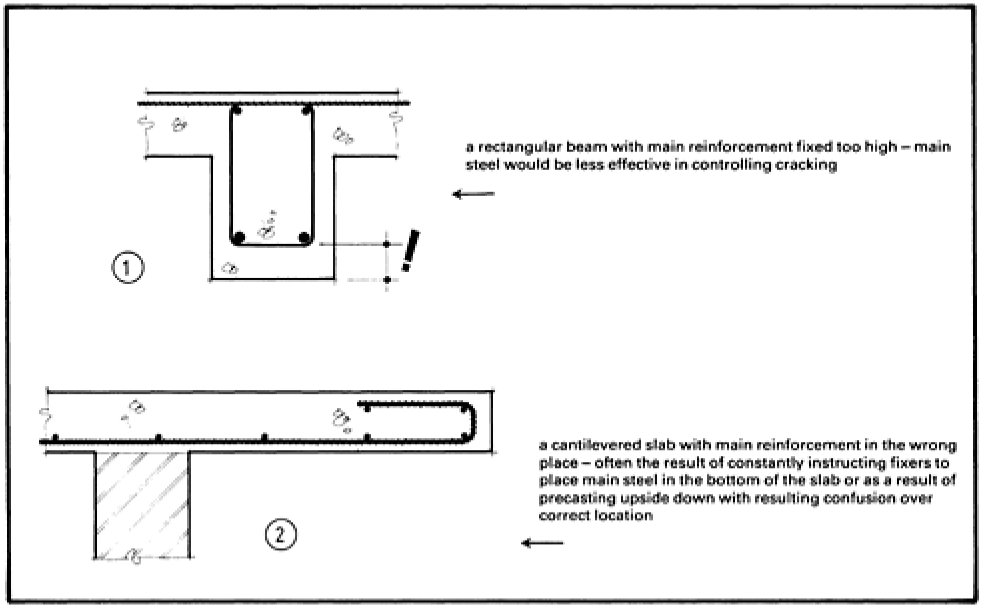
In the context of reinforcement detail, the author had the opportunity of examining two sets of steel details for a particularly complicated precast concrete component. One set of details was prepared by a detail draughtsman in the normal course of preparation of standard reinforced concrete details. The second set was prepared under the guidance of an engineer who had been involved as a site engineer in the construction of elements reinforced in this standard way. The result —the steel detail for the second operation was simpler to cut and bend and infinitely easier for the steel fixers to assemble within the very complicated jig used in fabricating the cage. The resultant cage was accurate, rigid and ensured the maintenance of cover, yet the bars were all of simple shape.

Incorrect positioning of reinforcement

The exact position, shape and type of reinforcement is shown accurately in the drawings of the designer and detailer. Any error in reading the drawings or misfixing the reinforcement may have disasterous results. Two simple examples of misplacement are shown below:

Points of supervision

1. Maintain up-to-date schedules
2. Record all deliveries of steel onto site
3. Identify bundles and shapes



4. Stack materials to avoid contamination
5. Retain copies of labels from prestressing tendons, wires and strand to link with test certificates.

16.
Batching and mixing concrete

The objective of all supply and handling must be to provide concrete in sufficient quantity, of acceptable quality and of suitable workability at the point of placing to enable the construction to proceed systematically and economically. Determination of the means of batching, mixing and handling concrete are generally critical decisions made in the precontract planning stages. The plant selected will be based on a number of factors:

site location and available space;
service availability;
scale of operation;
location of batching plant;
distance of transport;
type of concrete to be produced;
required rate of placement;
ground conditions;
tide or flow conditions in or over water;
detached operations (jetty, tunnel construction, etc.);
vertical and horizontal travel.

There will also be purely economic considerations, such as available equipment, cost of hire or purchase and possibility of further use on successive contracts.

The type and size of batching plant ranges from the "coffee pot" mixer used so effectively by the small builder and contractor, through tilting drums, reversing drums, pan and paddle mixers, to the huge electronically controlled plant which can be worked through a shift with little or no manual intervention. Certain types of construction and various techniques demand particular means of handling and in some instances the means of handling combines with the method of achieving compaction, as in placing using pneumatic placers, spray application of concrete and similar processes. The supervisor should install and maintain control on a weekly and day-to-day basis in the course of construction to ensure continuity of concrete supply. Points such as maintenance of equipment and selection of operators depend on the supervisor and it is his attention to detail which ensures that the plans prepared in the precontract and planning stages can be taken to a successful completion.

A well ordered batching plant with effective bin dividers worked by boom scraper (Benford Limited)

Receipt of materials on site

The whole process of supply begins with the acceptance and storage of concrete materials. The quality of the materials is generally specified by reference to British Standards and Codes together with the local specification governing the sampling and testing procedures which must be adopted on site. Regular checks should be maintained as set down in the local specification and certificates obtained for compliance of materials to the established and relevant Standards.

Batching

Batching is the term used to describe the process of collecting together and measuring, preferably by weight, the correct quantities of each of the materials specified to be included in the concrete mix. Batching includes the proportioning, according to the mix design, of some of the following materials:

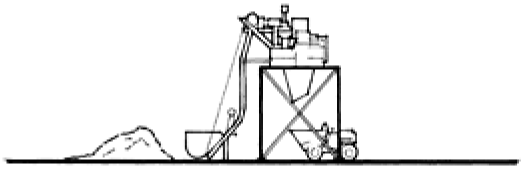
Aggregate—coarse, fine, graded, single sized, "all-in", lightweight, dense, natural and man-made

Cement—Ordinary Portland, rapid-hardening Portland, sulphate-resisting Portland, Portland blastfurnace, white, low-heat Portland, masonry, waterrepellent, hydrophobic Portland and high alumina

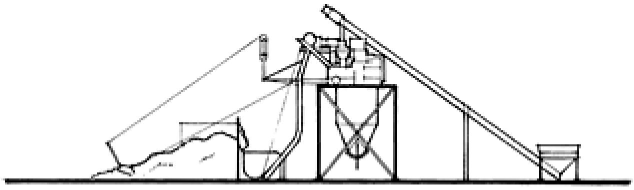
Admixtures—accelerating, retarding, water-reducing, accelerating water-reducing, retarding waterreducing and air-entraining

Water

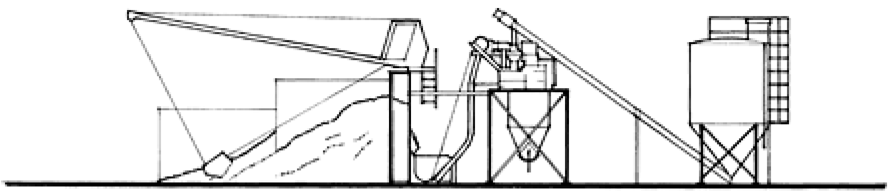
The batching process may be simply carried out using small balance type weigh hoppers in conjunction with mobile mixing plant, or automated in terms of measurement by load cells incorporated in weigh hoppers as part of a complete storage and dispensing system. In this instance, proportioning may also be carried out by load cells in conjunction with moving feed belts. An essential requirement of weigh batching equipment is typical batching plant set-ups



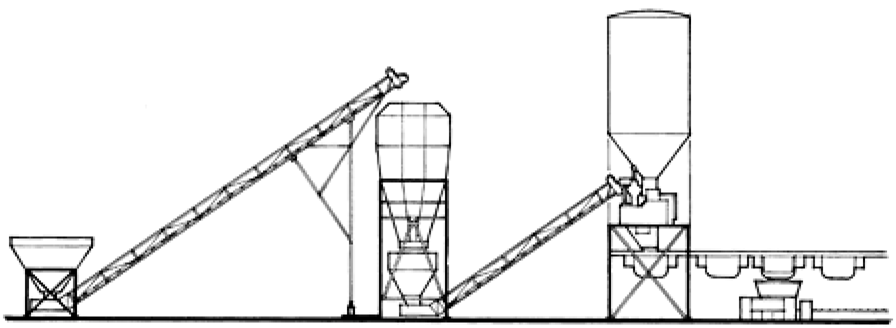
a) set-up suitable for small to medium sized site



b) equipment for medium sized site



c) continuous production for large site or readymixed concrete production



d) high volume plant for factory production

Taking the plant to the work—batching plant and mixer on barge adjacent to the point of placing

that the cements and aggregates must be weighed separately, as aggregates are generally in a moist condition.

Mixing

Types of mixer are clasified by BS 1305:1974 into four groups identified by the initial letters:

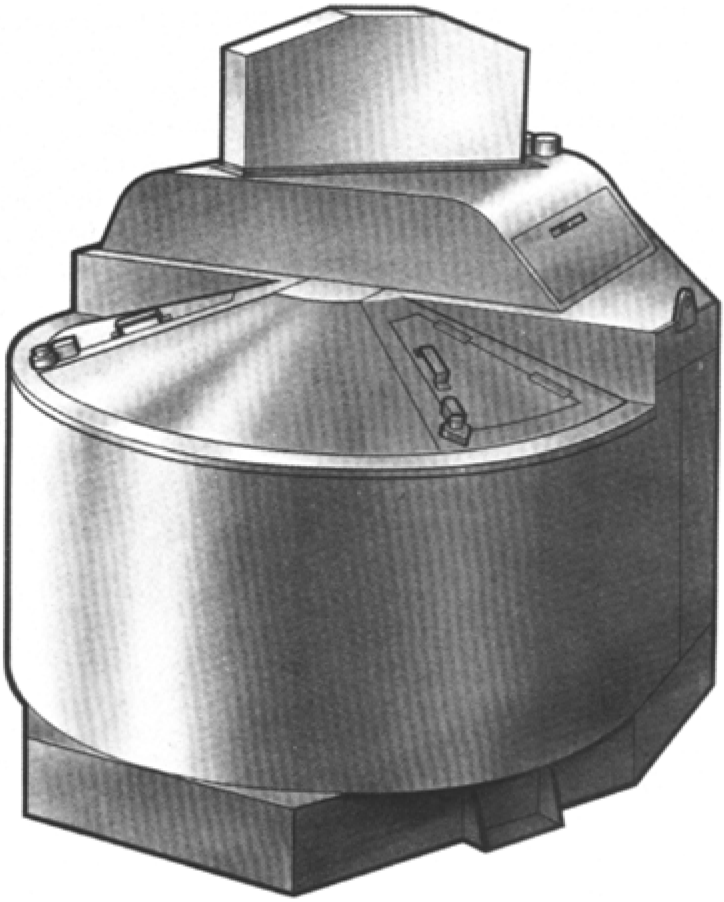
T	=	tilting drum
NT	=	non-tilting drum
R	=	reversing
P	=	forced action

The main characteristics of these mixers are as follows:

Tilting drum mixers (T) are suitable for medium strength concrete in the capacity range 100–200 litres and for producing mass concrete with large (150 mm) aggregate in 3 and 4 m^3 batch size. Materials are poured into the drum and discharged by tilting the mixer drum. Front to rear mixing is good provided the specified drum angle is maintained (generally 20–30° to the horizontal). To avoid clogging of the mixer, the drum water inflow should be started prior to the dry materials being loaded into the drum. To prevent loss during charging, the cement should be sandwiched between aggregate and sand in the weigh hopper. Material left sticking to the blades will impede the mixing action and hence effect the quality of concrete produced. The blades lift the concrete to the top of the drum and allow it to fall, encouraging mixing.

Non-tilting drum mixers (NT) are very rarely seen today. Materials are poured into the drum and discharged by a chute which pivots into the mixing drum, catching material as it falls from the top. They are not good for high strength or lean mixes and have cycle times of about 3 minutes—the discharge is particularly time-consuming. The BS output capacity range for these units is 200–750 litres.

Reversing drum mixers (R) have two openings and two sets of blades. Materials are loaded at one side and efficiently mixed by the one set of blades. When the rotation of the drum is reversed, the second set of blades empties the concrete out of the other side. These machines are good all-round mixers and are found



Forced action pan type mixer with planetary action—this equipment combined with central visual control ensures continuous consistency of concrete supply (Liner-Croker Limited)

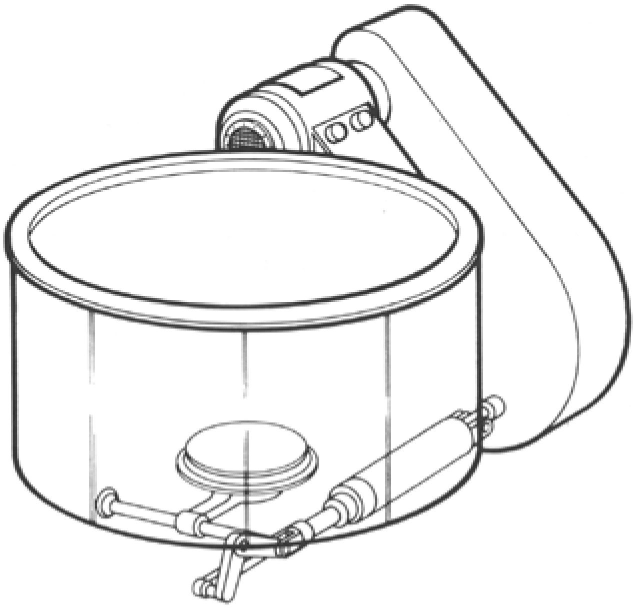
on many medium sized sites. They can cope with most concrete, except lean and sticky mixes and range between 200–500 litres output capacity.

[The 3 previous mixers are known as “free fall” mixers where a certain amount of gravity is used in mixing]

Forced action mixers (P), as their name implies, only use mechanical power to combine the constituents. Because of this, mixing is much more thorough and all types of concrete can be produced. This makes them the most versatile, but at the same time the most expensive in energy consumption and mechanical wear. Capacity ranges from 200 litres–3 cubic metres.

There are two types of pan mixer:

(a) stationary pan with rotating blades on central axis;
(b) rotating pan with rotating blades on an eccentric axis.



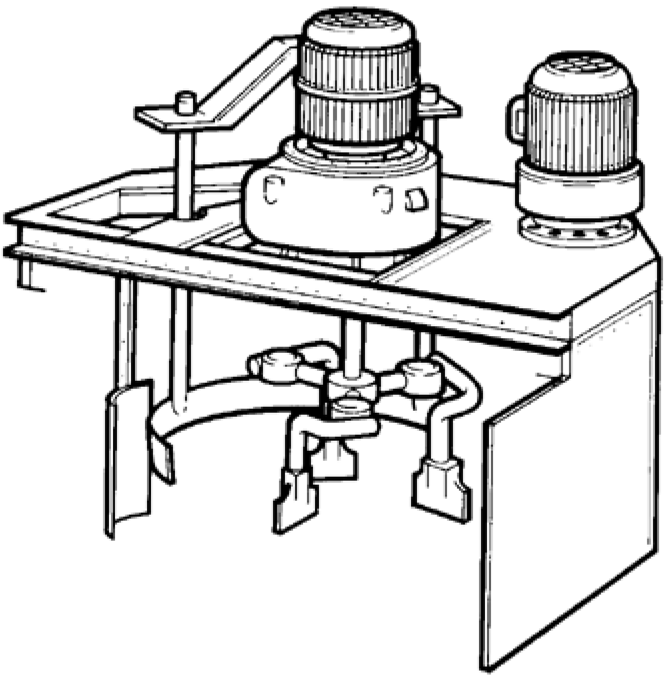
The pan is mounted horizontally and discharge is through doors on the pan floor. Materials are usually weighed whilst the previous batch is being mixed. With the fast discharge, the complete cycle time will be between 1−1½ minutes. Another type of forced action mixer is the trough mixer which has paddles rotating about a horizontal axis set in a semi-circular trough. Other parameters are similar to the pan type.

Mixer outputs

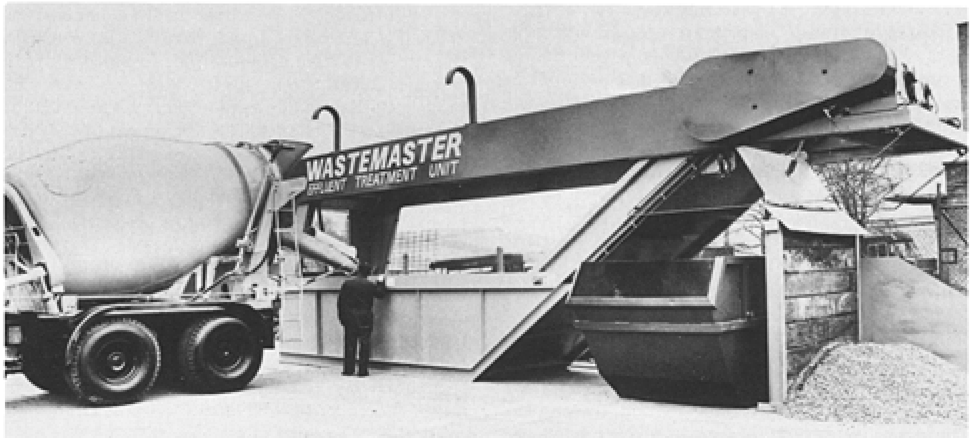
The amount of concrete a machine will produce depends on its type, the workability of the concrete and the cycle time. Theoretical outputs in m^3/hours are given in the following table for various machines. Actual outputs are generally about half theoretical, but theoretical outputs can be attained when required.

Location of equipment

The location of equipment on the construction site must be related to site access, the flow of materials in the process, the location of areas of greatest demand, and a number of other factors, the most critical of which must be access for vehicle delivery of materials such that handling of the fresh concrete can be carried out using the simplest and most economic means. This may mean the adoption of dumpers, trucks, conveyors, pumps and placers, skips handled by tower crane, hoists or a combination of one or several of these measures. The location of storage, handling and mixing equipment should be determined by the geography of the site, access to main roads or, in the case of rail supply of materials, access to railway siding. It is usual to pave the area adjacent to the plant and, in the smaller operation, the mixer may well be set up on a part of the permanent access road system. In an ideal situation loaded dumpers and so on should run downhill from the plant and some degree of elevation ensures that aggregate bins drain effectively, standardising stocks in hand. Where small plant is concerned, a mixer set up on a sleeper built bay will enable skips and dumpers to be located below the discharge chute to receive freshly mixed concrete batches running out from below the plant by gravity.



The effluent treatment unit which recycles the cleaning water forms a useful addition to the readymixed plant—four vehicles can be washed at a time and the aggregate re-used (except for quality concrete) (Batching Plant Limited)



The location will, of course, be related to the area of the site where the maximum demand is going to occur in the course of construction. It may be desirable to locate ancilliary plant in strategic positions of considerable demand. For example, with a substantial raft to cast, it may prove economic to set the mixer up on a platform such that it can discharge directly to the point of placing or to chutes which will be used to distribute the concrete. An extension of this system in work ad jacent to water and in the maintenance of river and canal walls and bridges, is the barge mounted plant complete with storage bins for aggregate and a

Cycle time [sec]	Mixing time [litres]										
	100	150	175	200	250	350	500	750	1000	1500	2000
60	6	9	10.5	12	15	21	30	45	60	90	120
75	4.8	7.2	8.4	9.6	12	16.8	24	36	48	72	96
90	4	6	7	8	10	14	20	30	40	60	80
105	3.4	5.1	6	6.9	8.5	12	17.1	25.7	34.3	51.5	68.6
120	3	4.5	5.25	6	7.5	10.5	15	22.5	30	45	60
135	2.7	4	4.7	5.3	6.7	9.3	13.3	20	26.7	40	53.3
150	2.4	3.6	4.2	4.8	6	8.4	12	18	24	36	48
165	2.2	3.3	3.8	4.4	5.4	7.7	10.9	16.3	21.8	32.7	43.6
180	2	3	3.5	4	5	7	10	15	20	30	40

Mixer type: T = ———; NT = — — — —; R = - - - - - - -; P = —·—·—·

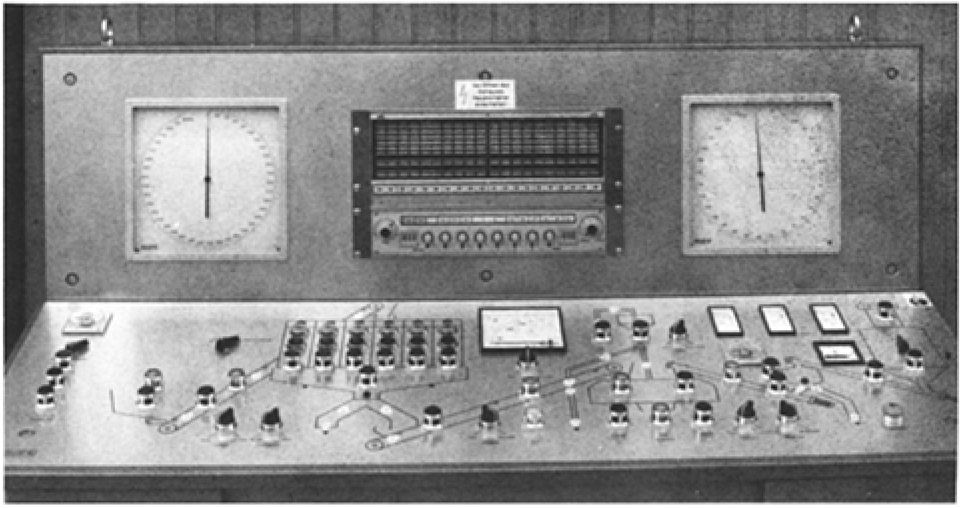
small hoist for discharge into form work. Massive vessels loaded with aggregate and cement together with a batching plant are occasionally used to supply concrete to sites in extremely difficult locations, such as the construction of oil platforms and similar, where distances are too great to allow economic transport by pumping.

As a general rule, services should be taken to the plant rather than the plant located at available supplies of water and electricity. Water supply to the plant must be provided from tanks fed by a substantial mains or by pump from bowsers. Air at the required pressure will be provided by a local compressor. Electricity supply must be guaged to the demand and the establishment of a supply sub-station at site may be necessary. Drainage must also be considered as a substantial amount of water is required in washing down. In the case of the larger operation, a proper wash bay should also be incorporated for cleaning vehicles used to transport the concrete about the site. Larger plants today incorporate a control room providing sound working conditions for the operator as well as protecting control equipment. Winterised plant will incorporate insulated bins and discharge equipment as well as a supply of hot water or steam. In plant designed for use in hot countries, the cabinet protecting equipment may be pressurised to exclude dust and where plants are located in exposed sites in very hot countries and concreting is carried out in extremes of heat, ice dispensers may be incorporated into the plant, discharged crushed ice as part of the water introduced to the mix.

The location of batching plant in precast operations, whether on site or in a purpose-built factory, will be determined by access, means of transport, and will generally be so located that the operator has a view of the making bays. Here again the plant must be located in such a way as to minimise the distance to be travelled by the fresh concrete to the points of maximum demand. High demand is generally met by the use of “bullets” or high speed skips running on monorail.

Storage of aggregates

Aggregates will normally be stocked in heaps between bin walls or dividers. Where possible the bin bottoms should be paved to prevent contamination of aggregate by soil or surface water. The paving should drain to a sump or away to an adjacent soakaway. Bin dividers should be of substantial concrete—sleepers



Control panel for a modern batching plant—the display panel indicates which mix is being prepared and the state of stocks, a print of the actual mix proportions and quantities is delivered for each batch (Cornelly Equipment Company Limited)

or precast elements serve well. Walls should be able to withstand the considerable force arising from the materials in stock as well as possible impact from delivery vehicles or the bucket of the boom scraper. Most large plants are now fitted with boom scrapers, manually operated or latterly automatic. Automatic scrapers are controlled by sensors which determine the level of bin stocks and switch the scraper accordingly. In this instance the point of delivery of aggregate must be guarded either by sensor or by the provision of a switch overriding the automatics. Operatives must also be prevented from inadvertently walking into the area swept by the scraper.

Delivery to hoppers is generally by conveyor or sometimes by direct discharge into receiving hoppers. Receiving hoppers such as those which feed conveyors must be guarded with a grillage which protects the worker and guards against debris being discharged into the conveyor. Elevated bins provide storage for aggregates in 400–500 tonne lots. Bins are usually provided for four or six different materials. Again the bins must be covered by grilles to prevent operatives falling through or into the aggregates. Although this is a well known hazard, there are still many accidents and some fatalities reported due to the omission of such safety features. Sand stocks provide a particular hazard as a person is easily suffocated, even when only partially immersed in sand. The material often cavitates at the discharge door and collapses with dire results should a man venture onto the surface.

Stocks should be prevented from becoming contaminated—in extreme conditions from aggressive dust and salts and in rural situations from wind blow leaves and rubbish or mud splashed by passing vehicles. It is generally advisable to stock two or three days supply of aggregate so that they drain down and standardise. In extreme weather stocks should be heated and protected from freezing by insulation. The cut-off doors on bins are particularly prone to freezing, especially where pneumatics are used as motive power. All receiving hoppers should be clearly marked with the size to be tipped. Quality control can be drastically effected by even a part load wrongly tipped.

Storage of cement

In the case of bagged cement, adequate protected storage space should be provided. High stacks should be avoided and rotation of stocks is essential. It is generally sufficient on the smaller site to allocate an “elephant” tent whilst a Nissen hut may be appropriate where larger stocks are to be maintained. The cement should be stacked on duckboards with sufficient space for access where necessary without damage to the bags.

Bulk supplies of cement are generally stored in silos with gravity or screw feed to the mixer. The silo itself must be watertight. The pipes for introduction of the material must be clearly marked and located such that the hoses from delivery vehicles can be easily attached, avoiding sharp curves. The inlets should be marked with the type of cement stored in the silo to avoid wrong delivery of mixing materials. The filters on the exhaust must be cleaned often, to avoid excessive dust being expelled when filling is in progress.

Storage of admixtures

Whilst small quantities of admixtures may be stored in drums and dispensed by the mixer man, it is essential that admixtures used in large production runs should be dispensed by a properly calibrated device. The majority of admixture suppliers offer equipment which has been designed specifically for this purpose and their advice should be sought at the time of installation of main plant. The dosage for each batch must be clearly stated on the batch card to which the operative refers when setting up for a particular mix. The admixture should be discharged into the mixing water as it is introduced into the mixture. Where an admixture is added manually, slightly longer mixing time should be allowed.

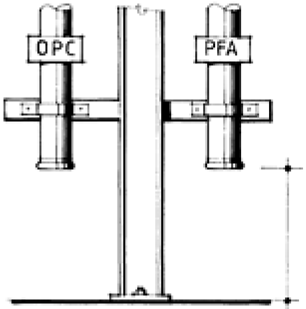
It must be noted that admixtures containing chloride must not be used in prestressed or reinforced concrete.

The large batching and mixing plant

This equipment, suited to the larger scale building or civil engineering contract, is in fact a concrete production factory in its own right. The mixer will range from 1–4 m^3 capacity, fed by a boom scraper from elevated bins or ground level storage bays. Consumption of aggregate is considerable, 150 tonnes or more per hour. Good access roads for tipper trucks and cement lorries delivering bulk cement to an elevated storage hopper are essential for efficient production. Cement is screw-fed or blown to a weigh hopper separate from that in which aggregates are weighed. In more modern equipment the batching plant is controlled automatically by programmes contained in micro-processors which receive data from various sections of the plant. A typical control system is linked to:

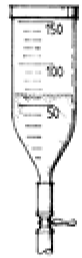
1. the electronic load cells used in each of the plant batch weighing systems
2. electro-pneumatic circuits controlling the flow of water/cement and aggregate
3. all motors and limit switches
4. an automatic boom scraper to control the stocks throughout in direct relation to the selected mix design
5. a memory bank which stores information necessary to handle 100 or more different mix designs
6. a print-out producing a permanent record of date, time, mix time and actual batch weights
7. a stock control system providing records of the state of stocks at any given time.

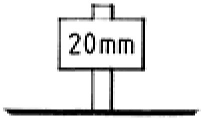
The controls are such that at any one time in the batching and mixing cycle, one mix is being weighed, one is being elevated and one is being mixed by a high speed compulsory pan mixer. Facilities are normally



provide adequate ground clearance at silo inlet pipe – mark pipes clearly to avoid wrong delivery

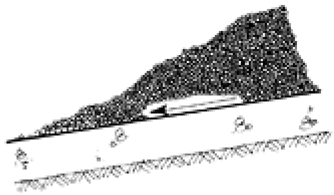
admixture dosage must be carried out by dispenser or provide measure – particular care is necessary when batching part mixes





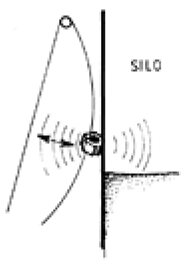
clearly mark aggregate bins – a wrongly tipped load upsets quality control

ensure that aggregate stocks have adequate drainage



maintain adequate stocks to ensure drain down and standardisation of water content

ensure that bin dividers are maintained throughout course of the work



a heavy nut on an endless line allows silo to be sounded to establish cement levels provided for the use of hot water, or possibly steam, in the mix. Dispensers allow the accurate dosage of admixtures and additional silos will accommodate pfa if required. A number of techniques have been employed for the measurement of water, ranging from electronic sensors to watt meters recording the electrical consumption of the plant as a means of assessing workability (and, indirectly, wate content). A recent technique uses an electronic device measuring variations in moisture content in the aggregate as it is discharged into the mixer. In this case the amount of water added to the batch is automatically adjusted to compensate for varying moisture content of the aggregate from stock.

In automated supply, such as in the on-site production of precast elements, the transporting equipment may be automatically activated. Each time a batch of concrete is mixed, a skip is filled and travels at high speed by monorail to the mould or machine where it is discharged into the receiving hopper. Automated supply can also be used to produce varying graded batches of concrete where, for example, cement replacement by pfa is automatically adjusted according to the location of that batch within the production along a precasting line. Sophisticated plant is available, capable of batching and mixing hot concrete, using either hot water in the mix or steam injection through the blades of the mixer or by sparge pipe. The provision and use of hot water in concrete is one means of combatting cold conditions on site, although the method of transport must be such that the heat so introduced is conserved throughout handling and placing.

Small mixers in general use on site

Usually, whatever the scale of construction, it will be possible to find one or two coffee pot mixers somewhere on site. These mixers are used for mortars, floor toppings and even (unsuccessfully!) to mix grout. They have their place in construction and the production of small batches of such special mixes. Unfortunately, even on the best organised of sites, due to lack of permanent operation they are often neglected and damaged by hammering in the cleaning process. The supervisor would do well to ensure that such equipment comes under the control of one man who should be responsible for its cleaning and maintenance.

Fresh concrete storage

In some situations it will prove advantageous to install a receiving hopper or wet hopper at the batching plant, although this can lead to problems where more than one set of mix proportions are in use. A wet hopper increases the output of a particular plant by reducing waiting time when a mix must be held in the mixer pending discharge into the transporting equipment. It will be obvious that any delay in transit or in placing will otherwise delay the next mixing operation.

Air compressors and air receivers

In most batching plant and in some mixing equipment, air is used to activate doors and cut-offs. The air supply is taken from a compressor and associated air receiver.

Absolute care must be taken to ensure that such equipment is fully maintained and that the installation complies with relevant sections of the Factories Act and appropriate Health and Safety regulations. Unfortunately, compressors, particularly hired equipment, are often kept running for excessive periods and yet maintenance is carried out on the basis of a 30–40 hour working week. The nett result is that breakdowns occur, often just when the equipment is urgently needed, and usually at considerable cost. Responsibility for maintenance must, therefore, be clearly established.

Maintenance and inspection of equipment

The mixer must be thoroughly cleaned down after every usage—daily in the case of continuous production, and more frequently where intermittent use is made of equipment. It is important that the concrete is not allowed to stiffen and build up on the equipment as the use of bars and hammers can dent and distort the plating from which the mixer is constructed, leading to further build up in subsequent use. Coarse aggregate and water run in the drum for 10–15 minutes after discharge will clean the equipment and prevent further build up. The following checks should be made daily on the equipment:

Check that the blades are not bent, broken or loose;
that all nipples are greased;
that no wire ropes are damaged;
that the water guage is working;
that safety guards, fences and so on are in place.

The supervisor must ensure that all electrics are guarded by an approved isolation switch and that whilst maintenance work is in progress, no working parts of the machinery are activated or any electric power goes into the plant.

Checklist

Are bins marked with aggregate size?
Are inlet pipes for cement, pfa, and so on, identified clearly?
Are sizeable stocks adequately drained?
Are gratings/grillages in place at discharge points?
Do incoming stocks meet specification?
Is silo watertight?
Is water supply adequate?
Is mixer/driver/batcher man trained?
Are mixes clearly established?
Are admixtures dosed by meter?
Are doors, ramps and moving parts guarded?
Has weigh gear, etc., been calibrated and check weighed?
Are mixer blades properly adjusted?
Is there provision for washdown of plant and equipment?
Can mixer meet peaks in requirement?
Can electrical system and power supply be isolated?
If more than one type of mix is produced, can it be correctly routed to the right part of the job?
Are regular checks made on stocks of aggregates, cement and admixtures?

17.
Readymixed concrete

By R.E.LAVERY HNC, MICT

The term readymixed concrete, familiar to most people in the construction industry, is generally taken to mean concrete which has been batched and mixed at a permanent plant away from the site and then delivered, readymixed, in purpose-built mixer trucks, agitator trucks or, occasionally, in some form of tipping vehicle. The plant and vehicles are usually owned by the readymixed concrete company (although many trucks are still owner-driven) and may be one of a handful of major operators supplying the bulk of rmc used in the UK or one of the small independent firms still to be found in out of the way areas.

BS 2787:1956 *Glossary of terms of concrete and reinforced concrete* describes the material thus:

> *Readymixed concrete:* concrete delivered at the site in a readymixed condition and requiring no further treatment before being placed in the position in which it is to set.

The Standard differentiates between two distinct types of rmc:

1. *Plant mixed concrete:* aggregate cement and water are completely mixed at a central mixing plant and delivered in containers fitted with agitating devices, or in trucks specially designed to prevent segregation.

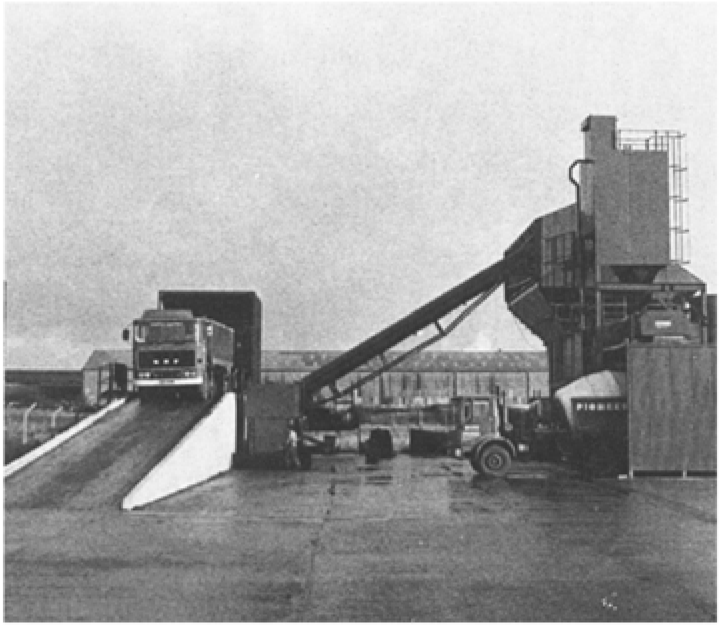
   COMMENT: apart from having to be transported a longer distance, the concrete is produced in the same way as it would be on site. However, plant is likely to be larger and, except on major projects, will have more advanced means of quality control than its site counterpart.
2. *Truck mixed concrete:* aggregate and cement are placed in a truck mixer at the batching plant, and after the addition of water, mixing is carried out entirely in the truck mixer.

   COMMENT: the concrete is batched at the plant but the mixing is completed in the truck mixer and visually checked for workability before the vehicle leaves for the site. Contrary to popular belief it is rarely mixed en-route.

The terms "plant mixed" and "truck mixed" concrete are not in universal use and variations may be encountered. The two types are often referred to as "wet mixed" or "wet batched" and "dry mixed" or "dry batched", while some specifications use the term "centrally batched" to indicate plant mixed concrete. Only a proportion of rmc plants are of the latter type. Such a specification clause, if enforced, effectively excludes the use of truck mixed concrete and failure to note its significance may prove expensive at a later date. The contractor may have to obtain concrete from a plant mixed source which is much further away, or may even have to install a more costly batcher set up of his own.

When considering the BS definition of rmc it should be remembered that it was first published in 1956 and today there may be exceptions to the statement that rmc means concrete delivered to site "ready for use

Typical rmc plant



without further treatment”. For instance, superplasticising admixtures are almost always added to the truck mixer after arrival on site and the concrete remixed. Few suppliers will agree to add it at the plant as not only would the amount of concrete which could be carried in the drum mixer be reduced, but its fluidity would make the journey difficult if not actually dangerous. In addition, the travelling time would reduce the period during which the admixture remained effective. Similarly, traffic conditions in urban areas or unusually long journeys may make it difficult to maintain uniform workability during a series of deliveries and so it may be agreed to add some of the water after the truck has arrived on site.

Types of trucks

BS 4251 gives the requirements for trucks used both as mixers and agitators as follows:

1. *Truck mixers:* The majority of delivery vehicles are of this type and are used to transport both plant and truck mixed concrete. Their carrying capacity varies but six cubic metres is the most common size in use. When used as a truck mixer, mixing is considered to have commenced when all the materials, including water, have been added to the drum. The drum must rotate during mixing at between two to 14 revolutions per minute and some specifications will require that, unless a lower figure has been specified or established from trials, it must continue for not less than 100 revolutions.

   When used as an agitator, i.e., when carrying concrete which has been plant mixed, it may be remixed upon arrival at site. Agitating or mixing en-route is normally precluded either by the design of the truck mixer or safety regulations.

Typical rmc truck

2. *Agitators:* Few of these vehicles are now in use. They are generally of a smaller capacity than truck mixers and can usually be identified by their rather elongated rotating drum. The rotation of the drum provides no real mixing action but by revolving at two to three revolutions per minute can maintain the concrete in its mixed state for a considerable period and so prevent stiffening of the mix.

Production of RMC

The method of manufacture and supply of rmc is described in several publications. BS 1926:1956 *Readymixed concrete* is still incorrectly referred to in specifications as it was withdrawn in 1981 when BS 5328:1976 *Method for specifying concrete* was revised to include rmc. Retitled *Method for specifying concrete including rmc,* it sets out the obligations of both the specifier/purchaser and the concrete supplier.

Until recently two trade bodies were responsible for the maintenance of standards for the production of rmc. The older of the two, The British Readymixed Concrete Association (BRMCA) was formed in 1950 to improve the image of the industry and to promote the sale of rmc. By progressively raising the standards of quality and service, the use of rmc has been encouraged and now accounts for a large percentage of the total concrete placed in the UK. In 1982 several major producers of both rmc and aggregates, together with suppliers of other construction materials (including coated macadam and hot rolled asphalt) joined up with other independent trade organisations to form a new association known as The British Aggregate Construction Materials Industry (BACMI). Both groups run broadly similar voluntary schemes to provide and maintain high standards of production and quality control throughout the country. Critics of these selfgoverning systems claimed them to be largely ineffective because they could not be said to be truly independent. To meet the demands of major purchasers and specifiers, an independent, non-profit making organisation was formed in 1984. Called The Quality Scheme for Readymixed Concrete (QSRMC), it is responsible for administering and enforcing the rmc industry's new quality assurance scheme. Based on BS 5750: *Quality systems* and BS 5328, it sets out the technical requirements covering the entire production and sale of rmc with which participants of the scheme must comply in order to remain members. The scheme is based on the principle of Quality Assurance Schemes, that is:

> to provide a product (rmc) which, when delivered to the purchaser, will be fit for its intended purpose and comply with the relevant British Standards or Specification.

Status of suppliers

Approved members of QSRMC can be expected to produce and supply prescribed and designed mixes to BS 5328. For a period pending the introduction and approval of QSRMC's complete range of Technical Requirements for the production, control and supply of rmc, some plants will be restricted to the production of prescribed mixes only, unless a purchaser agrees otherwise.

If a supplier is not a member of QSRMC it will be up to the purchaser to establish whether the requisite quality and standard of control can be achieved with confidence. In many instances the specifier will leave the contractor with no choice, and only concrete produced by an approved member of QSRMC will be acceptable.

The use of readymixed concrete

There are few limitations to the kind of concrete which can be processed through an rmc plant and with sufficient pre-planning, even the less common types of concrete can be provided. Exceptions are when the constituents are such that mixing and handling are no longer practical or economic. Included in this category are mixes based on unusually large sized aggregates such as might be used in mass concrete gravity construction, mixes based on unusual types of aggregate requiring additional temporary storage facilities, or those using very heavy aggregates such as lead shot or steel punchings.

From this it follows that the first step is to determine whether the rmc plant can actually supply the type and quantity of concrete required in the proposed time period. For small jobs this usually means little more than ensuring that the plant is an approved one. The larger the project, the more important it becomes to visit the plant or plants and check at first hand that the facilities offered can cope with the proposed work load and that the standard and quality are those claimed. This should be followed by a visit to the source of the aggregate to appraise ability to provide an adequate, uniform supply of acceptable material throughout the job. Most specifications insist on one source for each material so it should be ensured that this requirement can be met.

A simple list of items is given later which can form the basis of a concrete plant check sheet. It is not intended to be comprehensive but can be added to almost indefinitely and can be expanded to cater for the most detailed of checks. Each plant can then be visited in turn, inspected and an opinion formed about overall suitability.

READY MIXED CONCRETE PRODUCTION: Preliminary plant inspection sheet

Company: Plant status: QSRMC YES/NO

Location: Other:

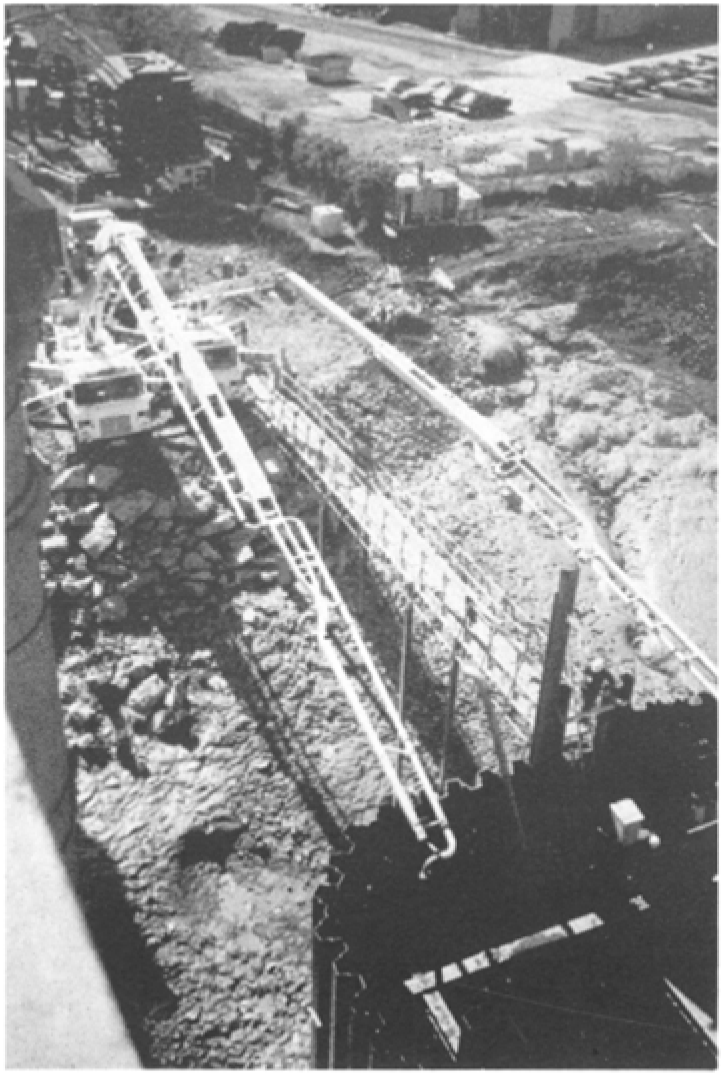
Telephone No:

Plant manager and Tel. No.	
Technical manager and Tel. No.	
Wet or dry batched	
Distance from site (miles)	
Estimated round trip (miles)	
Number of truck mixers available	
Maximum daily output (cu.m)	
Full output available	
Notice required	
Cement types and source	
Storage capacity (tonnes)	
Fine aggregate source	
Storage capacity (tonnes)	
Coarse aggregate source	
Storage capacity (tonnes)	
Test data available	
Current s.d. (N/mm^2)	
Workability estimated on	
Cement replacement available	
Lean mix production	
P.Q. production	
If limestone, accelerated wear test data?	
Back up plant? If yes, see separate sheet	

Advantages

Using rmc enables concreting of all kinds to be carried out where restricted access, a congested working area or, occasionally, local planning objections to a sitebased concrete plant, would not otherwise permit it. Concrete can be delivered to a precise timetable at rates varying from a few cubic metres a day to concentrated pours utilising the entire output of several plants and supplying in excess of 100 cubic metres per hour for many hours. This is useful when the need for concrete is either intermittent and spread over such an extended period that the cost of a site based plant cannot be justified or where concrete is needed in such large quantities that a site based plant could not cope with the demand.

Typical restricted access



Many rmc plants are able to supply heated concrete so that concreting can continue during periods of cold weather which would prevent most site batched concrete being produced.

The self-imposed code of practice followed by the industry, in conjunction with the British Standards, means that the same control standards apply to the occasional truck-load of concrete as to a whole day's output. These standards applied to materials, batching, mixing, transportation, delivery and testing, mean that small quantities of rmc are likely to be of a higher and more consistent quality than the site batched equivalent.

Disadvantages

The contractor loses direct control of the design of the mix and of the production process itself, though the various Codes of Practice and British Standards allow him considerable scope to oversee the operations if he so wishes.

Achieving and maintaining the specified workability of rmc is much more difficult than for site batched concrete. Considerable differences in travel time caused by fluctuating traffic conditions, particularly in hot weather, lead to disputes about the suitability of the concrete for placing. The problem increases with the distance of the plant from the site and is one of the prime causes for the reluctance of some clients to use rmc. In the event of some unplanned delay, for example, pump or crane breakdown, the plant can be contacted immediately to cease batching, but the problem remains of the truck loads of concrete in transit or already on site.

Specifying

As previously mentioned, the well known BS 1926 for rmc was withdrawn in 1981 and BS 5328:1976 *Specifying concrete* was revised to include rmc. For the benefit of the client, contractor and producer, it sets out their respective responsibilities, gives guidance on ordering concrete, on checking compliance with what has been specified and, by means of data sheets, provides a standard method of specifying various types of rmc. Appendices B and C of BS 5328 set out the requirements for *prescribed mixes* and *designed mixes* (including special prescribed mixes) respectively. The purchaser merely indicates his choice by ringing a particular item, for example, cement type, or by inserting a figure, say for the workability or minimum cement content. The choice, therefore, is broadly divided between prescribed mixes and designed mixes.

Prescribed mixes

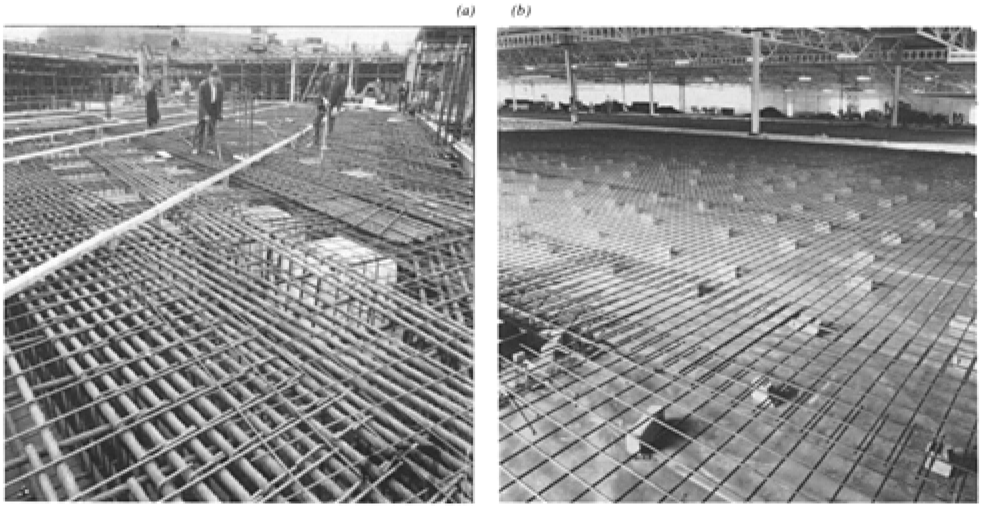
The purchaser designates the mix proportions and assumes responsibility for whether they will provide the quality of concrete which he requires. Note that proof of the use of the correct proportions is deemed to be sufficient for acceptance and, despite its inclusion in many specifications, strength testing *does not* form part of the compliance requirements of BS 5328.

Prescribed mixes are generally cement-rich and virtually guaranteed to produce a specified grade of concrete from a combination of either opc, pbfc or src, and natural concreting aggregates from almost any source complying with BS 882 or BS 1047. Their use may be dictated by circumstances—small jobs where quality control and supervision are likely to be minimal, when the protracted trial mixes are not justified or as a means of getting a project underway while the results of such trial mixes are being established. High cement content of prescribed mixes also provides another means of ensuring durability.

Designed mixes

For this category of concrete the purchaser/client is responsible for specifying his exact requirements and from this the producer must decide on the most suitable mix proportions to meet them. The choice open to the purchaser/client is much wider and includes the use of other cements, aggregates, admixtures and an extended range of strength grades. The producer thus has the opportunity to use his specialised knowledge of locally available materials to produce the most economical mix.

Order concrete with a much higher slump for situation (a) or you will receive 50 mm slump concrete only suitable for structure (b)



Ordering

Ordering is often a two stage operation, the first part consisting of obtaining an overall quotation from the producer on which to base a tender figure and the second part, after winning the contract, of the day to day ordering of specific quantities of particular concrete grades. In both instances it is essential that the producer is given as much information as possible about the scope of the job and the types and quantities of concrete required.

Preliminary ordering

At the tender stage it is prudent, whenever possible, to accompany the enquiry for prices with a copy of all relevant parts of the concrete specification and obtain some form of acknowledgement of its receipt. Attention should be drawn in writing or by marking up the specification where necessary to any unusual requirements or conflicting and contradictory clauses which could affect the price. In addition to those associated with bridge weight limits or one way circuits, the contract may impose restrictions on the routes which construction traffic may use and early co-operation with police and/or the Local Residents Association is recommended.

It must be remembered that a producer can only base his offer on the information made available to him. If this information is inadequate or misleading, expensive revisions may be necessary at a later stage. For instance, if no indication is given that to place concrete in a particularly difficult situation a 100 mm slump is required, the producer will base his offer on a much lower workability, usually 50 mm slump. Any later adjustments of the mix to enable it to be placed properly will be at the expense of the purchaser/client. Similarly if the producer is not aware that the main requirement of a particular concrete is an unusually high grade finish, his cement content, although sufficient to meet the strength specified, will often be inadequate. An embarrassing and expensive increase in cement may then be the only solution for the purchaser.

The information provided should include obvious general details such as the names and addresses of (a) the purchaser/client, (b) the site and (c) some idea of the start, duration and proposed completion time envisaged. An indication of the type of construction is also useful, whether civil engineering, factory floor, domestic housing, and so on, and who the specifying body is. The latter is often of considerable importance. Some clients are known to interpret specifications more stringently (or in a different way) to others and such knowledge may indirectly affect the price quoted. In rare instances the producer may even decline to quote for work if it is known that it will be supervised by a particular client. Many of the nationalised industries and public utilities work to their own specifications. Others, in an attempt (usually misguided) to cover all possible eventualities, concoct specifications based on combinations of clauses selected from a variety of British Standards, Codes of Practice, and other publications. The producer will be familiar with the idiosyncrasies of many of these and how they affect his quotation, but he must always be given the earliest opportunity to take them into account.

Finally, although it may not be possible to be too specific at the tender stage, some attempt should always be made to offer a provisional construction programme, particularly if the quantities required on certain days will be unusually large (the producer has other customers to consider) or will require the incorporation of say, fly ash, which might mean the erection of additional storage silos.

BS 5328:1981 Appendix B: Form for specifying ordinary prescribed concrete in accordance with BS 5328

Grade (ring one)		C7.5P C10P C15P	C20P C25P C30P
Permitted type(s) of cement (ring those permitted)		BS 12(OP) BS 12(RH) BS 146	BS12(OP) BS 12(RH) BS 146 BS 4027
Permitted type(s) of aggregate (ring those permitted)	*Coarse:*	BS 882 BS 1047	BS 882 BS 1047
Fine:	BS 882	BS 882	
Reconstituted:	BS 882	N/A	
All-in:	BS 882	N/A	
Nominal maximum size of aggregate (mm) (ring one)		40 20	40 20 14 10
Workability (ring one)		medium high	medium high

Any additional information

Day to day ordering

Without doubt the most essential requirement for a successful relationship is direct communication between representatives of the producer and the purchaser. On bigger projects these individuals should be named, their respective duties and responsibilities clearly defined, and if possible some arrangements made for each to be contactable outside of normal contract hours.

For a large part of many contracts, telephone contacts will suffice, but at other times it will be necessary for more formal meetings to be held well in advance of the proposed concreting date. On these occasions, often with the client's representative present, the capabilities of the supplier and the needs of the purchaser can be thoroughly discussed and mutually acceptable arrangements agreed upon.

Routine ordering

To avoid ambiguity and unintentional misunderstanding, the producer should be provided with all the information about the concrete and its proposed use as early as possible. This will obviously include all the data referred to in Appendices B and C of BS 5328 and will cover such items as cement type and minimum/maximum quantities, type and maximum size of aggregate, grade of concrete, test requirements, permitted workability, maximum water/cement ratio, use of admixtures and any restrictions on the temperature or density of the concrete itself. In addition, the purpose for which the concrete is to be used, particularly if unusual, such as pumping or placing underwater, should be made known. How it is to be placed and whether there is any restriction of access or vehicle weight is also important.

Finally, the supervisor should ensure that both the quantity of concrete ordered and the delivery time are correct. If the amount ordered is more than one truck load, the total amount should be included, together with the rate at which it is to be delivered. Err on the side of caution with respect to the latter. One of the most common mistakes made when ordering rmc is to assume that the preparatory work in hand will be satisfactorily completed and passed as acceptable by the inspector in time for the arrival of the first truck load of concrete. It is a comparatively simple matter to speed up deliveries once the placing is successfully underway, whereas a rapid build up of loaded trucks caused by an unforeseen site difficulty may mean the additional cost of standing time or the rejection of one or more truck loads of concrete which are no longer acceptable to the client.

On large sites where more than one grade of concrete is required over an extended period of weeks or months, it is a good idea to agree with the supplier some form of shorthand or code to identify each type of mix. For example, a request for 20 m^3 of "Bloggs LM 18" could mean that 20 m^3 of lean mixed concrete based on proportions of 18:1 is wanted at Bloggs' site. In the same way, "Bloggs 30/20 S 75" might stand for 30 N/mm^2 structural concrete with 20 mm maximum aggregate and 75 mm workability for use on the same site. As long as there is no chance of confusion (rmc plants supply other customer too!) the means of identification can be simplified even further to single letters or digits.

It is usual for the supplier to make up individual batch cards for each mix for the use of the plant operator. These contain details of the mix proportions, workability, type and quantity of admixture and so on, as well as adjustments to be made for varying moisture contents in the aggregates. With such a system ordering several types of concrete in any quantity is quite simple.

Receipt of concrete on site

Before considering the receipt of any concrete, ensure:

1. the formwork and any reinforcement in it has been checked in every respect and passed as ready by the clients representative
2. the grade, type and quantity is that which is required
3. the time and rate of delivery is correct
4. sufficient plant and labour is available to deal with placing and compaction
5. access is adequate

Concrete may then be ordered with confidence. Considerable thought should be given to the mechanics of delivery. Fully loaded concrete truck mixers weigh 20–25 tonnes. Attention should be paid to the possibility of damage to newly laid concrete or drainage and the access route should be kept well away from unconsolidated areas, open excavations and overhead cables of all kinds. The vehicles, which have large turning circles, need a surprisingly large area to manoeuvre if a succession of time-wasting three-point turns are to be avoided. Their overall dimensions (approximately 2.5 m wide, 8 m long and 3.5 m high) mean that they cannot be expected to negotiate sharp turnings easily or use openings which are much less than 3 m wide or 4 m high. If a succession of trucks is needed, every effort should be made to provide a site route which will enable a full truck to arrive and deliver its load without hindrance from the manoeuvring of an empty truck trying to leave. If this cannot be arranged because of the site layout, nominate a particular person as traffic controller—nothing causes more confusion than every other person in the vicinity giving a series of conflicting instructions to truck drivers.

The rate of delivery of concrete will be affected mainly by the means available to place it from the truck. The quickest and simplest, of course, is direct placing from the vehicle's extended chute, whereby 6 m^3 can be deposited in a few minutes. Unless ramps are built, the height of depositing the concrete is limited to about 1.5 m above ground level and the length of the chute confines the delivery area to slightly over half a circle with a radius of about 3 m. For anything other than easily accessible foundations and paved areas, therefore, other means of placing will have to be used. The type of work and availability of plant will decide the most economical method. Some choices include chutes, skips, dumper trucks, tipper trucks or, occasionally, site storage hoppers.

Placing by concrete pump, even for what seems quite small quantities, requires considerable forward planning and very close liaison between all concerned. Pumping is discussed in *Chapter 19* and additional information on this type of operation can be found in specialist publications such as *Manual of Pumped Concrete* published by the British Concrete Pumping Association.

The use of rmc for major roadwork using paving trains is unusual and unlikely to be encountered. Huge quantities of concrete are needed daily, sometimes for many weeks. A fixed form paver, for instance, often places 1700–1800 m^3 in a 10 hour period and slip form pavers are capable of even more. Pours of this size, of course, can be organised as the occasional one-off operation, but few rmc companies can muster the resources for such an extended operation.

Site hints

In some circumstances, a superplasticiser or some admixture may have to be added to the mixing drum after the truck arrives on site. As well as arranging that this can be done efficiently, it is advisable to take care how and where it is added. Many admixtures are very penetrating and can cause unacceptable staining on new hardstanding and paved sections. If such an area is the only one available, arrange to protect the surface with a layer of sand or polythene or similar.

Where a vapour barrier in the form of polyethylene sheet is specified to be laid below the concrete, truck mixers must be able to reach their point of discharge without running over it, otherwise multiple punctures of the sheet may render it useless for its purpose. Sometimes laying the sheets in a different direction may be all that is required. Failure to cater for this may lead to the debonding of many moisture sensitive floor coverings at a later date, creating considerable debate both as to the cause and the division of responsibility for repairs.

A particular person, preferably a site or section engineer, should be nominated to accept each delivery of concrete. This is important. The truck driver is understandably only interested in obtaining a

BS 5328: 1981 Appendix C: Form for specifying designed mixes or special prescribed mixes in accordance with BS 5328

SECTION 1: essential items

Type of mix (ring one)		Designed or Special prescribed			
Permitted type(s) of cement (ring those permitted)		BS 12(OP)	BS 12(RH)	BS 146	BS 1370
		BS 4027	BS 4246	BS 4248	
Permitted type(s) of aggregate (ring those permitted)	*Coarse:*	BS 882, 1201	BS 877	BS 1047	BS 1165
		BS 3797			
	Fine:	BS 882, 1201	BS 877	BS 1165	BS 3797

Nominal maximum size of aggregate (ring one)

40 mm 20 mm 14 mm 10 mm

Grade: designed mixes only (ring one in either Group A or Group B or Group C).

Group A-Compressive			Group B Flexural	Group C Indirect tensile
C2.5	C20	C40	F3	IT2
C5	C25	C45		
C7.5				
C10	C30	C50	F4	IT2.5
C12.5	C35	C55		
C15		C60	F5	IT3

Mix proportions: special prescribed mixes only

cement .... kg

coarse aggregate .... kg

fine aggregate .... kg

Minimum cement content ....kg/m^3

Rate of sampling

Number of cubic metres per sample ....

signature, anyone's signature, on his delivery ticket, so that he can be on his way for the next load. It is surprising how many people, often with only a marginal connection with the pour, are quite happy to sign a delivery ticket when it is thrust in front of them by an impatient driver.

Clause 13.5 of BS 5328 lists the minimum information to be provided on the delivery ticket. The purchaser may require additional information to be included and the nominated checker should run through the ticket very carefully to see that the contents match what has been ordered and then satisfy himself that the concrete itself is acceptable. For many loads this will be no more than a visual inspection but others will be tested, at an agreed rate, for workability and samples taken for making strength test specimens, checking air content and so on. A written record of all such actions should be maintained, with sufficient detail to enable the position of the load of concrete to be identified with some degree of confidence in the event of any dispute about its quality or performance at a later stage.

As empty trucks move away from the discharge point, dollops of concrete may fall from the chute and, although to a great extent this is unavoidable, such spillages should not be overlooked. It is much easier and cheaper to remove fresh concrete and hose down the area than resorting to pickaxes and jackhammers at some later date and usually after receipt of a strongly worded memo from the client!

An area will be needed for the trucks' drum mixers to be washed out before returning to collect another load of concrete or finishing for the day. A surprisingly large amount of water, contaminated with cement and aggregate particles, is produced and provision must be made to allow for it to run to waste. This must be arranged so that the water cannot enter site drainage where the solids in suspension can settle out and harden. If this happens the discovery will almost always be made near the end of the job when drain testing prior to final handover is being carried out, at which stage blockages can be difficult to deal with and expensive excavation and reinstatement is often the only solution acceptable to the client. In some instances, particularly where large quantities of concrete are to be used, settling tanks may have to be constructed and the resulting highly alkaline water neutralised before discharge into a stream or sewage system. Advice on suitable methods of treatment and permission to discharge the effluent can be

SECTION 2: optional items

Workability (enter value for one only) Slump ....mm VB............s Compacting factor	Maximum free-water/cement ratio .... Maximum cement content .... kg/m^3

Special cement(s)

Special requirements for aggregates *Coarse:*
Fine:

Admixtures Specified: Quantity required
Prohibited:

Air content	**Temperature of fresh concrete**	**Density of fresh concrete**
.... % by volume	..............°C maximum ....°C minimum	.... kg/m^3 maximum .... kg/m^3 minimum

Specification of trial mixes

Details of test procedures

Method of assessment of concrete As BS 5328
Or (details of method) ....

Other requirements

obtained from water authorities or river boards, who often insist upon making random visits to the site to sample and test the effluent being discharged into their system.

Compliance

The requirements for workability, air content and so on do not differ greatly between specifications and, except for cases where normal limits have been tightened up by a specifier, compliance does not normally present any unsurmountable problems.

The requirements for strength, however, can differ considerably. It is now usual to specify a characteristic strength below which not more than a stated percentage of results may fall. This may range from a modest one in 10 result to one in 100. In addition the cube results may have to be considered singly, in pairs, as groups of four or, as in BS 5328, as overlapping groups of four. The way in which the strength is to be monitored will influence both the mix design and the degree of control exercised by the producer. BS 5328 specifies a characteristic strength below which 5% of all results may be expected to fall, which is not an onerous requirement. However, the secondary requirement of considering the results in overlapping groups of four means that a single low strength result can affect concrete represented by up to seven other acceptable results. To reduce the risk of having complying concrete rejected, producers have found it necessary to raise the standard of control (or add more cement to the mix) so that only one in 40 or even one in 100 results are likely to be below the characteristic requirement. The new QSRMC requires producers to base their calculations on a failure rate of one in 40 results instead of the one in 10 required by BS 5328, unless their experience suggests that a lower figure will be adequate.

The method of quality control adopted by almost all rmc producers is based on the cumulative sum technique (cusum) and has been widely used for many years. Minor variations of the system have evolved within different rmc groups and most have been computerised for greater speed and efficiency. BS 5073: *A guide to data analysis and quality control using cusum techniques* describes the method. The systems provide, in the form of a large chart, a continuous daily record of the trend in the average values of strength and standard deviation. The need for some remedial action, such as increasing or decreasing the cement content, is quickly apparent and can be acted upon. A brief description together with a worked example is also given in the appendices of the QSRMC manual.

Testing for compliance

The number of tests applicable to rmc is large and reference is made below to the more common tests. Some tests relating to workability may be carried out fairly often, while others, such as the determination of the fresh density of the concrete, may either be infrequent or not required at all. However, whatever the reason for the test and whatever its frequency, the same rules apply:

Each test must be carried out strictly in accordance with the method given in the relevant British Standard, Code of Practice or particular specification

Records of testing must be kept and be detailed enough so that the concrete covered by the agreed sampling rate can be identified and located within the structure or other area of concrete.

Sampling

The results of tests on almost anything can be seriously affected by the way in which the material to be tested has been sampled. In the case of fresh concrete a method of sampling has been developed over the years which, if complied with, ensures that a reasonable relationship can be established between the results of tests carried out at different times on similar concretes. The most recent version is described in BS 1881: Part 101:1983 *Sampling of fresh concrete on site*. For the slump test only, an alternative method applicable to sampling fresh concrete delivered in a mixing or agitating truck is given in Clause 4.2 of BS 1881: Part 2: 1983 *Method for determination of slump*.

Yield

Few specifications require the yield of fresh compacted concrete to be determined as a matter of course, but it is wise (and indeed, may be necessary) to carry this out from time to time. The usual reason is disagreement about the amount of concrete ordered and the amount over and above that which is needed to complete the pour. In accurately dimensioned and erected forms such as for walls, the room for error is small but with large areas of flooring or paving, the discrepancy can be alarming. One reaction of the purchaser is likely to be that he has been receiving short measure, but before such accusations can be levelled the accuracy of the thickness of the floor must be known—preferably before the pour commences. Thickness greater than specified, especially if top reinforcement has to be placed with a minimum cover requirement, are more common than the other way round. Similarly, the neat accurate thickening up to form edge beams shown on drawings is rarely achieved and again oversize is more likely than undersize. If it can be shown that the setting out and dimensions were accurate, the possibility of short measure, however caused, must be checked.

BS 1881: Part 107 sets out the procedure for determining the density of fresh compacted concrete and the mass of concrete discharged from a particular truck mixer can be found by using an approved weighbridge. From these two figures, fresh compacted weight and mass discharged, the volume of concrete can be calculated and compared with the batch figures. When considering the results bear in mind that batching tolerances of up to ± 3% are permitted by BS 5328 for cement, aggregate and water, but loads that show a continual tendency to be underweight should be viewed with suspicion.

Workability

Although not always appreciated, the commonest test of workability is a simple, visual inspection during which the concrete's condition is compared, consciously or otherwise, with something which has previously been agreed as acceptable. Except for work of the highest standard, it is not usual to test the workability of every truck load of concrete. Supervisors and operatives quickly learn to assess the appearance and behaviour of concrete of a given workability and with a surprising degree of accuracy. Part of the reason for this is probably that operatives soon make their feelings known about concrete they consider to be below the agreed workability, while supervisors are often as swift to detect mixes which swing too much the other way. On the majority of jobs, therefore, the required workability is quickly established by testing the first few loads and further tests are random and at less frequent intervals. The intervening loads are judged entirely by eye.

Slump test

This, one of the oldest and best known of the workability tests, is considered suitable for testing concrete of medium to high workability. It has been revised slightly and the prepared sample of concrete is now placed in three layers of 100 mm depth instead of four layers of 75 mm. Each layer is rodded 25 times as before. Note that if using the alternative method of sampling previously discussed, an average of two slump tests is required. The permitted range of the slump tests is set out in BS 5328: Clause 16.6: *Workability*. The recommendations are often overruled by specifying authorities who sometimes attempt to apply quite unrealistic limits of their own. In such a case it is essential that the rmc producer who normally supplies to BS 5328, has been made aware of any unusual requirements and that his price allows for such differences.

BS 5328:1981 Appendix D: Form for scheduling the specified requirements of several different mixes to be used on one contract

CONTRACT			Mix descriptions used in bills of quantities					
Type of mix (P, SP or D)*								
Type of cement		BS no.						
Type of aggregate		*Coarse:* BS no.						
		Fine: BS no.						
Nominal aggregate maximum size (mm)								
Grade								
Minimum cement content (kg/m^3)								
Sampling rate (m^3)								
Workability	Slump (mm)							
	VB (s)							
	Compacting factor							
Maximum free-water/cement ratio								
Maximum cement content (kg/m^3)								
Special cement								
Special aggregate	*Coarse:*							
	Fine:							
Fine aggregate (%)								
Admixtures	Specified							
	Prohibited							
	Amount							
Air content								
Temperature of fresh concrete (°C)	Maximum							
	Minimum							
Density of concrete (kg/m^3)	Maximum							
	Minimum							
Additional requirements on attached schedule								

*** P — prescribed; SP — special prescribed; D — designed.**

Compacting factor test

This test, covered by BS 1881: Part 103:1983, is considered suitable for workabilities ranging from low to high. It is most frequently used for testing the workability of pavement quality concrete and is not often encountered in ordinary construction.

Vebe time

This test applies a standard degree of vibration to a sample of concrete formed in a circular container by a modified slump cone. The time in seconds for the sample to take up the shape of the circular container when it is vibrated is then measured. The vibration makes the test suitable for concrete with low or very low workability and BS 1881: Part 104:1983 describes the method. It is rarely seen at the point of concrete delivery and its use tends to be restricted to the laboratory.

Flow test

None of the foregoing tests is suitable for concrete with very high workability, although many still attempt to make use of the slump test. With the increasing use of superplasticised concrete, the slumps are collapsed and often in excess of 200 mm. BS 1881: Part 105:1983 *Method of determination of flow* contains details of what is called the "flow test". Similar in many respects to certain continental and American tests, the workability is determined by carrying out a modified slump test (with a slump cone 200 mm high) on a folded rectangular table which is hinged along one side. The upper metal section, which weighs about 16 kg, can be raised a restrained distance of 40 mm ± 1 mm and dropped, causing the cone of concrete to spread progressively further out with each jolt. The workability is determined by measuring the average final spread of the concrete after it has been jolted 15 times. A common figure is a spread of between 520–620 mm and, although not strictly comparable, it is roughly equivalent to a slump of between 190–225 mm.

There is considerable controversy over the suitability and effectiveness of this test, but on balance it seems to be preferable to either the slump test or compacting factor test.

Cannon test

This American test is based upon a modified vebe test and was developed as a means of testing low workability mixes containing large amounts of fly ash incorporated as an additional aggregate rather than as a partial replacement for cement. This type of concrete is widely used in the USA and elsewhere but is only just beginning to be used in the UK and there is little practical experience of it here.

There is no direct relationship between the results of the four workability tests described in BS 1881: Parts 102–105 and it is not possible to say, for example, that a vebe time of so many seconds is equivalent to such and such a slump or compacting factor value. Similarly, the figures obtained for the workability of one concrete may not necessarily be the same as those obtained from another, nominally similar concrete made with different aggregates. The reason for this is probably that fresh concrete is known to behave as a Bingham material and its flow properties are consequently affected by both its yield value and its plastic viscosity. None of the present BS workability tests measure both parameters and so can only correctly indicate changes caused by differences in water content. Inadvertent changes in other aspects of the concrete mix, such as variation in cement content or aggregate gradings, provide misleading results and explain the often unpredictable behaviour of a given mix. Tattersall has developed a series of two point test apparatus for a range of concrete workabilities and reports from independent users show it to have considerable promise for identifying the true causes of change in workability. Despite favourable comment, it has yet to be generally accepted as a standard workability test, but the current demand for quality assurance may revive interest in the method.

The degree of workability of concrete which logically should be the prerogative of the party having to place it, should always take account of where and how it is to be placed. Too many specifiers attempt to enforce the use of concrete with a workability far too low for the purpose, in the mistaken belief that higher strength and quality will ensue. If the main object of producing the concrete was to make test cubes this would, undoubtedly be true, but if placing is difficult and full compaction consequently hard to achieve, a honey-combed and permeable concrete with a poor finish is inevitable. A deliberate policy to change the general slump of concrete from the almost ritual figure of 50 mm to one of at least 75 mm would eliminate many of the producer/user problems experienced with rmc.

Strength

The commonest way of deciding whether a concrete complies with the specification is to take samples and then test them for strength. Depending on the use of the concrete and the reason for testing, the strength may be derived from cubes, cylinders, or beams made from concrete sampled at the time of placing or from cores extracted later. The strength parameter examined may be compressive, tensile, indirect tensile, flexural or shear. The most frequent test is for compressive strength carried out on 100×100×100 mm or 150×150×150 mm concrete cubes.

Most concrete is specified to comply with a characteristic strength given in N/mm^2 when tested after 28 days. The results are then examined statistically and compared with what has been specified. An important point to remember is that unless the rmc producer has been instructed otherwise, he will supply concrete to the strength criteria set out in BS 5328. Many specifiers decline to use BS 5328 and produce strength acceptance procedures of their own which often contain conflicting requirements for cement content, workability and water/cement ratio. The rmc supplier must be informed, as compliance with a specification other than BS 5328 often means that more expensive concrete containing more cement will have to be used.

Cube test

The sampling of concrete, making of cubes, curing of cubes and testing of cubes are described in Parts 101, 108, 111 and 116 respectively of BS 1881:1983. The aim is to provide a uniform method of obtaining results which are truly representative of the concrete under test. Most disputes between supplier and purchaser concern low cube strengths. If the former can establish that any part of the recommended sampling, making, curing or testing regime was not strictly followed, any subsequent claim will be considerably weakened, if not rendered null and void. For this reason it cannot be overstressed that the BS procedure must be followed exactly.

Indirect tensile strength

Since the introduction in 1969 of the D.O.T. Specifica tion for Roads and Bridges (the “Blue book”), the strength of pavement quality concrete has been measured by crushing 150×150 or 150×300 mm cylinders on their sides, then applying a simple formula to the result to calculate the splitting or indirect tensile strength. Currently described in BS 1881: Part 117, it has always been a controversial test method and in the latest revision to the “Blue book”, the method of strength determination is likely to be based on cube strengths once again.

Flexural strength

This type of test, covered in BS 1881: Part 118, is rarely called for and will not, therefore, be discussed further here. Tests for tensile and shear strength are fewer still and no BS procedure exists for them at present.

Concrete cores

Certain specifications for airfield pavement construction still include concrete cylinder tested in compression as a means of quality control, but are not often encountered. Cores drilled and extracted from hardened concrete, capped and then crushed, are much more likely and BS 1881: Part 120 describes the procedure. Cores are used for routine checking of strength and density and are also often taken as a means of settling disputes about the in situ concrete. Note, however, that some authorities now use the air void count method described in BS 1881: Part 120, as another means of checking in situ compaction.

Action on non-compliance

From time to time and for a variety of reasons, the strength of the concrete being tested will not meet the agreed acceptance criteria. The power conferred on the engineer in these circumstances varies considerably from specification to specification and the action required can range from a simple increase in cement, to complete removal and replacement of all the concrete represented by the test results. A careful examination of the implications of failing to meet the strength requirements must be made at the tender stage. If the consequences of not complying are particularly onerous it may be wise, despite the initial extra cost, to use a higher cement content or provide for a higher standard of control.

In the event of a dispute arising from low strength results, it is of prime importance that all parties concerned are involved at an early stage. The purchaser and client will obviously be aware of the position on receipt of test results, but the rmc supplier is often completely overlooked. He must be contacted and given the opportunity to join the discussion at the earliest possible opportunity. The main object will be to determine whether the results in question are, in fact, valid, because it is well documented that low cube strengths are much more likely to be due to differences in sampling concrete and in making, curing and testing cubes, than to substandard concrete. Two publications provide extensive and comprehensive guidance on organising an appropriate investigative procedure:

1. BS 6089:1981 *A guide to the assessment of concrete strength in existing structures*
2. Concrete Society Technical Report No. 11: May 1976 *Concrete core testing for strength*

Both sources stress the early co-operation of all concerned and of agreeing, in advance, the number of cores, how, when and by whom they will be taken and tested. It must also be agreed how the results will be interpreted and how the cost of remedial action, if any, will be apportioned. This will prevent the investigation developing into a “best of three” contest!

During any investigation to determine the quality of the concrete alleged to be substandard, a careful inspection of the concrete represented by the low results should be carried out. The men who placed the concrete should be consulted, they will almost always remember a delivery of concrete which was different, too wet, too dry, under or over sanded, an unusual colour or having a funny smell. Poor quality concrete, when visible, is usually self-evident, it looks and, when struck, sounds different to good concrete. Conversely, concrete which looks and sounds good, generally is so.

Contrary to the belief of many experienced engineers, the strength of in situ concrete, even when produced, placed, compacted and cured correctly, is almost invariably lower than that of cubes made and tested in accordance with the procedures set down on BS 1881, and the reasons for this should be selfevident. Extensive data exists to support this view and many design procedures include an allowance or “safety factor” to cater for it.

When dealing with suspect rmc, the problem will be approached in two ways. The client will usually be interested in the actual in situ strength. The supplier, however, who has no control over what happens to the concrete after it leaves the truckmixer, will wish to establish only that the concrete supplied was of the appropriate grade and quality at the time of delivery. Concrete Society Technical Report No. 11 therefore makes provision for estimating both a concrete’s in situ strength and what it refers to as its “potential” strength. The former, expressed as an equivalent cube strength, estimates the strength of the concrete as it is in situ, that is with no corrections made for age, curing method, or degree of compaction. The calculation of potential strength takes such variations into account and provides a strength based on that of 28-day cube made to the requirements of BS 1881. The reliance which can be placed on the results obtained is related directly to the number of cores taken, so that the more cores taken, the more dependable the information will be and the more likely that the results relate to the strength of the concrete in question.

If the actual strength or potential strength arrived at from a joint investigation is agreed to fail the specification requirements, it is then incumbent upon the engineer to appraise the situation and apply sound and unbiased engineering judgement to arrive at his decision. Except to comply with the most ill-conceived and punitive of specifications, this should not automatically entail breaking out or replacing such concrete. For example, a structure is designed to take account of the worst loading conditions and a calculation of the actual stresses in the position concerned may show that, when other factors such as durability are considered, the residual strength is still more than adequate. Similarly, a finish which is currently visually unacceptable may be destined to be buried or hidden by cladding of some kind, so that strict adherence to the specification re quirements is not entirely justified.

Points of supervision

1. As early as possible, provide the producer with all information available concerning the required concrete. Pass on any variations or additional data at the first opportunity.
2. Do not order concrete until all arrangements on site are complete and final approval obtained from the client.
3. Whenever possible opt for mixes with a designed workability equivalent to at least 75 mm slump.
4. Carry out all tests on fresh and hardened concrete strictly in accordance with the clauses of the relevant British Standard. Maintain a reliable written record of all testing.
5. In the case of disputed quality, involve all parties concerned and establish the validity of any test results.
6. When results are shown to be valid, discuss in advance a suitable investigative procedure and agree the interpretation of results and the responsibility for any remedial action necessary.

18.
Handling and transporting concrete

Simple concrete handling methods

Considerable quantities of concrete can be handled and placed throughout the works using manual effort, such as headpans, wheelbarrows, prams, buggies, chutes and so on. Remarkably, in periods whilst a regular supply of concrete is available, quite high rates of placement can be achieved, particularly in areas where a considerable number of operatives can be employed. The use of any wheeled vehicle, barrows, prams and such like, requires the provision of adequate running surfaces. Planks, duckboards, hardcore, blinding concrete or similar surfaces are all adequate. In the case of even the largest vehicle, bad ground causes jolting of the mix, separation or partial compaction of component parts of the mix and thus delivery to the point of placement of substandard concrete. Dumpers and motorised buggies provide high outputs for quite small expenditure. It is possible to hire equipment onto site for short periods where the high demand for concrete handling is unlikely to be continuous throughout the course of construction. Care must, however, be taken to ensure back-up facilities to cover eventualities such as breakdown of the only dumper available, particularly during some fairly substantial concreting operation.

Crane and skip handling

In many operations, chuting in the early stages followed by crane and skip handling are fairly typical means of handling. Where skips are used it is advisable to provide two skips—one for filling and handling and the other for emptying at the point of placement. Rails set under the mixer discharge allow bodies carrying skips to be run under the plant for filling. Full skips run *down,* out to the lifting point and empty skips are pushed *up* to the loading position.

The use of dumpers

Dumpers, being all-purpose vehicles, are generally abused, overloaded and subjected to damage. Where possible vehicles should be allocated to specific drivers and kept to particular duties. A dumper having some form of controlled discharge mechanism is ideal, otherwise the concrete flows uncontrolled from the hopper when the catch is released and the skip rotated. Dumpers with hydraulic controls are excellent—controlled discharge can be achieved either forward or to either side.

The ability of dumpers to negotiate bad ground is often featured as a selling point. It must be remembered that while negotiating bad ground, most wheeled vehicles churn such ground making it even worse. Blinding, hardcore, mesh or military track should be laid on areas where there will be considerable traffic.

Readymixed concrete discharged at point of placement ready for screeding

The timing of road and access construction forms an important factor in the planning of the concreting operation.

Normally dumper trucks have wide general purpose skips as standard. These are not desirable for most concreting operations—the hopper shaped bucket gives better discharge, rotating or side discharge increasing the value of the dumper as a concreting tool. The latter is particularly important where, for example, precast elements are being cast on site. Electric trucks and dumpers are now available, either with fixed hoppers or removable skips, and some models have built in weigh gear to allow batching operations to be carried out in small quantity situations.

Skips and buckets

The container used to transport concrete by crane or hoist is usually called a skip. Larger containers holding several cubic metres are often called buckets. Skips can be of various design and are best selected for a particular duty. Heavy, substantial roll-over type skips, for example, for use where the skip is crane handled between the batching point or readymix truck, are designed to be laid down by a rolling action which locates the mouth of the skip beneath the discharge of the plant or truck. Lifting rotates the skip into the discharge position where a lever-controlled chute allows controlled discharge at the point of placing. Small bottom-opening skips are more desirable where receipt from a readymix truck or mixer and transport by crane over a small distance is being carried out, where for example the truck is delivering to a crane sited at the point of placing.

The size of skip should be related to the output of the plant and type of placing operation, i.e., whether placement is into an open situation, foundation or floor bay, or a confined space such as a column or wall form. Skips are available as standard equipment from suppliers in sizes ranging from 0.3–6 m^3, although a specialist supplier will manufacture to any specification.

A most important aspect of skip design is the mechanism by which the concrete is discharged together with the configuration of the mouth or chute. The skip must be capable of discharging at the appropriate rate with good control, thus avoiding problems associated with dumping or impact as concrete lands on or enters the form work. Low workability concrete may need energising by vibrator mounted on the skip and the doors may well be activated pneumatically from a supply contained in a receiver mounted on the skip.

Wheel controls are preferable to levers where manual operation is concerned, as levers tend to cause sudden opening and a rush of concrete, which overflows the form or chokes the area into which the concrete is being placed. Vibrators to assist in discharge can be electrically driven, the supply being taken from the crane. The discharge door can be operated from an air supply taken from an air receiver, charged when the skip is at the batching plant or by rams as the skip is lifted to operate the cut-off doors. In the event of the supply becoming exhausted before discharging is complete, the skip is lowered to the ground and lifted again to provide a further charge of air.

Vehicular transport

As the scale of the operation increases, the need for larger vehicles for concrete transportation will increase. The lorry-mounted transporter used in much civil engineering work is hydraulically tipped for discharge, the hopper being provided with paddles or tongues to control the discharge and perform some amount of remixing. These vehicles can be used to convey concrete over reasonable ground conditions in quantities up to 3 m^3 at one time. Where large quantities of concrete are necessary in really bad conditions, a new generation of dumper truck has been developed. These are articulated and have hydraulic drive and hydraulic controls and can negotiate most ground conditions. They are expensive but reliable and are able to take heavy punishment.

To reduce handling costs, the whole operation must be carefully planned and appropriate quantities produced, handled, transported and placed, must be watched throughout the whole programme. On extremely large sites where considerable distances are travelled, the use of truckmixers or agitators may prove economic. These vehicles are rugged and can negotiate most dressed surfaces. Chutes allow discharge over a wide area and agitation of the mix provides a substantial uncoupling element between batching and placing. Recent developments have included trucks with mixing and pumping facilities on the same chassis.

Forklifts and humpers

A number of forklift trucks and tractors now available for use on rough terrain have exceptional facilities to reach heights and lifts up to three or four storeys. Whilst they cannot reach into the building, they can be

Concrete being delivered into the receiving hopper of a trailer pump –this unit can pump at more than 30 mlhour and can pump vertically to 75 m and horizontally in excess of 400 m (Crowe Hamilton and Company Limited)

used to fill wet hoppers or to feed a chute or conveyor at the perimeter of the slab. They can be used to collect concrete from the mixer, travel over rough ground and supply concrete to the point of placing. The humper type of vehicle is often articulated and generally features four-wheel drive. Unfortunately, although their use is essential in bad ground conditions, there is a tendency for such vehicles to disturb normal access routes, churning up mud and spoiling the general access.

Cranes, hoists and similar transporting plant

The crane most commonly used in concreting is the crawler crane, able to negotiate bad ground, economic and generally reliable, although the latter attribute will be a function of the maintenance schedule and the care with which the operator carries out daily oiling and greasing. Tower cranes are used in most building construction and where the crane can pick up a skip from the mixer or a readymixed concrete truck discharge point and transport it to the point of placing, considerable economy results. A recently published account of the use of tower cranes in multi-storey construction is indicative of the type of thinking which must be applied to crane utilisation programming. In the instance quoted, a four-level car park with three lift shafts was to be constructed in 78 weeks. The cranes were tower cranes capable of lifting 3.8 tonnes at 55 m radius—reducing to 6 tonnes at 37 m radius. The cranes were initially erected to full height, founded in a 5.5 m square concrete slab foundation. The construction included 1500×2.5 tonne double tee beams (precast), each 6 m long×2.5 m wide. These units were topped with 50 mm screed and the building envelope comprised precast spandrel units each of 3.5 tonnes. The day’s schedule of crane operations was set as follows:

07.30	place concrete in floor screeds
08.45	form work striking and steel supply
10.00	offload and erect 14 tee beams

11.00 lunch break
13.30 form work, steel and pour structural concrete

(Precast erection three days per week, 60×3.5 tonnes panels in each three-day period)

On completion the cranes were dismantled using a 400 tonne mobile working at about 44 m radius (the latter factor governing the crane capacity). During its stay on site the mobile placed the last of the precast elements to close the openings in the structure where the tower masts had been. Critical decisions were:

1. Crane location within the structure to give optimum coverage for unit handling
2. Two unswept areas needed servicing by mobile cranes
3. The factor of erecting to full height at commencement
4. The decision to use only two cranes, taking advantage of the manufacturer's trend toward longer, more slender jibs, capable of lifting a 1 m^3 skip at 55–60 m radius. This decision increased the need for careful allocation of crane time.

Unfortunately, contracts involve handling of multiplicity of stores, steel and form work as well as concrete, and it may be necessary, particularly in the case of multi-storey work, to provide hoist facilities complete with receiving hoppers to reduce some of the time which the crane would otherwise take to hoist the material. Attention must be paid to the number of skips made available to reduce delays caused in filling and discharge and to uncouple the processes of mixing and placing.

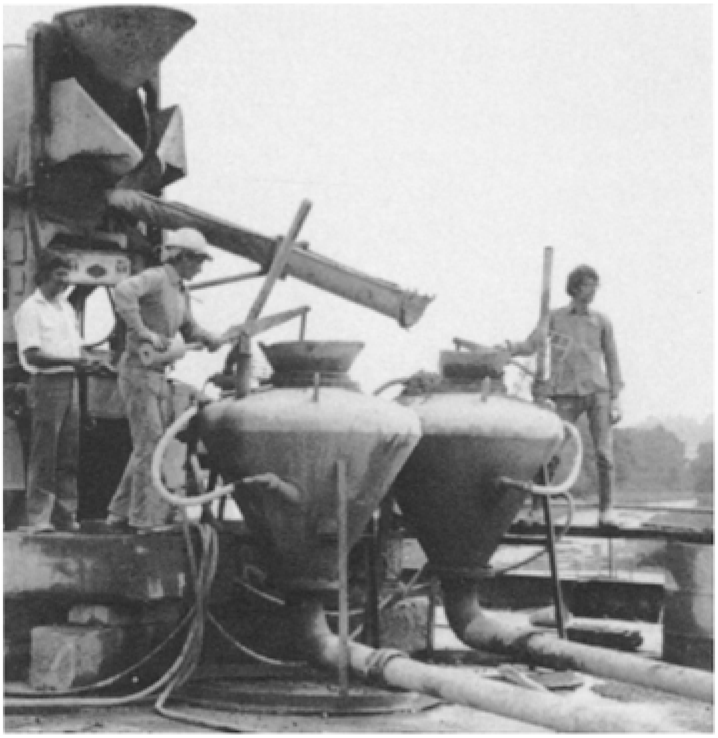
Conveyors, elevators and chutes

In America for many years hoisting and chuting techniques were used, comprising what were essentially "mobiles" of trunking which enabled concrete of high workability to be delivered at any point within the construction. Whilst ropeways are used for massive construction, the tendency has been towards the use of conveyors which can be designed to handle most types of concrete of varying consistencies. These conveyors are air-impelled, hydraulically or electrically powered, and can be ganged and extended.

Conveyors work best when material is moved upward, along inclines and this technique is used to provide height at the discharge point into chutes or large diameter trunking. Outputs are high, 40 m^3/hour being consistently achieved. Plain conveyor belts also have their place in concrete distribution, and can be used in end discharge situations, giving a capability of continuous travel over a number of units, or using belt scrapers in side discharge format. The latter facilitates discharge at any point along the line and provides a simple mechanism for use, for example, in pouring a raft. The side discharge has also been used effectively in the mechanised production of piles and walls where gangs and battery casting techniques are used.

The range of equipment is enormous and equipment is available which can be built into compound trains so that concrete can be accepted, for example, at motorway formation level, elevated by conveyors to bridge deck level and then distributed by conveyors with side discharge to any point on the bridge deck. Feeder conveyors, each discharging into the next can be used to carry concrete over large distances, although of course stiffening and drying of the mix in transit must be avoided. Chutes can be fixed at the end of discharge to enable local spreading of the concrete as required. Care must be taken with conveyors handling such large quantities of concrete that the discharge is controlled, the concrete being spread uniformly over the area being placed. The quantity of concrete handled by conveyor is, of course, dependent on the relative amounts of vertical and horizontal travel. So fluent are current systems that the quantity which might be handled is generally in excess of the capability of the batching plant in use!

A twin pump set up—compressed air is used to impart a vortex action which screws the concrete into the pipeline smoothly and continuously—pumping rates for individual units are in the order of 20 m/hour (Crowe Hamilton and Company Limited)



The conveyor is particularly economic where large quantities of concrete are to be placed and the following are outputs recorded on several contracts of differing proportions:

foundation work in a massive power station—153 m^3/hour transported 160 metres;
placing concrete in bridge piers, midstream in a river—76 m^3 cast in each pier daily;
concrete in limited access area with large amount of reinforcing steel making crane access difficult and in some areas impossible—210 m^3/hour delivered to a 15 m radius spreader;
road paving placed from a side discharge hopper at the rate of 50 m/hour;
concrete being discharged from readymix trucks at the foot of abuttments and delivered by side discharge 10 m below the main conveyor.

For information on concrete transportation using pumps, the supervisor is referred to Chapter 19: *Supervision of pumping concrete*.

Checklist

Upon what methods was the tender based?

The ease of access achieved by the use of concrete pumping equipment is clearly shown in these illustrations of bridge construction—careful programming of delivery and adequate site preparation for readymixed concrete is essential (The Pochin Group)

Do weather conditions call for changes in method?
Can improvements be achieved in the light of present knowledge of site conditions?
Does method allow uncoupling of placement from supply?
Can simpler methods be used—chuting, use of pump, and so on?

Have hardstandings and discharge points been established?
Is a washdown facility available?
Have concurrent operations been considered—steel and form handling and so on?
Do skips suit form openings?
If transportation method changes from that envisaged, have formwork and falsework designers been consulted?
Are supervisors and operatives aware of safety requirements of method selected?
What are the quantities involved?
What are key stations for receipt of concrete on site?
What are major locations of greatest bulk of concrete in repetitive cycles?
How can receipt or batching and mixing processes be uncoupled from placing?
Does the means of transport suit the type of concrete specified?
Can three-dimensional handling overcome site conditions?
Can advantage be taken of natural geography of site, for example in chuting?
Is the equipment available suitable or will hire be necessary?

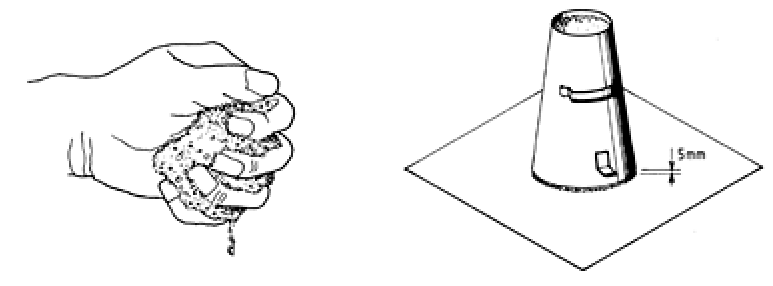
19.
Supervision of concrete pumping

By ROBIN HAROLD-BARRY, B Sc(CEng), MICE, MASCE, MICT

One advantage of using special placing equipment, such as a concrete pump, is that the crane is released for more labour intensive jobs which should not be interrupted, such as steel fixing and form work erection. Another advantage is that of quality assurance. A pump can handle a lot of concrete in a short space of time, requiring a great deal of concentration on the part of the concrete producers, who know that if the concrete is not consistent, with the correct cement content, it may be rejected by the pump operator. The pump operator, in turn, helps towards assurance of good uniform concrete, as he quickly acquires an expertise in judging the properties of concrete and does not want a bad load to overstrain his pump, cause extra wear or even create a blockage. It goes without saying that the contract for the supply of concrete should include a clause that the concrete can be satisfactorily handled by the pump to be used, although disputes have arisen where people have made unrelated contracts with a readymix supplier and a pump hirer, leaving one blaming the other for the concrete not going through the pump. The contractor will get a better job if he can get his sub-contractors to work together.

Planning and checking the mix

As with any task, careful planning is very important. The mix has not only to be designed for the pour, but has to be checked for pumpability. Having designed the mix for strength or durability, or both, the workability and cohesiveness should be checked to ensure that the concrete will flow through the reinforcement and around and under the obstructions. A check can then be made on the pumpability.



if ground escapes between your fingers the mix is pumpable

if the cone lifts by 5 mm or more the mix is pumpable

One check is to take a handful of concrete (if you are unable to wash hands immediately afterwards, wear gloves) and squeeze it. If grout escapes between the fingers, it is pumpable. Another check is the standard slump test, but before lifting the cone, allow it to lift itself under the pressure of the concrete—if it lifts by 5 mm or more it is pumpable. The slump should generally exceed 50 mm, although a 25 mm slump can be pumped, with difficulty.

Aggregate grading

If grading curves and quantities per cubic metre are all there is to go by, then the overall grading can be plotted on the pre-Second World War grading curves (see Figure 00). If the curve lies in the coarse area, increasing sand content can make the curve finer. This may also require an increase in the cement content. Another important point to watch is the weight of all solids passing the 300 µm sieve. This includes cement, pfa, dust, silt and other fine solids, as well as the very fine fraction of sand. Table 19.1 gives recommended weights:

TABLE 19.1
Fines required for pumpable concrete

Maximum size of aggregate in the concrete	Minimum weight of fine solids passing the 300 µm sieve
40mm	380 kg/m^3
20mm	440 kg/m^3
10mm	520 kg/m^3

Note: The nominal maximum size of aggregate should not be much more than one quarter of the pipeline diameter.

The void meter

Another aid towards designing a pumpable concrete mix is the void meter. The proposed proportions of dry aggregate are mixed without cement or water. The mixture is added in layers and compacted in a glass cylinder. An air-tight lid is bolted on and a partial vacuum is applied via a column of water. The movement of the water gives an indication of the amount of air in the voids between the aggregate particles. Several tests are carried out with differing aggregate proportions to find a combination which gives the minimum voids. For a mix to be pumpable, there should be enough cement (or similar fines) to fill these voids, assuming the cement or fines have a bulk density of 1440 kg/m^3. For the cement to be as densely packed as this, the water/cement ratio would have to be 0.37. Of course, a mix with densely packed aggregates whose voids are filled with densely packed cement which contains so little water would be extremely difficult to pump and in practice the water/cement ratio needs to be at least 0.4 to separate and lubricate the solids in the mix. It may be necessary to use a plasticiser with water/ cement ratio less than about 0.45.

Water content and blockages

The greater the water/cement ratio the lower the pipeline resistance. However, with a plain concrete, a water/cement ratio greater than 0.6 can lead to difficulties if the pump has to stop for some reason, as this quantity of water will rapidly bleed through the concrete and rise to the top of the horizontal sections of pipeline. When pumping recommences, this water is pushed more easily along the pipe than the rest of the concrete leading to scouring and segregation of the concrete over which it travels and possibly to a blockage.

Lightweight aggregate has a high capacity to absorb water, especially when pressure is applied. If the water of workability is lost into the aggregate, a blockage results. There are two approaches to overcome this. The first, originating in America, is to vacuum soak the aggregate—unfortunately this leads to a higher density concrete if it does not dry out. The second is to use an admixture to thicken the water so that it is not forced into the aggregate so easily. Air-entrainment also helps. Gentle application of pressure when pumping is also important. The manufacturers of Lytag seem to have done the most work in producing pumpable mixes, and they recommend the following:

Concrete Grade (N/mm^2 at 28 days)	20	25	30	35
Total water (including 15% for absorption)	308	308	308	308
Ordinary Portland cement	330	370	410	450
Natural concreting sand (M)	780	750	720	690
Pumping grade Lytag (0.65 m^3)	520	520	520	520
Conplast 242 or Cormix PA	1	1	1	1
Total (kg/m^3)	1939	1949	1959	1969

Blockages can also be caused by loss of grout from the concrete through leaking joints. It is important that joints are properly cleaned, not only to ensure a good seal, but to ensure that there is no build-up of material making closure of the joint couplings difficult. *A sledge hammer should never be used on a coupling*. A sledge hammer was used in the days when joints were closed by driving a couple of wedges to give a tight fit! A modern coupling does not require such brute force and to abuse it could strain it such that failure under high pipeline pressure is likely. The backlash of two pipes parting under pressure could knock someone off the structure.

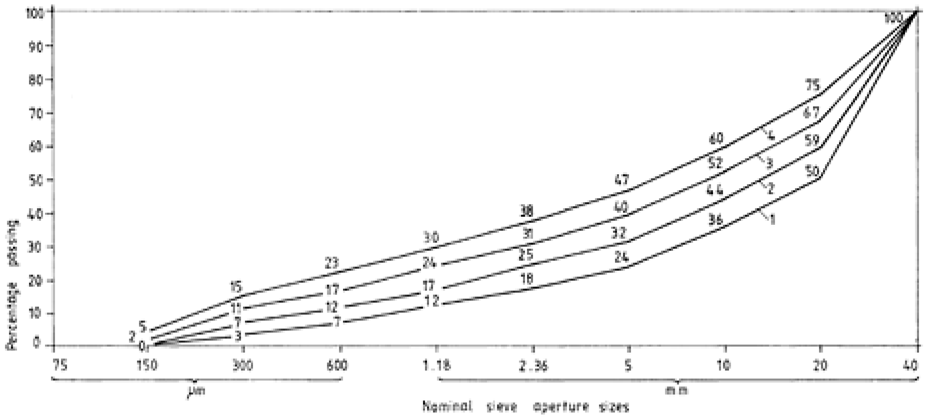
As the concrete is pushed through the pipeline, all but the outer 3 mm or so travels together at the same velocity like a plug. The outer 3 mm is the lubricating layer, consisting of water, cement and very fine aggregate. The coarser aggregate is pushed away from the pipe wall by the tumbling rolling action of the lubricating layer which is only travelling at half the speed of the rest of the concrete. Therefore, prior to ordinary concrete being pushed through the pipeline, an adequate quantity of this lubricating mix should be pushed ahead of the rest of the concrete. The water/cement ratio should be about 0.6 and, although sand is not usually necessary, on a long line a sand/cement ratio of up to 0.5 can be used. If the pipeline is not already damp, and especially if it is long or new, a bucket of water should be pushed ahead of the lubricating mix.

The following formula may be used to decide the minimum number of bags of cement required for the lubricating mix:

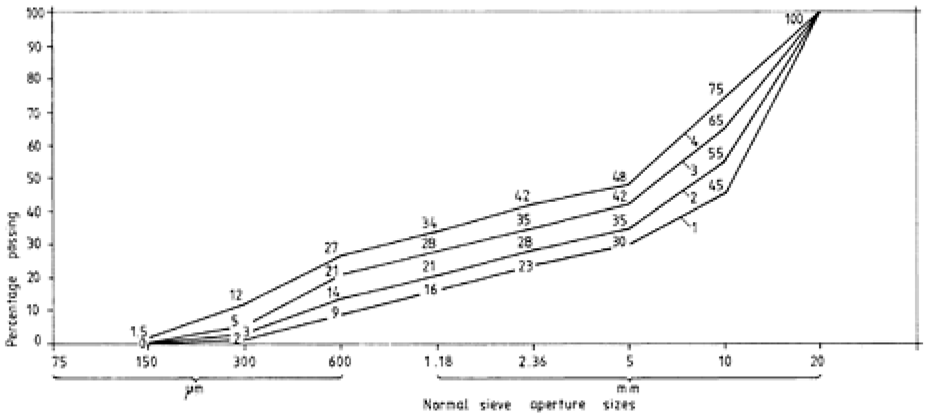
> The pipe diameter (mm) is divided by 5000 and multiplied by the pipeline length (m). This is equal to 1 kg of cement per metre of 100 mm diameter pipe. For new or difficult conditions, it may be safer to use twice, or even three times, as much.

$$\text{Minimum number of bags of cement} = \frac{L \times d}{5000} \qquad \text{...(a)}$$

where: L=total pipeline length including bends (m)
d=pipeline diameter (mm)



grading curves for 40 mm maximum aggregate size



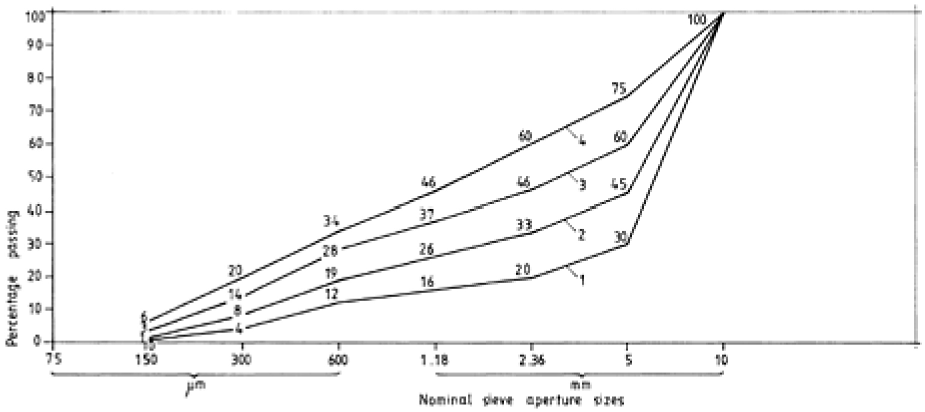
grading curves for 20 mm maximum aggregate size

The pressure required to pump concrete

The pressure required to move concrete through a horizontal steel pipeline will be proportional to its length and to its circumference (or diameter) and inversely proportional to the cross sectional area of the pipe (or diameter squared). The resistance of a flexible rubber hose is three to six times that of steel; six will be assumed. Since the concrete is not a liquid but a suspension of solids in liquid, a certain pressure will be required to start the concrete moving and above this the additional pressure will be proportional to velocity. Because the initial pressure is difficult to determine, it will be assumed that pressure is proportional to velocity (although this will lead to inaccuracies at very high or very low velocities). Velocity is proportional to the rate of placing and inversely proportional to the cross sectional area of the pipe (or diameter squared).

Note that the pipe diameter has been mentioned three times. Pressure is therefore proportional to $d\times[1/d]^2\times[1/d]^2=[1/d]^3$ or inversely proportional to the cube of the diameter.

The pressure will also be greatly affected by the water content, workability or slump of the concrete. The slump is a very convenient and universal method of measuring workability but rather imprecise. However, it is such an important factor in relation to pressure required that an attempt, however imprecise, has to be made to quantify it. From a study of available literature, it is reasonable to assume that the pressure required



grading curves for 10 mm maximum aggregate size

halves for a 41% increase in slump; in other words, the pressure is inversely proportional to the square of the slump (1.41 squared=2).

If the concrete is being pumped to a different level, extra pressure will have to be added which is proportional to the density of the concrete and the height to which the concrete is being pumped.

There are several other factors which could be taken into account in determining the pressure required to push concrete through a pipeline, if more was known about their effect. The following factors may cause the pressure found to be different from the pressure calculated:

pipe smoothness; pipe hardness; size of gap at each coupling; aggregate hardness; aggregate texture; aggregate grading; aggregate size; aggregate shape, cement content; concrete temperature; any changes in diameter of pipe; number and radius of bends.

If the length of the bend is included in the overall length of the pipeline, which it should be, a large radius will cause less pressure loss than a small one. Available literature does not agree on an allowance for bends, but a compromise of an extra 1 m of pipe per 90° bend will be used here. The literature does approximately agree that the pressure required to push 100 mm slump concrete through 200 m of horizontal 100 mm diameter steel pipe at 25 m^3/h, is 33 bar or 6 m per bar when pumping continuously. Collating this information we find the following formula:

$$P=\frac{(L+(6\times F)+B)}{6}\times\left[\frac{100}{d}\right]^3\times\frac{R}{25}\times\left[\frac{100}{S}\right]^2+\frac{H\times D\times 9.81}{100000} \qquad \text{...(b)}$$

where:

P	=pressure required to push the concrete	(bar)
L	=total length of steel pipeline including bends	(m)
F	=total length of flexible rubber hose	(m)

B	=the number of 90° bends	
d	=pipeline diameter	(mm)
R	=rate of pumping concrete	(m^3/h)
S	=slump of concrete	(mm)
H	=height to which concrete is to be pumped	(m)
D	=density of concrete	(kg/m^3)
1 kg	=9.81 N (in earth's gravity)	
1 bar	=100000 N/m^2	

The power required from the pump

The power given to the concrete, W (kW), multiplied by a constant, c, to tie the units together, is equal to the pressure in the concrete, P (bar), multiplied by the rate of pumping, R (m^3/h):

$$W(\text{kW}) \times c = P(\text{bar}) \times R(\text{m}^3/\text{h})$$

where c is a constant connecting the units together.

Now, substituting for c:

$$W \times 1000\ (\text{Nm/s}) = P \times 100000\ (\text{N/m}^2) \times \frac{R}{3600}\ (\text{m}^3/\text{s})$$

The units all cancel, leaving:

$$W \times 36 = P \times R \qquad \text{...(c)}$$

Note:

k stands for kilo or 1000
W stands for watts (1 kW=1 kJ/s= 1 kNm/s= 1000 Nm/s)
J stands for joules (1 J=1 Nm) (the standard unit of energy)
N stands for Newtons (the standard unit of force)
m stands for metres
s stands for seconds
h stands for hours (1 h=3600 s)
1 bar=0.1 N/mm^2= 100000 N/m^2 (about 1 atmos-phere)

To obtain the power required from the pump power unit, the pump efficiency, which is usually 70–80%, must be taken into account. 70% will be assumed so 30% of the power is lost due to friction within the pump. The constant to be used in practice, therefore, is 36 multiplied by 0.7, which is about 25. To find a suitably powerful pump for a given job, the maximum pressure must be found and this is multiplied by the maximum output required and then divided by 25. You may find it easier to multiply by 0.04:

$$W = P \times R \times 0.04 \qquad \text{...(d)}$$

Schwing, in their booklet *Pumping concrete and concrete pumps,* discuss the "Technical Identification Number, TK" of a pump, and give the formula:

$$\text{TK} = \text{m}^3/\text{h} \times \text{bar} \qquad \text{...(e)}$$

This is also equal to the power of the pump (kW) multiplied by 25. It must be remembered that pumps have a maximum output no matter how low the pressure and a maximum pressure no matter how low the output, so the above formula only works between these limits.

Comprehensive pumping formula

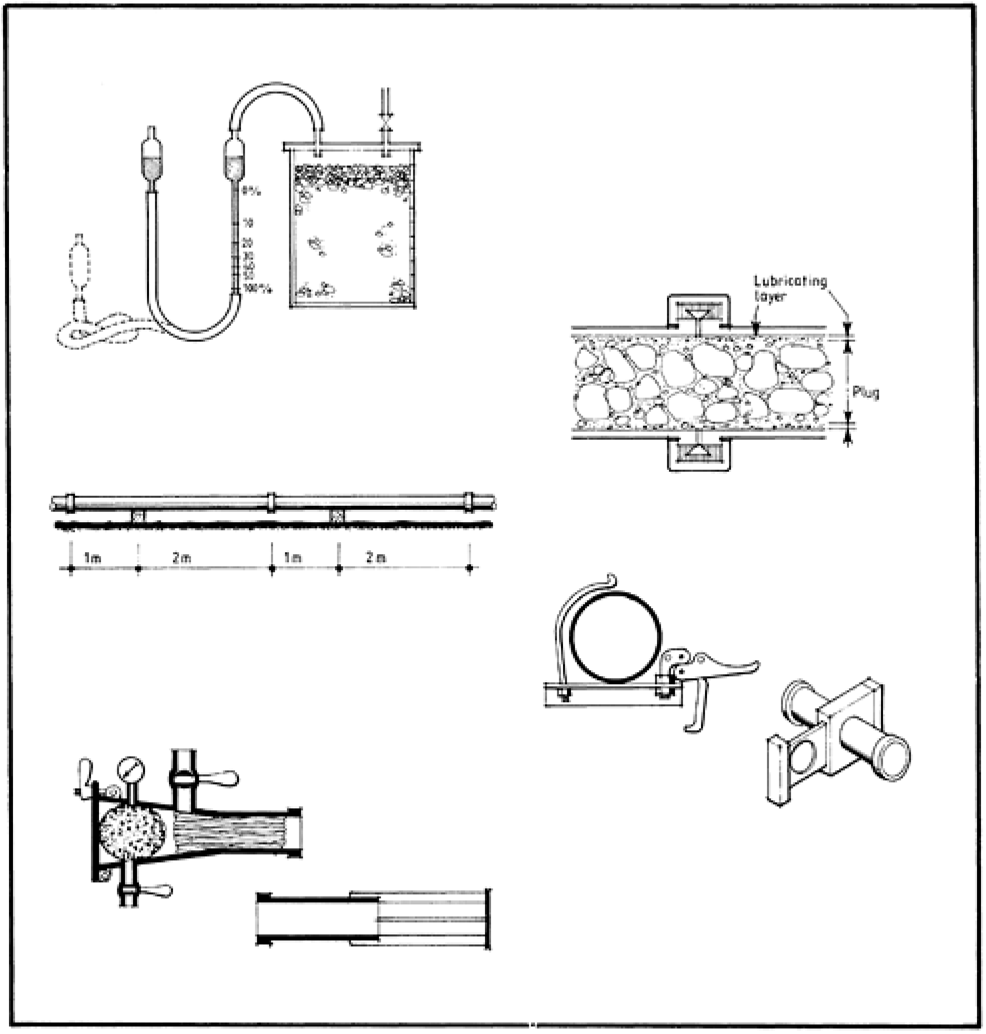
Formulae (b) and (d) can be combined to give the power requirement of the pump:

$$W = P \times R \times 0.04$$

$$= \left[\frac{F+L+B}{6}\right] \times \left[\frac{100}{d}\right]^3 \times \frac{R^2}{25} \times 0.04 \times \left[\frac{100}{S}\right]^2$$

$$+ \frac{H \times D \times 9.81}{100000} \times R \times 0.04 \qquad \text{...(f)}$$

$$= \left[\frac{100}{d}\right]^3 \times \frac{2.7\,(6F+L+B) \times R^2}{S^2} + \frac{H \times D \times R}{255000} \text{ kW}$$



Safety

The British Concrete Pumping Association (BCPA) has produced an excellent booklet, with the help of the Health and Safety Executive, entitled *The Advisory Code for Safety in Concrete Pumping*. Amongst other things, it recommends the following:

a skid mounted pump should have a permanent notice indicating its overall weight;
vehicle mounted pumps should have a notice in the driver's cab indicating the maximum travelling height of the unit;

a notice near each outrigger should indicate the maximum load that could occur at the foot of the outrigger when fully extended;

a hinged grille on the hopper should have parallel bars not more than 60 mm apart capable of supporting a 75 kg man;

opening the grille or valve chamber should dissipate all power to the operating mechanisms;

cleaning tools must not be passed through the grille when the agitator is operating;

the placement boom should be designed to carry placement hoses 8 m long including the contained concrete, but check with the manufacturer that this is so for their pump;

it is obviously important not to suspend more than the recommended length of hose from the boom;

if abnormally heavy concrete is being placed by boom, the maximum reach should be correspondingly reduced;

the boom should never be used as a crane;

hydraulic rams supporting booms must have lock valves so that the boom does not collapse should a hydraulic hose fail;

controls should automatically turn off when released;

separate guages should indicate pressures to 1) the concrete pumping mechanism, 2) the valve mechanism, 3) the agitator mechanism and 4) the boom;

pipe ends must be a shoulder type 17.5 mm wide and at least 6 mm high; a groove in the end of the pipe is not acceptable;

there is little danger of pipe failure due to wearing through, but a coupling which slips off the end of a pipe could cause a very serious accident;

worn pipes should be used towards the outlet of the pipeline where the pressure is lowest.

Pipe thickness

In a straight pipeline of constant diameter, the pressure will be proportional to the distance from the outlet, provided there is no blockage. This means that the pipe thickness halfway from the pump to the outlet need only be half the thickness required at the pump. The following rule of thumb is a useful guide for mild steel pipes. The minimum pipe thickness (*t* mm) equals the pressure in the pipe (*P* bar) multiplied by the pipe diameter (*d* mm) multiplied by 3 and divided by 10000:

$$t = \frac{P \times d \times 3}{10000} \text{ mm} \qquad \text{...(g)}$$

Regular turning of a static pipe will keep wear uniform. The greatest wear occurs on the invert of the pipe. When a pipe does wear through it shows as a small spurt of grout. Extra friction further down the line due to the loss of grout will cause extra pressure which may tear the pipe open where it is worn through. This tear will be gradual and relatively safe.

Pipe supports

Each length of horizontal pipe should be supported to avoid bending stresses in the couplings. Each length of vertical pipe should be secured with chains (not ropes) or preferably clamps. The bottom bend should be adequately supported so that it can carry three times the static weight of concrete about it, or alternatively the full pressure capable of being generated at the pump, whichever is the least. It is useful to incorporate a shut off valve at the bottom of a large vertical rising pipeline to enable blockages to be cleaned without emptying the vertical section of the pipeline. Blockages, if they do occur, usually happen near the pump, usually in the valve mechanism or in a taper section. The shut-off valve is a plate with a hole in one half which slides across the pipe either under hydraulic power or by being hit with a sledge hammer.

Where bends occur and the pipeline is clamped to falsework, the thrust due to the surge of the concrete (*T* N) in the following straight must be allowed for in the falsework design. It can be taken as the length of the following straight section (*l* m) divided by the length of the whole pipeline (*L* m), multiplied by the pressure available at the pump (*P* bar) divided by 10 to convert bar to N/mm^2, multiplied by the cross sectional area of the pipe.

Therefore, thrust

$$T = \frac{l \times P}{L \times 10} \times \frac{\pi d^2}{4} \text{ N} \qquad \text{...(h)}$$

Avoid sharp bends, especially kinks, in the placement hose. If a blockage occurs, release the pump to drop the pressure before a coupling is released.

Cleaning out

Cleaning the concrete out of the pipeline should be done with a sponge ball and a cylinder made from old saturated bags which are pushed through the pipe by high pressure water. *Compressed air is potentially hazardous and should not be used. However, if in exceptional circumstances, there is no practical alternative, it should only be carried out under the very close supervision of a competent person.* Personnel should wear protective clothing, safety helmets and eye protectors in these circumstances. The placement hose and all other flexible hoses must be removed and emptied separately. A catch-basket should be fitted to the end of the pipeline, which should remain properly supported. The dimensions of the paper bag cylinder should be such that it prevents the following sponge ball from leaving the pipe.

The possibility of concrete emerging at very high velocity due to the expansion of compressed air must be considered. The direction of discharge must be such as to minimise damage. Personnel must stand well clear of the whole pipeline and they must be in effective communication with the operator. Compressed air can then be applied to the concrete via a purpose made washout adaptor which must have an air release cock whose diameter is about half the diameter of the pipeline. If the speed of the emerging concrete becomes excessive, air must be dumped immediately to bring the velocity down to a safe level. It is important to ensure that there is no pressure in the pipeline before any couplings are released.

If a boom is used to pump concrete upwards or the pump is near the bottom of a vertical pipeline, a wet sponge ball can be inserted into the end and sucked back by putting the pump into reverse. Atmospheric air pressure pushes the sponge and the concrete ahead of it back down to the hopper which can be discharged onto the ground or into wheelbarrows. If a boom is not being used the pour should be started at a point farthest from the pump. Pipes are then uncoupled individually and upended to empty their contents into the pour. Each pipe is cleaned ready for the next pour. The couplings and rubber gaskets must be thoroughly washed to remove all traces of grout to ensure a proper fit without strain.

The operator

No-one but the authorised pump operator should operate or move the pump or its placement boom. Good communication between operator and placement gang is essential so that the pump can be stopped without delay.

The pump

Pumps have been subject to many improvements since the first mechanical patents were registered in 1913. Mechanical pumps for mortar are still being produced, but most manufacturers have now turned to hydraulics to drive concrete pumps. Hydraulic oil has the advantage of being able to push the piston at relatively constant velocity from the beginning to the end of each stroke. Power from the hydraulic pump is switched at the end of each stroke to the valve operating mechanism and then to the other cylinder. The short interval between strokes temporarily causes the pressure to drop in the pipeline. The pulsations which this causes in the pipeline can sometimes lead to problems wih falsework so that it is essential that all timber wedges are secured and that nothing can work loose. The elasticity of the pipeline and any compressed air in the concrete coupled with the inertia of moving concrete, tends to smooth out the pulsations. Difficulty has sometimes been experienced with the valve changeover when pumping air-entrained concrete because the pressure in the pipeline tends to be maintained, so that more power is needed to make the changeover sufficiently quickly for concrete not to reverse its flow through the valve mechanism, although most modern pumps are able to cope with this.

In the following table, which has been derived from manufacturers' literature, the figures in columns 4 and 5 are theoretical values and can rarely be achieved at the same time. However, the maximum product of pressure and output is given in column 6, which is dependent on the power available from the engine, which is column 3 multiplied by 25.

If a pump is to be fed by trucks with more than 25 m^3/h of concrete, then access to the hopper will have to be provided for two trucks at a time because of limitations on the discharge rate of a truck. It is also important to have enough manpower to place and compact the concrete. It will depend on the workability of the concrete and the complexity of the pour, but an initial estimate is to have one vibrator for every 10 m^3/h of concrete.

Pumps are available in many sizes and forms—diesel or electrically powered, static, skid mounted, trailer mounted, lorry mounted or truck mixer mounted. Each manufacturer has his own valve designs and each proclaims special advantages for their own make. Placement booms can be attached to lorry mounted pumps, then detached and remounted on a tower in the centre or at the edge of a structure to give increased cover. The reach of booms varies from about 16–60 m. Hand operated distributors are also available which are attached to the end of a pipeline and consist of two vertically hinged counterbalanced pipes. They enable concrete to be placed where required by one man more easily than by two men manhandling a rubber placement hose.

1		2	3	4	5	6
Name and Model Number		Diesel (D)/ Electric (E)	Engine power (kW)	Maximum pressure (bar)	Maximum output (m^3/hour)	Maximum work rate (bar × m^3/h)
Ackpump	P25	D	30	42	25	750
P40	D	60	42	40	1500	
Blastmixer					10–25	
Crow	Sem 150 L			7	10	
Hamilton						
500 L			7	30		
Sidewinder	D	60	60	30	1500	
SW 30						

1		2	3	4	5	6
Name and Model Number		Diesel (D)/ Electric (E)	Engine power (kW)	Maximum pressure (bar)	Maximum output (m^3/ hour)	Maximum work rate (bar × m^3/h)
SW40	D	60	45	40	1500	
ELBA	K4016	D	70	53.5	39	1750
K6018	D	80	74	62	2000	
K6018NMV	D	80	105	46	2000	
K8018	D	80	74	80	2000	
K8020	D	80	60	82	2000	
K8020–1800	D	80	58/93	85/60	2000	
K10020–1800	D	100	58/93	103/65	2500	
K10023	D	100	70	102	2500	
B2016D	D	25	54	19	625	
B2516D	D	47	93/105	27/25	1175	
B2516E	E	45	93/105	27/25	1125	
B3518D	D	45	73/104	35/19	1125	
B3518E	E	47	73/104	35/19	1175	
B4516D	D	69	93/132	43/30	1725	
B4516E	E	75	93/132	43/30	1875	
B5516D	D	69	93/132	57/40	1725	
B5516E	E	75	93/132	57/40	1875	
B5518D	D	69	73/105	55/38	1725	
B5518E	E	75	73/105	55/38	1875	
B7518D	D	69	71/105	73/50	1725	
B7518E	E	75	71/105	73/50	1875	
B9020D	D	69	91/64	60/85	1725	
B9020E	E	75	91/64	60/85	1875	
BSH 21555 16 D	D	152	215	55	3800	
BSH 21555 16 E	E	132	215	55	3300	
BSH 17075 18 D	D	152	170	72	3800	
BSH 17075 18 E	E	132	170	72	3300	
BSH 1409020 D	D	152	137	88	3800	
BSH 1409020 E	E	132	137	88	3300	
T 1012 E-NM 1.7	E	30	55	10.5	—	

1		2	3	4	5	6
Name and Model Number		Diesel (D)/ Electric (E)	Engine power (kW)	Maximum pressure (bar)	Maximum output (m^3/ hour)	Maximum work rate (bar × m^3/h)
T2016E-NM3	E	45	73	20	1125	
T 2516 E-NM3/FB	E	45	132	27	1125	
T 4516 E– NM 5	E	75	132	43	1875	

Putzmeister	BSA 1005 D	D	50	58	50	1250
1005 HD	D	50	85	50	1250	
1005 HE	E	45	85	62	1125	
BSA 1405 D	D	50	85	50	1250	
1405 E	E	45	85	62	1125	
1406 D	D	75	70	60	1875	
1406 E	E	55	94	77	1375	
1408 HD	D	118	70	85	2950	
BRS 2100	D	200		150	5000	
Pumi	16.46	D			40	
16.66	D			60		
16.46 SM	D	50		40	1250	
21.46 A	D			40		
21.66 A	D			60		
21.46				40		
21.66				60		
Shayler Plant	Bulldog TF 40		45	45	40	1125
Schwing	BP250 HDD	D	49	87	32	1225
BP250 HDE	E	45	87	27	1125	
BP 350 D	D	49	60	46	1225	
BP 350 E	E	45	60	38	1125	
BP 550 HDD-15	D	111	101	47	2775	
BP 550 HDE-15	E	90	101	47	2250	
HDE-15	E	110	101	47	2750	
HDD	D	111	70	66	2775	

HDE	E	75	70	66	1875
HDE	E	90	70	66	2250
HDE	E	110	70	66	2750
BP 800 D	D	111	57	100	2775
E	E	90	57	82	2250
E	E	110	57	82	2750
BP 3000 HDD-15	D	132	200	50	3300
HDE-15	E	132	200	50	3300
HDD-15	D	157	200	50	3300
HDD-20	D	111	110	75	2775
HDE-20	E	110	110	75	1750
HDD-20	D	132	110	90	3300
HDE-20	E	132	110	90	3300
HDD-20	D	157	110	90	3925
HDE-20	E	160	110	90	4000
BP 5000 HDD-15	D	2×111	200	67	5550
BP 5000 HDD-20	D	2×111	110	115	5550
BP 750 RE	E	22	65	36	550
RD	D	38	65	30	950
RD	D	26	44	30	650

Note: The Blastmixer uses low pressure air to carry material along a 150 mm diameter pipeline. Pumping distances of 200 m horizontally or 75 m vertically are claimed. Crow Hamilton produces two Sem pumps of 150 litre and 500 litre capacity to push concrete through the pipeline by air pressure for 150 m horizontally or 20 m vertically.

Points of supervision

Contract—ensure tie up between supplier and pumper

Falsework—check design for pulsations, check wedges secured, check vertical pipes clamped and horizontal pipes chocked

Formwork—check design for high speed pour and ensure grout-tight joints

Pipeline—ensure pipeline is laid to far end of pour and couplings are clean and secure

Pump—check adequate capacity pump for the pour, located for easy access by two trucks and pump in good working order

Boom—check adequate reach and outriggers extended onto strong sound support

Concrete—check for pumpability and adequate cement for the lubricating mix

Clean up—ensure water available under suitable pressure, or air if necessary, and provide a wash-out place

Accessories—ensure the following accessories are available: wash-out gun, wash-out balls, saturated used cement bags, ball catch-basket, shut-off valves and first aid kit

Supply pump time, rate of delivery, communication links, fuel for pump and vibrators and compaction equipment.

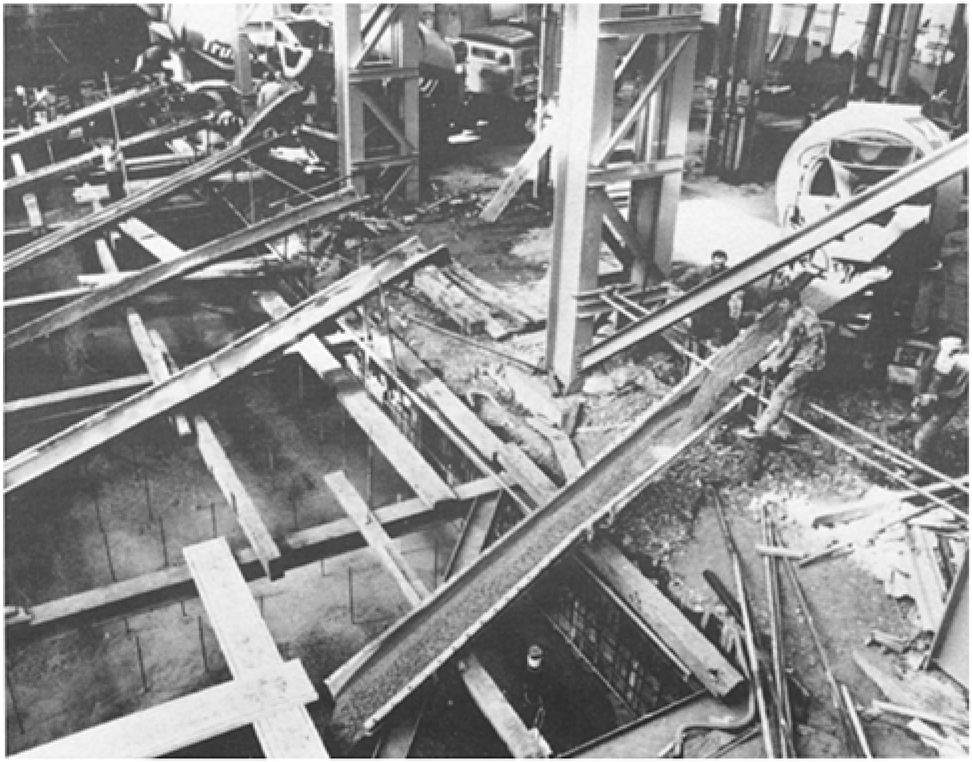
20.
Placing and compaction

Access for concrete placement

The importance of good access to the form cannot be overstressed. Without good, safe working platforms (which are, of course, mandatory) the operatives are unable to concentrate on or apply the necessary effort to the work in hand. Working platforms, complete with handrails, toeboards and ladder access, ensure that concrete can be placed at or near its final position in the structure. Where columns or isolated walls and beams are being cast, stable mobile platforms, provided with positive braking facilities, may provide an excellent access arrangement. As the element of the structure being cast increases in size, so does the need for a more substantial platform, either attached to the forms or freestanding. Access platforms are often incorporated in an overall access/working scaffold. In this case it is necessary to ensure sufficient clearance between the face of the structure and the scaffold standards to allow erection and striking of the forms to proceed unhindered by the standing scaffold. It must be remembered here that the space required to a large extent depends upon the type of tie and the form of carcassing member selected. Where extremely deep lifts of concrete are being cast, it will be necessary to provide intermediate access levels to allow men access to install and remove tie bolts, place concrete into openings, compact the concrete and so on.

Access for the skip is also important. A number of accidents have occurred where skips handled by crane have dislodged scaffolding or access towers when the skip has struck a projecting tube. Forms full of fresh concrete are also sometimes subject to impact from skips and equipment, with resultant damage to the eventual structure. The requirements of the *Construction (Working Places) Regulations,* 1966, must be observed and it should be mentioned that ladders used for local access often contravene regulations in that they are neither securely fixed, nor do they extend sufficiently above the working platform. Ladders roughly constructed on site must not be used.

It is generally sufficient for the purpose of placing concrete to have good access to just one side of a wall form. In the case of columns it is helpful for all concerned to be able to walk on platforms on two adjacent sides of the column. Allowance must always be made for the steel starter bars which project above the form. Access to the point of placement in slab construction is often overlooked and as a result men clamber on the steel reinforcement—a hazardous occupation in deep slabs—and their work rate is considerably reduced. It is better to provide properly constructed walkways to the key areas of activity from which duckboarding can be rigged to the point of placement. Suitable access will also exclude the likelihood of steel deflection or displacement during the concreting operations.



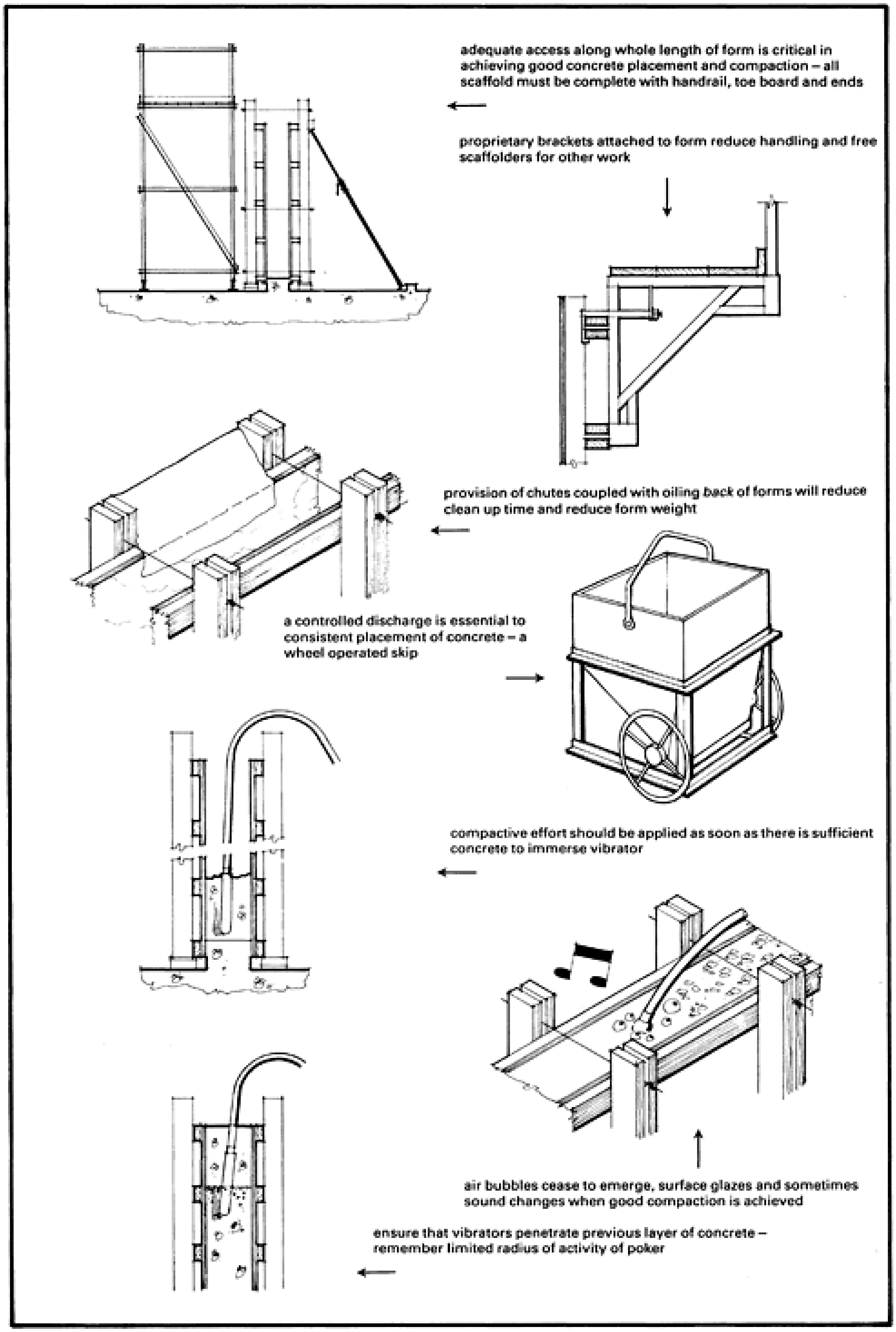
Chuting flowing concrete into a machine base—the concrete has admixture to achieve ease of placement with minimum plant requirements

Compaction

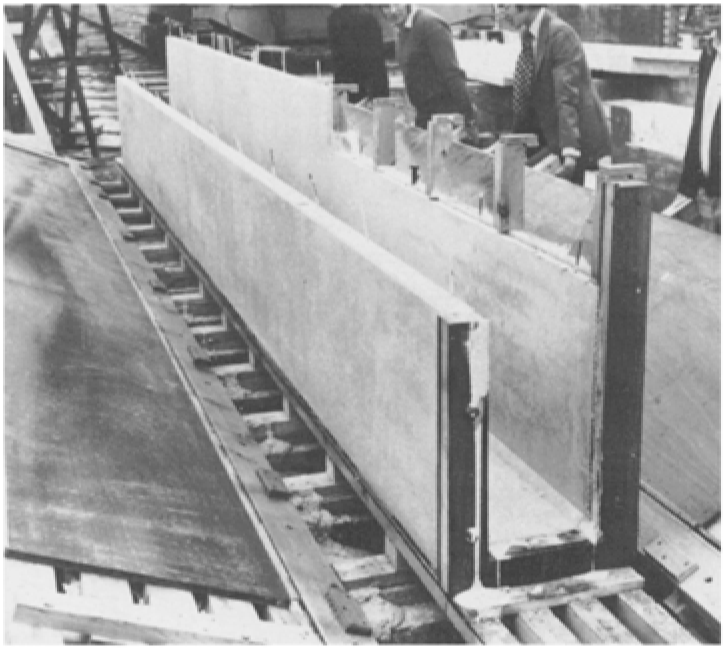
One of the least understood activities of the concrete construction process is that of actually compacting the concrete. The durability of concrete can generally be related to its density and permeability. Permeability affects the rate of water penetration and thus the rate at which, for example, steel will become rusted by the ingress of water or vapour. Permeable concrete, subjected to freezing conditions, will suffer spalling due to expansive forces. Permeable concrete also encourages the ingress of aggressive materials, such as salts and similar agents, which again cause concrete failure. Voids in concrete detract from the strength of the material and should ideally be reduced to an acceptable amount of the compactive effort. The means of compaction must, of course, be suited to the structural element under consideration. For any compactive effort to be successfully applied, the forms and mould must be substantially constructed and grout-tight.

Poker or internal vibrator

For general purpose work, such as columns, beams, slabs and walls, and for the precast structural element, the poker vibrator is an acceptable, portable and reasonably simply maintained tool. Internal or poker vibrators can be obtained in various blade sizes ranging from 25 mm-200 mm or more for special applications. Smaller sizes can be energised by a motor-in-the-head mechanism or from a small motor carried on the operative’s belt. The intermediate range of sizes, from 50–75 mm, are generally powered by


adequate access along whole length of form is critical in achieving good concrete placement and compaction – all scaffold must be complete with handrail, toe board and ends
proprietary brackets attached to form reduce handling and free scaffolders for other work
provision of chutes coupled with oiling *back* of forms will reduce clean up time and reduce form weight
a controlled discharge is essential to consistent placement of concrete – a wheel operated skip
compactive effort should be applied as soon as there is sufficient concrete to immerse vibrator
air bubbles cease to emerge, surface glazes and sometimes sound changes when good compaction is achieved
ensure that vibrators penetrate previous layer of concrete – remember limited radius of activity of poker

Superplasticised concrete has been used in this slender precast element to achive sound, dense concrete in a difficult cast



packs which contain petrol, diesel or electric motors. A number of motor-in-the-head tools are pneumatically powered.

The size of poker selected must be related to access, to steel spacing and to the workability of the concrete. The radius of action of poker vibrators is limited and initial experiments with the type of concrete in the section of the structure will determine the points of insertion required to ensure overlap of the radius of action and the achievement of a consistent degree of compaction. As well as ensuring an overlap of the radius of action of the vibrator, it is essential to achieve penetration of the preceeding layer of concrete to ensure that any excess fines and water are drawn through the concrete mass and each layer is knitted to the previous layer. Concrete should be fed to the vibrator which should be started as soon as there is sufficient volume in which to place the blade. As the concrete becomes compacted and after considerable initial settlement of the mass, bubbles of air cease to surface and break, the sound of the vibrator may change and the surface of the concrete may glaze over, after which little extra application of the vibrator is required. Continued vibration is not a hazard and it is better to continue than to cease vibration too soon.

The actual placement of the poker should be carried out methodically and a discipline on timing maintained. Fast insertion, vibration for some consistent period and slow removal of the vibrator will avoid the formation of pockets of entrapped air or accumulation of fines at the point of withdrawal. For as long as the concrete remains workable, that is as long as it can be mobilised by poker without any conditioning or use of water, then it can still be vibrated. In some cases it may be advantageous to re-vibrate to eliminate any settlement cracking which may take place in the fresh concrete.

Where there are openings, a discipline must be imposed to avoid choking forms. Fill should be carried out in such a way that the concrete flows around and under cores. Only when the level of concrete reaches the level of the underside of the former should concrete be placed at the further side. When filling thin sections,

The plant which has revolutionised concrete placing—this typical piece of equipment can place more than 35 m^3*/hour through its 16 m long placing boom (Putzmeister)*

care must be taken to avoid hang-ups or bridging between form faces and the steel or any included ducts or cores. In water-retaining structures, particular care is required to ensure compaction at the joint with the kicker and adjacent bays of concrete. In the case of day joints and stopends, concrete should be fed to a vibrator in such a way that the concrete flows up the face of the stopend former, driving out unwanted air and preventing the formation of voids. When the concrete reaches the top of the form and vibration has ceased, the layer of laitance or workability fines should be removed and replaced by fresh concrete which in its turn should be compacted and re-vibrated.

One problem encountered where internal or poker vibrators are used is that of damage to the form face, or the formation of "poker burns" as they are known, in the case of softer sheathing materials, where an indent or "burn" can form. The concrete fills the indent so formed in the face and hardens. At the time of striking, this projection, particularly if filled with aggregate, tears fibres from the sheathing and damage then becomes progressively worse. As a result, within a small number of uses the quality of the face deteriorates to a point where the form can no longer be used to form visual concrete. Rubber collars or rubber tips are available for poker blades to prevent such burns and, although these can be effective, the best remedy must be to avoid contact in the first instance.

Various configurations of poker blade are available —round, oval or square in section—and claims have been made that some blades are more efficient than others. These claims, however, are generally difficult to prove. The most important considerations would appear to be the blade size and the amplitude and frequency of action. Only trials in the working conditions with concrete of typical workability can ensure adequate compaction.

External vibrators

The majority of the description above for the use of immersion or poker vibrators also applies to the use of externally mounted vibrators. Systematic concrete placement is essential, and continuity of vibration important. Vibration should commence at first placement with the motors being activated or moved to energise the fresh layers of concrete as they are placed. It is often more important to supplement the energy imparted via external means by the use of additional poker vibration, particularly where forms become immobilised by being clamped to previously cast kickers, lifts or bays of concrete. Immersion vibrators

Precast mould of slender section prepared ready for filling

should be used to promote the compaction of the concrete adjacent to stopends, previously cast concrete and, in slab casting, previously cast slabs or the road forms at the perimeter of the bay.

Where external vibrators are used, very substantial fixings must be made to the form carcass. Most manufacturers provide quick-release clamps to promote ease of removal and replacement. Failure to move the vibrators as the fill proceeds will result in sub-standard concrete, particularly as regards surface finish, as hang-ups occur over steel reinforcement or settlement cracking takes place where the upper concrete is immobilised by steel or stopend detail. The location of external vibrators is also critical. As with internal vibrators, each motor unit has a limited radius of activity and the manufacturers' literature will give details on required spacing of the motors. It is possible for motors on one side to nullify the action of those on the opposing form faces. One problem which arises from the mislocation of motors is that where a pumping action develops as the two faces vibrate, each in phase with the other. In the worst cases this pumping action tends to force the form to climb off the kicker or become displaced. The solution is to move the motors in sequence to fixings located in a staggered fashion on the forms. Unfortunately, external vibrators do tend to promote the appearance of the defect known as "aggregate transparency", which results from the fact that under the influence of form vibration, fines are drawn to the concrete face as larger aggregates are impelled into the concrete mass.

The use of admixtures

Vibration of concrete is a means of imparting energy and fluidising or promoting the flow properties of the material. Currently, large amounts of concrete are being placed using superplasticisers which completely change the flow characteristics of a mix in its early, fresh state. Superplasticised concrete and concrete of such consistency that it can be placed by pumping is not the complete answer to achieving compaction. Where some special finish is required, where for example the concrete is to be exposed for visual purposes, it may be advisable to use concrete of normal workability and achieve compaction by using vibration. The action of vibrators on superplasticised concrete tends to result in the promotion of bleeding, which becomes particularly apparent when the concrete is subsequently tooled or the aggregate is exposed.

General points on compaction

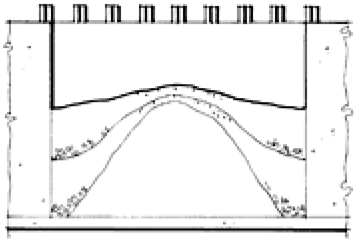
The supervisor should ensure that the poker vibrator is not used as a placing tool. Concrete should be placed by whatever means is appropriate (shovel, chute, skip and so on), and *then* compacted using the poker or external vibrator. The means of compaction to some extent determines the materials to be used for formwork, or at least the way in which the materials are to be fabricated and fastened. Under the influence of vibratory effort, whether internally or externally applied, form faces tend themselves to vibrate and flutter. This sympathetic movement can tend to promote production of concrete which, whilst being structurally sound, exhibits defects which detract from its visual quality.

Joints must be made tight, both to prevent grout leakage and to ensure that each panel of sheathing is effectively secured to those against which it abutts. Where the surface finish is critical, it may be advisable to close up the formwork carcassing members to centres closer than those derived from calculation, thus avoiding flutter and quilting.

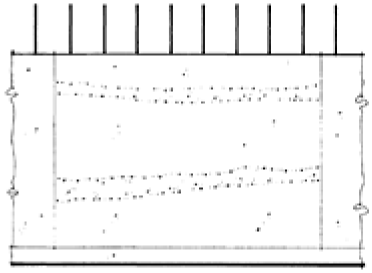
All plant requires regular maintenance and this is particularly so in the case of vibratory equipment. It is generally advisable to have access to stand-by equipment. The leads and couplings should be checked frequently and the equipment cleaned after each use. It should be mentioned here that most internal vibrators depend upon immersion for cooling and they should not be run other than for short periods out of the concrete.

From a supervisory point of view, the most critical aspect of compaction is that the operative understands *why* he is required to use the vibrator, *what* compaction means and the importance of the operation to the eventual performance and appearance of the concrete. It is helpful in instruction to remember that for every 1% of entrapped air, the strength of the concrete is reduced by about 5%, and a concrete containing 3% voids will lose 15–20% of its potential strength. In simple terms it could be said that poor compaction may result in the wastage of one in every four bags of cement, and most certainly costs a considerable amount in terms of time wasted in rubbing down and on remedial work to the concrete after form work striking.

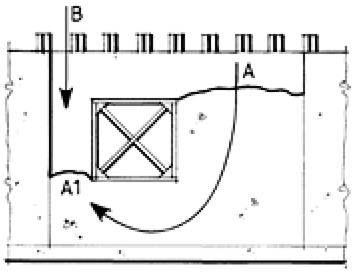
The instruction given to the man who operates the vibrator can best be illustrated by drawing his attention to previously cast concrete where such details as air entrapped below formers, areas requiring greater



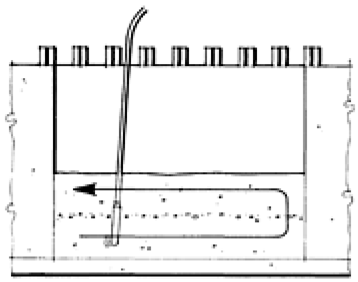
poor or localised access for concretors will result in "dumping" concrete in one spot and flowing it into position – separation takes place



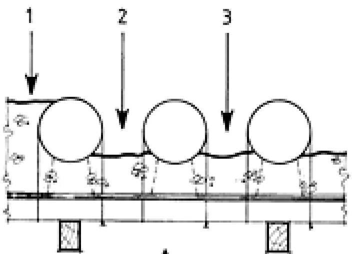
concreting should be carried out in one continuous operation – breaks and stoppages will result in strata lines



where openings occur in a lift, concrete should be placed at A until surge is seen at A_1 – only then should concrete be placed at B

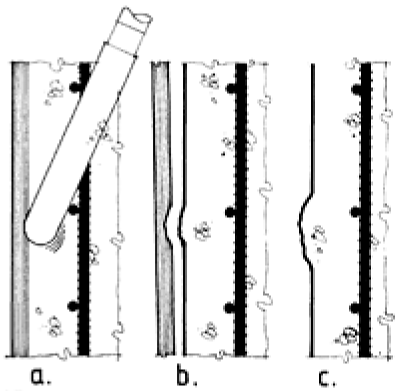


concrete should be placed continuously and systematically, the poker being used to knit succeeding layers and bring fines up to the surface



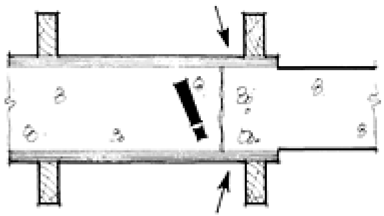
placement of concrete around cores (suitably restrained) must be carried out in a controlled fashion

vibration burns are caused by accidental contact between poker and form face causing local damage – hardened concrete leaves further damage at time of striking leaving progressively worse defects on face



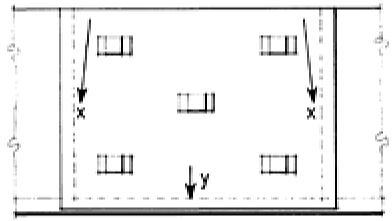
The skills of concrete placement and form design are evident in this board marked concrete work (J Laing Construction Company Limited)

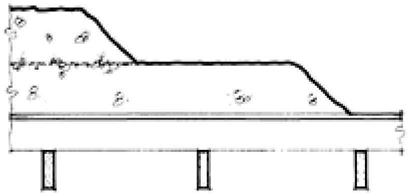
application of effort and such problems as poker burns on formwork faces, can be found. It must be borne in mind, however, that good compaction using any kind of vibrator can only be achieved in combination with sound placing techniques. The concrete must be placed as near as possible to its eventual position, in quantities which do not result in trapping air or choking the formwork opening. The concrete must be laid maintaining a fresh, workable face which can be mobilised by the available equipment.



compactive effort is often negated by clamping action between form and previously cast concrete

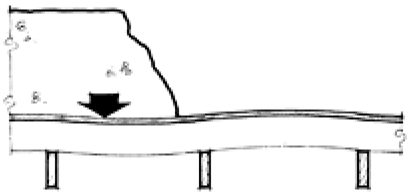
where external vibrators are used they should be supplemented by poker at x and y

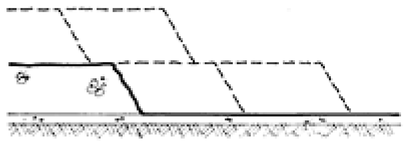




integral retarder (subject to approval) will avoid possibility of dry joints between layers in deep fills

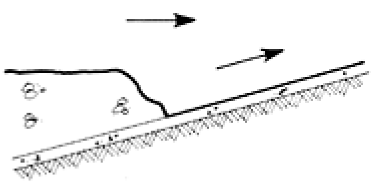
retarder (subject to approval) avoids differential deflections in deep fills

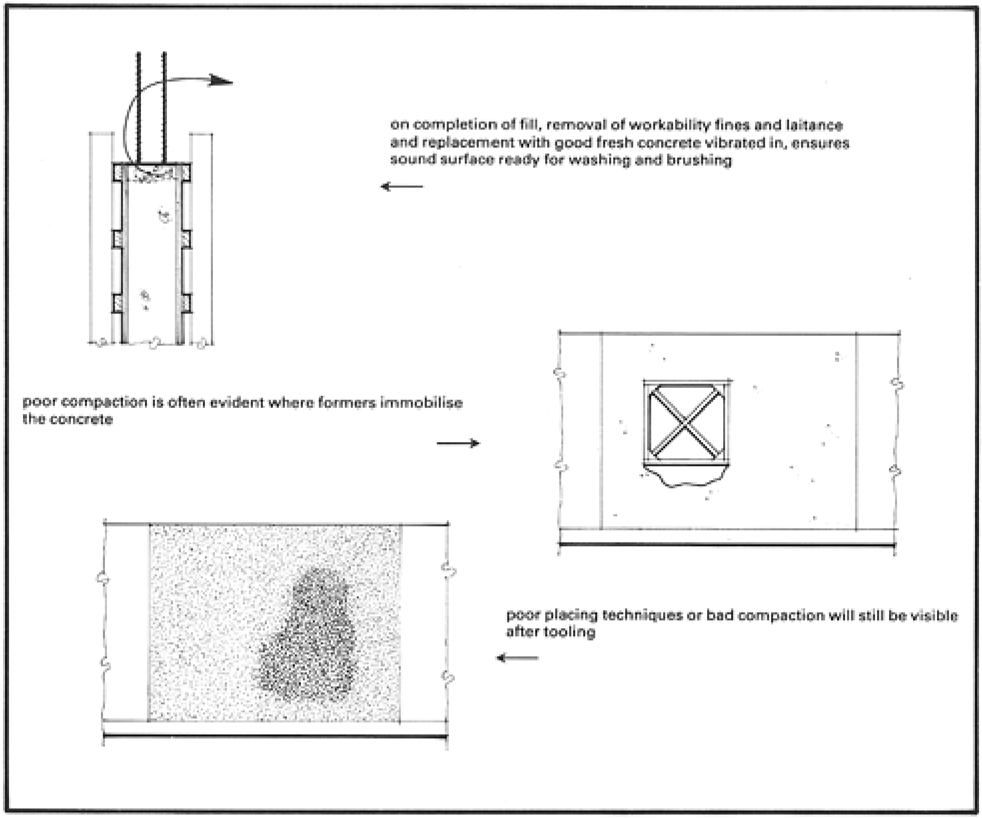




concrete must be laid in such a way as to maintain a face of workable concrete

on gradients concrete placement should be commenced at the lowest point and succeeding layers placed, working in the same direction

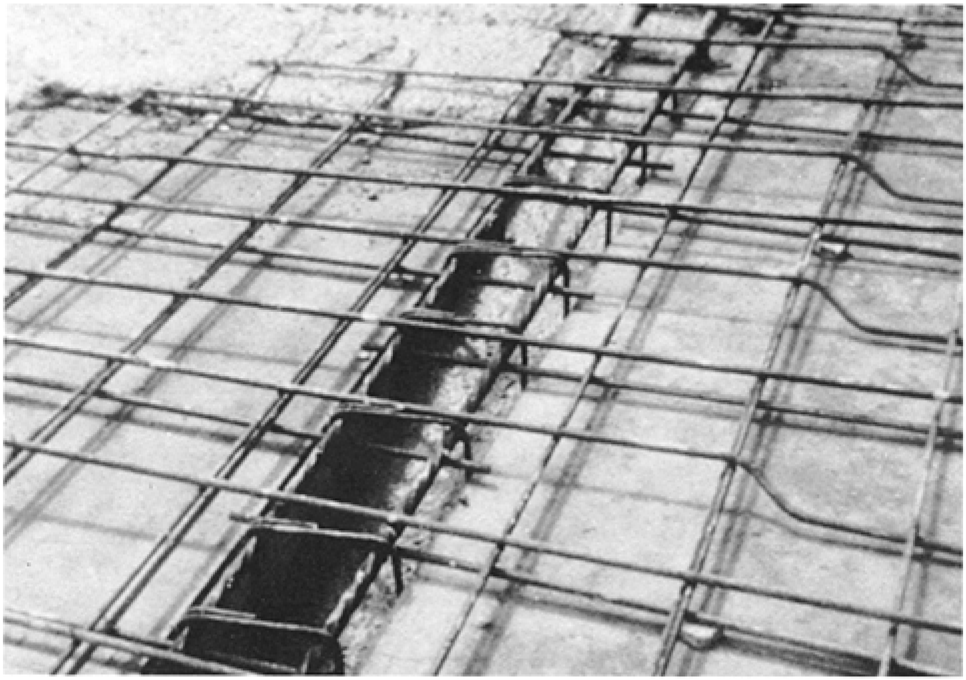




Compaction of precast concrete

Pokers are used in normal wet-cast production. Considerable use is also made of external vibrators, either mould mounted or attached to tilting tables and battery units, as well as purpose-made steel formwork. The input of energy can be improved by mounting moulds on what would otherwise be known as anti-vibration mountings, pads of rubber sandwiched between two bolted plates. Care is necessary to avoid local immobilisation of concrete by heavy cast-in fixing plates or by mould elements of heavy construction. On the European continent considerable amounts of concrete have been cast using *shock compaction* methods, where the moulds are physically raised and dropped over small distances, the impact promoting settlement and compaction.

The manufacture of many precast elements depends on a specific means of compaction. Pipes are spun, vibrated and pressed, or in some cases extruded. Spinning with roller compaction is also used. Floor units are cast by extrusion as are tiles, kerb and flag, some pavers and many other of the smaller precast elements are compacted by pressing or a combination of pressing and vibration. Glass-reinforced cement and some fibre-concrete elements are produced by spray processes. Reconstructed stone elements are produced by hand tamping and the use of pneumatic hammers. Whatever the process, the object is generally to increase the density of the concrete in the product with a view to improving durability. In some of the processes mentioned above, compaction is also used to improve the cohesion of the concrete allowing mechanisation and early or instant demoulding.



Placing concrete containing a superplasticiser, casting an in situ beam—the flowing concrete is settling into the space between forms without vibration

Points of supervision

Train the operative and inform him of the objects of compaction;

Select the most suitable vibratory equipment by trial casting in similar section;

Ensure sound access for men and machinery;

Ensure that forms are sufficiently substantial to allow good compaction;

Place concrete as close to its final position in the structure as possible;

Commence vibration as soon as placement commences;

Ensure secure fixing of external vibrators;

Supplement external vibrators using pokers inserted at the critical point adjacent to kickers and previous work;

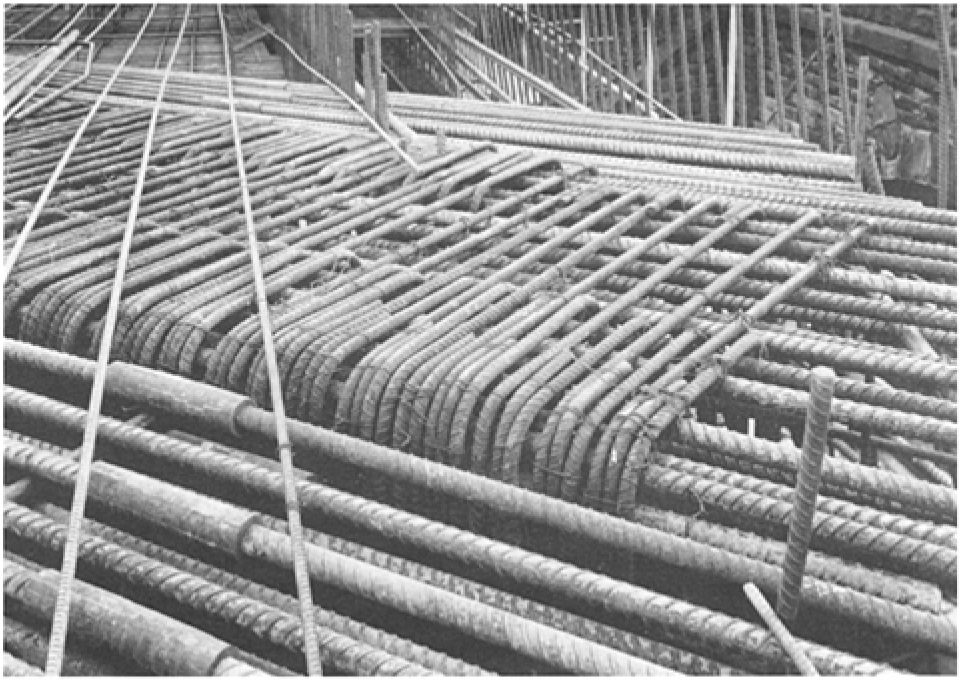
Avoid poker contact with form faces;

Move drive boxes, shafts and head using a properly constructed tray to avoid damage;

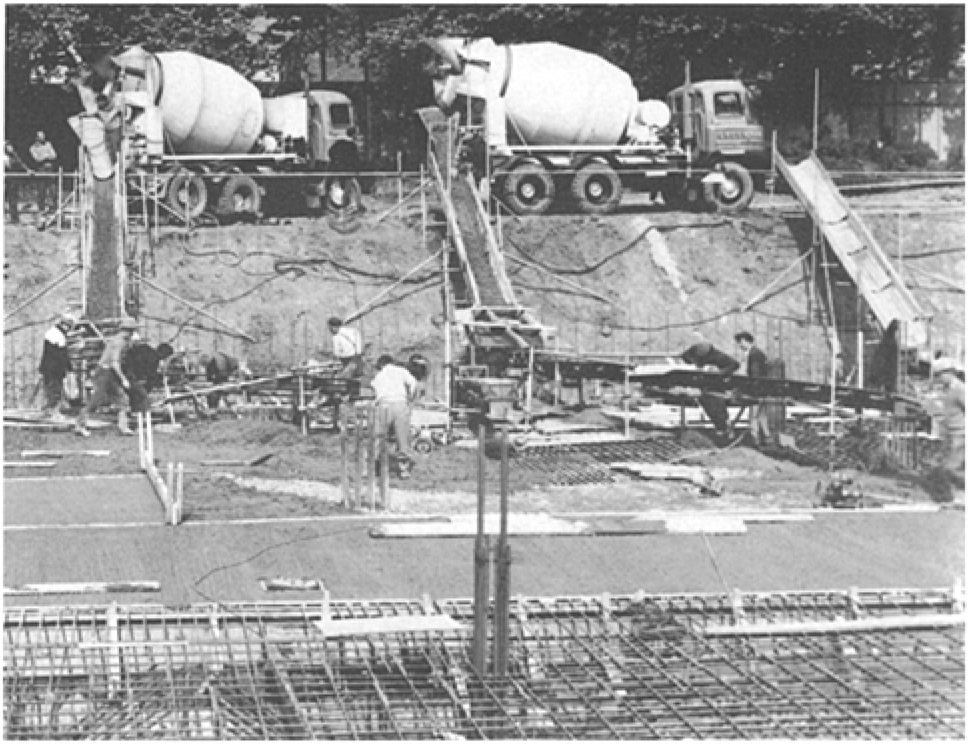
Provide access doors to deep lifts;

Ensure equipment is properly maintained and cleaned after use;

Make stand-by equipment readily available.



The workability of concrete placed in sections containing this amount of reinforcement demands special consideration – pumpable concrete provides benefits in the placing process



A foundation slab being concreted with discharge down chutes direct from the truck. Note the use of a conveyor belt on the right to transport the concrete to the centre of the slab

21.
Curing

One aspect of concrete production which is often badly executed and sometimes completely omitted, is the curing process. The chemical action of hydration must be allowed to continue uninterrupted during the stiffening and hardening processes, as the products of hydration are essential to the development of strength and the establishment of an impermeable, durable matrix. During hydration, strains are set up as a result of shrinkage of the matrix and it is most important that the crystal growth resulting from hydration should contribute to the strength sufficiently to ensure resistance to cracking and in some circumstances, such as slender sections and thin slabs, to avoid distortion of the member. Surfaces which are allowed to dry too quickly may be liable to dusting in use. If concrete temperatures are allowed to fall below freezing, expansion of the water in the mix may cause damage. Curing involves both retention of moisture and maintenance of concrete temperature.

For the hydration products to be able to fill the pores in the matrix, temperature control and continued retention of water is essential, otherwise moisture will evaporate due to differing conditions of humidity between the concrete and air and under the influence of conditions such as wind and heat which will promote drying.

Curing implies moisture retention and protection against heat, cold and drying winds and there are a number of measures available to the constructor which will afford such protection.

With many structural elements and in precasting, the simplest means of curing is that of leaving forms and moulds in position whilst the maturity of the concrete develops (and thus its resistance to frost and mechanical damage). The climate in the UK is particularly kind to concrete which is fortunate as otherwise structures in which the curing is neglected would show a considerable number of defects such as cracking and corrosion of reinforcement due to increased permeability and increased porosity caused by the early rapid loss of water from the concrete. Leaving the forms in place and covering down with wet hessian and a plastic sheet overall is sufficient in most cases, with care being taken to avoid draughts and drying winds.

Many specifications in the past have advocated spraying water to keep the concrete surface constantly moist. Whilst well intended, problems arise in this case when the concrete suffers sudden cooling or thermal shock. Tensile stresses build up and if the matrix has not achieved sufficient strength to accommodate the resulting strains, then cracking and crazing or distortion can result. Where water spraying is adopted, only a fine mist spray should be used and under no circumstances should water of a markedly different temperature to that of the concrete be used. A further problem in the adoption of water spray curing is that unless the concrete is sufficiently hard at the commencement of spraying, fines will be washed away from the face leaving an exposed aggregate finish.

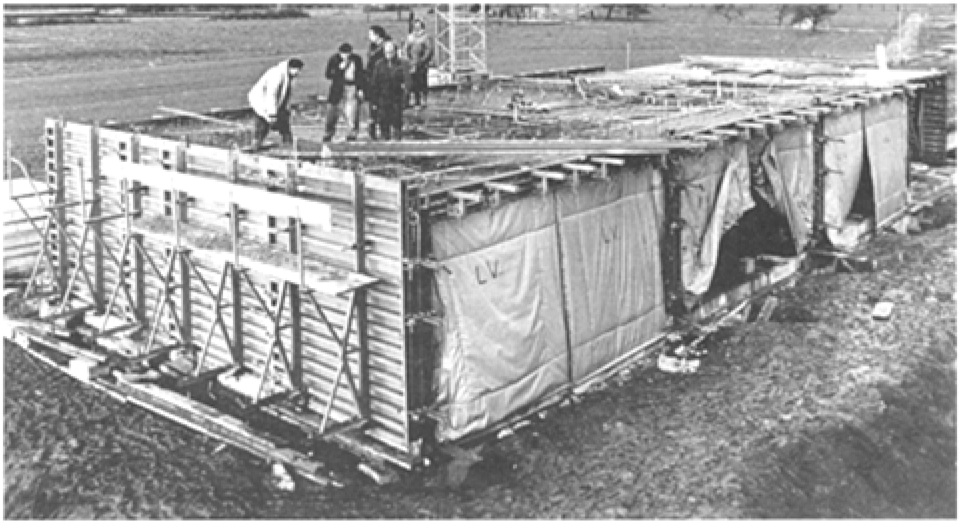
Damage to the surface from water drops due to condensation can be avoided when tenting the concrete by sloping covers away from the exposed concrete so that condensation drains to the side of the slab.

Curing waffle slab—note joint location and prepared joint face

In extremely hot climates, water curing is carried out in a variety of ways. Total immersion by forming clay dams at the perimeter of slabs is used, as is constant wetting by wrapping the structural elements with coir rope and hessian mats and feeding water to the surface by a combination of capilliary action and evaporation. Total immersion of precast concrete products is, in this instance, particularly beneficial to strength and durability. However the curing process is carried out, the principle is the same—that of retaining the moisture within the concrete for the longest possible time consistent with the manufacturing or construction method employed.

Sprayed membranes

Freshly exposed concrete, and particularly concrete laid in large areas such as floors and slabs, can be cured effectively by application of various proprietary sprays. These sprays, applied as a mist, contain a form of chemical barrier (wax or resin) and are deposited evenly over the concrete surface once it has achieved a suitable texture which is free from water and glaze. The solvent phase evaporates, leaving a film of curing compound to seal the surface preventing further evaporation. It is not sufficient to simply protect the top of a unit from wind—sides and ends must also be protected. Sometimes a pigment or fine powder is incorporated into the membrane to avoid damage by sun rays. The colourant is so formulated that it will fade away in a matter of weeks, but at the time of spraying it also serves to ensure an even coating. Where



The tentage acts as container for free steam used in curing these system cast buildings (Uni-form Limited)

construction joints are concerned, the best means of curing after washing and brush techniques have been used is to drape with hessian and polythene to avoid excessive drying of the concrete via the surface.

Curing in structural applications

Particular care is necessary when curing concrete in structures such as chimneys, vents, silos and similar chambers where natural convexion currents cause a drying draught of air up the shaft. This draught should be minimised by restructuring openings, although temperature build up must also be regulated. The same problems of drying draughts can also affect newly laid floors within areas enclosed by cladding as well as precast products in a factory. Door and window openings, if unglazed or unfilled, allow penetration of cold draughts causing differential curing and local drying, the results of which can be quite drastic.

In the case of thin toppings and prestressed elements differences in curing regime affect the ability of the concrete to resist those forces which it must sustain, resulting in distortion and variable camber. In the case of precast products, there must be absolute control over curing as many panels, particularly those with openings or which comprise two types of mix in facing and backing, can be severely cracked by sudden thermal shock as they are outloaded from the warm making place into severe cold or even frost. Precasters generally aim for high early strengths to assist in early demoulding and handling, the concrete thus produced usually develops a compressive strength such that the tensile strength is sufficient to resist the stress caused by sudden cooling at 15–20 hours after casting. In bad weather and extreme conditions, however, it may be necessary to keep the product in a protected condition to facilitate strength gain. This is important in the cold of Scandanavia and the heat of Middle Eastern countries for instance.

Maturity

Mention has been made previously of the “maturity” of the concrete element. The maturity concept is extremely interesting and knowledge of the subject will assist the supervisor in consideration of further aspects of curing, such as accelerated curing, winter concreting and resistance to frost attack. The attribute of concrete known as the maturity is a measure of the age of the concrete combined with its temperature history. Maturity is stated in terms of °C/hour, the function of the temperature in °C and times during which the temperatures have exceeded a base (chosen as –10°C), being that temperature below which there is apparently little increase in the strength of the concrete. Concrete strength for a given mix proportion can be related to the maturity of that concrete so that maturity becomes a useful criterion in establishing form striking times, strength to resist mechanical damage and handling and also the establishment of the degree of resistance to disruption by frost.

The British Standard Code of Practice CP 110, sets down some guidelines on maturity and the disciplines which should be observed when accelerating the curing of concrete. Unscientific application of heat can adversely affect the concrete strength and, of course, its durability, thus the Code of Practice recommends that the rise in concrete temperatures should be controlled and should not exceed 15°C for the first three hours and that further rate of rise and fall should be maintained at less than 35°C/hour.

A number of researchers have devised formulae to match the maturity of concrete, Sadgrove and Vollmy being two whose formulae are frequently referred to in manuals. For site determination of maturity, although this can be calculated from temperature records against time, there are several meters which can be connected to probes set into the concrete which will give a direct reading of maturity in °C/hours. These meters assist in decisions on site and in works regarding timing of striking formwork and stripping moulds. Once some sensible correlation has been obtained between concrete characteristics for a given mix of controlled proportions and agreed water content, then agreement can be reached on a suitable maturity reading to be achieved on site using the same concrete at which it will be reasonable to strike the forms leaving the concrete suitably supported.

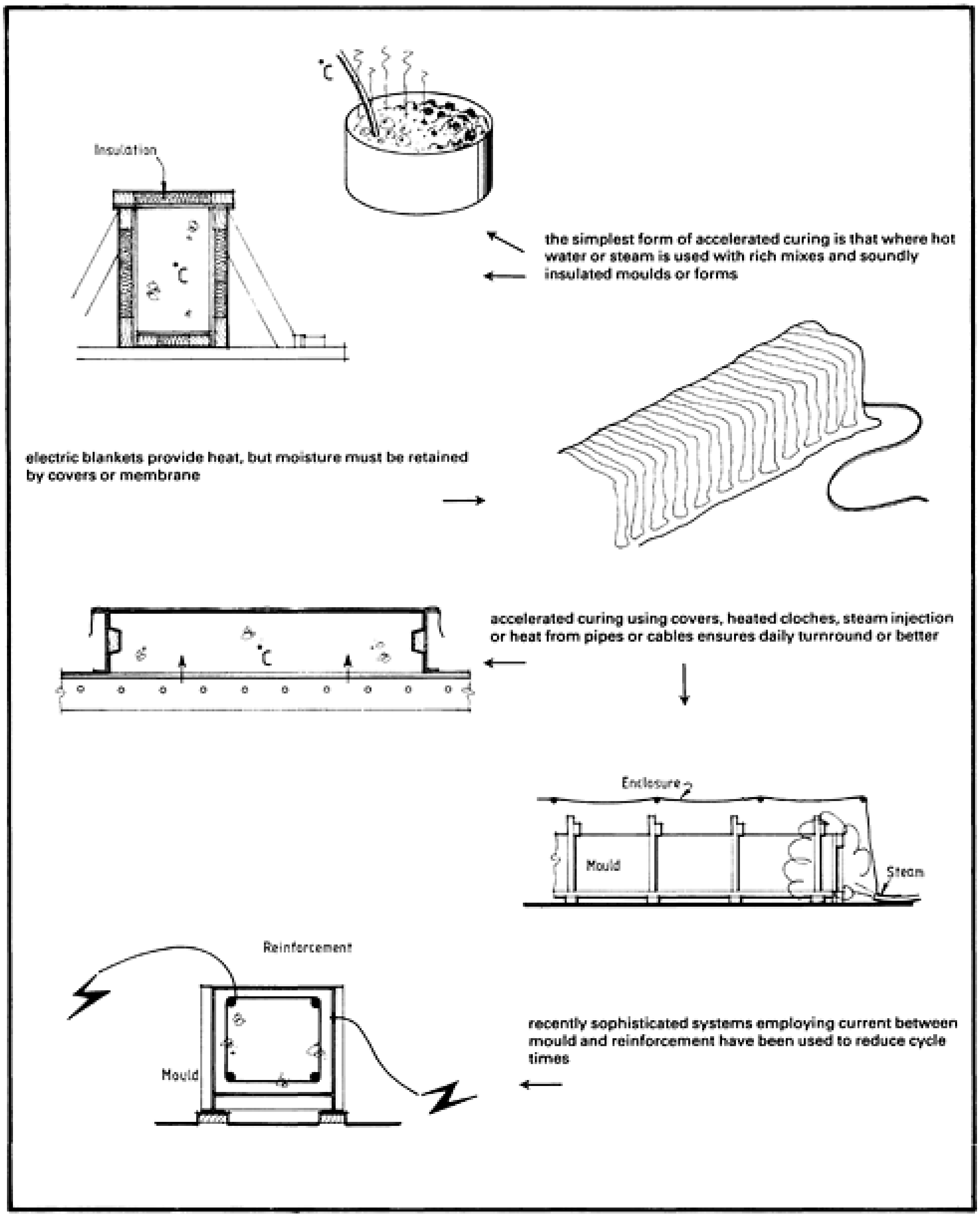
Accelerated curing

Frequently the need arises for a greater re-use of moulds or faster turn around of formwork than can be achieved using normal curing cycles. In precast production, whilst the norm is to make one unit per mould per day using wet cast techniques, it becomes possible to make more than one per day using accelerated curing and simple demoulding arrangements. It is, of course, ideal to make and demould twice in the working shift using accelerated techniques, filling the mould twice during the shift and then allowing normal curing to take place overnight. In this way the cost of accelerated curing is kept to a reasonable level.

Accelerated curing is achieved by various means, such as:

1. shrouding the product in steam
2. electric heating elements applied to or built into the mould
3. electric current passed through the concrete
4. hot water, oil or steam passed through pipes in the mould or under the casting bed
5. autoclaving.

The majority of these methods are expensive and possibly the most economic means is that of introducing heat at the mixing stage by the injection of steam or heated mixing water. The concrete so produced is placed and compacted taking care to avoid loss of heat during transporting and handling. The heat is then contained by insulation so that the warmth achieved from this mixing combines with the heat generated by the hydration process. When recorded graphically, the temperature increase attributable to heat of hydration



can be clearly identified and indeed care must be taken with rich mixes to control the increase of temperature within the 15°C/hour noted in CP 110.

The combination of high temperature and reduced time provides early maturity, allowing the concrete to be handled sooner than would be the case with normal curing. A paper by Kirkbride sets out calculations which can be made to establish methods of achieving the maturity required for early handling and striking processes. In in situ work, the gain of strength can be achieved using methods 1, 2 and 4, combined with that of using heated concrete. The methods using heated forms or current through the concrete are extremely direct and give most positive results. With accelerated curing, as with normal curing techniques, the retention of water within the concrete is of paramount importance. This is, of course, easily achieved using free steam, but particular care must be taken in shrouding such as plastic sheeting to achieve correct curing in the case of other techniques.

Arrangements using dry heat will damage the concrete and some means of introducing moisture, such as by spray or atomiser, is essential where, for example, concrete cast on tunnel forms or apartment forms is heated using blowers or forced air heating. In the case of precast products, water ponded below units undergoing curing provides the required humidity for curing.

Where it is intended to achieve early strength using accelerated curing, it is essential that the aggregates used in the mix should be maintained at a reasonable temperature in the bins or aggregate piles, and certainly protected from frost. Ample supplies of steam at the mixer using a package boiler will permit steam lances to be used to protect the aggregates in the pile, or piped hot water can be circulated around storage bins for the same purpose. In transit in truck, dumper or skip, the concrete mix should be covered down by tarpaulin or hessian and forms and moulds should be pre-heated wherever possible—where steam lances will again prove helpful. When accelerated curing is used, it is even more important to avoid thermal shock at demoulding, striking or at removal of the freshly cast concrete from the casting shop. In some cases the shrink wrapping process will greatly assist in protecting the concrete.

Table 9.1 indicates the methods of curing used in a variety of production processes and site operations. In addition to these techniques, there is a growing use of electrical curing, carried out by passing current between the reinforcing cage and the mould or formwork. Yet another technique employs cable or wire (even scrap crane bond is useable), embedded into the concrete, along which a current is passed, heating the cable and thus the concrete. The cable remains in the concrete after casting and obviously the rules of cover must be applied to avoid subsequent corrosion and disruption of the concrete.

Where electric “blankets” are used to shroud the concrete, care must be taken to observe the manufacturer’s recommendations regarding the maximum temperature to which the blanket should be subjected. The temperature evolution due to heat of hydration of the cement combined with the energy input from the blanket can easily result in quite dramatic sudden increases in temperature which may damage the equipment.

In all instances where external sources of heat are used in curing, trial runs should be made to establish the most desirable heating regime. The use of temperature measuring equipment (thermistors) or thermocouples actually in the concrete mass, will allow establishment of the recommended rates of heating and cooling to avoid damage to the concrete.

Temperature control

Although attention in the UK usually focusses on promoting or containing heat to accelerate or maintain the most suitable curing conditions, it should be borne in mind that in extremes of climates other factors will govern. The supervisor working in the Middle East or Far East will, to a large extent, be concerned with avoiding the development of excess heat. Concreting may be carried out late in the day or even at night. Crushed ice or cooled water may be used and admixtures to slow the hydration process may be introduced into the concrete mix in these instances.

TABLE 9.1

Curing techniques

Element	Curing technique	Remarks
Structural concrete and walls, columns, beams and so on	After removal of forms use polythene and hessian or a sprayed membrane	Cover down exposed surfaces whilst forms are in place or use sprayed membrane
Roads and ground slabs	Tentage and sprayed membrane	Avoid drying winds and exposure such as clear night skies
Floor toppings	Waterproof paper and polythene sheeting Damp sand	Watch for staining
Heavy slabs	Insulated forms	Maintain concrete temperature outside vs. inside within 12°. Cover with straw mats or use heating elements
Precast concrete products—pipe, kerb and flag	Free steam	Avoid differential heat distribution
Blocks	Free steam or autoclaving	
Prestressed units	Heated casting beds using steam, water or electricity	Avoid draughts which affect strength development and cause distortion
Precast walls, slabs and structural elements	Heated moulds (oil, electric or water), top surfaces cover with polythene and hessian	Avoid thermal shock after stripping
Battery and gang cast products	Heated moulds (oil, electric or water)	Mould arrangement conserves heat of hydration and accelerates curing

Points of supervision

Curing must commence at the time of placing concrete
- Avoid draughts under tentage and through openings in buildings
- Timber forms act as insulation and continue the curing process
- Avoid thermal shock, cold air or cold water
- Retention of heat of hydration is an important step in ensuring adequate curing
- Control temperatures to avoid differential movement
- Remove restraints, such as rigid opening formers
- Ensure membranes do not cause debonding at construction joints
- Cure concrete at stopends as well as at concrete face

Checklist

- What does specification require?
- Are curing compounds acceptable?
- Are covers required?
- Do special finishes require additional curing time?
- If accelerated curing is to be employed, how will this be controlled?
- Can hot water/steam in mix reduce curing costs?
- If forms are not required immediately can they be retained in place to promote curing?
- Are operatives and supervisor aware that curing is essential to achieve strength and durability?

22.
Quality control of site produced concrete

The supervisor responsible for the concrete structure will generally have the benefit of substantial back-up as regards concrete quality control. Most contractors have a department, or at least a person, usually an engineer, to deal with the underlying concrete technology of construction. The duties of this department or person will include:

formal details of quality control;
ensuring that aggregates, cement, water and admixtures conform with the local specification;
carrying out prescribed trial mixes;
sampling and testing materials and fresh concrete;
testing hardened concrete and ensuring compliance with specification requirements;
ensuring that weigh batching plant and measuring equipment is maintained and regularly calibrated;
conducting special tests such as using covermeter, Schmidt hammer and pulse velocity equipment in non-destructive testing, as required;
dealing with problems which arise in the event of non-compliance with specification.

The supervisor should be conversant with the work involved and must be able to supervise such work as will be carried out on his site or in the section under his control.

Where concrete is being supplied by a readymixed concrete producer, that producer can produce test results for their standard mix. Other information will depend upon the status of the readymixed plant regarding quality control arrangements. The contractor will be required to present test results to the client's representative and these requirements, again set down in local specification, must be met. Specimens and samples should be taken from the readymixed concrete as delivered, and tested by an independent testing house, a local laboratory or the local technical college. The laboratory should be nationally accredited.

On the smaller construction site and in direct works situations, it is likely that the concrete is specified in terms of the prescribed mixes set down in BS 5328. This simplifies matters considerably, but does not remove the responsibility for control of materials quality and the preparation of samples for testing.

The supervisor should familiarise himself with the following tests and procedures

for aggregates	aggregate sampling procedures
	sieve analysis
	silt testing
	siphon can test
	drying test

	moisture in sand tests
and for concrete	concrete sampling procedures
	slump test
	compacting factor test
	fresh wet density test
	cube making and curing

The tests are set out in detail in BS 812:1975 and BS 1881:100 series.

Most quality control activities can be carried out on the smaller site in some part of the site office or stores set aside for the purpose. Records should be maintained in the site diary. Care must be taken that sampling, storage and testing of specimens conforms with BS requirements.

The concrete cube

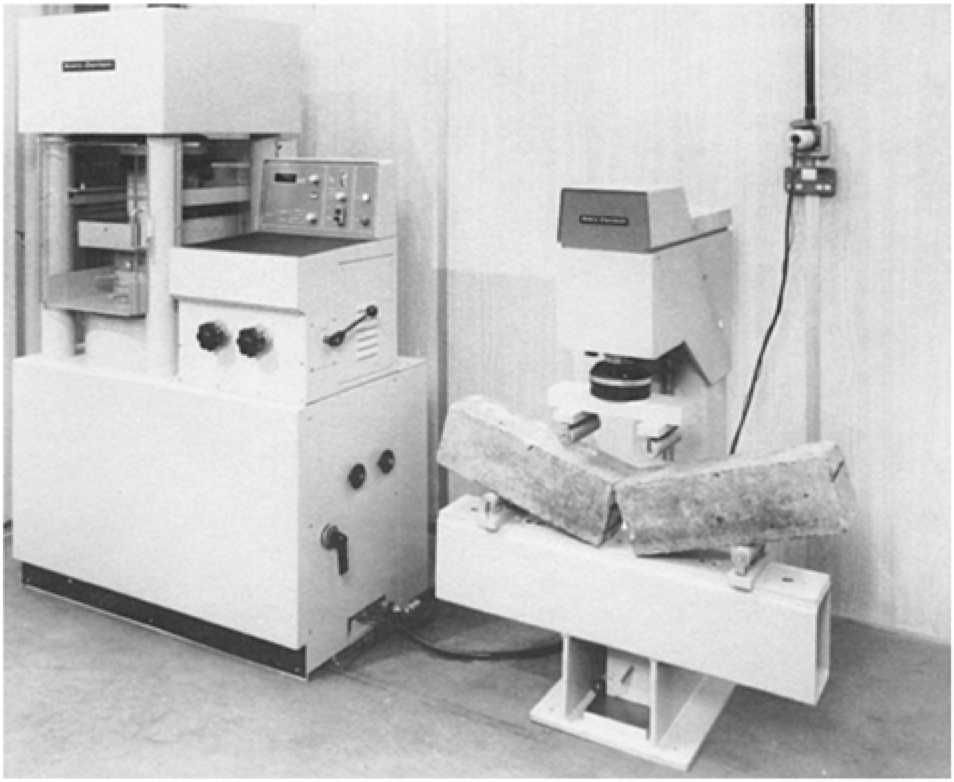
For many years the concrete cube test has been used to assess the (potential) strength of the concrete used in a structure. The cube test is specified as a control measure in the majority of specifications and considerable research has been carried out to establish the value of the test and the relationship between the specimen and the concrete in the structure. Research and measurement has also been applied to the machine used to test the cube and the influence of the machine on test results.

Regarding the concrete, it is evident that the results of cube tests relate to the sample of concrete from which they are made. The concrete in the structure undergoes a variety of further operations in placement, compaction and curing, which affect the characteristics of that concrete. There is, however, sufficient information resulting from research to prove that the cube test can give some sensible indication of the quality of the concrete in the structure. Having selected a grade of concrete for a particular application, the designer can make appropriate adjustments during the design process to ensure that, provided concrete samples represented by the cubes meet specified strength criteria and that the concrete in the structure is handled and placed and then compacted to acceptable standards, the structure will perform satisfactorily. He does this by the adoption of safety factors in design.

The rate of testing is related to the quantity of concrete, varying from 1 test per 10 m^3 to 1 test per 150 m^3, in such a manner that a reasonable guide to the quality of concrete in the structure is achieved. The chief acceptance rule or criterion is based on the probability in statistical terms that a given number of cube results will fall below the characteristic strength. It is important that the supervisor should understand the implications of the occasional low value and know whether or not, after consultation with the concrete engineer, to institute changes in mix proportions for example. Sampling, cube making, storage prior to test, testing procedure and the status of the test machine are all critical in the achievement of reliable results, and these are the first items to be scrutinised in the event of exceptional results.

Key points which the supervisor must observe in setting out to achieve meaningful control of quality by means of cube testing are:

method of sampling;
accuracy and condition of cube moulds;
initial curing as regards moisture and temperature;
avoidance of damage during demoulding and marking;
temperature of water used in curing;
condition of cube at the time of testing;



Compression testing machine with transverse testing attachment for concrete beam specimens (Avery-Denison Limited)

status of testing machine.

These points are all covered in BS 1881: Parts 1, 2, 3, and 4, and the concrete supervisor is advised to obtain a copy of these codes for his personal bookshelf.

Quite apart from the knowledge of strength achieved at the testing machine, the mode of failure of the cube can sometimes be interpreted by an expert to provide information on the quality and condition of the machine and the skills of the operator. Comparative tests can be carried out by comparing with results obtained from specially prepared cube specimens, some of which are tested in the local machine and the remainder in a reference testing machine maintained to high standards. This service is valuable when there is any question of the accuracy and repeatability of load measurement and may be required on an annual basis if the testing machine is to be accepted by NATLAS (National Laboratory Accreditation Scheme).

Compliance and non-compliance with specification

The supervisor on the concrete contract will generally receive information on the concrete strengths being achieved in the form of test records from the testing laboratory of the construction company, from the laboratories of the supplier, from an independent testing authority or consultant and in some instances from the local technical college.

The status of the testing laboratory and the equipment used therein must meet the requirements of the local specification. It is likely that a suitably qualified technologist or engineer will have inspected the laboratories or that the laboratories will have provided evidence of their ability to meet established standards in tests and equipment.

BS 5328 sets out in detail the compliance requirements and for designed mixes these are as follows:

> Compliance with the specified 28-day characteristic strength is assumed if the following conditions are met:
>
> 1. The average strength determined from any consecutive group of four test results exceeds the specified characteristic strength (the characteristic strength is that strength below which not more than 5% of test results are expected to fall in the long run), by 3 N/mm^2 for concretes of Grade C20 and above and by 2 N/mm^2 for concretes of Grade C15 and below.
> 2. The average strength determined from any test result is not less than the characteristic strength minus 3 N/mm^2 for concretes of Grade C20 and above and 2 N/mm^2 for concretes of Grade C15 and below.

The rate of sampling will be determined by local specification which is likely to refer to the recommendations of BS 5328. The rate will be set according to the importance of the concrete to the performance of the structure and its location within the structure. As an example, it will be evident that concrete in columns and cantilever beams will be sampled more frequently than that in foundations.

The samples should, wherever possible, be taken from a moving stream of concrete. BS 1881: Part 1 describes the method of sampling and, as with all such control operations, this must be carried out in a methodical fashion. Two cube specimens are made from each sample and are tested at 28 days. The average of the results obtained from the two cubes is taken as the cube result for the sample. The difference between the two cube results should not exceed, say, 10% of the average value. If it does, the process should be checked.

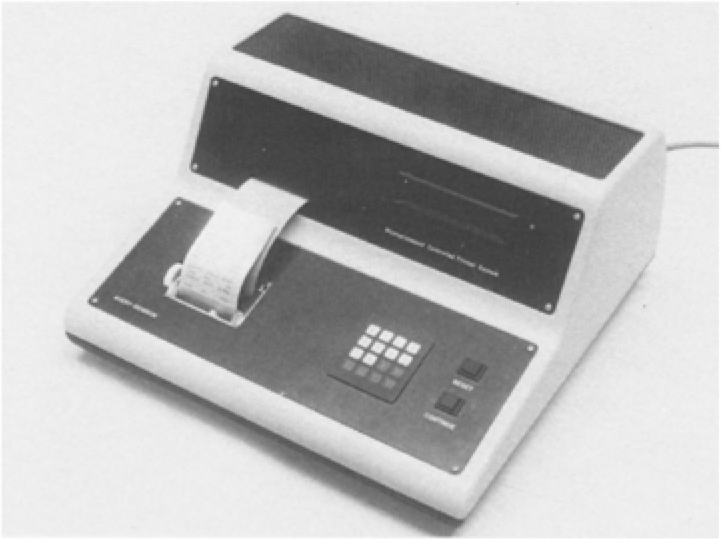
Action in the event of non-compliance

The supervisor must understand that in the event of non-compliance with the testing plan, on the evidence of cube results, the concrete in the structure must be rejected and the engineer may insist upon removal. In less severe cases there may be some qualified acceptance. It must be borne in mind, however, that whatever eventual decisions are taken, the result will be delays in the construction process, considerable upset, time consuming meetings and expenditure of valuable supervisory time. The last fact alone underlines the importance of care over the various activities of cube making, storage, curing and testing.

Action to be taken when exceptional results occur

The supervisor must take care to establish the requirements imposed on concrete quality. These requirements will be related to BS 5328:1981. He should also determine what is the quantity and location of the concrete represented by the failed specimen(s). It is important to check that the results are valid and do not result from neglect of one of the details previously discussed. If this is the case, after consultation with the engineer and technologist, and depending upon instructions from the site or contract manager to whom he is responsible, he should discuss the matter with the client's representative with a view to establishing

Microprocessor controlled printer calculator—when linked to machine provides printed information on inputs and results (Avery-Denison Limited)



some reasonable means of determining whether the cube is representative of the actual concrete in the structure. The most direct methods are the best and, ideally, upon agreement with the authorities, some simple comparative test should be made on the hardened concrete.

It is not possible to achieve a direct measure of the strength of the concrete in the structure and thus means must be used to obtain an estimated *in situ cube strength*. The tests most frequently encountered on site include:

the core test;
ultrasonic pulse velocity test;
Schmidt hammer tests;
pull out tests.

Core testing

The testing of cores cut from the concrete is the most direct method of establishing in situ concrete strength. With consultation it will be possible to locate the positions from which the cores are taken such that the structure, if proved to be sound, can be simply repaired. Concrete Society Technical Report No. 11: *Concrete core testing for strength,* sets down recommendations for the use of cores in assessing the quality of the concrete provided to the structure and the quality of the concrete in the structure as well as any deterioration in the structure, such as that due to chemical action. BS 1881: Part 121:1983 is now the authoritative document for assessing the estimated in situ strength. BS 6089:1981 gives the engineer guidance on interpreting core results. Potential cube strength (i.e., the quality of the concrete provided at casting by the RMC supplier or contractor) is rarely accepted by engineers because of the many unknowns intervening between the original concrete placement and core taking and testing.

Ultrasonic and rebound hammer testing can be used to supplement core testing by locating areas of potential weakness, the variability of the concrete and to minimise the number of cores required particularly where larger areas or volumes of concrete are concerned.

The cores may be taken to enable an estimate to be made of the actual strength of the concrete or the potential strength. In the case of a core to assess actual strength, it is likely that the specimen will be taken from an area of bad compaction. When assessing potential strength, the specimen will be taken from concrete thought to be representative of a batch.

The drilling of cores is quite expensive and care must be taken to ensure that cores are removed from parts of the structure which will provide the necessary information to the engineer and technologist. Care must also be taken to cut the cores from concrete representative of the suspected defective part and those cores must be of the required diameter and length and taken from correctly oriented drillings.

Cores must be carefully marked with an identification number, direction of coring and distance from surface, and a record established to enable the exact location of the core in the structure. In the laboratory the cores will be cut to length, weighed, capped as required, and then tested. Correction factors may be applied to the test results to compensate for poor compaction, steel inclusions, and so on.

Ultrasonic pulse velocity testing

The use of the ultrasonic pulse velocity meter has been widely accepted as a reasonable means of assessing the quality of the concrete in situ. Probes are used to introduce an ultrasonic pulse into the concrete. The transit time is measured electronically to a high degree of accuracy in microseconds. Given an accurate measurement of the thickness of the concrete, the pulse velocity through the concrete can be established. Generally the stronger the concrete, the faster the pulse will travel. Voids or lower quality areas of concrete give slower pulse travel. Adjustments may have to be made for location and direction of steel and inclusions. A survey can be made and contours of pulse velocity established.

If cubes are available, a correlation can be achieved between cube strength and pulse velocity. Given sufficient results and reasonable correlation, a prediction can then be made of the strength of the concrete in the structure. Comparative tests are again possible between acceptable concrete and the concrete represented by suspect cubes. It must be borne in mind that correlations are usually only valid for a particular concrete of given mix proportions and aggregate type and that humidity and particularly dessication can adversely affect the results achieved from ultrasonic testing.

One interesting application of the ultrasonic pulse velocity test is the survey plotted in terms of contours of like velocity readings. These surveys have been used to establish the location of voids in the concrete and areas occupied by concrete of a quality differing considerably from the remainder.

The impact hammer (Schmidt hammer)

This is a useful tool for comparative testing. Ideally a correlation should be obtained between Schmidt hammer readings on a number of cubes which are then crushed. The cubes are lightly gripped in the testing machine and, say 12, readings taken by Schmidt hammer. The high and low values are discarded and a mean of some ten readings taken for plotting against the crushing strength as indicated by the cube test. This correlation can be used with discretion in estimating the strength of the concrete in the structure.

Alternatively, comparison can be made with concrete of acceptable quality in the structure by a survey of readings taken on that and the material in question due to low cube results.

It must be remembered that the graph on the case of the instrument only relates to one particular type of concrete, hence the need to achieve a correlation between the readings on the hammer and the actual concrete in use. A further important point is that the readings obtained probably err to the extent of ± 18% in 19 out of 20 cases. This latter point does not, however, prevent the equipment being used to provide useful comparative results between sound and suspect concrete.

Pull out testing

Where there is a need to test concrete less destructively in, for example, completed structural elements, then the BRE internal fracture test can be used. A hole is drilled, cleaned of dust and debris and a 6 mm diameter anchor bolt is inserted and set such that the anchor wedges onto concrete 20 mm below the concrete surface. A purpose-made bridge is used in conjunction with a torque measuring device and load is applied at a specified rate, noting the readings obtained. After reaching a maximum torque, the readings will begin to fall. This maximum can be used to set up a correlation between torque and concrete strength. Because of the test variability, at least six tests are needed for a single result.

Points of supervision

Ensure that samples are taken in accordance with specification and standards BS 1881 and BS 5328: Part 1.

Inspect specimen curing and storage arrangements as well as marking and recordings and ensure that these comply with BS 1881: Part 3.

Ensure that results of tests are recorded, making use of site diary.

Liaise with quality control technicians and concrete technologists.

Take care that equipment for tests is in good order, batteries charged, and so on.

Be aware of the implications of tests and the deviations inherent in results.

23. Precast concrete

The construction process can, in certain instances, be sped up by the adoption of precast concrete as a construction material. Precast concrete is that which is cast other than where it is used. The concrete may be cast on site or at works, it may be cast as far away as several thousand kilometres from where it will eventually be used or as near as 300 mm to its eventual position in the structure, as instanced in Table 23.1:

TABLE 23.1
Distance of place of production from location in the construction

Distance	Type of element	Remarks
300 mm-3 m	Beams used for underpinning, segments and beams subsequently post-tensioned	Access or surface finish, cast adjacent to final location then jacked or rolled into final location
30m	Segments and lift slab components	Simplification of casting, cast at site and subsequently jacked or thrust into final location
300m	Bridge elements, piles, building components	Manufactured at site by main contractor where there is any great number of standard elements
300km	Most precast products and elements	Manufactured by proprietary suppliers and transported by road/rail to site
3000km	Civil engineering components, precast structural elements, building products	Shortage of materials or skilled labour at site. Shipped from country to country

*300 mm-3 m:*In the case of some special beam or lintel to be introduced to span an opening in existing construction. In this instance the beam element would perhaps be cast, post-tensioned then jacked sideways into its final position in the structure. Tilt-up construction is done by precasting virtually at the eventual position and then rotating elements into position.

30 m: Here a bridge is required to replace an existing structure. The new bridge is cast adjacent to the existing bridge and subsequently jacked into position with minimum upset to users.

300 m: It is not unusual for bridge elements and building components to be cast on site and transported across the site to their final location. Segmental cast bridges have been constructed as a ribbon of elements subsequently jacked into place using a launching nose to span the gap. Lift slabbing procedures are, of course, an application of precast techniques—the slabs being cast at ground level in most cases and subsequently lifted into their eventual position.

3 km: This is not excessive travel for components in bridging. Elements for building may be manufactured in a centralised works, and it is often convenient to set up manufacture in a convenient quarry or gravel pit and travel the elements over temporary roads.

300 km: This is about the longest distance over which it is economic to transport precast products and elements in the UK. For example, exposed aggregate cladding elements and structural components are frequently made in the West Country and shipped to the Midlands. A considerable number of products such as kerb, flag and pipe, are manufactured in quarry based works in the Midlands and shipped around various parts of the UK.

3000 km: There has been a history of exporting concrete, particularly sleepers or rail ties, although special buildings such as hotels and villas have been shipped from the UK to the Meditteranean and Middle Eastern countries. On the grand scale, it is not unknown for mammoth structures in the North Sea oil and gas exploration to be precast in dry docks for subsequent transportation to the site in the North Sea. Many such structures utilise precast concrete elements where the repetitious elements can be cast using factory rather than site techniques.

Precast concrete can be cast other than where it is used for reasons of economy, because of engineering requirements, or because of some visual requirement imposed by the architect, which may be simpler to achieve using precasting techniques. Precast concrete units, or elements as they are often called, are in general terms more expensive unit for unit than an equivalent piece of in situ concrete. Economy, if there is any, is achieved in terms of time saved or by the use of resources which would otherwise have been employed in the in situ production of the element. Considerations regarding the decision to use precasting techniques include:

- visual requirements;
- structural requirements;
  - physical details of work such as geometry, shape and form;
  - finish required;
  - accuracy required;
  - repetition/number of units required;
  - rate of construction;
  - labour availability and skills;
  - complexity of reinforcement or prestressing arrangement;
  - economic considerations.

Economies resulting from the adoption of precast construction are mainly in respect of the most precious of commodities in any programme—that of time. Precast elements can be designed, manufactured and stockpiled using time other than that critical to the duration of the contract. Then, when foundations and certain services have been installed and suitable access provided, the phased erection of the precast structure can commence. Precasting is often carried out in works where the contractor can take full advantage of the skills of the precaster, using the precaster's plant, equipment and experience in production matters.

The supervisor should make himself familiar with the Specification for the precast elements for which he will eventually become responsible. This responsibility may simply be for the acceptance of units delivered to his site, or for the acceptance and erection. In cases where the contractor elects to manufacture his own precast products for reasons such as the need to maintain progress or to overcome particular problems which would arise were the structure or elements manufac tured in situ, then the supervisor may be responsible for all aspects from the establishment of standards to final handover of the structure. Where a contractor wishes to maintain the initiative and is reluctant to sublet parts of the contract which may offer some of the previously mentioned advantages of precasting, then it is quite often practical and economic to set up

Glass reinforced cement is an emerging precast product as illustrated by these elements for a prestige office development (Wates Developments Limited)

precasting facilities on or near the main construction site. Bridge elements, piles, dolos units and building components have all been produced in this fashion for various reasons.

Information included in this Chapter is intended to provide a basis upon which the supervisor can build his programme. The activities of precasting are similar in many ways to those of an in situ concrete works. Indeed each precasting operation amounts to a minicontract which offers possibilities for innovation and development of ideas. Provided the supervisor follows the established principles, there is no reason why he should not produce acceptable units under site conditions.

Regarding means of transport, precast concrete is usually moved on wheels although in the case of bridges and similar structures, rail and water have been used. The size of precast elements is governed by a number of factors, such as access to site, motorway bridge clearances and so on. The larger units used in bridges and special structural applications can generally be moved on low loaders within the limits set for widths, headroom, and so on. Units over 100 tonnes have been transported by road and rail, although for extremely heavy or large units the economics would indicate site production.

Applications of precast concrete

The adoption of precasting techniques has advantages for all concerned. Quality control is easier to maintain in the enclosed environment of the casting works. Mechanisation can be employed and indeed many precast producers depend upon some particular process, usually a method of obtaining concrete compaction, to achieve specific attributes of a product. Table 23.2 indicates various means of compaction and some of the products manufactured using these means. It is by no account exhaustive and some products can be manufactured by one or more of the techniques. There are also other techniques employed in the manufacture of, for example, lightweight concrete, where fluid mixture is poured into moulds, foamed and expanded and then baked. No compactive effort is required. The supervisor is advised to ask for information on such products at such time as his work brings him into contact with them.

TABLE 23.2
Manufacturing techniques employed in the production of precast concrete

Poker or internal vibrator	Most wet cast products or section large enough for insertion of vibrator	Beams, columns, cladding panels and structural elements such as bridge beams, and cattle slats
External or clamp-on vibrator applied to mould	Products where it is not easy to introduce poker, such as large, flat units	Cladding panels, walls and floor units, prestressed flooring, sea defence blocks, cattle slats and agricultural elements
Vibrating tables on trestle onto which moulds can be placed	Often used as part of a flowline production set up	Structural elements, building panels for garages, etc, and landscape products
Shock tables where low frequency, high amplitude effort can be applied	Considerable capital investment in heavy plant installation and very specialised	Cladding panels and building elements
Mechanical and hydraulic presses, some utilising vibration in combination with pressing forces	Wet process products. Considerable investment in machinery, curing halls, etc.	Kerb, flag, pavers, tunnel segments, silo staves, masonry products
Extrusion techniques using screws or vibrating cores or moulds to lay products	Considerable investment in machinery, making beds, accelerated curing equipment and so on	Piles, beams, floor slabs, poles, lintels, tiles
Egglaying techniques—mobile presses which vibrate and deposit components into a slab or stack	Semi-dry process products. Require large areas of manufacturing space–often outside on quarry, floors, and so on	Blocks, posts, lintels, masonry products, beams, pavers and panels
Roller compaction where a heavy roller compacts concrete into a mould	—	Pipes, floor slabs, wall units
Spinning equipment where moulds are centrifuged	Also used for repetitious structural elements	Pipes, poles, piles, pileshells, lighting standards, bus stops, fence posts
Placing machines and plate vibrators	Machines travel on rails over preset moulds to generate curves and so on	Shell units, domes, flooring and walls
Spraying techniques	Manual or continuous mechanised process	Geometric concrete, grc sheet and products such as cladding, form work, landscape furniture
Hand tamping and mechanical tamping	—	Reconstructed stone products, lintels, mullions, balusters and copings

Filling moulds for wall units on tilting tables in the precast works– cube moulds are ready for specimens to be used in determining demoulding time

Flowing concrete using superplasticisers	—	Small products, slender sections and some reconstructed stone

A considerable number of precast concrete products are reinforced (except, of course, blocks, bricks and tiles, kerb, flag and some pipe). Many elements can be prestressed using the long line pre-tensioning process which is often featured in flooring and lintel and beam production. Reinforced and prestressed elements are generally cast using a daily casting cycle—that is, being cast during one day and stripped and cast again the following day. Precast concrete is generally cast using high early strength concrete to ensure sufficient strength (between 5–10 N/mm^2) in the concrete to allow early handling without damage or loss of detail. Prestressed concrete elements are cast using concrete capable of achieving strengths of 30–40 N/mm^2, required to allow transfer into the unit of the prestressing force either on the long line bed or by post-tensioning techniques. The various mechanised techniques such as spinning and pressing provide a cohesive or wet strength, which allows the units, suitably supported by mould or pallets or utilising special handling techniques, such as vacuum pads, to be handled into the curing location with improved turn around time of the expensive moulds.

As well as the various means of production available when precasting is employed, it becomes possible to use alternative materials and techniques. Lightweight concrete is frequently used in precasting for thermal reasons, for acoustic reasons and for reasons of weight saving. Aerated or gassed concrete is produced in works and has major advantages in terms of all these attributes. Certain types of extra-lightweight concrete can be reinforced and used for structural purposes, thus offering a further advantage difficult to achieve in in situ construction.

The rate of manufacture of elements in precast works can be increased by the adoption of accelerated curing techniques where heat is applied using steam, electricity or heat and humidity to accelerate the hardening of the concrete to allow early demoulding and the acceleration of curing allows early handling. Both techniques create economies in space and reduce cycle time. Mechanisation also improves output by allowing gang or multi-element production as well as reduced cycle time—many vibrated and pressed products, for example, are cast in batches of 20 or more units in one operation. Of course, the introduction of pressing machinery means that a fixed multiple mould in the machine is repeatedly re-used on a cycle of only seconds to produce literally thousands of elements per shift. In the case of tile manufacture, a stream of extremely cohesive concrete mix is extruded onto a line of tray moulds which pass through the making station. Further along the line, these trays are parted and stacked to be passed into the curing area. The whole process is continuous and highly mechanised.

Precasting of structural elements is carried out in a number of ways, the main techniques being summarised below, by moulding techniques:

Individual moulds comprising sides, ends and base or bases	Cladding, sandwich panels products
Battery and gang moulds	Panels, slabs, walls, piles, tunnel segments
Tilting frames or tilting tables	Cladding, structural elements,
Long line bed casting	Flooring, wall panels, beams, double-T, U and I sections, box sections and planks

The supervisor who finds himself involved with precast manufacture, either as a user or producer, will do well to obtain copies of the relevant BS Codes of Practice, which will give guidance regarding standards of finish, accuracy or permissible deviations and all the critical details such as concrete grade, cover to reinforcement and so on. The Codes of Practice covering precast products (BS 8110, CP 115, CP 116 and CP 297), are particularly informative and include considerable useful detail.

Deciding upon supplier

The first and most important task is to establish the suitability of the supplier. This can be assessed by visiting the suppliers works, visiting sites to which the supplier has delivered goods in the course of past contracts, and talking to people who have employed the supplier on work of a similar nature.

During his visit to the works, the supervisor should assess the following factors:

- the skills of labour and supervision;
- the quality of plant and equipment;
- the back up in technical and service departments;
- the suitability of available transport;
- the standard of goods in stock;
- the condition of stockyards;
- material storage facilities;
- the degree of control over production;
- the quality assurance arrangements and laboratory facilities.

It should be mentioned here that assessments should be made as objectively as possible. Although the company may apparently be lacking in one or other of the above areas, it is the suitability of the product which is paramount, combined with the supplier's ability to meet programmes. The supervisor and supplier are largely inter-dependent. The accuracy of construction achieved by the supervisor in his foundations, the structure and the fixings for precast superstructures or cladding elements, will to a large extent govern the speed with which the precaster can carry out his part of the work. The supervisor, particularly in the case of the precast superstructure, depends on the speed of erection for the subsequent gainful employment of his labour force. Where cladding is concerned, there is particular need for close co-operation to ensure that fixings and joints are easily and accurately made.

Standards

It is advisable that, the standards having been agreed, sample products or panels are set up on site as a visual reference to what will be acceptable—the architect and the engineer should be involved in this process of establishment of standards as they are the eventual arbiters of what is acceptable to the client. The erection of a mock-up part of the structure or a section of the cladding, either in the works or on site, is an essential step in the establishment of standards. The positioning of elements or cladding into some temporary framework will establish a large number of important points of appearance and performance early in manufacture, and will prevent argument or discussion later. Carried out early enough in manufacture, it will be possible to modify or redesign parts of the structure or cladding which would otherwise result in damage during handling, poor fit in the construction or difficulty in manufacture and erection.

Finishes and accuracy

Some elements are precast for reasons of surface finish. Certain finishes are difficult to achieve in situ and the possibility of orienting units during precasting to facilitate incorporation of brick slips, tiles, mosaic, and such like, using simply skilled labour, tends to reduce production costs. The possibility of rotation of a suitably reinforced element can be exploited for the purposes of achieving special finishes using thin layers of exotic aggregates or inserting insulation or water-proofing membranes.

Indeed, the possibility of manufacturing units whichever way up that provides the best results in the finished product introduces considerable opportunity for the precaster to simplify the production of finishes which would otherwise be difficult and expensive to produce on site. Finishes which are currently popular with architects are those where aggregate is exposed using surface retarders applied to moulds and finishes which incorporate brick, slip and tile. The latter finishes are manufactured using features and fillets which ensure the individual facing tiles and facing bricks are accurately located whilst the concrete is cast. Many manufacturers use post-casting pointing techniques, although even the pointing is sometimes done in the mould.

Regarding accuracy, BS 8110 gives an indication of the accuracy which can be achieved using precasting techniques. In fact, the manufacturer can frequently halve the permissible deviations at no extra cost to his client, although closer accuracy is bound to cost more. Where cladding element manufacture is concerned, the permissible deviations are set in different, less permissive terms (CP 297). The intention is, of course, to avoid cumulative errors preventing the proper location of cladding elements into the allocated spaces. The supervisor should bear in mind that where part of the element is removed by tooling or by brushing away retarded fines to expose aggregate, then due allowance must be made on the sectional sizes of members to avoid reduction in cover to the reinforcement.

Ribbed or striated precast concrete panels form the elegant envelope to the Law Courts, Liverpool

Codes of Practice and Standards, and sometimes Specifications, describe concrete in terms of *smooth, ex-mould, plain,* and so on. These terms are not helpful! The finished product becomes subject to a series of extremely subjective inspections as it will not be easy to reach agreement on what is acceptable in terms of the description. It is essential that there should be some visual reference. The reference in the first instance, whilst administrated in the preparation of Specifications and Bills of Quantities, must be in terms of description accompanied by illustration. Some research has been done on surface defects and colour gradation and it may be that the type of illustration given here could become used in future when

Demoulding a roof unit using mobile crane and specially fabricated lifting connections (Higgs and Hill Limited)

communicating standards. For the present, the sooner words can be translated into samples of the largest possible size, and produced under similar conditions using similar processes and labour to that which will be used in the eventual work, the easier it will be to establish standards and get on with the production of suitable and acceptable finishes.

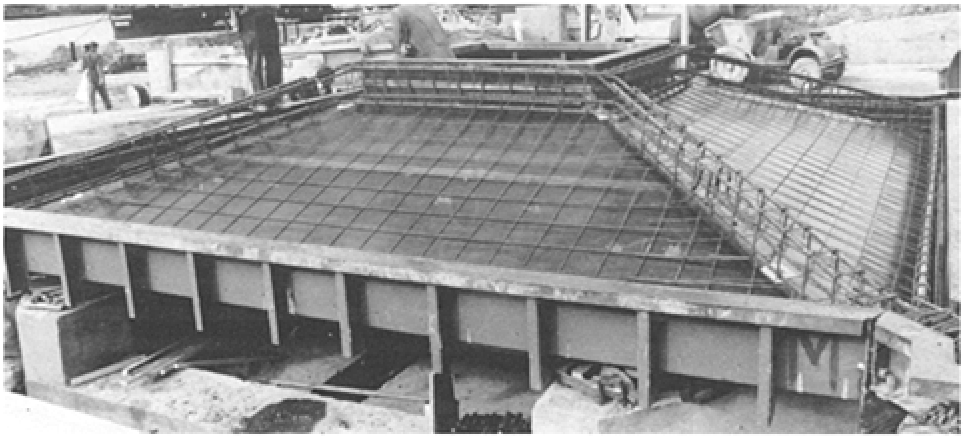
Acceptance of manufactured elements and units supplied with erection service

The supervisor must ensure that he is aware of the requirements of the Specification and should, in consultation with the surveyor or contract manager, ascertain exactly what are the conditions of the contract for supply. He should at an early stage take the opportunity to meet the precaster's technical representative and ensure that delivery date, means and rate of delivery are clearly understood. In his turn, he should ensure that he is aware of the requirements of the precaster with regard to access, use of craneage, dates for preparation of foundations, details of holding down bolts, pockets and so on, required for commencement of erection.

Particular attention must be given to sequence of erection, siting of craneage and, of course, the relationship between the precast erection and other phases of the construction. Attention should also be given to the way in which units are mounted on the delivery vehicle—this may save double-handling of units or turning of the elements at the time of erection. Where elements are to be erected immediately, an inspection should be carried out to avoid installation into the structure of sub-standard units. Where some stocks are to be held on site, suitable racks, stillages or hard standings should be prepared. Precasting is a handling intensive process—some standards must be set for repairs and remedial work, generally by reference to previous successful repair.

The manufacturing process

The arrangements for precast manufacture on site will normally be of a fairly simple nature. Where large quantities of products are concerned there may be a considerable amount of mechanisation, the introduction of gang and battery moulds, tilting tables and the like. Where tunnel segments and similar repetitive



Site precasting of special roof units allowed premanufacture and reduced quantities of falsework and formwork (Higgs and Hill Limited)

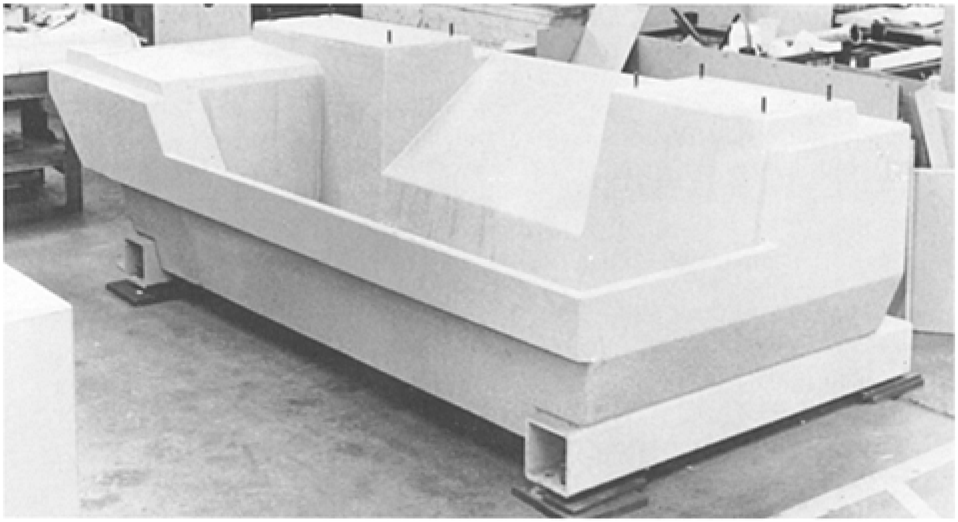
products are concerned then some mechanisation will be introduced. For the purpose of this book and to deal with principles, the simple method of manual or semimechanised production of a few simple elements will be considered. The principles identified can be applied to the manufacture of any other precast element regardless of the scale of production. Certain basic requirements exist, as follow:

space in which to manufacture;
a supply of concrete;
equipment to handle concrete and manufactured product;
storage areas for steel, sub-assemblies and finished product;
moulds;
vibratory equipment;
curing equipment.

The set-up should reflect the shape of the product. Linear products such as beams, columns, piles and so on, being cast on a flowline arrangement, whereas reinforced concrete panels, cladding and flooring, can generally be manufactured in a more compact area, provided there are suitable gangways for access to the moulds and in this instance the production is more of a jobbing operation.

The sketches illustrate the relative positions of moulds, services and storage area. It is, of course, possible to precast using readymixed concrete or concrete from a central batching plant, but for special aggregate products, or where a battery casting machine or press is in use, there must be a continuous supply of material from a plant especially established within the precasting area.

Moulds will be set up on what are known as antivibration mountings which are, in fact, used to allow the moulds to vibrate freely whilst being adequately supported. The materials for mould construction are legion and most are discussed elsewhere in this book. Site precasting is often carried out using timber moulds, on the basis of lead time and availability, and where there is considerable repetition, manufacture is commenced using timber and ply frames to establish the suitability of the design, subsequently using steel moulds for the main production. In the main, timber moulds and simple moulds from glass reinforced plastics, glass reinforced cement, and so on, can either be manufactured using site skills or brought in from

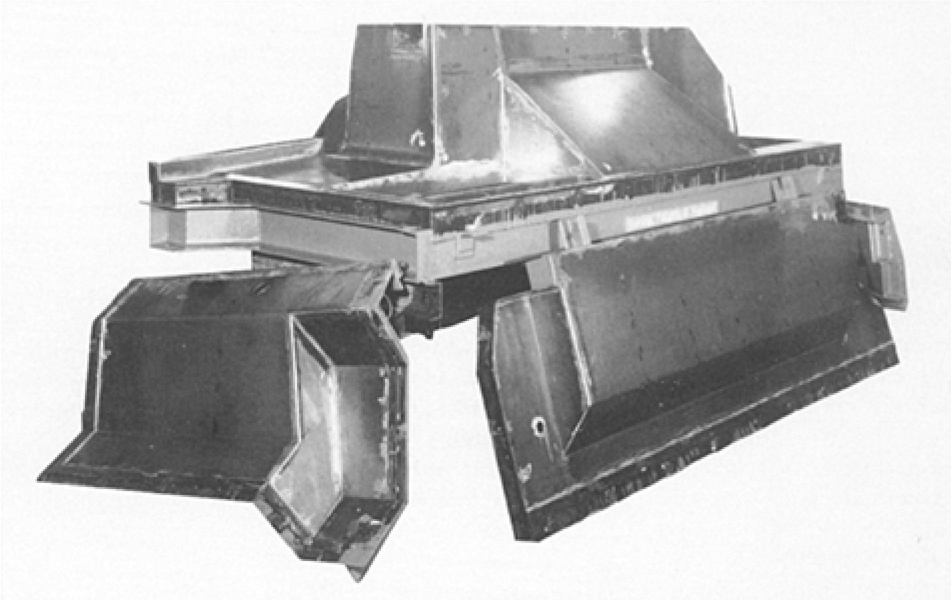


This machine base is typical of complex precast elements which demand careful mould design and detail (Wexham Developments Limited)

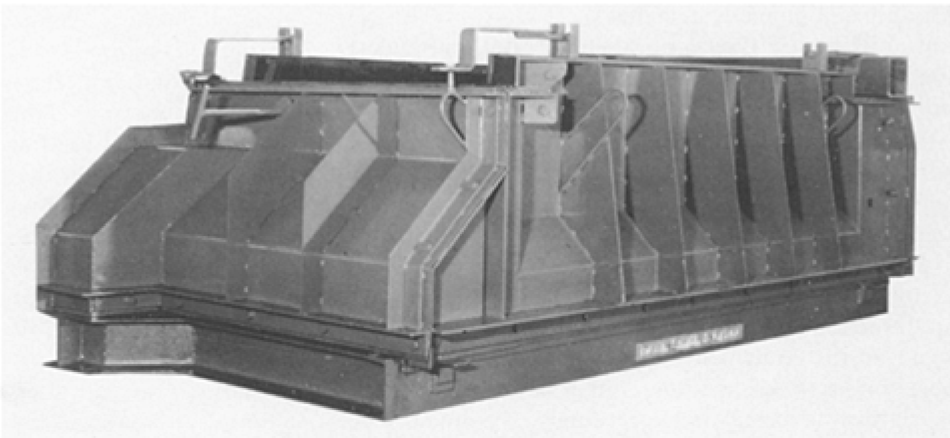
a subcontractor. Steel mould manufacture for anything other than very simple elements is perhaps best left to the specialist who may supply not only the moulds, but casting machines, handling equipment and so on.

In all but the worst weather, or where extremely complex elements are cast, the elements will be produced on a daily cycle. On site it may prove desirable to provide additional bases to moulds to allow rapid reuse of side members, yet allow cast units to mature prior to handling. In normal circumstances with adequate reinforcement the elements can be handled once the concrete has achieved a compressive strength of 5–10 N/mm^2. Long or exceptionally wide units may require some external support or strongback to ensure that the stresses resulting from handling do not damage the units. The handling of steel, both in raw stock and as manufactured cages, must be carried out using strongbacks to avoid damage and distortion. It is likely that the steel itself will be bought in cut, bent and bundled to reduce the demands on site labour. It is quite possible, however, to produce the steel for precast elements, which in itself is generally a simple matter, using only a cropping machine and bender. Modern equipment is such that these machines are now not much larger than a power hand tool, particularly the cropper, which has been developed for use at the point of construction.

Storage areas must be calculated to ensure that sufficient space is available for stocks of steel, cages and finished elements. Elements and cages may be stacked in tiers, although this should be planned to avoid double-handling to meet programmes. A considerable stock will build up where elements are cast daily and erection is limited to those elements which have achieved the equivalent of a 7-day strength (a reasonable condition for handling and erection), so that the space must be calculated accordingly. Curing arrangements can be as simple as those applied to the majority of in situ concrete—covering down, spraying with curing membrane and generally protecting newly cast concrete from heat, cold and drying winds. Simple accelerated curing can be achieved by the use of free steam under tarpaulins, although in most cases where accelerated means are used, it will be advantageous to use steam or hot water in closed circuits of pipe or passed through the mould, which must be constructed with this in mind.



This complicated mould was built to extremely high standards of accuracy—it casts the reinforced concrete machine base, inverted for ease of concrete placement (Wexham Developments Limited)

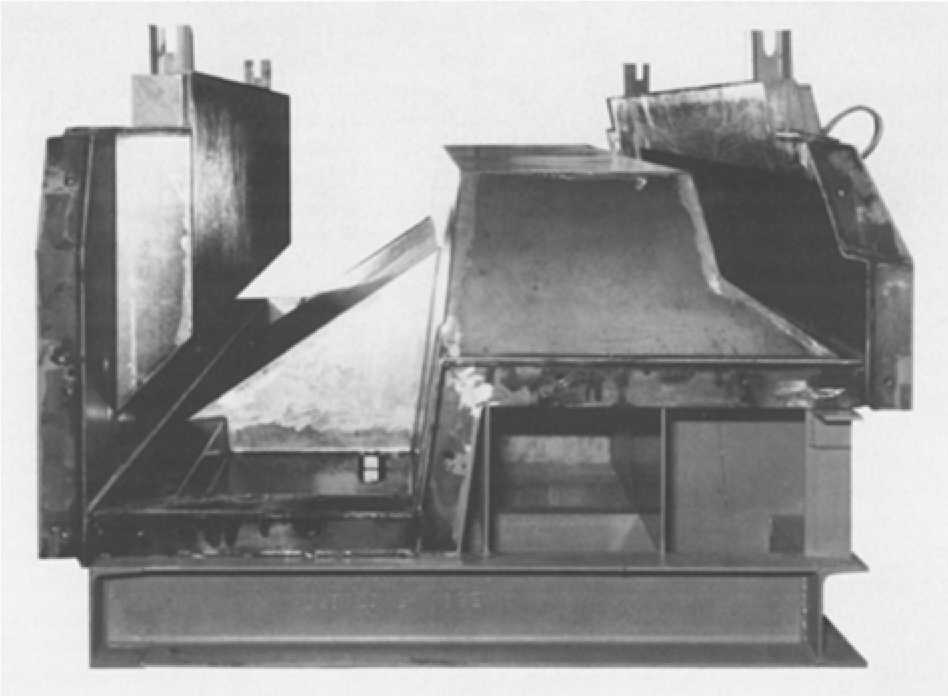


Trail assembly of mould—the next steps will be to check installation of steel and inclusions prior to oiling and casting (Wexham Developments Limited)

Wet-cast precast production

The process of repetitive production of structural precast concrete is based upon the use of concrete which develops sufficient strength to allow demoulding and possibly handling at between four to 15 hours.

For casting purposes, units are divided into groups or families and provision made in the design of the mould for its re-use to cast varying numbers of units. A timber-framed plyfaced mould may allow the casting of 30 or more units without major refurbishment; a light steel mould may be used 100 times or more



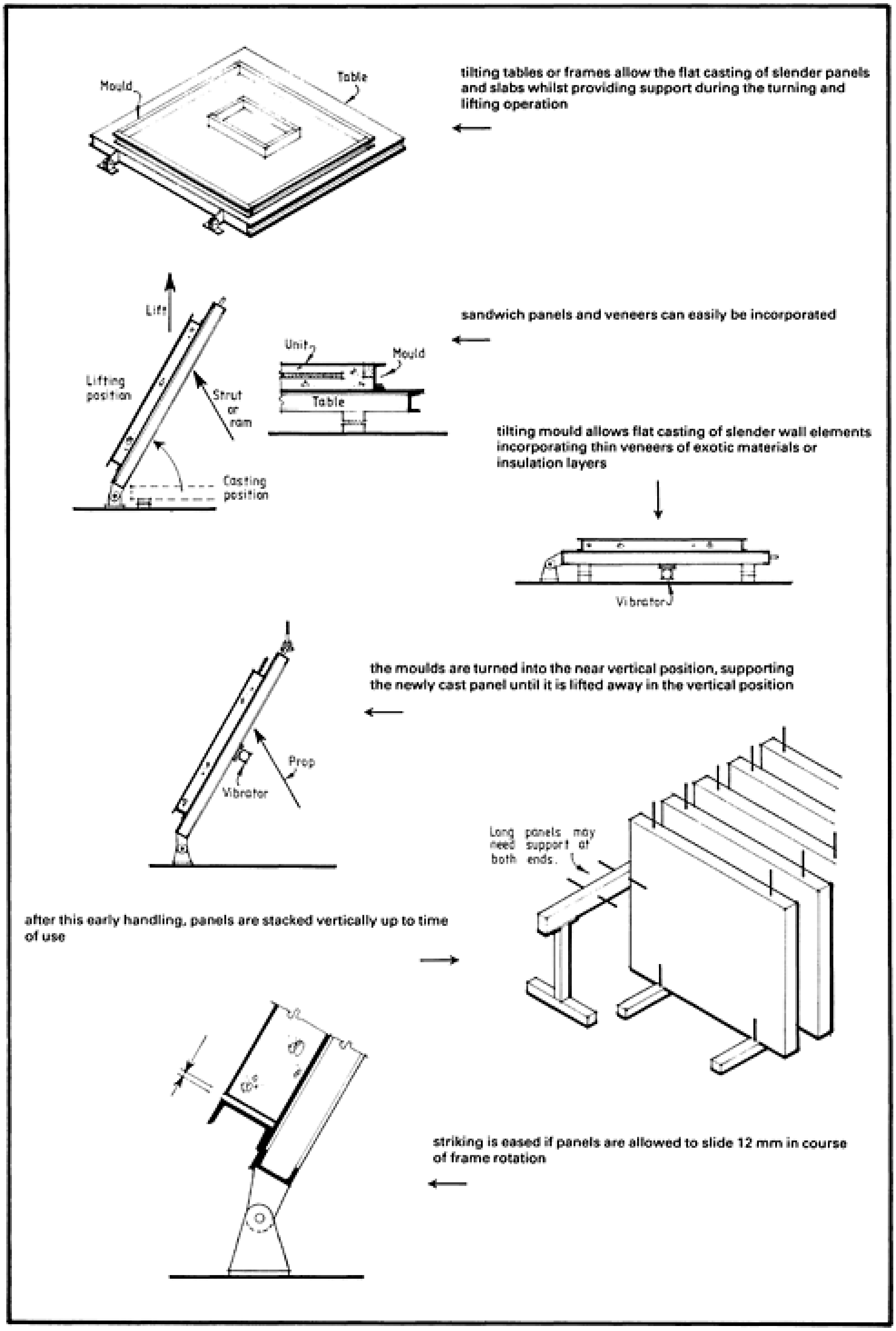
Partially assembled machine base mould showing carefully folded and welded plate sheathing (Wexham Developments Limited)

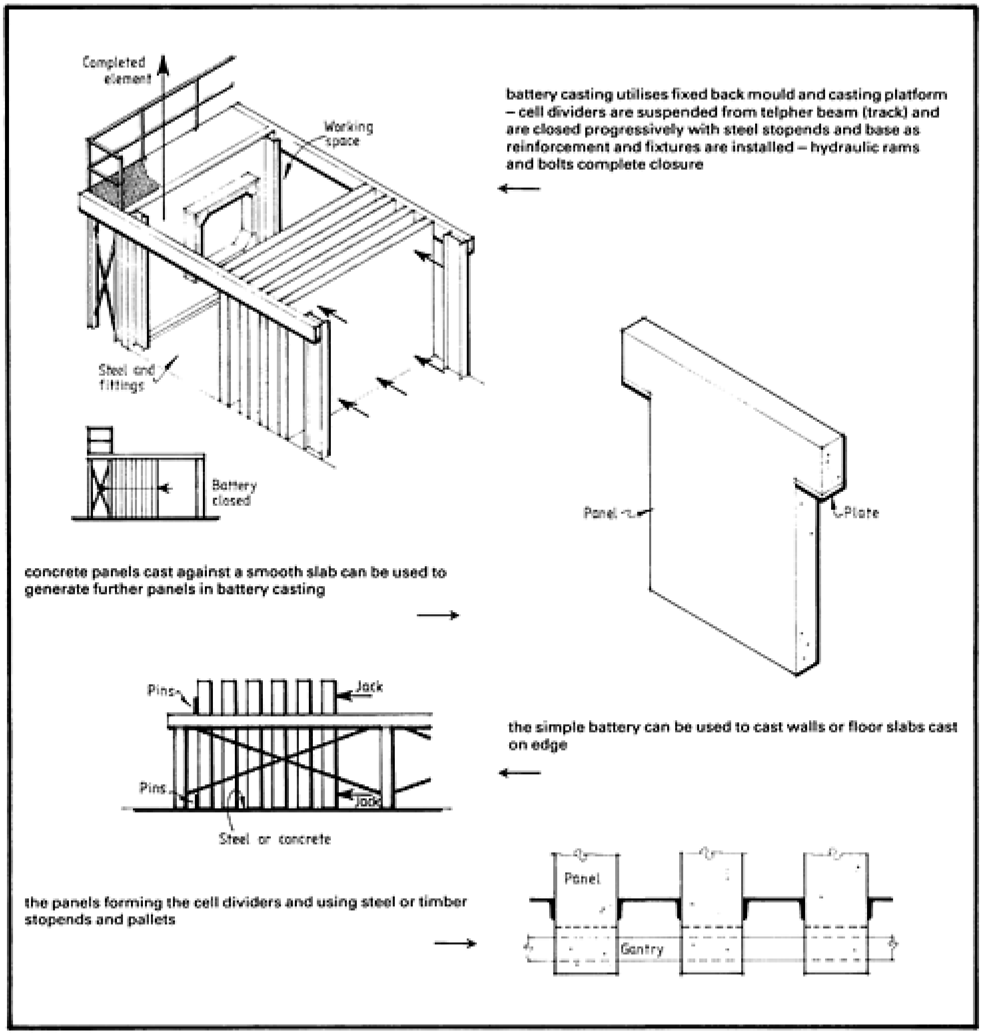
and a heavy steel mould over 1000 times. Glass reinforced plastics and glass reinforced concrete allow the production of highly geometric forms, but the number of uses may be limited to 30 or thereabouts. Combinations of these materials can be used and, of course, dense concrete can be used as a backing to grp, grc, or as a mould material in its own right. Concrete moulds can be readily formed, are stable and massive and can be used several hundred times provided their corners are suitably rounded or strengthened and lead and draw are provided on the principal faces of the element being cast.

The degree of alteration which a mould must undergo in casting a group of elements is one of the factors deciding mould quantities. This must be balanced against the delivery programme in the light of available resources, such as skills, operatives available and concrete supply.

Preformed, preferably jig-assembled cages of steel reinforcement are assembled into the moulds, fixings and connections installed and the jig located. After moulds have been checked, the concrete can be placed and compacted. Curing by enclosure, the use of membranes, steam or applied heat follows. When the concrete in the element achieves a strength between 5– 10 N/mm^2, demoulding and, in most instances, handling, can take place.

Considerable care must be exercised over the selection of faces to be cast from the mould, as this choice governs the ease or otherwise of achieving compaction, surface finish and so on.


Mould
Table
tilting tables or frames allow the flat casting of slender panels and slabs whilst providing support during the turning and lifting operation
Lift
Lifting position
Strut or ram
Casting position
Unit
Mould
Table
sandwich panels and veneers can easily be incorporated
tilting mould allows flat casting of slender wall elements incorporating thin veneers of exotic materials or insulation layers
Vibrator
the moulds are turned into the near vertical position, supporting the newly cast panel until it is lifted away in the vertical position
Prop
Vibrator
Long panels may need support at both ends.
after this early handling, panels are stacked vertically up to time of use
striking is eased if panels are allowed to slide 12 mm in course of frame rotation

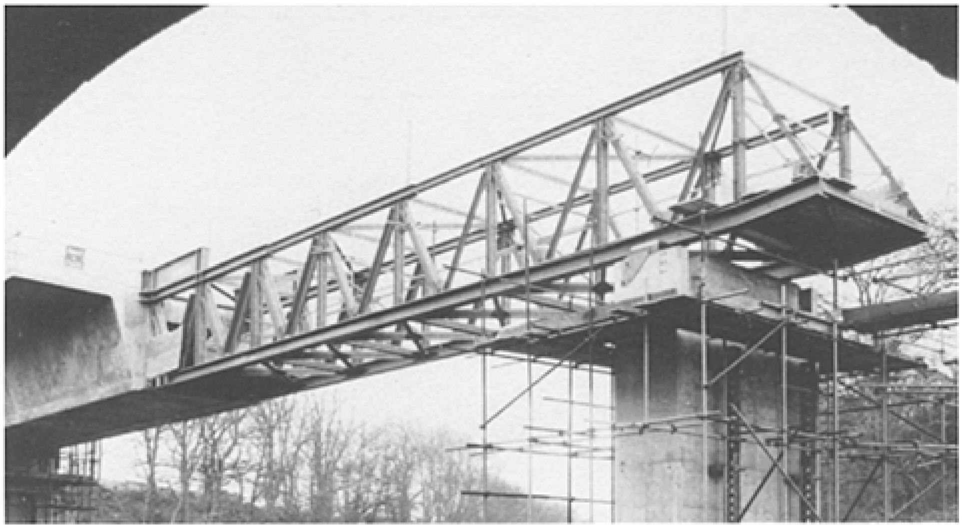


Segmental construction

Over the years bridge beams have become longer, deeper and heavier to the stage where transport presents a considerable problem. A recent trend in design takes advantage of the possibilities offered by post-tensioning to reduce the amount of falsework and temporary works used.

Segmental construction is carried out casting the beams of the bridge, generally of box configuration, in a series of transverse sections. The sections are cast one against the other to ensure an intimate connection, transferred to their location in the structure and then post-tensioned into place. Temporary works are limited to travellers and gantries working on the newly constructed deck. Supporting works are not required, other than at pier positions, for the construction of the piers themselves and thus traffic can be allowed to pass uninterrupted during all stages of the construction. One form of segmental construction is that where segments are constructed at one side of the bridge site over, say, a river or railway. The elements are jacked or thrust across the gap, a temporary launching nose being used to cantilever across the space between

Bridge jacking—the launching process commences (British Railways)



The launching nose— recoverable—reaches the first bridge pier (British Railways)

casting location and far abutment or intermediate pier. As each segment is cast and stressed into a continuous member, the bridge is jacked forwards, the launching nose thus bridging the jack during the process in much the same way as the Bailey Bridge was launched during wartime. Once the ribbon of segments has reached the far side of the opening, the launching nose is removed.

Monitoring progress in the launching process—the lattice steel launching nose will be removed once the bridge concrete reaches the abutment (British Railways)

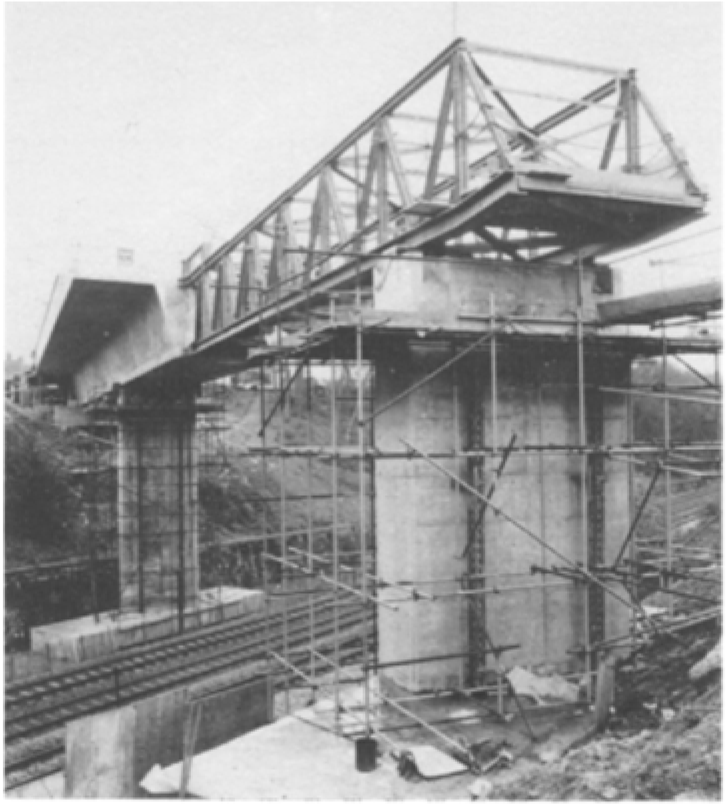
Contact casting

Contact casting of elements has been carried out for many years, particularly on the European continent. At one time linear bridge beams were cast side by side, one against the other, to achieve an intimate contact between units, such that when transverse stressing cables were inserted into place the loading on the bridge deck was distributed uniformly between individual units. As bridge span lengths increased, the technique of segmental contact casting was developed either as a site operation or as a factory process.

The casting operation can be carried out using two methods:

1. Using a mechanised mould in such a way that once a segment has been cast it can be displaced by the segment width and another cast adjacent to it. The machine is so devised to allow adjustment of the geometry to deal with the profile of the bridge and also to permit adjustments to be made to allow the bridge to be steered into position in space as it is assembled.
2. Segmental contact casting is sometimes carried out using a complete mould, yet casting the elements in sections along the beam. This allows individual units to be accurately cast in such a way that they will fit intimately when assembled onto the falsework in the construction of the structure.

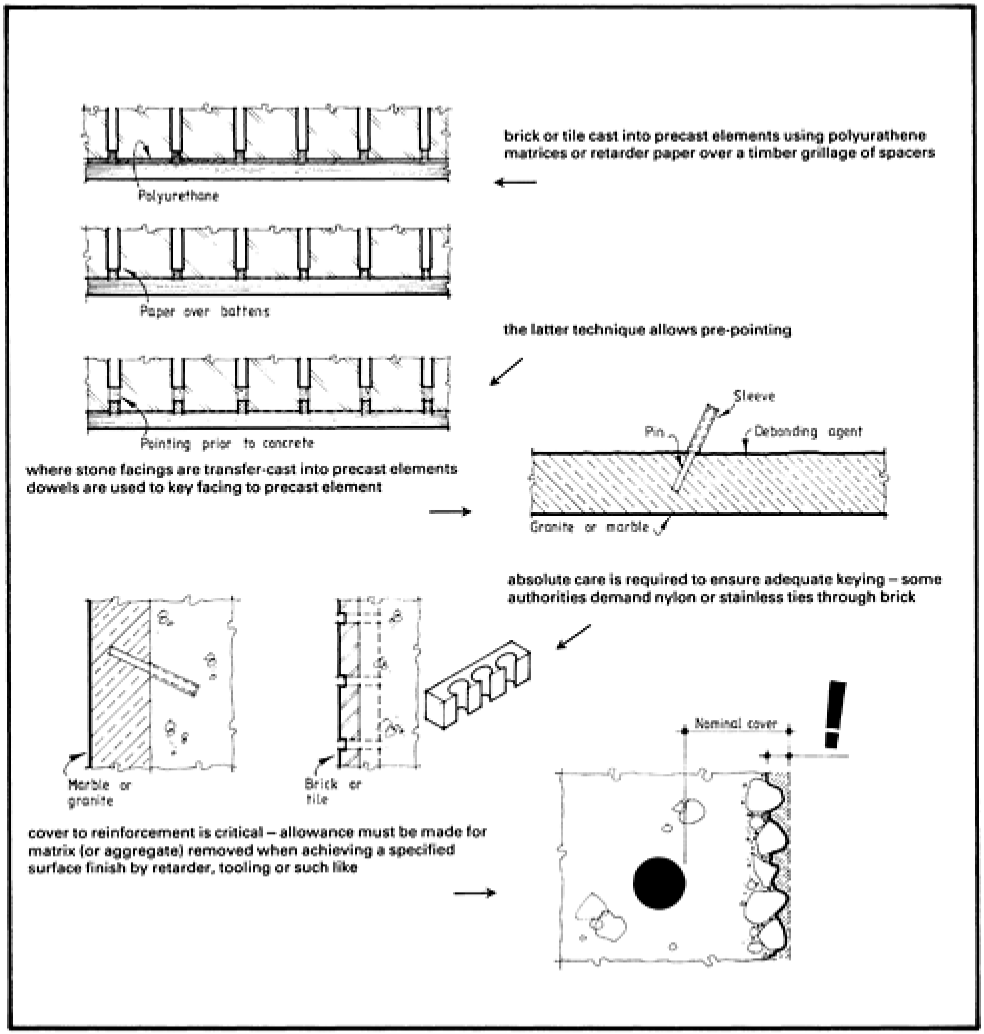
This bridge was cast in 40 tonne segments at one abutment then jacked into position—the segments were joined by post-tensioning (British Railways)



Lift slabbing

This method of construction is essentially an extension of precasting practice, with the floors of a multi-storey structure being cast other than in their final position within the structure. The technique depends on the configuration of the building. Where there are a number of similar floors, then these are stack cast one upon the other at floor level. The reinforcement is carefully designed to deal with the stresses resulting from the handling process where floor elements are jacked up and columns inserted into holes left through the stack. Columns for multi-storey work can be jointed using normal precast connections, so that buildings of any number of floors can be constructed using this technique. A development of lift slabbing, which capitalises on the flexibility of prestressed concrete, is warped slab construction, where suitably stressed floor slabs are jacked by varying amounts to incorporate ramps and cambers into slabs such as those incorporated in parking lots. The slabs in lift slabbing are fixed to the columns by welded connections and, of course, particular attention has to be applied to the maintenance of the stability of the structure as the lift proceeds.

The quality of finish to soffits is dependent upon the upper surface of the slab below, although of course skilled trowel hands equipped with mechanical floats can achieve excellent results. Parting agents include



lime wash, white wash, chemical parting agents and plastic sheeting. The separation between slabs in the stack is also dependent upon the infiltration of air into the space as the slabs part.

Tilt-up construction

This technique has not been used to a large extent in the UK, although it is at present sweeping the USA, given impetus by the ready availability of pre-mixed concrete. The technique is usually employed where there are large areas of external walling on structures such as markets, sports centres and similar construction.

The ground floor slab is constructed using normal flooring techniques, the surface is finished to a high level of accuracy. Edge forms, features and fillets, which determine the panel size and decoration, are laid into the base, the steel reinforcement is placed and the panels concreted. Lifting arrangements, carefully located to limit bending forces due to handling, are cast in during the placement of concrete. The panel surfaces are trowelled or finished as required, the panels are cured and, when the concrete achieves specified strength, the panels are tilted up into position and fixed to structural supports onto the edge beam of the foundation slab. The lifting arrangements are quite complicated and often include running gear to allow lifting cables to adjust to the forces encountered in the lifting and to cater for the change in direction of the lifting forces as the element is rotated into the vertical position.

Extremely high rates of production on repetitive contracts with large quantities of panels have been achieved using pavers of the type used in minor road construction. There are no limits to the decorative effects available using tilt-up construction and, of course, it is possible to incorporate all service installations, conduits, switch boxes, door frames, windows and so on, as well as membranes and insulants, which can be cast into the concrete in battery or tilting table construction. Recent techniques have included the casting of quite complicated geometric panels using tilt-up methods.

Battery casting

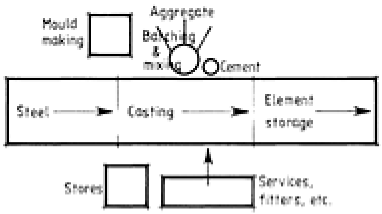
Where there is a need to produce large quantities of wall or floor slabs, or even quite complicated elements such as angle walls for lift enclosures, then a variety of gang mould known as battery mould or battery casting can be used. Batteries are assemblies of steel or concrete mould panels capable of casting between two to 20 wall and floor elements in one operation. Where short walls are required, these may be cast end to end within the battery “cell”. In some countries where massive demand exists for industrialised elements, continuous batteries comprising up to 100 cells are used on a closed circuit gantry which allows round the clock assembly, casting and striking operations. The machines incorporate means of mould divider handling independent of outside lifting equipment and, where equipped with a gantry for concrete and element handling, allow the output of large quantities of elements with relatively small teams of workers. The batteries used are such that two or three teams set in steel and fixings working at assembly points, with the whole system of cells being closed and concreted in one operation involving 20–40 metres of concrete. The batteries have integral vibratory equipment capable of imparting massive compactive effort and most also contain heating elements or some means of accelerating curing of the product.

Gang casting

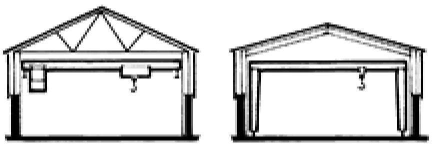
Wherever there is a demand for large quantities of units of similar section, such as beams, columns, poles, piles, lintels and similar products, it may be worthwhile considering gang casting the units. The principle often adopted in long line casting depends on setting a number of units into a mould in such a way that the mould construction is simplified (concrete moulds may perhaps be cheaply produced from simple master units), and the concreting operation is simplified (concrete may be cast from a telecrete vehicle or a readymixed concrete truck). Lifting and handling operations can also be combined in such a way that a complete gang width of elements can be lifted at the same time. Gang casting of even the simplest elements is a highly productive method and can result in high outputs from small teams of simply skilled men.

Long line casting

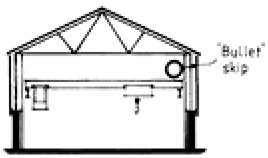
This technique is largely used in the production of prestressed elements, where pre-tensioning is carried out between abutments placed at the end of the casting bed or table. Use of the process is not, however, limited to prestressed concrete production and there are a number of instances where long line casting has been



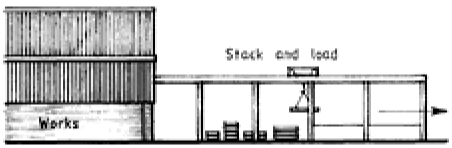
the layout of the works must suit the product – here linear arrangements promote throughput



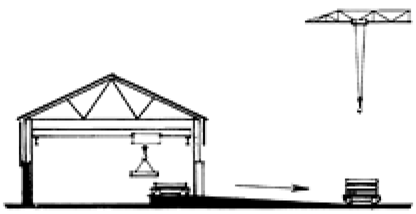
handling within the works is likely to be carried out by gantry crane from substantial columns or by goliath on ground rails



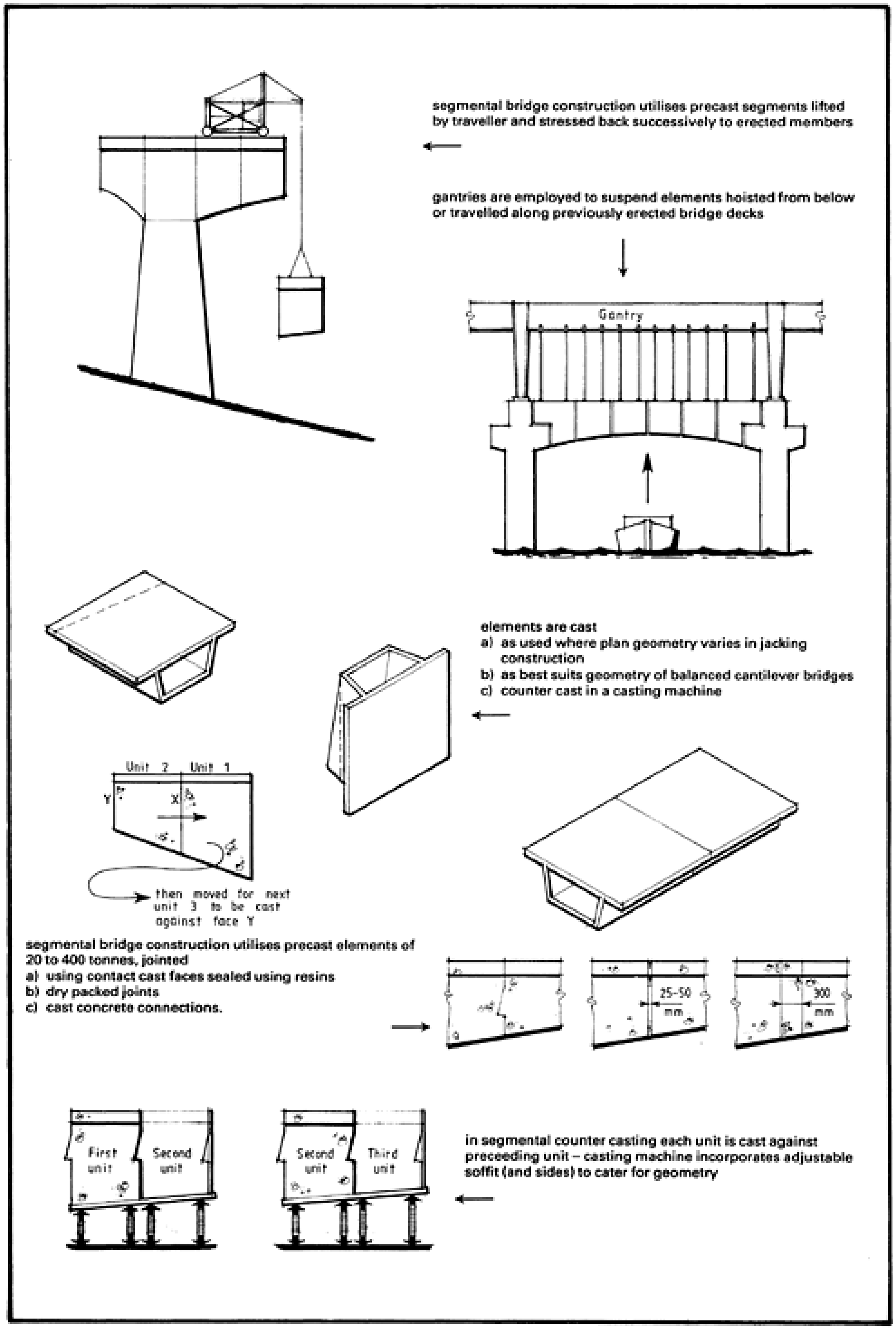
the installation of a bullet, a fast skip independent of gantry, provides concrete where demand is high

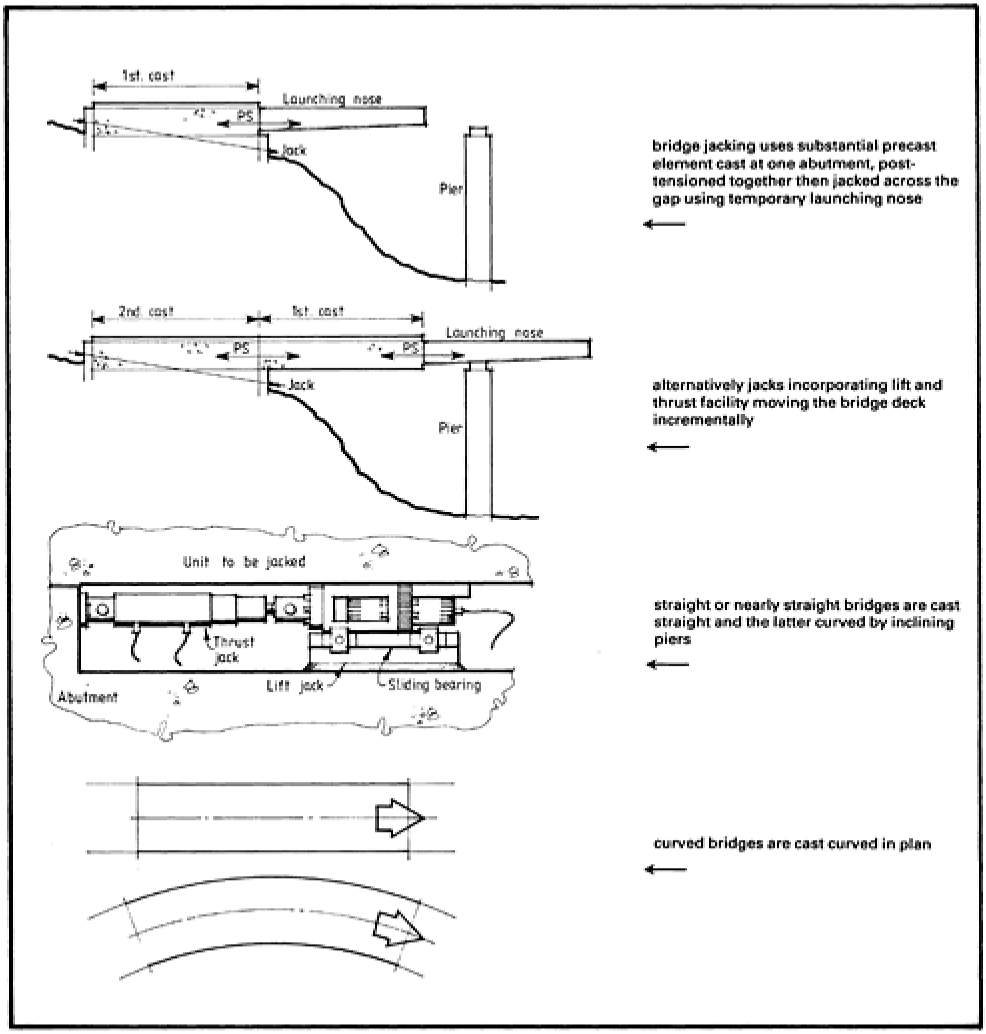


the gantry (or goliath) extends beyond the works building to cover stacking and loading areas



gravity rollers or bogeys capable of handling a days production uncouple manufacture from stack and load operations


segmental bridge construction utilises precast segments lifted by traveller and stressed back successively to erected members
gantries are employed to suspend elements hoisted from below or travelled along previously erected bridge decks
Gantry
elements are cast
a) as used where plan geometry varies in jacking construction
b) as best suits geometry of balanced cantilever bridges
c) counter cast in a casting machine
Unit 2
Unit 1
Y
X
then moved for next unit 3 to be cast against face Y
segmental bridge construction utilises precast elements of 20 to 400 tonnes, jointed
a) using contact cast faces sealed using resins
b) dry packed joints
c) cast concrete connections.
25-50 mm
300 mm
First unit
Second unit
Second unit
Third unit
in segmental counter casting each unit is cast against preceeding unit – casting machine incorporates adjustable soffit (and sides) to cater for geometry



used to achieve multiple re-use from column and beam forms, and indeed where contact casting (previously described) techniques are employed, to ensure accuracy of fit where multi-storey construction is concerned. Where lead and draw can be applied to the section, beds and side members can be combined to produce what are, in fact, complete moulds. Otherwise it is common practice to use bed plates with one fixed side member, the other side being hinged or ram activated to allow removal and adjustment of unit size.

Provision must be made for the installation of bearing plate connections and so on, and a variety of means are used to avoid defacement of the mould face which would detract from the finish of later elements cast from the same mould. Where prestressed beams are being cast using long line techniques, care is necessary to accommodate the movements resulting from camber of units and contraction of the free wires between the units. In this instance the beam sides are generally removed prior to the transfer of prestressing force when movements take place which can trap and damage forms. The main materials used in long line mould construction are steel and concrete, although for short runs of production, timber framed ply panels may provide the required number of uses.

Stack casting

Where any considerable number of flat panels or in some instances, profiled frame elements, are to be cast it may be economic to employ stack casting techniques. The stack casting technique is generally carried out using a carefully finished flat slab incorporating some means of fixing for pallets or soffits which are used to generate an accurate profile. Side members of depth just slightly less than the depth of the unit to be cast and the pallet or profile, are fixed into position around the profile, bolted through the pallet having a sleeved bolt or form tie set at a corresponding distance below the top of the mould face.

After the initial casting has been made, a parting agent is applied, such as lime wash, chemical release agent, or even a polythene film. The side members are raised, re-fixed by through-bolting and the steel reinforcement is introduced. The fact that the side bearers are kept below the top edge of the mould simplifies the screeding and trowelling operations.

Advantages of precasting

The advantages to the supervisor in the selection of precasting concrete result mainly from improved control. Some further advantages are as follows:

precasting allows achievement of difficult geometry and form more easily than in situ work;
precast buildings provide covered working space for all trades early in the contract;
precasting allows reduced programme time; quality should be easier to maintain in works than on site (this is dependent on having selected an appropriate supplier);

The following sections discuss certain of the products and techniques which can be advantageously adopted when precasting is selected for the various stages in the construction process:

Stage 1:
Design and planning

Precasters offer preferred dimensions, schemes and standard products.

Precasting presents the planner with discrete, predictable items which can be readily programmed.

Precasting eliminates items from the critical series of events which determine the overall duration of the contract.

Precasting allows the use of someone else’s funds of plant, skills and money.

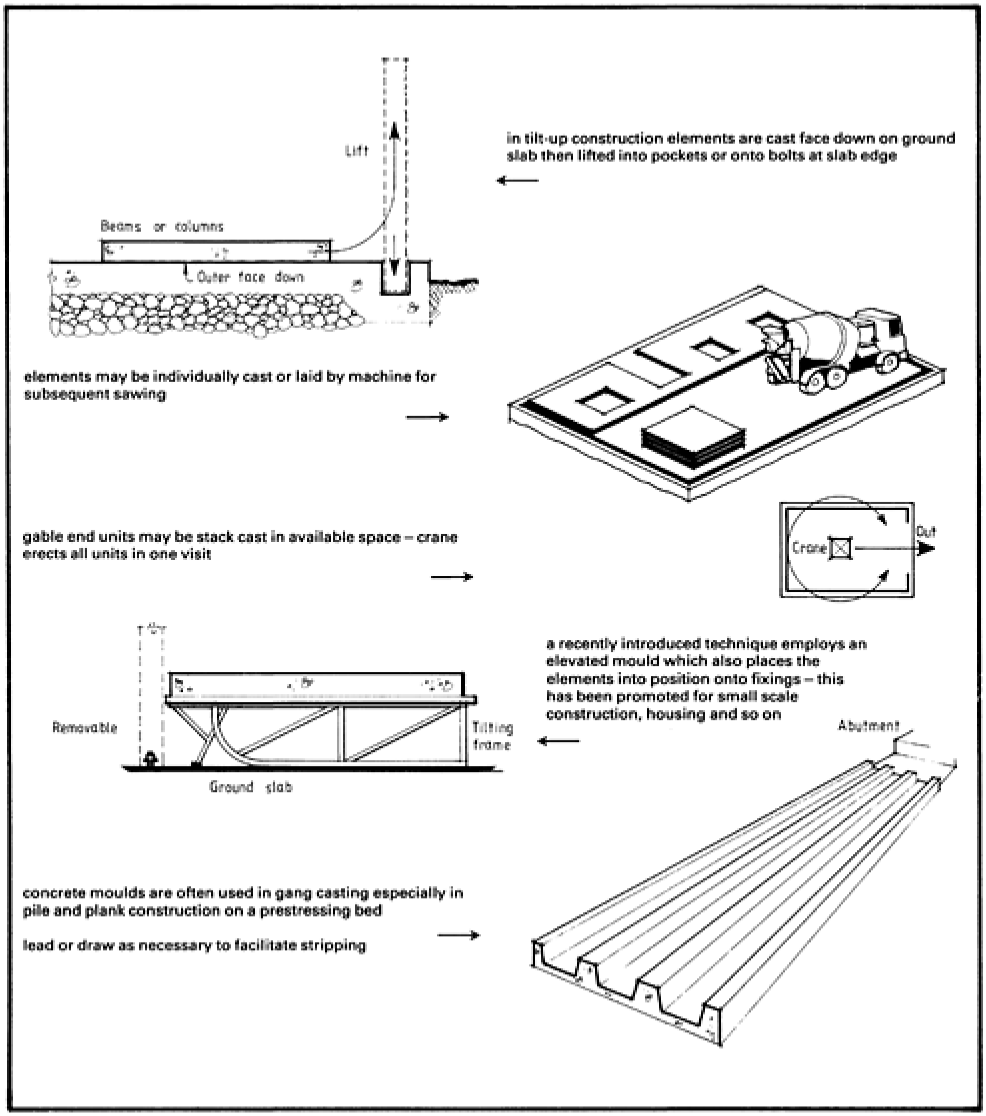
Early prototypes allow trial erection to be carried out.

Stage 2:
Groundwork and foundations

Precasters can offer piles, pile casings, culverts and pipes.

Site casting of caissons, piles and tunnel linings are possible.

Defence units, dolos, tetrapods, and so on, can be cast on site.



Stage 3:
Erection of superstructure

Skilled erectors are available.

Deliveries of frame elements, and so on, provide regulation of other works.

Precasting ensures early covered working space.

Facilities are incorporated in precast concrete to allow installation of services.

Access to all floors is possible via stairs installed as work proceeds.

Precast concrete elements can be used to speed work in the ground

–retaining wall units are being landed onto a prepared foundation

–light units such as these make ideal bins for aggregate storage and silos

Stage 4:
Service installation and completion of structure

In-built facilities speed work of subcontractors and other following trades.

Most precast elements are self-finished, requiring only cleaning down prior to handover.

Illustrations accompanying this chapter show the various arrangements for handling and stacking precast elements which are determined by the location of the reinforcement within the panels. Failure to stack and handle the panels correctly may result in damage or distortion of the panels and will actually cost a great deal of money, as well as causing delays whilst replacement units are made. The supervisor must especially note the various requirements regarding precast reinforced concrete and precast prestressed concrete.

Appearance of precast concrete

Virtually any required finish can be achieved using precast concrete and the following range of finishes is discussed elsewhere within this publication:

tooled concrete;

exposed aggregate;
split-face or striated concrete;
acid-etched concrete;
grit blasted concrete;
tile, mosaic and slip face concrete;
marble face concrete.

It must be remembered, however, that while a degree of consistency can be achieved in the appearance of the elements, complete uniformity of finish cannot be achieved. Whilst a number of aspects of manufacture can be controlled to quite a high degree, there remain such matters as natural variability of aggregates, size of brick and tile, shades of cement and so on, which are difficult, if not impossible, to standardise. Bulk purchase of aggregates and stock-piling of cement, tile, mosaic, brick and such like, go a long way towards achieving consistency but it must be understood that, particularly where plain and self-coloured concrete is concerned, complete uniformity is not possible. Such matters as consistency of mixing time, time between mixing and placing, time during which vibration is applied, time to demoulding and orientation in the stack, can all be controlled but not completely standardised. Where there are slight differences in the appearance of panels, it may be that random selection from stock can be employed to avoid dramatic differences becoming apparent. All concerned, however, must appreciate that consistency results from care at all stages in manufacture.

Trial erection or mock-up

As previously discussed, this is a very important part of the precast construction process. As soon as some element has been cast, either on site or at works, elements should be assembled dry to ensure that they meet the requirements of accuracy and surface finish. At this stage the design of such detail as service installation, curtain walling, glazing units, and such like, can be checked. Jointing arrangements can be checked under normal handling conditions and it is possible to ensure that special lifting tackle and connection work can actually be made when the units are in position. At this stage the architect, engineer, designer and site authorities, should be given the opportunity of inspecting the units and commenting on the standards achieved. This will save time and eliminate problems which may otherwise only come to light at the time of the first erection on site—the worst time for upset and delay! The early use of elements in a mock-up also ensures that the design is validated and that necessary changes can be made before too many units have been cast.

The way up of casting

It is possible, after checking with the design engineer, to locate the unit within the mould in the way which best suits the casting equipment, allows formation of critical geometry from the mould and simplifies the achievement of the required surface finish. As an example of the principle it is worth considering the production of the simple element illustrated. By rotating the unit through 90°, 180°, and so on, various possibilities present themselves—possibilities of ease of fill, simplification of mould work, generation of geometry through the mould and so on. These gains will apply when the general principle is applied to the production of any piece of concrete which has been designed for precasting. It must be stated here that the term *designed for precasting* is critical—it is not sufficient to simply divide the structure into pieces for separate manufacture. The term *designed for precasting* implies the application of design skills and

Placing facing mix—it is essential that concrete is placed into eventual position avoiding flowing concrete by vibration

experience to take advantage of the possibility offered by precasting to introduce speed through simplicity of construction whilst allowing easier achievement of accuracy and quality of finish. Unfortunately, many precast structures have been designed and constructed using techniques closely based on in situ construction and disregarding the requirements of speed and simplicity essential to the precast operation. By their very nature, translations of in situ construction techniques into precasting limit movement and are thus liable to cause problems in the lifetime of the structure as shrinkage, creep and differential thermal conditions occur.

Joints and connections in precast concrete

Precasting techniques are employed for a variety of reasons, as already discussed, not least of which is the considerable time saving aspect. Time saving on the contract will reduce construction costs, supervisory costs, plant costs, and will free resources for other purposes. Precasting, even on the largest scale in civil engineering, implies breaking the structure down into a number of component parts. The optimum weight of elements in building construction appears to be in the order of four to six tonnes, or in bridge construction 20–60 tonnes, although exceptions do exist in each case where some particular problem can be solved by the introduction of a particularly massive element. The result of breaking the structure down into larger numbers of small elements is the introduction of joints. So that the economies of time and labour saving available from the adoption of precasting techniques can be realised to the full, it is essential that joint location, design and construction techniques be carefully considered. Joints must, where so required, transmit loads and forces through the structure, allow movement, be weatherproof, be simple to construct, allow early release of cranes and handling equipment, and allow for variability of the product.

Where possible, joints are made in such a way that use of formwork is reduced to a minimum and wet trades work is thus optimised. It is most important that a method statement or manual should be prepared so that the important aspects of the work involved in making the joint structurally sound or weathertight are clearly established. Joints between precast concrete elements can be made in a variety of ways—wet cast concrete, dry packed concrete, grouted or otherwise filled.

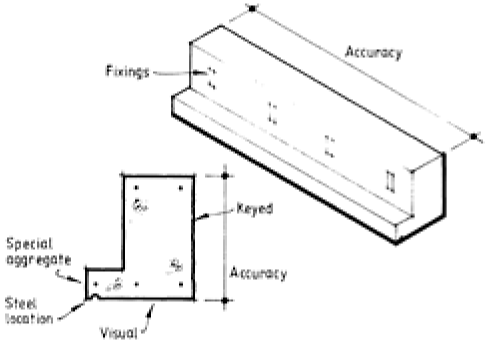
Generally joints include steel in some form to ensure continuity and to restruct tensile and shear forces. The steel in its turn may be connected by welding, bolting, swaging and by grout-in-tube or similar methods. The trend with building elements is towards the use of high tensile steel bolts torqued to a given force using some torque measuring device. This technique and the use of welded connections has been evidenced in many recent structures and has resulted in utmost speed of erection. In civil engineering works (and, indeed, in some building construction) the use of post-tensioning techniques has resulted in spectacular rates of erection as well as providing continuity to resist seismic shock.

Concrete joints

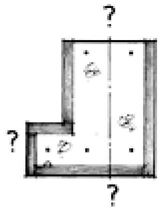
The supervisor must be clear as to the purpose of the joint and the contribution of the concrete. Dry pack joints, for example, have been misunderstood in many instances in the past as has the procedure for making the joint in conjunction with dowel bolts and levelling nuts cast into the elements. All jointing concrete should be regarded as structural concrete and the normal quality control procedures exercised including the regular sampling of materials and specified testing of specimens. Concrete joints must be compacted—in wider joints by internal vibrator, in narrow joints by ramming and tamping. As well as care in placement and compaction to exclude air voids and avoid pockets of air entrapped within detail, the concrete must be properly cured. By their very nature, construction joints are frequently made in exposed conditions and must thus be protected against freezing and the action of drying wind. Where the material is introduced in grout form, particular care must be taken over the water/cement ratio and the use of admixtures. The grout should be mixed carefully—ideally in a grout mixer using measured quantities of cement, sand and water. Grouted joint details usually include some form of bleed tube to allow egress of air and the technique of grouting must include a check on full flow of paste from these bleed points prior to sealing the system. Grouted joints are often made in conjunction with gaskets or seals which must be carefully positioned during erection, checks being maintained to ensure that they are not disturbed during the subsequent lining and levelling operations. The steel dowel component of grouted joints should be free of rust and loose scale. This can be achieved, where necessary by wire brushing, although a thin coat of cement slurry applied at or immediately after manufacture will maintain the steel in good condition until the joint is made.

Joints in steel

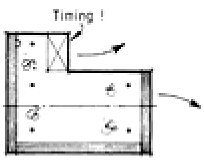
The lap of bars and the correct projection of threaded rods is critical to the success of the joint. Ideally these lengths will have been established by jigs in manufacture and, provided that the elements are correctly located within the designed location of space, then the detail will work satisfactorily. The use of ad-hoc inclusions of packing, particularly where welded connections are made, must be avoided as they are indicative that all is not well with the detail. Where bolted connections are used the joint should be checked for correct thread engagement. Torqueing of bolts is now commonplace to avoid the situation which often occurs where large diameter connections are under-tightened and small diameters are over-tightened. Joints incorporating angle brackets and specially fabricated connections must be located correctly axially as many



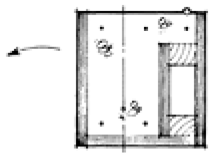
boot lintel illustrates principles of choice of way-up of casting and means of achieving specified accuracy and finish



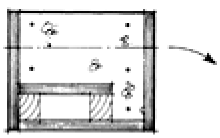
cast as drawn (as cast in situ) precasting offers no gain in placement, steel location, achievement of finish or accuracy



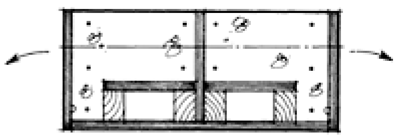
rotated through 90° fill becomes easier though timing is critical – key can be achieved by retarder, exotic aggregate or special finish being placed separately



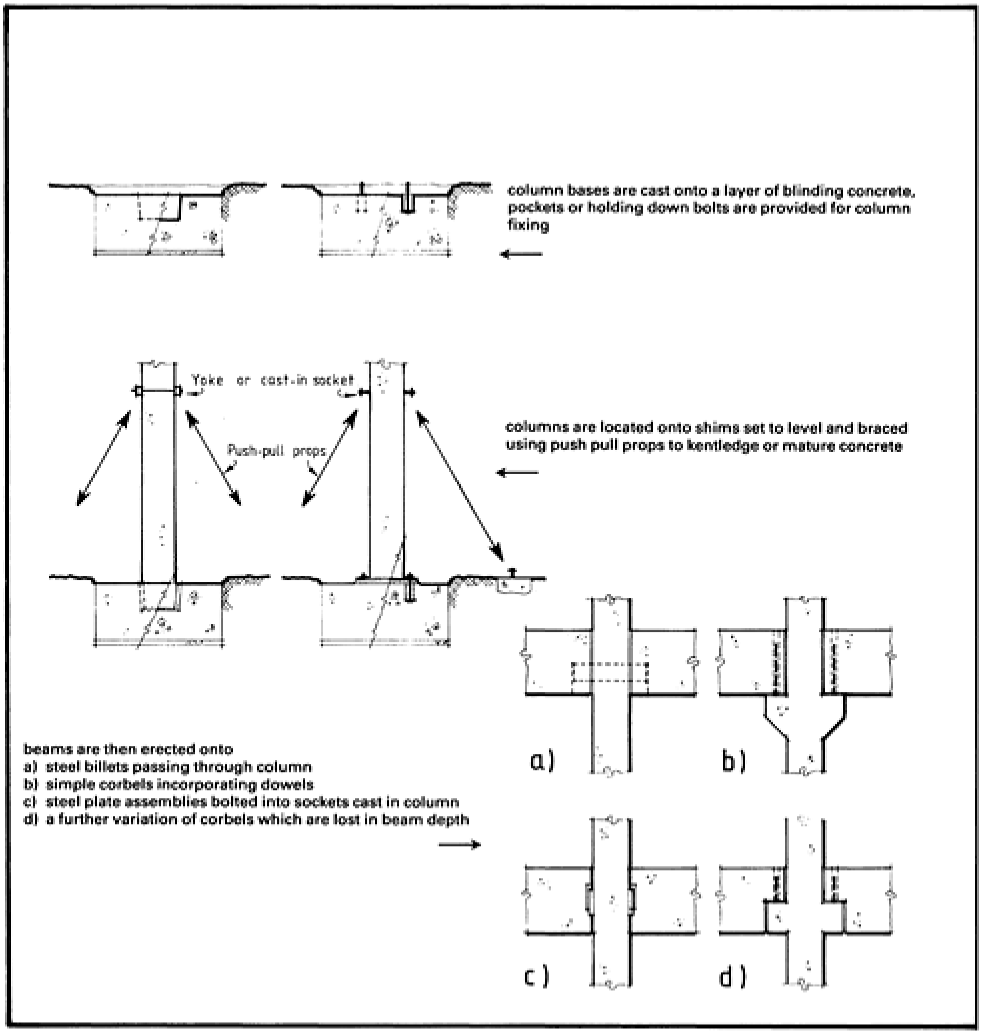
provided engineer agrees, inverted casting provides open mould for fill and ease of placement of special aggregate – steel location check is important, key using retarder



cast this way, largest part of geometry is fixed, good visual check on steel, exotic aggregate, tile, and so on, placed face down in nib



further developments include mechanisation of mould, placing in long line and so on



of them have serrations on the mating surface designed to combine fixity in one direction with freedom of movement in the other. Many of these joints call for antifriction washers of Teflon or PTFE and again it is essential these are correctly inserted and checked.

Prestressed connections

Prestressing has been widely used in connecting precast concrete elements which have been countercast or which have some previously prepared mating surface. In many instances prestressing is also used to provide continuity where connections have been made initially by the casting of concrete or the dry packing of concrete into the joint. Where ducts are required, as in the connected joint of about 300 mm width, proper formers must be inserted prior to the formwork assembly. These formers may be either rigid sheathing members screwed into position or inflatable duct formers which can be subsequently removed after deflation by pulling them through to the open end of the duct. The line of the duct must be smoothly maintained to avoid formation of upsets which will generate friction where the tendons are stressed.

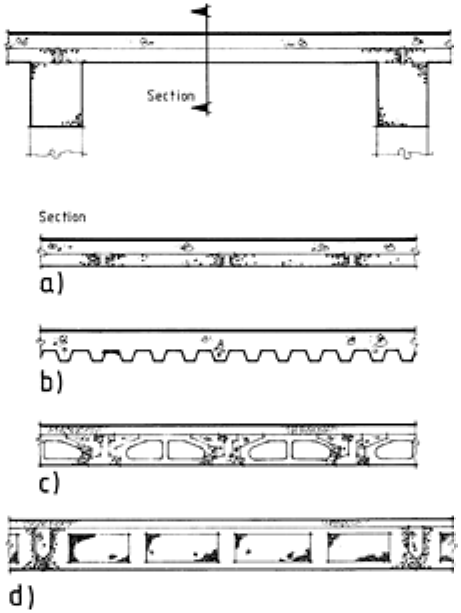
Erection of precast concrete

Not all precast erection is carried out by the specialist supplier or an erection specialist. The contract for precast concrete is frequently such that a contractor erects elements supplied on a vehicle by the manufacturer. Then, as when the elements are manufactured on site, the supervisor becomes directly involved in the erection sequence. The most important aspects of the handling and erection of precast concrete can be summarised as follows:

1. There must be a clearly established, safe method of working with a known sequence of erection
2. The weights of the units must be carefully calculated and preferably indicated on the units
3. The crane or mechanical handling equipment must be suited to the task
4. The location of cranes or crane track must be carefully planned in the light of crane duties, access and so on
5. The lifting arrangements, cast in connections or attachments, must be such that the units hang in an attitude suited to the placement operation
6. The connections must be positive and must allow early release of the crane for other duties
7. The placing operation must, wherever possible, be separate from lining, levelling and jointing operations
8. When placing the unit must be suitably braced to prevent accidental damage or displacement such as by impact of succeeding elements
9. All ancilliary steel, plates, bars and similar continuity arrangements must be checked in their final positions
10. All bracing walls, shear walls, and similar arrangements critical to the stability of the structure must be erected or built as the precast erection proceeds
11. The supervisor must be aware of special structural arrangements such as partial prestress prior to erection, stitching of in situ concrete arrangements to ensure structural soundness of the building.

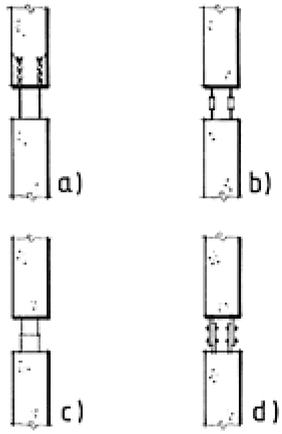
To achieve a successful outcome, the erection process should have been planned and arranged early in the chain of events which began at the time of preparation of tender or in pre-contract negotiations. It is essential to realistic pricing that there should be a planned method prepared early in the estimating stages incorporating an agreed sequence of operations to meet site programmes whilst recognising stipulations arising from the policy of the contractor regarding stock holdings, resource allocations and similar factors.

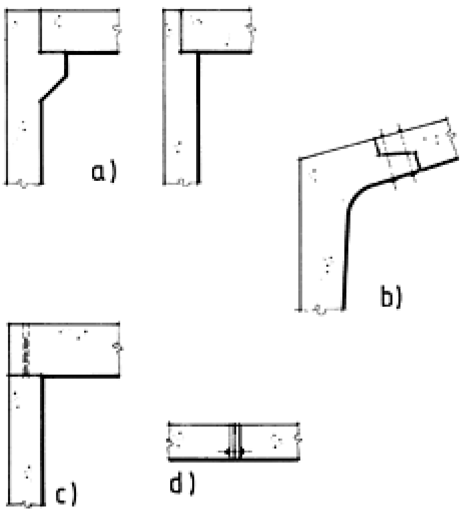
With precast construction, the manufacturer is not bound by the normal disciplines inherent in starting at the ground then working up, nor starting at one end of the site and working toward a particular direction. The precaster is able to manufacture in the sequence which best meets economic considerations regarding mould design and stock holdings. Equally, the erection of precast concrete is a process which can, with the consent of the main contractor, be broken down into discrete operations quite separately within the overall construction programme—in this way units of like design or of exceptional scale or proportion, can be organised into a particular part of the programme to allow the use of certain equipment to be carried out either when it is available or in a special period when, for example, a special heavy crane can be hired onto site. The precasting erection programme should, therefore, be published well in advance of manufacture and starting time on site. This guarantees that the works can programme the casting operation to meet the



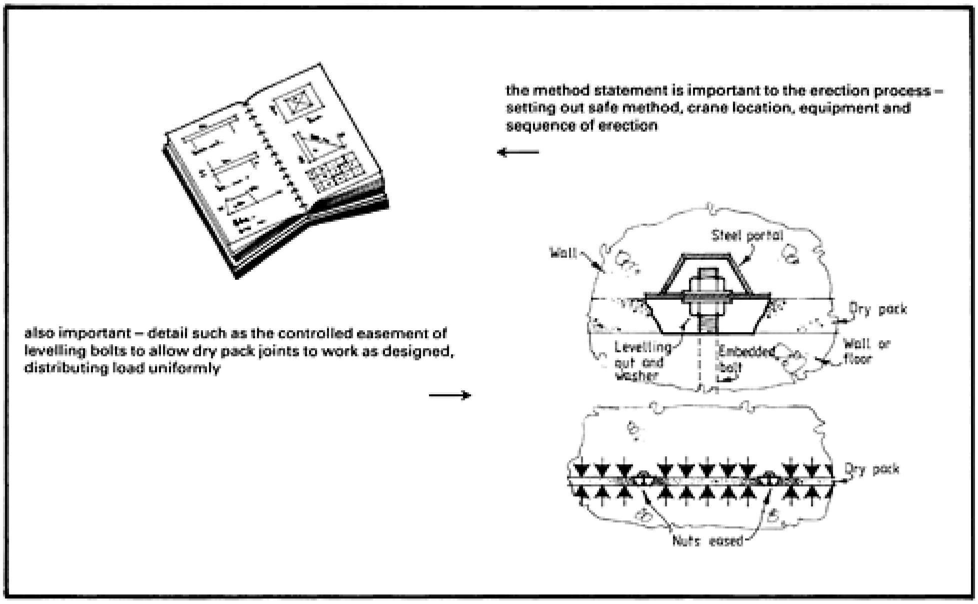
typical arrangements of precast floors comprise
a) precast plank and topping
b) steel permanent forms and topping
c) beam in infill block with topping
d) wideslab floor units

column connectors include
a) dowel in grouted sleeve
b) swaged connections on counter-threaded sleeves
c) welded plate joints
d) bolted plate joints





other connections include
a) corbel or bearing connections
b) scarf joints
c) dowelled bearing joints
d) torqued joints using embedded plates.



erection sequence whilst making the minimum number of moulds and also the minimum number of expensive alterations to moulds during the casting process. The sequence of operations may well have been determined by the structural designer, although generally there are opportunities for change. The direction of work and, of course, the speed at which the work is carried out, can be arranged to suit the other activities of the construction.

Assuming that a stock of units exists, that a mock-up or trial assembly has been made and the go ahead has been received to start the erection process, it is essential to consider in detail the steps which have to be taken to achieve an economic operation. These will include:

- staffing the operation;
- provision of stores, plant and equipment;
- checking setting out;
- provision of engineering services;
- provision of supervision;
- supply of fixings and fastenings;
- publication of method statement;
- arrangements for snagging and handover.

A knowledge of the weight of individual elements is essential in determining the type of equipment required to handle the units, the number of cranes, crane location and so on. It should be remembered that as work proceeds, stand-off distance and clearance for the crane jib over newly erected elements may be as important as outreach. Pre-assembly of a representative part of the structure will assist in ironing out any problems of accuracy or appearance and ensure that detail work is correct and that fixings and service connections are correctly located.

The way in which the units hang when suspended by the selected lifting arrangement is most important for successful erection. In some instances elements may be arranged to land onto the structure in a certain attitude to avoid edge or corner damage at the bearing. Where elements are delivered to site they are generally loaded in a manner which will ensure optimum tonnage in a load. The supervisor should ensure that the units are handled with suitable gear to avoid the imposition of bending stresses into elements which are not designed to take them. For example, where panels are delivered flat on the vehicle, tables or tilting frames may be required to enable elements to be rotated without damage.

The connections between units or between cladding and the superstructure should be carefully examined in the early stages of the manufacture and the assembly of the mock-up previously described. The design of the fixings will have been carried out to achieve a given degree of fixity or support whilst allowing thermal movements, shrinkage and creep to take place. The design must also allow for an early positive fixing, ideally by welding, bolting or stressing, which ensures instant fixity. Fixings which depend on grouting or concrete placement require that panels be supported by external means until the final fixing is made and, generally this means that cranes are tied up for longer than where bolting, welding or other more direct means are employed.

Bracing should be such that panels are securely supported against accidental displacement whilst being sufficiently mobile to be finally lined and levelled prior to jointing. A considerable amount of tie steel has to be incorporated into precast structures to comply with Code recommendations, designed to combat progressive collapse. The steel, often in the form of high tensile strand, must be physically checked as must the regular steel used to bridge across bearing walls and to tie panels, being erected in methods involving concrete stitching. Where bearing bolts support panels the nuts should be freed off once the stitch or packing has matured to allow the transmission of loads through the entire stitch or packing. Where a number of bolts or dowels or pins are to locate in a panel, it is helpful if one is extended to allow first location and subsequent lowering of the panel onto the remaining pins. Ducts for subsequent post-tensioning must be lined up and the continuity ensured by using duct connectors in foil or inflatable tube. There have been a number of accidents caused by the omission of bracing in shear walls, whether of concrete, brick or in the form of tie bars or angles. There is always a note on the general assembly drawing to the effect that these must be erected as work proceeds. Unfortunately, on some occasions this has been overlooked and buildings have thus failed. The supervisor must ensure that all trades are aware of the requirements regarding bracing and that the walls go in as soon as there is suitable access. During the construction of some precast frames, it is necessary to introduce external bracing to eliminate torsion and wind. These braces must be carefully installed and regularly inspected. There have been occasions when braces which have been temporarily removed for access have not been reinstated and the building has subsequently failed.

Regarding the structural requirements, the supervisor should ensure that he is fully conversant with the way in which the building or structure is required to work. He should understand how the various parts are tied together and how load transfer is effected. Discussions with the structural engineer are important as the supervisor can then check on the most critical aspects such as movement joints, ties, anchorage location and similar details.

Lifting equipment

The most important aspect of the lifting equipment is the spreader beam or spreader bar. These are available in adjustable form to be used,in a variety of lifts. The adjustment must, however, be such that eccentrically shaped elements such as walls with openings or beams with varying section, may be lifted whilst still remaining horizontal.

The designer of the element will bear in mind the location of the centre of gravity whilst detailing the lifting fittings and the person responsible for the handling operation must arrange the lifting tackle accordingly.

The fittings, fastenings or provision for joining the crane or spreader beam to the unit are many and varied, and include:

studs for use with patent claw connections;
plates with holes for shackles or patent hooks;
threaded inserts;
embedded bolts for use with lifting eyes or lifting boxes;
reinforcing bar or prestressing tendon;
through holes in the concrete element;
hook attachment to reinforcement;
slings wrapped around the element;

Whichever of these arrangements is used, it is essential that the force is applied normal to the surface and apart from instances where special facilities exist for turning the units, the force must be maintained vertically at all stages in handling.

Lifting tackle must never be removed from precast elements until the element is bolted down, welded to adjacent units, or braced using a properly designed prop or jig. Ideally, the unit should also be so designed that the operations of lining and levelling the unit into its allocated space in the structure can be carried out safely after the crane has been disconnected and removed.

Staffing the operation

Unless work consists of a few isolated elements, a small frame or something which the supervisor can control whilst continuing with the normal everyday tasks of site organisation, it will be necessary to appoint someone to be responsible for the erection process. For the smaller frame, a working charge-hand may suffice. At the other end of the scale in a precast intensive operation, it may be necessary to have a full contract staff with contract manager, supervisor, section controller, labourers and so on.

The method of erection is, of course, dependent upon the nature of the construction. Ideally the process should demand only a small team of men who, once they have completed a module in the cycle once or twice, will continue to work gaining speed as they learn the solutions to any special problems inherent in all construction work. The team normally work on the instructions of a working charge-hand. Where a supply and erect contract exists, there will normally be a visiting supervisor representing the supplier who liaises with the site supervisor on matters such as quality, accuracy and progress. It is essential that the erectors are experienced as much of their work is carried out in situations where access is difficult and provision of working scaffolds impossible. All erectors must have safety harnesses and hard hats, and the normal safety equipment of the construction worker.

Marking the units

Wherever the units are manufactured, it is essential that they are carefully marked for identification at all stages of the work. The reinforcement cages in a series of elements may vary slightly for reasons of construction or connection and it is thus critical that variations should be clearly indicated. It is helpful if the cage label is allowed to project at some point which will not be visible upon completion of the construction. Handed elements must be clearly marked to avoid expensive double-handling at a later stage. The units must also be marked with the date of manufacture— this is important from the structural point of view as there must be no doubt about the maturity of the concrete which is to be handled and erected. Usually precast concrete is demoulded at 15–20 hours and then stacked until the concrete in the units is judged to have achieved its 7-day strength. As precasters use high early strength concrete, elements can usually be transported and erected three or four days after casting. Units manufactured in a precasting yard should be marked with the number of the contract to which they are to be supplied.

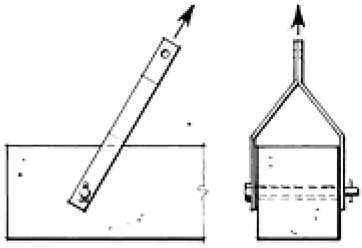
Points of supervision

In amanufacture:

Press for early completion of all details for precast elements
Establish standards for accuracy and finish
Check moulds prior to casting and periodically during casting
Check cover to steel and location of fixings and connections
Control concrete workability to ensure compaction
Ensure curing is correctly carried out
Handle elements using properly designed lifting equipment
Stack carefully on properly placed battens.

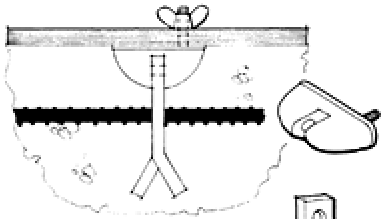
In erection:

Handle using correct spreader bars
Ensure that elements are properly seated and braces are installed
Check installation of water bars and weatherproofing
Ensure connections are properly made
Ensure concrete stitching is properly compacted
Remove or release shims and bolts to allow packed joints to work correctly
Be firm in rejecting substandard elements.

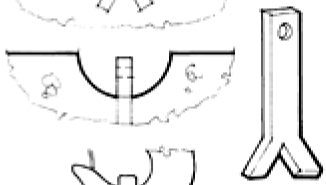


the simple through hole in conjunction with a lifting bridle forms an economic means of handling precast concrete – fitted pin must be suitably restrained

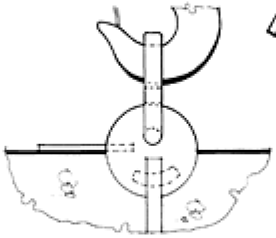
a typical proprietary lifting attachment consists of a rubber or plastic recess former which grips the attachment during casting



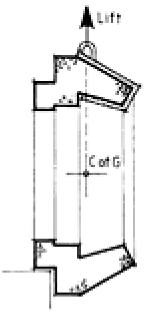
forming an accurately sized recess in the unit



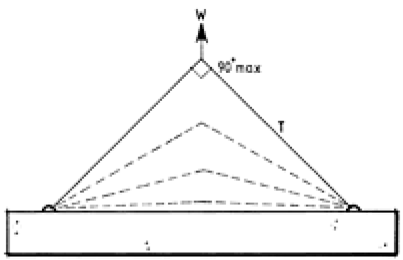
into which the latching lifting hook fits – the hook cannot come loose in lifting

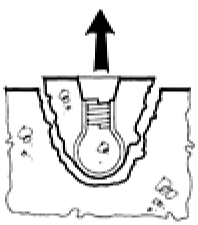


the recess can, if necessary, be filled with fine concrete on completion of operations



special brackets may be required to ensure that cladding elements hang in a manner to allow insertion of gaskets and so on in erection
Maximum angle should be 90°
at 120° T = W
at 150° T = 1.9 × W
at 175° T = 11.4 × W.





the capacity of any lifting (or fixing) attachment is a function of the concrete strength *at the time of application of load*

24.
Prestressed concrete

When concrete elements are used to support loads, various stresses are introduced into the concrete—mainly tensile, compressive and shear stresses. These stresses are countered by the strength of the concrete and the steel reinforcement, which provide the necessary resistance to enable the element to sustain the design loads and forces. As deflection under load takes place, steel elongates and the concrete in the bottom of the beam cracks. The deflection and cracking are determined by the designer within acceptable limits and the elements can be used economically during the lifetime of the building or structure. As spans between supports or the loads to be carried increase, so the section of the reinforced concrete must be increased or their spacing within the structure must be decreased. Greater volumes of concrete must be used, the additional mass of which further increases the stresses within the elements.

Prestressing provides an alternative means of increasing the loadbearing capacity of the concrete and the span of the elements. High tensile steel is used in conjunction with high strength concrete and, by using some means of jacking, a considerable amount of compressive force is introduced into the element in such a way as to combat the tensile and shear forces. The resulting prestressed elements are, for a given loadbearing capacity, lighter and more slender than the equivalent reinforced concrete beam.

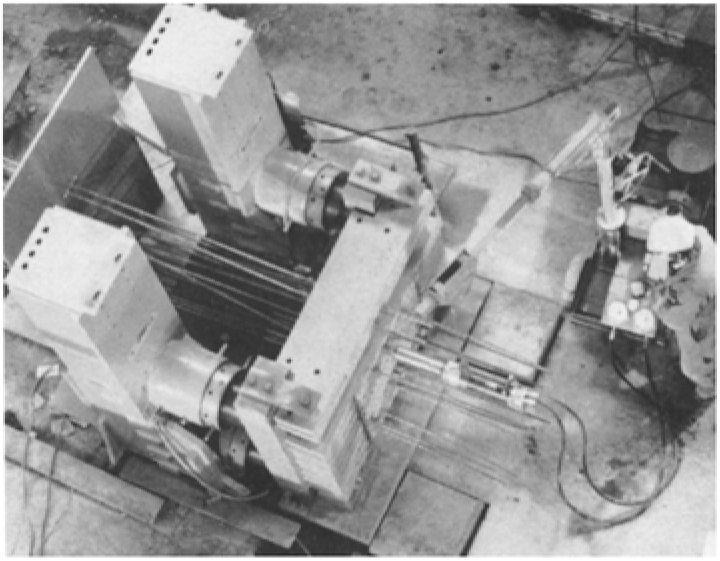
Prestressing can be advantageously introduced into most types of concrete component, including columns, beams, walls, tanks, cantilever members such as retaining walls, and floors. Prestressing can provide economic solutions where the design calls for large spans, slender sections, substantial loadbearing capacity or where complicated structures such as extremely long cantilever members, are used. Prestressed concrete is also used in a variety of extremely mundane applications, such as flooring production, lintels, pipes, poles and similar elements. Prestressed concrete, considered some years ago as a marvel, is now an everyday material in everyday construction. Some 20 years ago the prestressing process was regarded as being very technical and probably best carried out in specially equipped works—the processes are now carried out safely and economically on construction sites throughout the world by simply skilled people, although always under the control of skilled supervisors and engineers.

Prestressing can often be used as a useful adjunct to reinforced concrete construction to deal with local forces or to control cracking. Prestressing techniques can be used to connect elements within a structure or to fix components onto a structure. Prestressing is often used to secure massive elements to their foundations or back to ground. On large structures and in segmental construction, the stressing is incorporated in each axis. With deep beams it may become necessary to stress vertically as well as longitudinally and laterally.

The details set out in this Chapter are intended to provide the supervisor with sufficient basic knowledge to enable him, with access to a competent engineer, to supervise the process of prestressing. Above all else, it is essential that the operations be carried out bearing in mind the safety of all concerned.

Prestressing demands careful attention to a number of manufacturing aspects:

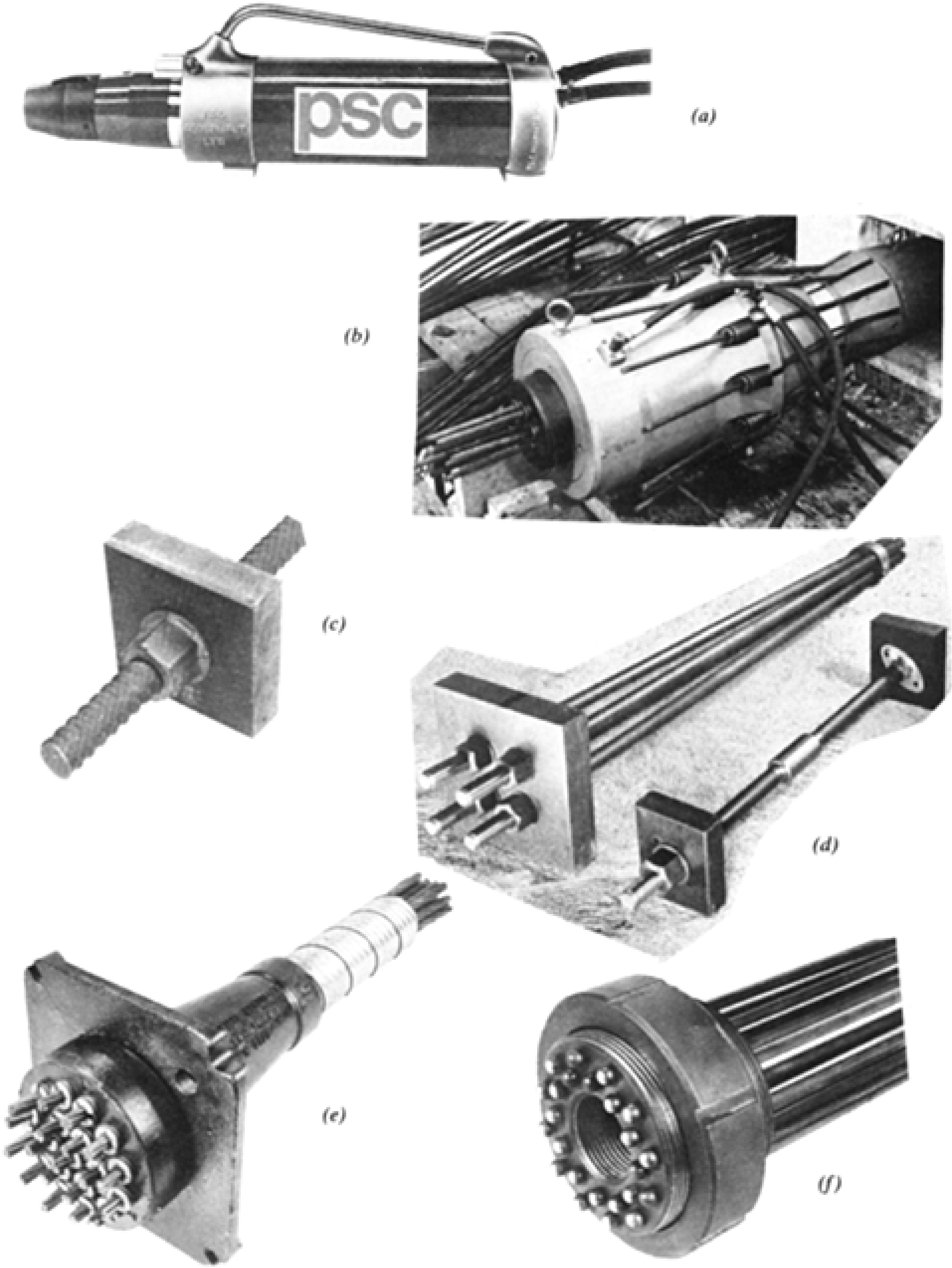
Aerial view of stressing abutment to long line bed—the stressamatic jack is used to tension tendons individually, the large hydraulic jacks are used at time of transfer of force into units



1. The formwork must be accurately constructed and the location of ducts and tendons must be correct within specified limits.
2. Concrete must be carefully batched, mixed, handled, compacted and cured, and must meet the requirements for characteristic strength as set down in the Specification.
3. The concrete must be carefully cured and any accelerated curing must be carried out using approved methods and temperature applied in a controlled and systematic way.
4. The specified prestressing force must be applied systematically and gradually, records being kept of forces, tendon extension, pull-in and other details, as required by the engineer.
5. Storage, transport and other handling must be carried out without damage or distortion of the units.
6. The workforce must, at all times, be aware of the safety points to be observed.

The following are important points which the supervisor must bear in mind when planning and organising the production or use of prestressed concrete:

1. The combination of high tensile steel with high strength concrete enables a reserve of compressive strength to be built into the element or structure to combat the tensile stresses due to the selfweight of the unit and the load carried. This is done by producing high strength concrete elements, jacking high tensile tendons and anchoring them into the concrete in such a way that the force is transmitted into the concrete introducing a precompression. The designer carefully calculates the prestressing force, bearing in mind losses in anchorage and due to friction, relaxation and creep, to ensure that the concrete does not crack under the normal working load. The resulting element will crack if subjected to load beyond the normal working load, but the cracks will close and disappear when the extra load is removed.



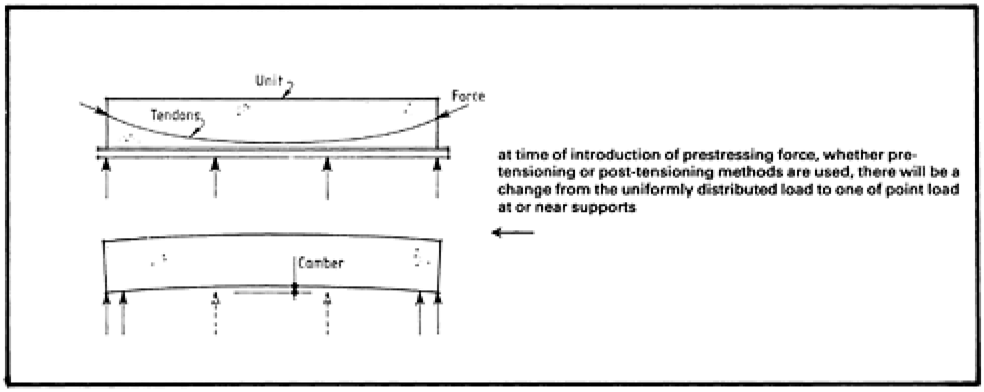
(a) jack for single wire or strand

(b) jack stressing multiple tendons

(c) & (d) formed and threaded bar anchorages

(e) anchorage for multiple stand system

(f) button ended tendons anchor



2. Prestressed concrete shortens and cambers on application of the prestressing force—provision must be made for any projections such as bolts through the beam side forms or bearing plates on underside of units such as beams, to move within the pockets of the soffit former.
3. As elements camber under the application of the prestressing force, the load on the soffit form changes from one of uniformly distributed load to one of point load at or adjacent to the supports, in the case of an in situ beam, or to the ends of the beam in the case of a precast element. The formwork and falsework must be designed with this in mind and mould work must be suitably strengthened to resist damage at that point.

In all prestressing work, the actual location of the tendons is critical to the performance of the element. The designer carefully calculates the location of the prestressing force relative to the section of the unit. This location determines the position of the application of force at any point along the beam and is so arranged to provide the compressive force necessary to deal with tensile and shear stresses. Wrong location of tendons can result in wrong application of force. Friction due to misalignment of ducts can result in loss of force. Either, or a combination of both these inaccuracies, can result in excessive camber, with perhaps sideways camber, with or without tensile cracking in the beam. Compaction is as important as concrete strength in that on application of force, defective concrete will allow excessive camber. In the case of pre-tensioned concrete, poor compaction may result in loss of bond between concrete and tendon.

At this stage it is essential to consider the main differences between pre-tensioned and post-tensioned prestressed concrete in terms of actual production activity. In pre-tensioned and post-tensioned prestressed concrete, the prefixes *pre-* and *post-*indicate the time of application of the force into the tendons relative to the placement of the concrete. In prestressing operations carried out by pre-tensioning techniques, the tendons are stressed, the concrete is cast around them and the force is subsequently transferred into the concrete when it has achieved a predetermined compressive strength. In prestressing operations carried out using post-tensioning techniques, the concrete is cast incorporating ducts or channels for the tendons. The tendons are subsequently inserted and when the specified compressive strength is achieved in the concrete, the tendons are stressed and the force transferred into the concrete by anchorage devices. In prestressed pre-tensioned concrete products, the force is transmitted into the concrete by the bond which develops between the wire and the concrete throughout the length of the element. In post-tensioned concrete grips are used which transfer the force from the wires onto bearing or anchor plates located at various points in the concrete element.

Pre-tensioned prestressed concrete is used in floor slabs, sleepers, lintels, posts, piles, pipes, walling elements, beams (including U section, I section, box section, T section and double-T section). Pre-tensioning is usually carried out in a works or in a casting yard attached to a construction site.

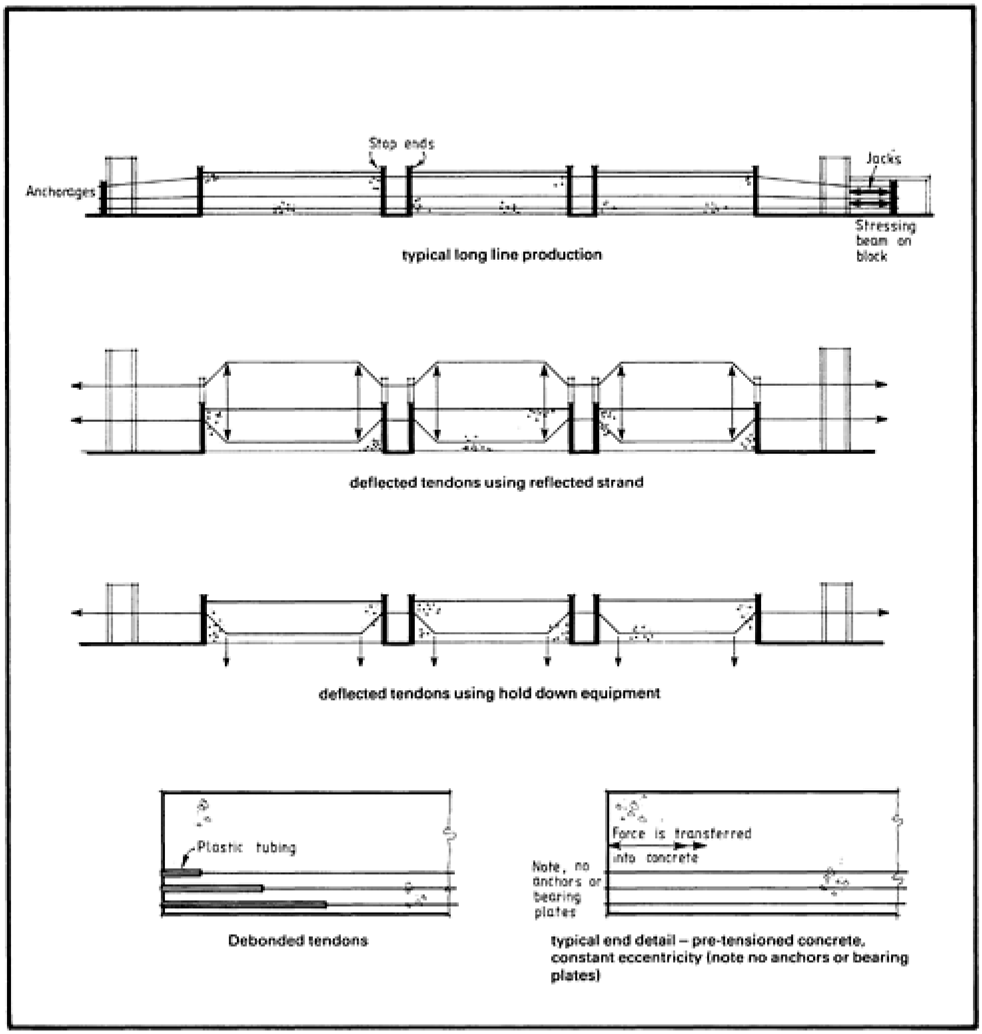
Post-tensioned prestressed concrete is used in bridge decks, floor slabs, beams of various configurations, silos, sleepers, tanks for bulk storage and segmental elements. Post-tensioning, while being used in some precasting operations, is more usually associated with in situ construction or the assembly of previously precast elements.

Pre-tensioned prestressed concrete

The production of pre-tensioned concrete is carried out on specially prepared casting beds or using suitably stiffened moulds. It is usually produced in specialist suppliers works, although where economies so allow, it may be produced on a construction site. Pre-tensioning techniques usually employ wire or strands, although bar tendons are used in some parts of the world.

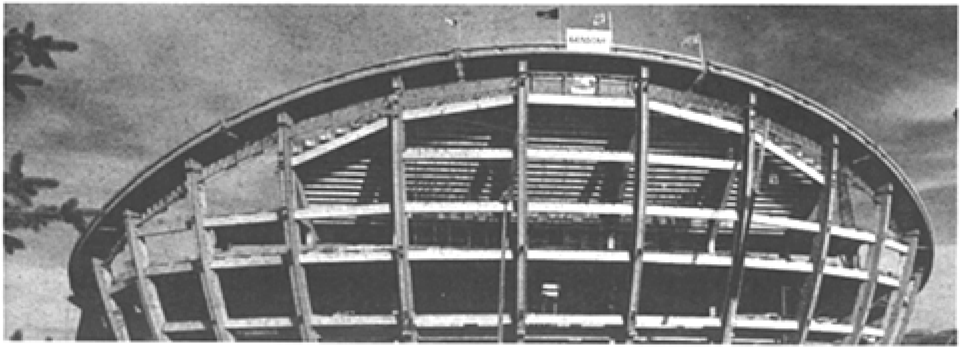
The pre-tensioning process commences with the threading of tendons through end plates or distribution plates and distribution steel, such as links and stirrups, along the prestressing bed or through the stiffened mould. Operatives must be provided with goggles for eye protection. The tendons are anchored at one end of the bed or mould using grips of some form, usually barrels and wedges. Similar grips are installed at the other end—the stressing end. A small uniform amount of force is applied using a load limiting device to ensure that all tendons are similarly stretched. This also ensures that the eventual force in each tendon will be equal. The main prestressing force is then applied by jacks or a jacking beam, the wires being stressed either individually or in groups. The operation is carried out in such a way as to ensure the introduction of a specified amount of force as indicated by the design engineer. At all times during the stressing operation, operatives must be kept clear of the areas where wire might fly in the event of a slip or wire breakage. Safety straps or cross-heads are laid over the beds to contain the force and men are kept outside an area of about 60° either side of the line of the jack at the jacking end of the anchorage and at the dead end. Barriers are swung into place as a protection to deflect wire ends which might otherwise fly under sudden release of force. The jacking operation is carried out slowly and systematically without sudden shock, working to the specified guage reading or extension. When these are reached wedges are driven home at the stressing end or the jacking beam is secured in its working position. The secondary steel and any cast-in connections are now secured in place to resist vibrational movement. The concrete is then placed either manually, by spreading machine or by extrusion. Sound compaction is essential, and is guaranteed by the use of the extrusion machine, but must be carefully supervised in all other cases. After placement, the concrete must be cured. This will be done by application of a spray membrane or covers with the introduction of heat either electrically or by steam curing. Cube specimens are prepared and stored under the same conditions as the concrete elements. These are used to establish the strength of the concrete for the purpose of transfer of force. When a specified strength has been achieved in these cubes, the prestress is transferred into the unit or line of units by gradual release of the tendon at the end of the casting bed. Prestressed concrete is, to a degree, selftesting, as excessive camber in the unit or bond slip visible at the end of the cut unit will indicate whether the force has been effectively transferred into the concrete.

Absolute care is essential in the maintenance of the grips and prestressing equipment. Grips should be regularly examined and discarded at the first sign of wear. The application of a proprietary release agent ensures that the wedges are quite free to slide in the barrel and thus grip the wire effectively where the force is transferred into the grip.



Where prestressed concrete is manufactured in long line beds, the mould sides are generally removed prior to transfer of force. Where products are manufactured in stiffened moulds, the force must be transferred into the units before the moulds can be released. Examples of this technique are encountered in pipe and pole manufacture, where balanced moulds stiffened to withstand the prestressing force are spun by machine to achieve good compaction of the element.

In some prestressed concrete manufacture using pretensioning techniques, the designer is concerned with the avoidance of build-up of excessive tensile forces at the top of the beam and with combatting shear. He may elect to do this by reproducing in the pretensioned unit the tendon arrangement used in posttensioned concrete whereby tendons are arranged to ensure the application of force as required. This may be done in two ways. Either by deflecting the tendons or by debonding the tendons in such a way that the amount and location of the force transmitted into the beam is controlled according to the design requirements. Deflection is achieved by using either holddowns or deflectors within the concrete or by setting up an



Slender sections made possible by prestressing techniques are evident in this "Saddle Dome" structure (Jan Bobrowski and Partners)

inverted pattern of the tendons above the forms on the long-line bed and spacing and tieing the tendons to reproduce the catenary within the concrete. Debonding utilises some form of plastic sleeving threaded around the wires or strands, the length of these debonding sleeves being determined by the required location of the force in the unit.

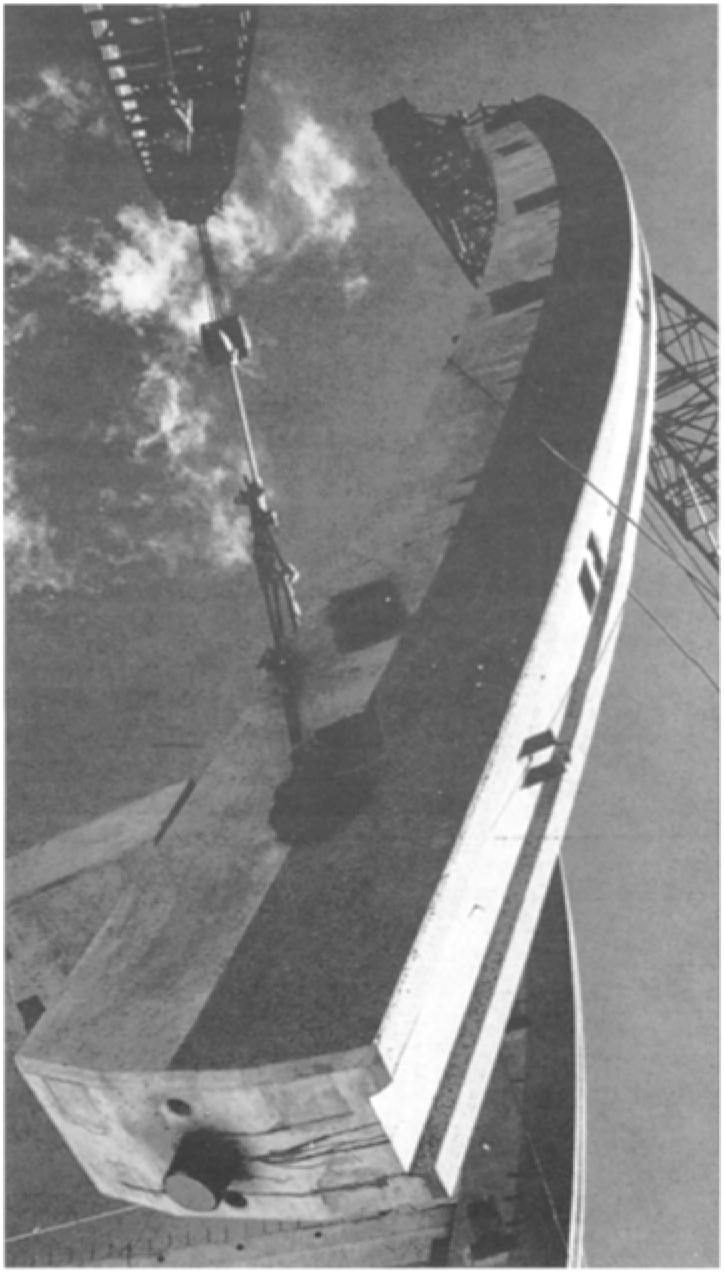
Post-tensioned prestressed concrete

In post-tensioned work the concrete is cast in forms or moulds according to normal in situ or precast practice. The steel reinforcement is set up on a soffit member or the casting deck. Ducts for the tendons are carefully located to the profile or catenary set out in the unit drawings. The ducts are supported by grids of steel attached to the main stirrups or by dowel bars which pass through the form work in the appropriate place. It is essential that the ducts are secured against vertical or horizontal displacement due to concrete placement, and the application of vibratory force or uplift due to flotation. The side moulds or forms are assembled and the duct location checked. In post-tensioning it is necessary to provide anchorages or bearing plates which transfer the force from the tendon into the concrete. These plates may be required at the ends or at various positions along the unit, depending upon the designed catenary or duct layout. The recesses around the anchorage must be of such dimensions that the jack nose can be inserted without obstruction at the time of application of the prestressing force. It is extremely important that the anchorages should line with, and the bearing surfaces be normal to, the line of the duct, both from the point of view of transfer of force and that of achieving satisfactory anchorage. Some anchorages are designed to incorporate recesses for grips, others provide bearings for barrels, others are so designed that the force is transmitted by screw thread and nuts or similar devices. There is often additional steel reinforcement in the form of stirrups or spiral bars around the anchorages to prevent bursting forces from damaging the ends of the unit at stressing.

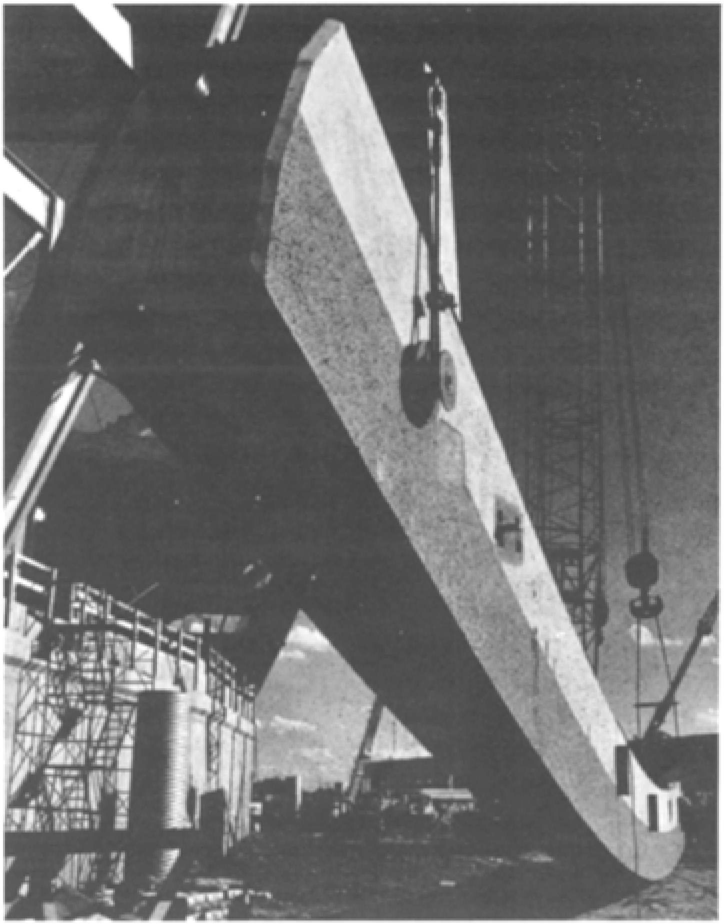
The concrete is carefully placed and compacted, taking care not to choke the mould or form. Particular care is essential to ensure adequate compaction of the concrete adjacent to the anchorages, where there is likely to be a considerable amount of steel. Internal vibration is helpful in this instance using the largest poker that can be introduced between the steel reinforcement. The upper surface of the concrete must be convered or sprayed with a curing compound, and the curing process using steam or heated moulds can commence.

Cube specimens are made and stored under the same conditions as the unit. They are tested to ensure that the compressive strength, as required by the engineer, is achieved prior to stressing of the elements. Stressing is carried out, after the insertion of tendons, by the application of force using jacks at one or, in the case of long or complicated duct profiles, both ends of the beam. It is essential that records of the guage

Erecting the unit—this designer produces detailed method statements as part of the design process (Jan Bobrowski and Partners)



readings vs. extensions, the pull-in at the dead end and pull-in at the time of transfer of force, are maintained. The designer can then calculate what is the actual force built into each tendon. In certain cases, *Preparing to lift one of the curved pre-tensioned column units (Jan Bobrowski and Partners)*



after a given percentage of the tendons have been stressed, a beam can be lifted away to a stacking area for further stressing. The tendons must always be tensioned in the specified sequence. This applies particularly where individual strands are stressed. In this way trapping of unstressed tendons against the wall of the ducts will be avoided. If at any time in the stressing operation the relationship between extension and guage reading should become other than linear, the operation should be halted and an engineer consulted.

The same safety precautions must be observed with post-tensioning as with pre-tensioning. On no account should people pass behind the jack whilst stressing is in progress and operatives working the equipment must be kept clear of an area 60° either side of the axis of the tendons. It is advisable that where only partial prestressing is carried out prior to handling, the state of the beam, whether partially stressed or unstressed, should be clearly indicated.

Handling prestressed concrete

Elements must always be lifted and stacked only at or adjacent to their ends.

Erecting a pre-tensioned ring beam member (Jan Bobrowski and Partners)

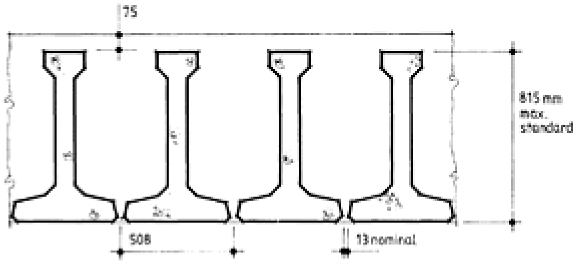
Long elements must be handled using spreader bars or very long brother chains.

Elements must only ever be landed onto *two* battens or bearers—a third intermediate bearer will not be level and will damage the unit. The exception is where floor slabs, finished top and bottom during manufacture, are rested one directly on top of another, in which case it is essential that the top surface is swept free of debris prior to stacking a further unit on top.

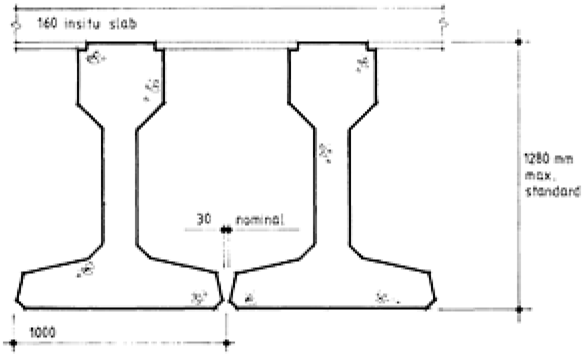
Elements must, at all times, be handled and stacked upright. Apart from the need for the mass of the beam to retain the prestressing force, there is the tendency of concrete to creep during prolonged storage with resultant problems when beams have been placed close to each other during erection.

In the case of bridge beam erection, it is essential that as each beam is erected, the holes for transverse prestressing bars or steel are checked to ensure that they are clear. Failure to do this may result in expensive delays as efforts are made to clear the holes after installation, this process often demanding the further use of cranes which may have to be specially brought back onto the site.

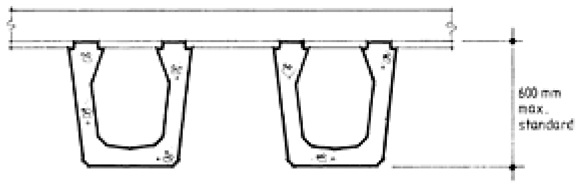
typical bridge sections using pre-tensioned beams



a) inverted T beams up to 18 m span

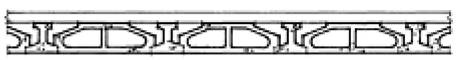


b) M beams up to 28 m span



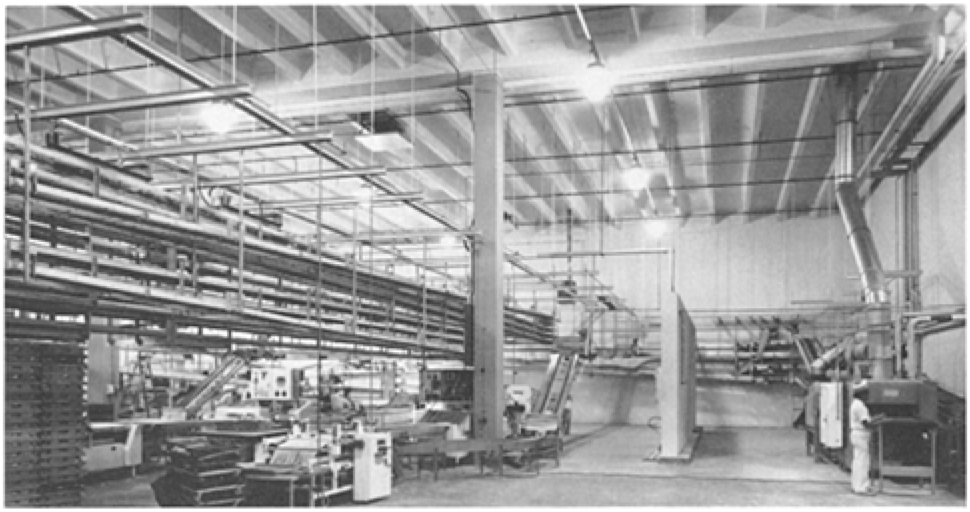
c) U beams up to 34 m span

double tee elements are an extremely economic unit – used either in floors and roofs or vertically as walls

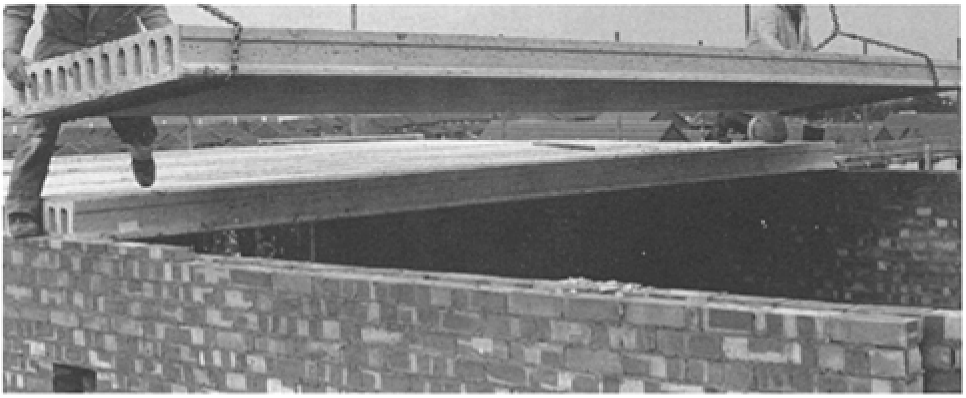


block and beam floors are fast to erect manually – an in situ topping completes the structure

extruded floor units are crane erected – they may be finished top and bottom in factory or used with in situ screed



Insulated precast and prestressed double-tee units form the walls and roof of this vast bakery structure (G Wimpey Limited)

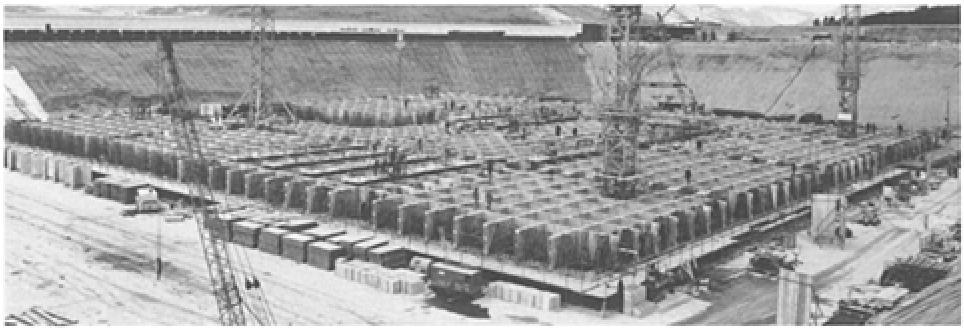


Prestressed concrete 'installation - wide slab units produced by machine on a long line bed (Bison Concrete Limited)

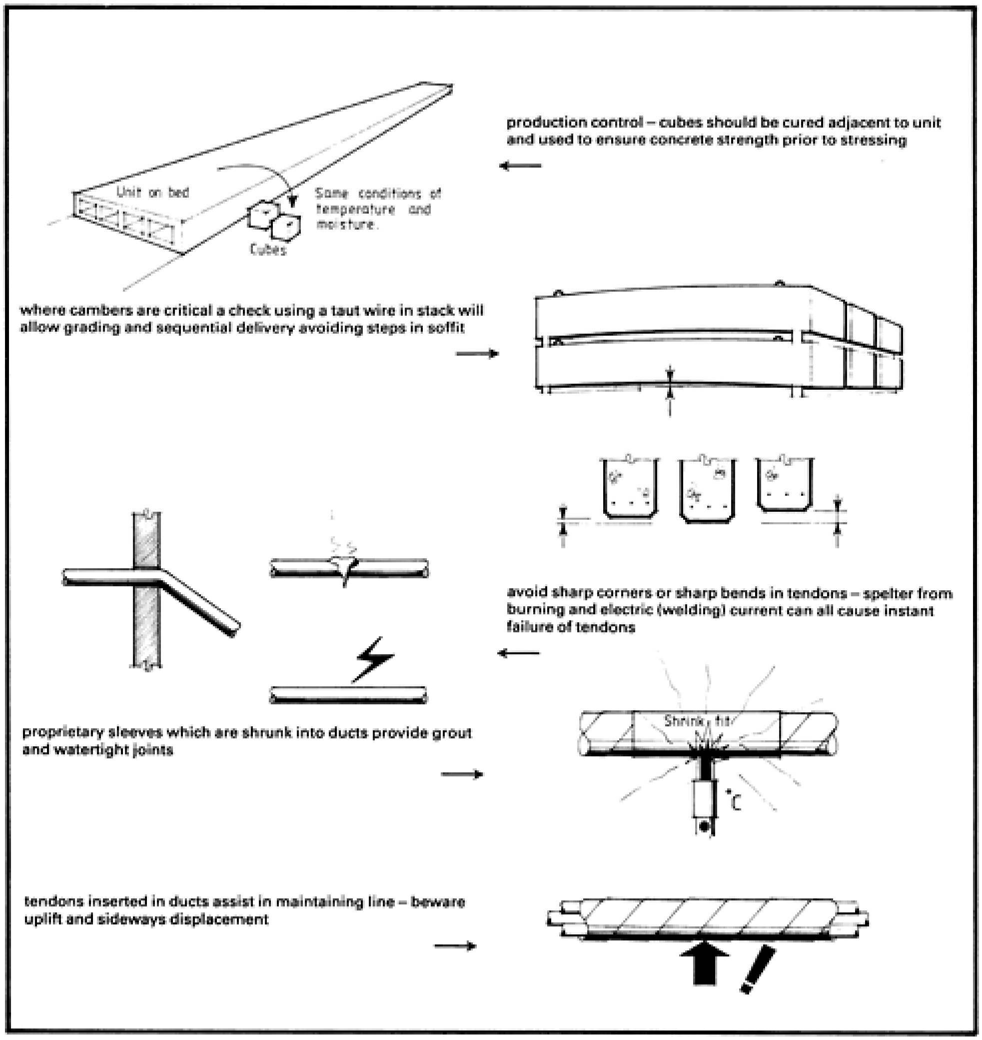
Prestressed floor planks and prestressed permanent formwork together with most prestressed lintels, require strutting until the part of the structure is completed by the mature concrete with which they act as composites. In the case of lintels, these must be supported for a given period after the brickwork above has been laid and the mortar joints have matured. It is apparent in each of the cases mentioned that the prestressed elements would not be capable of sustaining the dead load of the topping or brickwork plus live load or construction load to unlimited height.

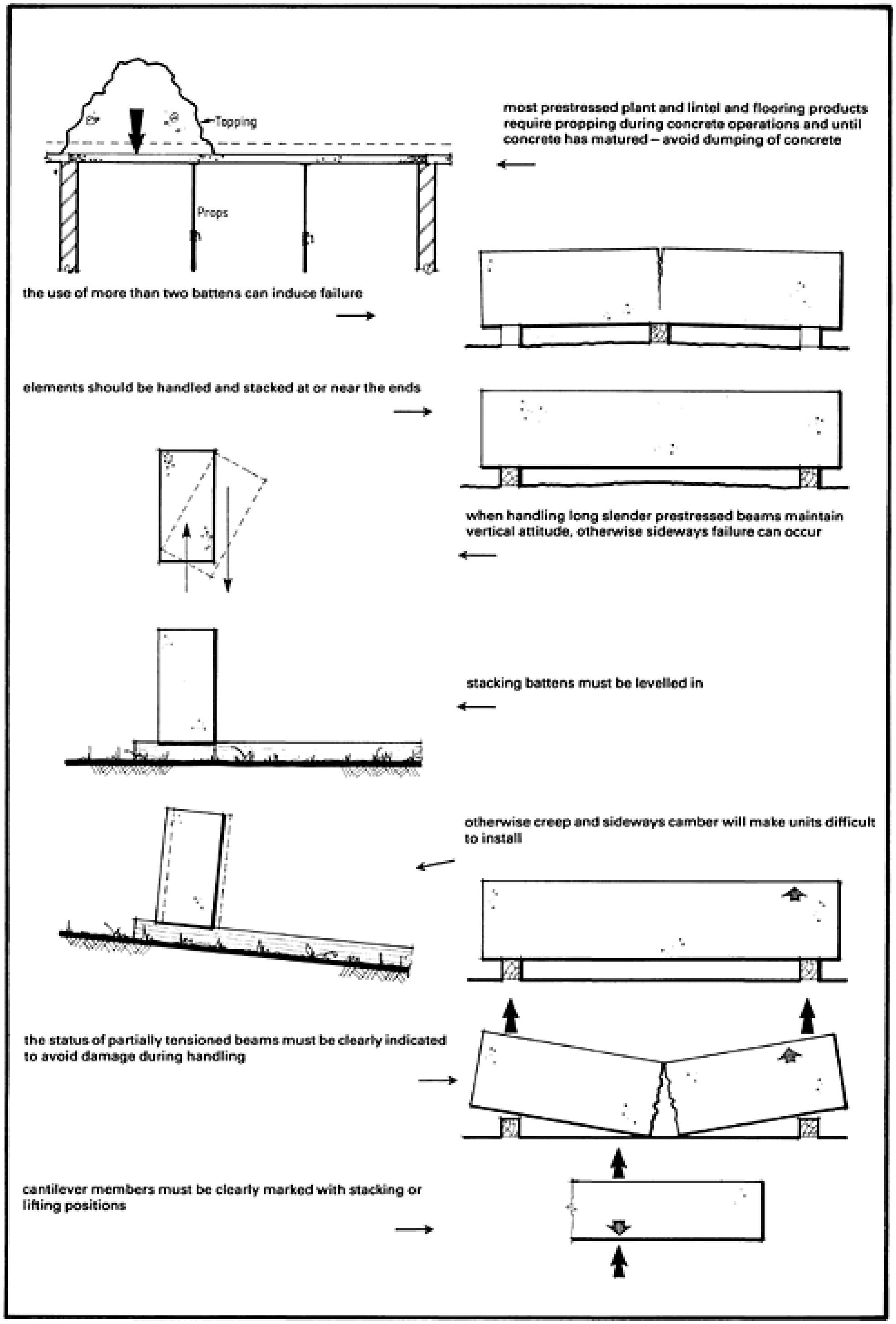
Some post-tensioned elements are partially tensioned prior to early removal from the soffit on which they are cast. These elements must be clearly marked accordingly so that the status of the beam, unstressed, partially stressed or fully stressed, is clearly evident to those responsible for handling operations.

Cantilever members must be clearly marked to indicate the positions in which they may be supported on bearers or battens.



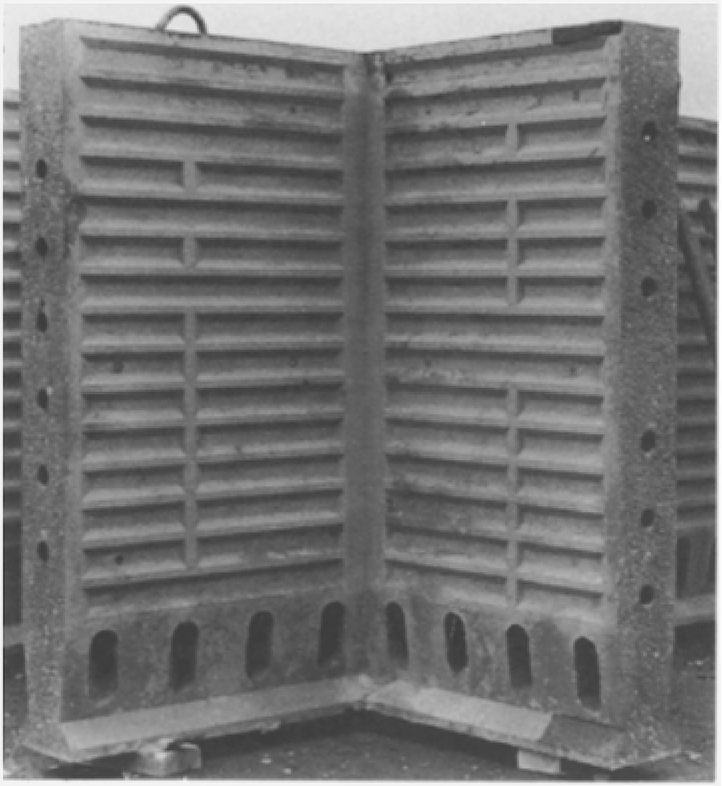
The elements (illustrated on p. 114) set up on site in preparation for post-tensioning together (Trent Concrete Company Limited)

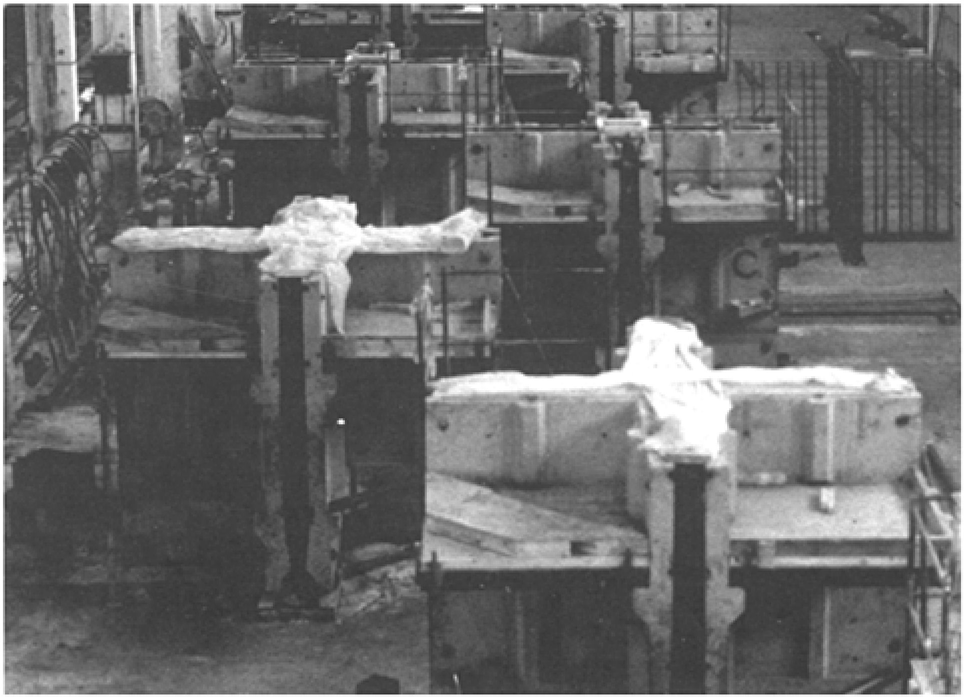

production control – cubes should be cured adjacent to unit and used to ensure concrete strength prior to stressing
Unit on bed
Same conditions of temperature and moisture.
Cubes
where cambers are critical a check using a taut wire in stack will allow grading and sequential delivery avoiding steps in soffit
avoid sharp corners or sharp bends in tendons – spelter from burning and electric (welding) current can all cause instant failure of tendons
proprietary sleeves which are shrunk into ducts provide grout and watertight joints
Shrink fit
°C
tendons inserted in ducts assist in maintaining line – beware uplift and sideways displacement



Topping
Props
most prestressed plant and lintel and flooring products require propping during concrete operations and until concrete has matured – avoid dumping of concrete
the use of more than two battens can induce failure
elements should be handled and stacked at or near the ends
when handling long slender prestressed beams maintain vertical attitude, otherwise sideways failure can occur
stacking battens must be levelled in
otherwise creep and sideways camber will make units difficult to install
the status of partially tensioned beams must be clearly indicated to avoid damage during handling
cantilever members must be clearly marked with stacking or lifting positions

The segments cast from concrete moulds showing nicely prepared ends for jointing (Trent Concrete Company Limited)





A precast production shop set up to produce segments for an oil production platform (Trent Concrete Company Limited)

25.
Special techniques

By R.A.WILSON CEng, MICE, FIStructE, FSCET

Gunite

Gunite, also known as shotcrete or sprayed concrete, is defined as mortar or concrete conveyed from the blending machine through a hose and blown by high pressure air from a nozzle onto a surface. Water is introduced at the nozzle. The force of the jet impacting on the surface compacts the material. Gunite can be blown onto walls, floors and ceilings. Uses range from repair, through refractory concrete to swimming pools and architectural finishes. The work is always carried out by specialist contractors and there are several slightly different processes. The course of the work lies in the nozzleman's hands (quite literally!). The speed at which the nozzleman can work will regulate job time and his skill and conscientiousness will determine the quality of the finished job. Nevertheless some general supervision should be maintained, if only to keep everyone on their toes!

Reinforcement is used but assembly and fixing are rather different to normal reinforced concrete. The outer of the two reinforcement layers should not be fixed directly above the inner layer, but to one side, so that it does not shade the inner layer. Similarly, bars are not laid or lapped beside one another. Laps are formed with an open staggered pattern, no two adjacent bars being closer than 65 mm. Mesh is often used and is lapped 1½ squares in both directions to give an open overlap. Because of the blast of concrete from the nozzle all reinforcement and mesh must be securely fixed to the backing. Staples are used with a wood backing, such as formwork, and shot-fired pins with bendable clips are frequently used elsewhere. Reinforcement must be supported clear of the backing, the distance depending on the largest aggregate size and the tension function of the reinforcement.

The grading of sand is a very important factor in good gunite. The grading will be specified and each delivery tested and inspected. The sand should be "sharp and abrasive", not dusty, soft or loamy. Generally the nozzleman will decide from experience whether the sand will be good enough for guniting, but a keen supervisory interest should be shown. Stocks of sand should be sited where they can drain freely. They should preferably be under cover and away from contamination, such as "rebound", leaves and mess from other works. If the sand is too wet, over 8% moisture content, it will probably block the gun or hose. It may be possible to dry the sand by mixing it with selected dry materials such as pfa, but this does, of course, involve extra work and must be carefully supervised to ensure mixing is thorough. The sand should be screened to remove stones, flakey mortar from the mixer and pieces of cement-bag, before being fed to the gun.

The layout of supply pipes will be influenced by height or depth of the shooting position above the mixing station and gun. It is comparatively simple to work downhill where a coil of pipe reduces pulsation and permits the mix to become properly suspended in the air stream. Working uphill is more difficult. If work is stopped with the mix in the pipeline, it will fall to the bottom end of the pipeline and may block it. A sensible precaution is to duplicate the hoseline so that work can continue while the blocked pipe is being cleared.

The working-face team will consist of:

1. a blowpipe operator, blowing away rebound material with compressed air followed by:
2. the nozzleman, shooting on the concrete, and sometime later, when the concrete is stiff enough to work:
3. a finisher, brushing or cutting the surface, depending upon the finish required.

The nozzleman directs the flow from the nozzle directly (at right angles onto the working area from about 1 m distance. A circular scrubbing motion spreads the concrete with the advancing edge being built up at an outward angle of about 45°. This allows “rebound” to fall clear. The surface under the jet will show a silky, glistening sheen. If the surface ripples, the gunite is probably too wet and if it looks dry and granular, the opposite applies. An alternate bay system is often used. The thickness of the gunite is guided by edge screeding boards and tensioned wire on the face. Screed boards are deliberately lifted clear of the base to avoid forming a pocket into which rebound material can collect. Construction or daywork joints are quite the opposite of normal reinforced concrete. The gunite is “run out” to a “feather edge” about 300 mm wide. Before starting the next bay the taper is cleaned and wetted with an air and water blast and fresh gunite shot on as soon as possible and the coat carried away from the joint.

There are two common problems in guniting which can cause faults and should be avoided:

1. *Rebound pockets* These can be caused by “shading”, “square-edging” and “overshooting”, all of which can be prevented if the blowpipe operator and nozzleman are alert
2. *Sand pockets and sand layering* Generally caused by some malfunction of the equipment or clogging of the various nozzles or pipes.

Sample cores are cut from the finished work (which is most inconvenient and difficult to reinstate) or from sample trays sprayed just prior to construction of the actual panel. Alternatively, sample cubes can be cut from the trays. The sample tray should be at least 600 mm square, but may need to be larger depending on the number of samples to be cut. The sample should be as thick as the work it represents and built up in the same manner. Reinforcement is omitted, although sometimes a mesh lining is used. Where samples are cut through this mesh, different results can be expected. In repair work other tests may be required, which could include:

1. Schmidt rebound hammer
2. adhesion or pull-off test
3. absorption and permeability test

For further reading, there is a publication entitled *Gunite: a handbook for engineers* by T F Ryan, published by Viewpoint Publications, London.

Underwater concreting and bentonite

It would be inappropriate in a book of this nature to consider major underwater construction as such work is highly specialised involving diving, working from barges and boats and considerable special equipment. Nevertheless, on many small sites it may become necessary to place concrete underwater or bentonite mud, for example during piling or diaphragm wall construction, and when building the base for a crane or underpinning an adjacent building. Of initial concern will be the condition of the bottom of the hole. Where water is involved there will always be sludge and the sides will tend to slump. Three basic approaches can be considered, as follows:

1. To form a barrier to the water so that the area inside that barrier can be pumped dry and cleaned out—practical if the water is not too deep, for example at the bottom of the excavation for a tower crane base where the groundwater level is a bit higher than expected.
2. By using a bentonite mud the sludge is held in suspension and is displaced by the concrete introduced beneath the mud with a tremie tube.
3. Often in combination with 2 above, sucking up the sludge with an "air lift", which works well when the bearing stratum is rock or similar hard, cleanable material. When bentonite mud is being used the air lift feeds a de-sander and the clean mud is returned directly to the works.

Attention must now be paid to the materials. Often, as in foundation work, the material is "designed" about a workability requirement rather than a strength—there is a common misunderstanding that a rich mix is required because "the water will wash out some of the cement", which is totally incorrect. The cement is there to make plenty of paste, the paste lubricates the mix and allows it to flow. Where plenty of cement is used, plenty of water is also used, keeping the water/cement ratio controlled at about 0.55 or 0.6. Other essential qualities, such as cohesion, resistance to bleeding and ability to self-compact are achieved as detailed in *Chapter 11: Groundwork (Volume 1),* that is:

Cement	not less than 400 kg/m^3
Water/cement ratio . .	not more than 0.6—giving a high slump-test value, in the order of 175 mm
Sand	between 35–45% total aggregate (well in the middle of Zone 2)
Stone	rounded aggregate preferred (10 mm and 20 mm sizes)

Admixtures to reduce water demand and retard set can be used to advantage. The workability (about 175 mm slump) should be available at the placing point—it is useless if the mix starts off workable but is delayed for so long that it has stiffened by the time it reaches the placing point. Similarly, poorly mixed materials giving lumpy concrete are not acceptable. All these matters must be resolved prior to the underwater pour of concrete which, once started, cannot be stopped until the pour is finished—cold joints and emergency joints do not exist in the vocabulary of underwater/bentonite construction.

Where a barrier is to be formed, concrete filled bags can be used, built up in stretcher bond and pinned together with short reinforcing rod pins. The bags are open weave hessian material, half filled with fresh concrete, the necks being tied or sewn up. A number of bags are placed on a pallet and lowered to the working gang. These half filled bags can be pushed into shape to make contact with neighbouring bags and grout seeping through from the mix helps bond the bags together. Every third course or so is spiked to the courses below by driving 8 or 10 mm reinforcing rod lengths through the still soft bags. These bags should weigh about 25 kg, which is about as much as one man can handle in the circumstances. Where work is urgent, three gangs at least will be needed, one gang filling the bags, one placing and one resting—short periods of working are preferable as the working conditions are wet and, most probably, cold.

Where the water/bentonite is deep, concrete will be placed by tremie tubes. A tremie is a jointed pipe (the joints being watertight) with a hopper fixed to the top. The pipe reaches from the surface to the very bottom of the excavation to be filled. The tremie will cover a maximum 2 m radius—if this is not sufficient to cover the area of the base, additional tremies must be used. The tremie should not be moved about to cover the base—the concrete will almost certainly completely run out of the tremie allowing it to flood and allowing sludge to foul the joint. The pattern of tremies should be such that the area can be concreted generously as several factors can hinder the flow of concrete and the maximum radius is often not achieved.

Initially the hopper should be wetted and a plug fitted to the tremie. Because there are no valves or other devices, when the tremie is first lowered into the hole the water will fill the tube and if concrete were poured into the pipe it would fall through the water and segregate. The plug is best formed with 300 mm deep expanded vermiculite. The highly workable concrete can now be poured through the hopper, the plug will be driven down the pipe expelling the column of water through the bottom of the pipe. This rush of water should scour away any sludge or mud which has accumulated since excavation. The concrete should flow without interruption with the tremie being lifted very slightly, about 50 mm, allowing the concrete to flow and spread. The concrete often tends to flow up the outside of the pipe before slumping outwards, causing a conical build up around the tremie which will spread out in a shallow slope. If pouring is too rapid the slope becomes rather steep and any free mud will flow down the slope becoming trapped and engulfed by further eruptions of concrete. Where several tremies are used, they should be used in turn so that the underwater surface of the concrete rises almost evenly or, at the most, in a flat quilted shape.

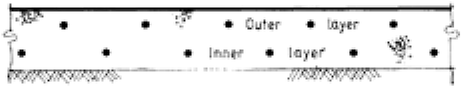
As the concrete fills the excavation, the water will need to be pumped away so that it does not flood the site. A suitable settling lagoon will have been built in a corner of the site, which will be capable of taking the expected volume of water. When the mud and so on have settled, the clean water in the lagoon can be disposed of.

Wherever possible the final level of concrete should be brought to a weir level and finished to about 100 mm above the final construction level. Inevitably some contamination of the surface concrete will have occurred which will need to be cut away before construction continues. If the cut-off level of the underwater pour is not controlled and is brought up, say, a metre or so above the required level, "to be on the safe side", annoying delays will result whilst surplus concrete is cut back to line and level. It must be remembered that the end of the tremie MUST BE KEPT EMBEDDED BY ½ m MINIMUM in the fresh concrete. If the lack of sufficient differential head of concrete is causing difficulties in getting the wet concrete to flow down and out of the pipe, the tremie can be surged, by lifting with the crane and allowing it to fall back into position, but the end of the pipe MUST be kept in the concrete.

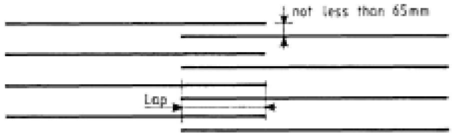
Grouting techniques

The highly specialised technique of grouting fissured rock and ground should not be supervised by the inexperienced—experience in this type of work is necessary in tunnels or for cut-off diaphragms around reservoirs. However, there are a number of techniques which are quite simple forms of grouting and which can be supervised by a non-specialist. The five most likely grouting techniques to be encountered requiring supervision, which are individually described below, are:

1. under-base-plate grouting
2. grout filled bags for riverworks

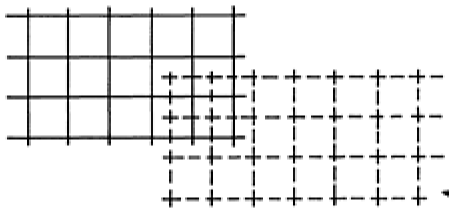


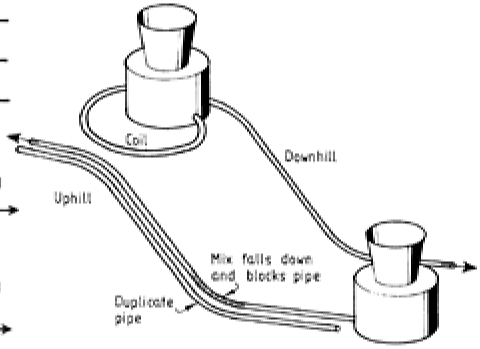
the outer layer should not shade the inner layer



laps are formed with an open staggered pattern

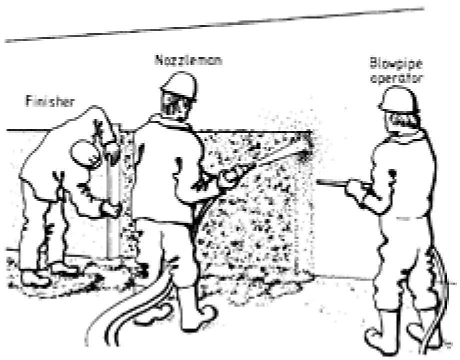
overlap with mesh reinforcement





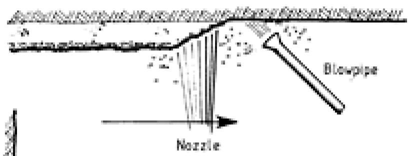
simple to work downhill

a duplicate hoseline so that work can continue while a blocked pipe is cleared

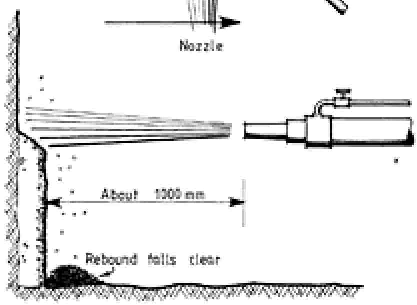


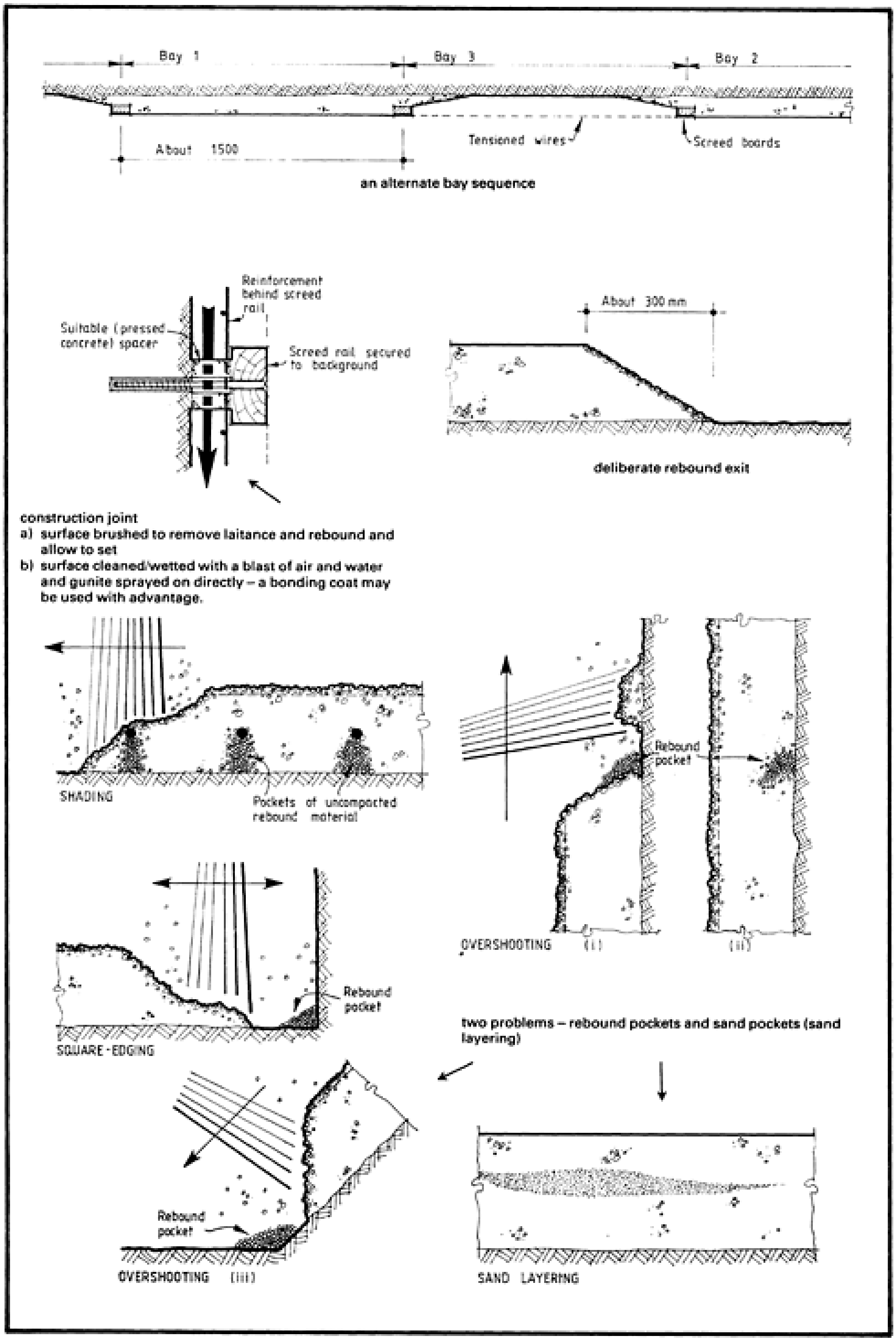
the working face team

nozzle shooting gunite while blowpipe clears rebound



the advancing edge being built up at an outward level of about 45°





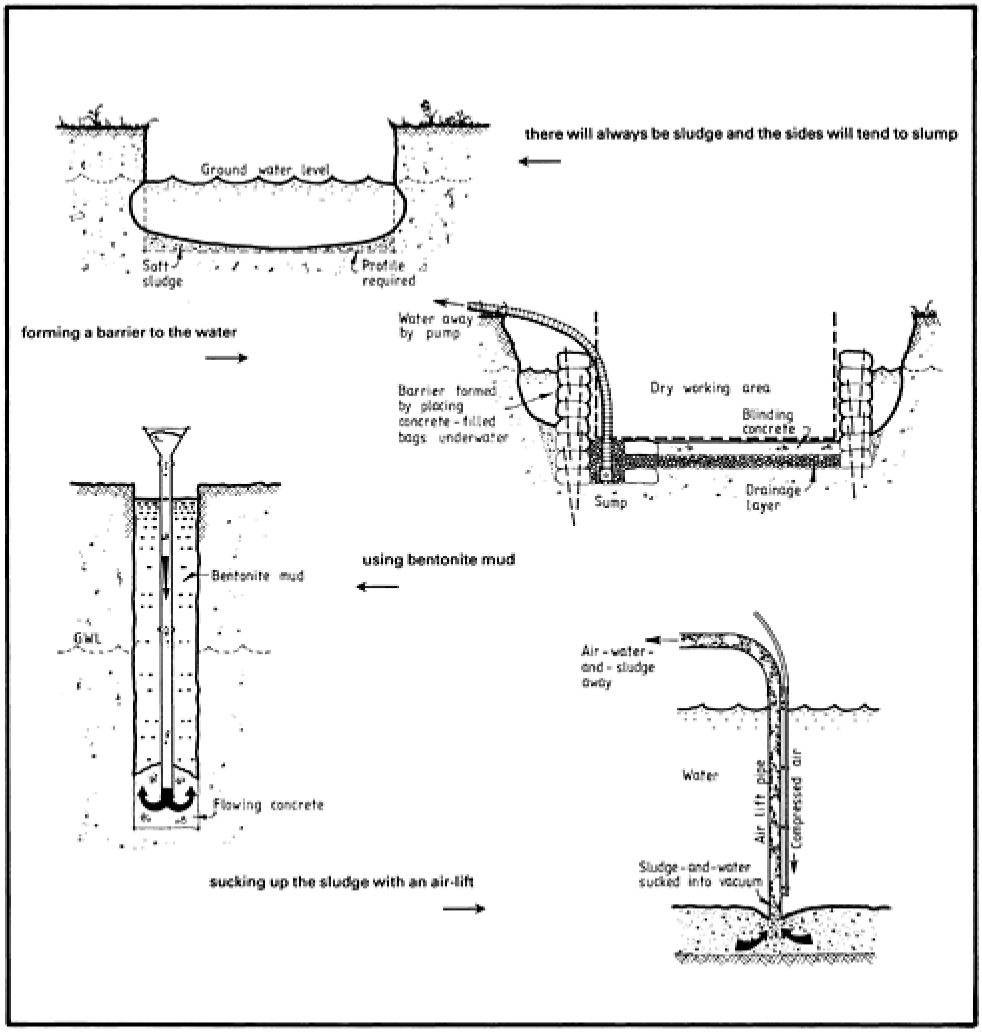
an alternate bay sequence

deliberate rebound exit

construction joint

a) surface brushed to remove laitance and rebound and allow to set
b) surface cleaned/wetted with a blast of air and water and gunite sprayed on directly – a bonding coat may be used with advantage.

two problems – rebound pockets and sand pockets (sand layering)

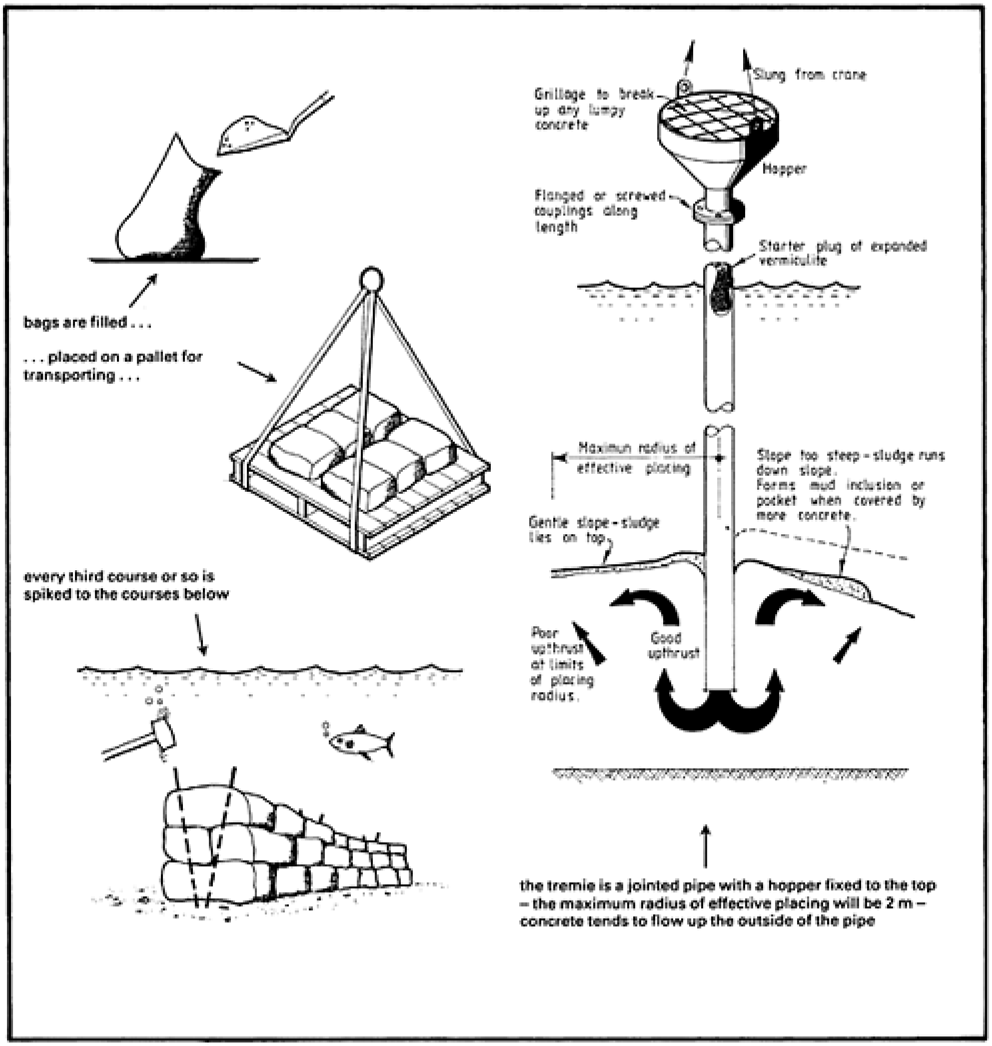


3. grouting leaking drains
4. grouted piles
5. "jet-grouting"

Under-base-plate grouting

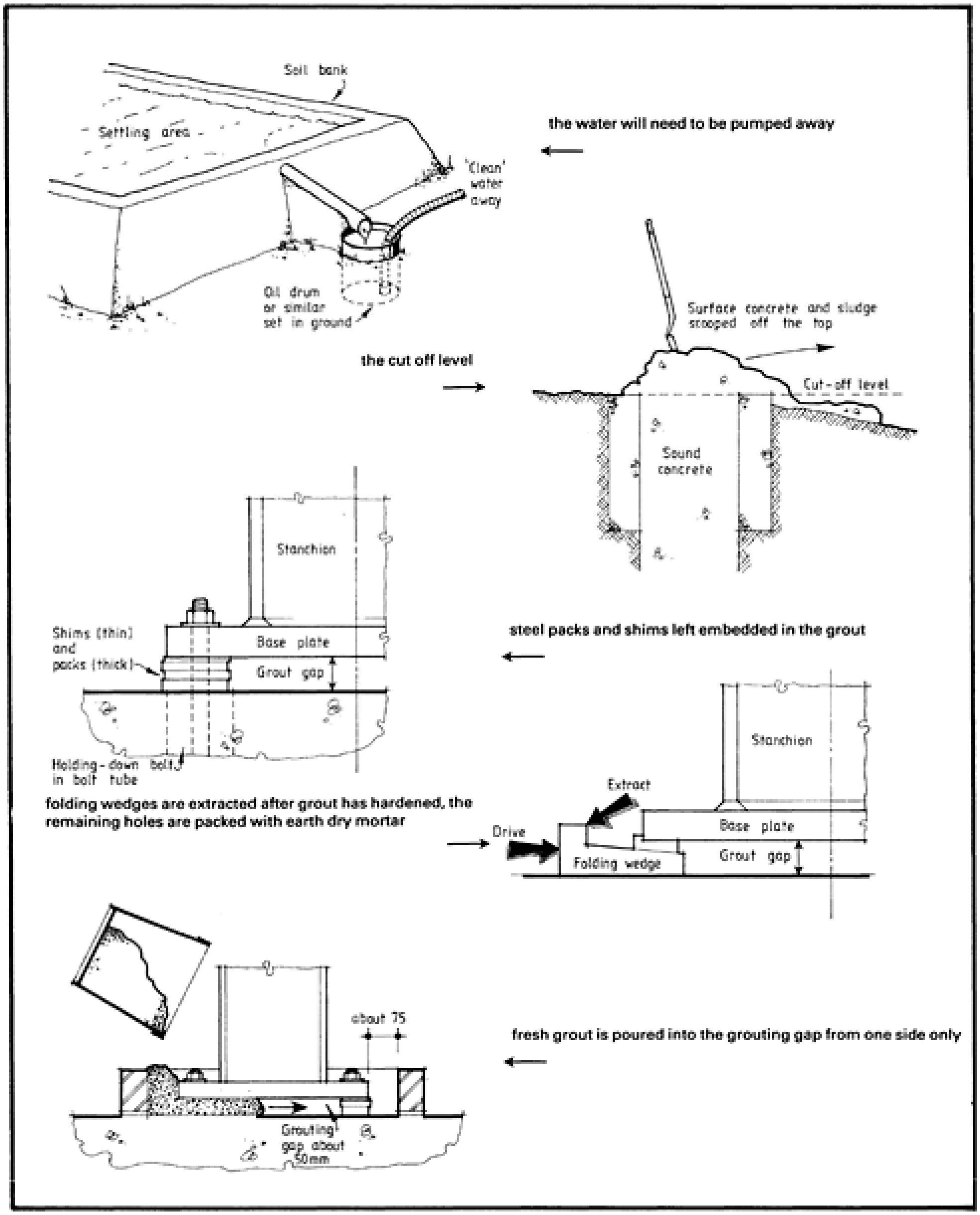
[The following section first appeared as part of an article in, and is reproduced by kind permission of, *The Journal of the Institute of Clerks of Works of Great Britain.*]

It is usual to fill the small gap between concrete foundation and the underside of a steel stanchion base or machine base with cementitious grout. Frequently, the base is temporarily supported on small steel packs and shims which are left embedded in the grout. This is not entirely satisfactory from the engineering point of view since the load continues to pass through these packs even after the base has been grouted and the load causes high stresses under these small packs. For preference, levelling and plumbing should be carried

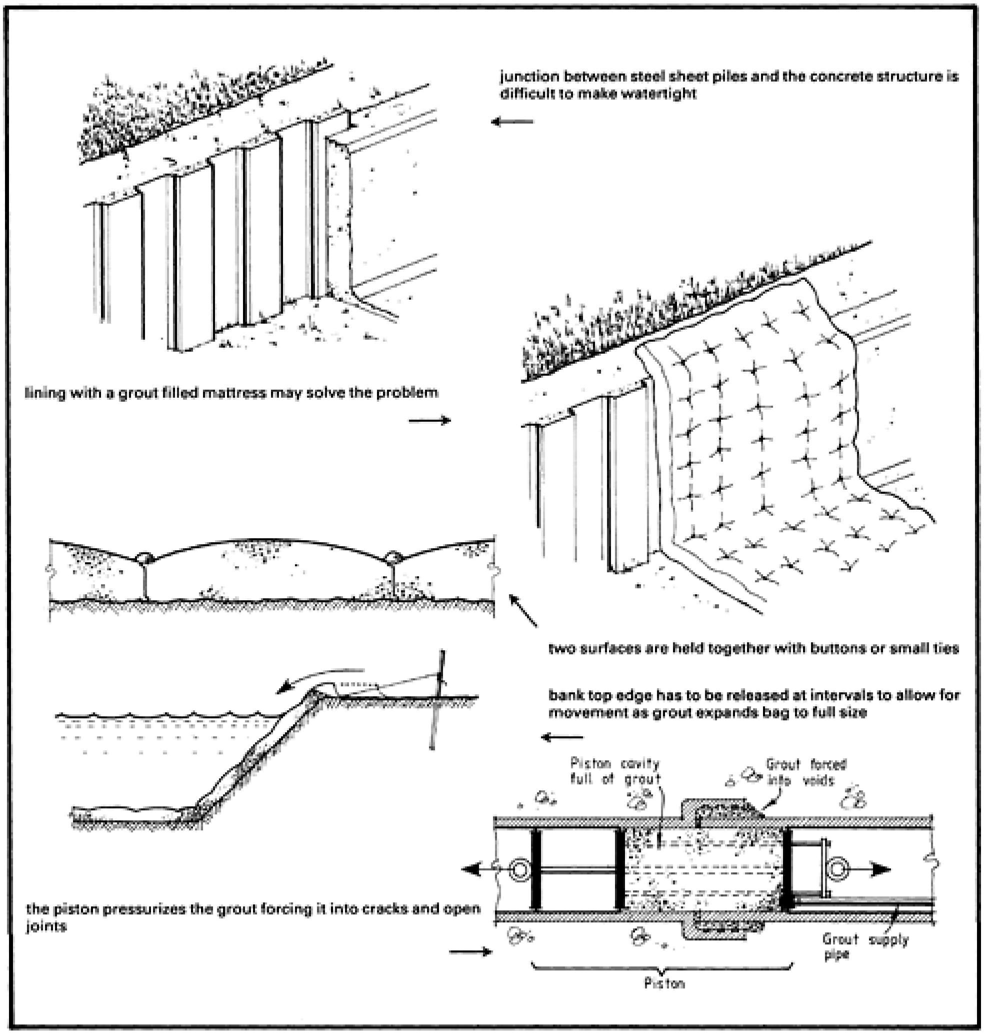


out using temporary steel wedges which are withdrawn after grouting the gap full. To assist with the withdrawal of the wedges, each wedge has an upstanding heel at the thick end which can be struck with a hammer to free it.

Grout mixtures are more reliably bought pre-bagged and a measured quantity of water added at site. Prebagged mixtures are blended with useful admixtures to improve workability and control bleed and setting time. The fresh consistency of the grout is a freeflowing creamy consistency, rather like wallpaper paste. The common practice of mixing grout in a bucket with a stick is quite unacceptable because the cement is poorly wetted and settles out. For anything but the smallest quantities, grout should be mixed into a stable coloidal suspension by machine. When allowed to stand for five minutes, no bleeding should be visible. The grout must not separate when placed or pumped. Since grout mixes are comparatively expensive, they should not be allowed to flow away wastefully. The area to be grouted should be surrounded with some sort of box securely held down onto the top of the concrete. The box needs to be



about 75 mm larger all round the base to be grouted and the top edge should not be lower than the top of the base plate. The fresh grout is poured into the grouting space from one side only and must flow through the gap until it is seen to appear at the other free edges. Too small a grouting gap makes work most difficult—50 mm is a convenient gap and 25 mm may be enough for a small base. Any water in bolt tubes or bolt pockets should be displaced upward by the denser grout trickling down the sides of the hole. This water must be removed from the grouting area. With large bases it may be helpful to encourage the grout to flow under the base with a loop of chain previously slid under and slowly pulled free. An alternative, used with larger bases, is to pump the grout through specially located holes in the base plate. If these have been numbered this will indicate the order in which the holes should be used. As soon as the grout has stiffened, the edge form work is removed, the edges neatly trimmed and curing commenced. Grout must be cured as any other cementitious product. The edges are often quite highly stressed and polythene sheet spread over the edges of the base will be sufficient for curing.



Grout-filled bags

This work is limited in application to riverworks and watery places. However, a small section of such work may creep in on motorway contracts, for instance, where a canal is taken over the carriageway in a posttensioned aquaduct and water is diverted with a couple of lines of steel sheet piling. The junction between the concrete and the sheet piling is difficult to make watertight and the lining of the channel with grout-filled mattresses can solve the problem. The bag or mattress is made of nylon fabric, the two surfaces held together with "buttons" or small ties. The edges can be joined together by sewing or with a special zip fastener. Bags are assembled on the bank alongside the section to be covered and are drawn into place by a gang of workmen. The bank-top edge of the bag is tied back at intervals with rope and stakes. The bag is quite light and can be blown by wind or be swept away by the water until it is filled with grout. Old tyres are often used to hold bags in place. A grout mill to mix cement, water and sand is set up nearby and connected to the grout bag with hoses. The end of the hose is fed down inside the bag. Where a considerable amount of protection is to be undertaken, the bag is prepared by threading stiff pipes inside the bag, at about 150 mm centres, and the grout hose is coupled to the tops of the pipes as required. The bag is filled from the toe upwards, the grout inflating the bag into a quilted mattress and displacing any water.

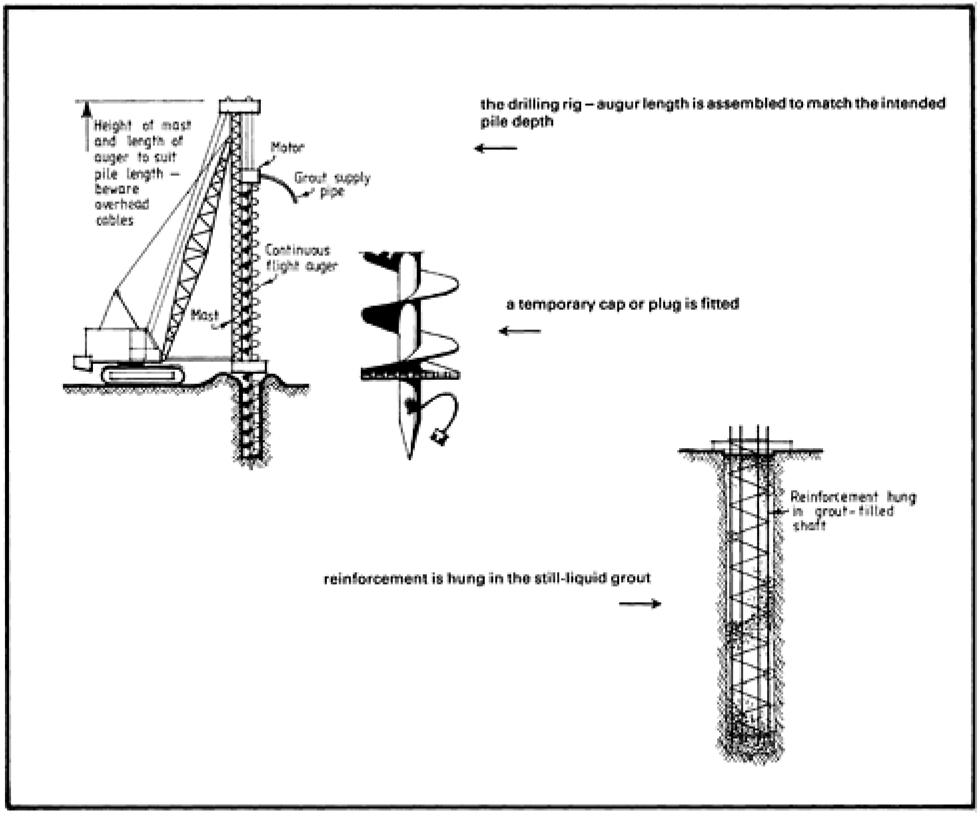
The fabric contains the grout but a slight cloudiness in the water can be seen where the grout is freshest. As the grout inflates the mattress, the fabric length reduces and the bank-top edge has to be released at intervals to allow for this shortening. The weight of the grout filled bag is considerable and would otherwise tear the top of the bag, snap the ropes or uproot the stakes. The top edge of the finished mattress is usually turned into a trench or buried under a bank-top slab.

Grouting leaking drains

Renovation of larger drains and sewers tends to be the province of specialist sub-contractors who employ an experienced workforce and have the necessary specialist equipment and, particularly because of the health hazard, the inexperienced person should not participate in this type of grouting operation without suitable training. Many smaller bore drains of the household variety, however, are often repaired, sealed or made re-usable by small local contractors. Grout is supplied to a piston which can be drawn slowly along the pipeline. The piston pressurises the grout and forces it into cracks and open joints. As the piston is drawn along the pipe, a rubber grout seal squeezes the bore smooth. The grout needs to be well mixed and a careful control maintained of the water/cement ratio. It will probably be necessary to use a special cement, either sulphate-resisting or a cement blended with pfa, because of the chemical conditions in the pipeline. The quantity of grout is probably quite small, which makes it uneconomic to use a grout mill. Satisfactory mixing can usually be achieved with an electric drill with mixing paddle attachment. Mixing should be reasonably long and thorough with a slow speed drill rather than a short frantic splash with a high speed drill, which will also mix in air—this is highly undesirable from both the point of view of strength and durability and also because bubbles will obstruct the injection into open joints.

The pipe to be grouted is well rodded and flushed with a hose to remove all debris. The grout supply pipe and the rope for pulling the piston through are threaded down the pipeline and connected at the downstream end of the pipe run to the piston. The piston is fitted into the pipe and drawn along to the first grouting position. If a television camera survey has been carried out, the position of cracks and so on will be known. It will otherwise be necessary to apply grout pressure all along the pipe run to be sure to find all the damaged and leaking points. The piston is opened to its fullest extent and grout pumped into this cavity with a hand pump, usually from the upstream end. With the body of the piston held firmly in position, the plunger is drawn up, pressurising the grout in the piston cavity and forcing it into any cracks in the pipe bore. If the plunger is easily pulled it probably implies that there is a large void to be filled and the plunger can be retracted, the piston cavity refilled with grout and further grout pumped into the void until movement of the plunger becomes difficult. Care must be exercised here, however, as if the plunger is retracted without pumping more grout into the piston cavity, grout can be sucked OUT OF THE VOIDS by the vacuum in the piston cavity. It is essential that the piston cavity be kept full with grout at all times.

When a section has been grouted, the piston is pulled along the pipe bore to a new position. Careful measurement along the ropes or with drain rods, will save too much overlap and prevent missing sections of the pipe. The pipeline should not be used for eight hours, or until the grout has hardened. It is preferable that a water (or air) test is carried out to confirm the efficiency of the grout repair.



Grouted piles

The technique of forming grout-injected piles has been around for many years, but recently there has been increased use. The drilling rig consists of a chassis with motors and tracks. A tall lattice mast supports a continuous flight auger (a flight is a spiral turn of the blade of an auger and a continuous flight means that the blade extends the whole length of the pile-forming auger, rather like a very long corkscrew). The head of the auger is turned by a motor which descends the mast as the auger is screwed into the ground. The head also incorporates the connections for the grout pipe.

Having fixed the pile position and set up the machine, the auger length is assembled to match the intended pile length. The whole auger is screwed into the ground very much like a corkscrew and this action is carried out clockwise. At this stage, very little displacement, if any, of the soil occurs. A central shaft of the auger around which the flights or blades are fixed is a hollow pipe (not solid). Through this pipe the grout is pumped and, to prevent the open end at the bottom of the auger becoming clogged with soil, a cap or plug is fitted which is blown off with the initial water pressure.

Grout is batched and mixed in conventional equipment, such as a reversing drum mixer. Cement and sand are mixed with water to a thick creamy mayonnaise consistency and admixtures are frequently added to plasticise the mix (reducing the total free water requirement), to control bleeding and setting time. The admixture is often pre-measured in small plastic bags and is a white powder. The batcher driver is instructed to empty one or more bagfuls into the mixer per batch. Each mixed batch is emptied into a wet-mix tank fitted with agitator paddles. The tank must be of sufficient capacity to supply one pile with its full grout content plus a reasonable margin over for filling pipes, overflow, waste and overdig.

The auger plugs are blown off with water pressure. Initially water squirts out of all the joints and showers bystanders indiscriminately, but as soon as the plug has been blown out, the water pressure stops and the shower ceases. The grout is now pumped down the auger shaft and into the base of the pile building up pressure. The auger, still rotating slowly clockwise, is winched up the lattice mast at a rate to match the injection of grout into the void formed. In principle there should be no void because the grout pressure should be pushing up the solid core of soil retained in the auger. As the auger is pulled out of the ground, the soil caught on the flights is cleaned away by hand, unlike conventional auger drilling where the soil is spun off the blades. The auger must turn slowly clockwise to extract the soil core. If the auger is reversed it unscrews itself from the soil core and a break in the pile shaft will result.

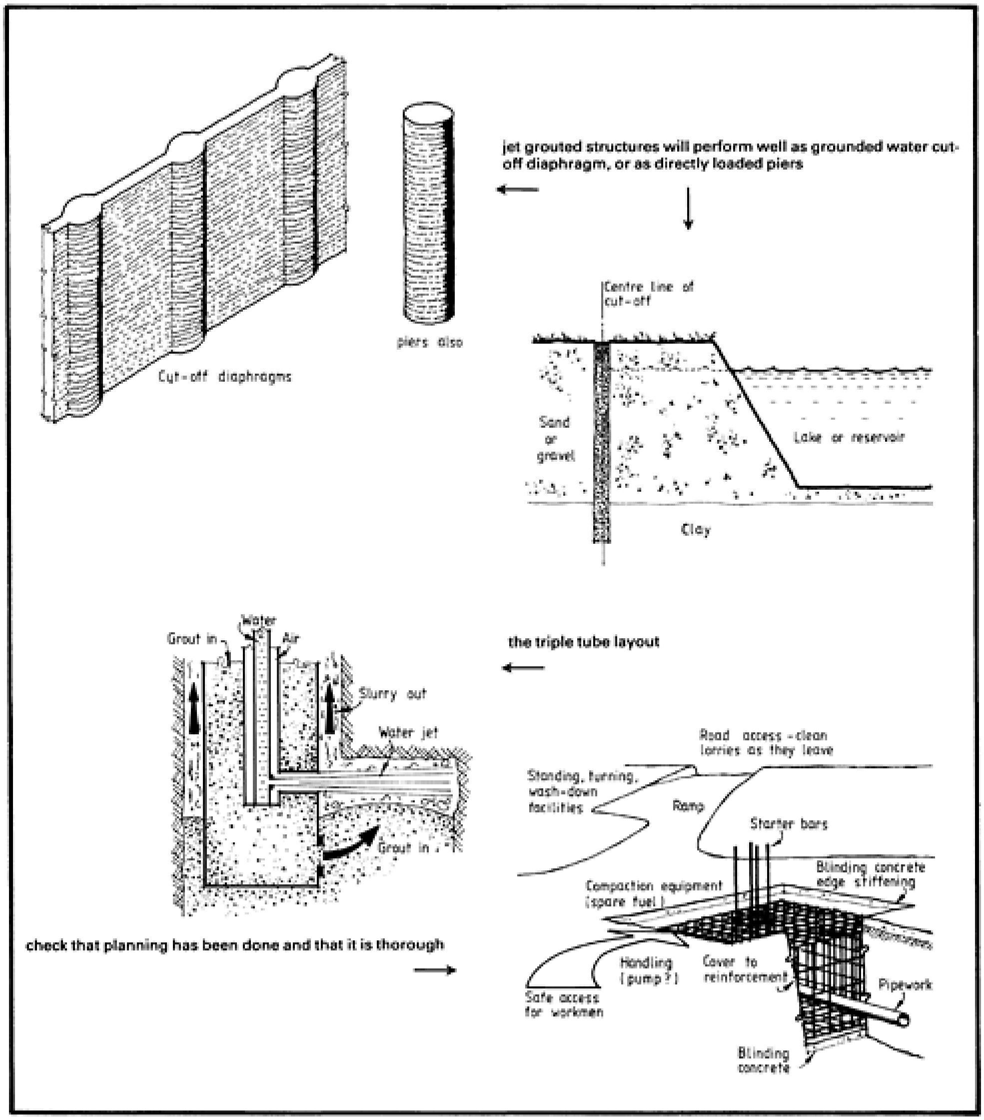
The whole length of the pile shaft is grouted in a continuous motion and any reinforcement is hung in the still-liquid grout as soon as the auger is clear of the hole. It is not practicable to have "blind bore" or to stop the pile shaft before it reaches the surface.

This process works well in most soils, even where the shaft penetrates the groundwater table. No casing is required and no water enters the shaft because there is never any void. Difficulties are met if there are buried boulders which are too large to fit between the flights of the auger, but a well conducted site investigation should discover the boulder clay before the piling system is selected.

Jet grouting

This process, developed in Japan from an originally British idea, involves excavation of a cavity with a water jet and introducing grout into this cavity to form grout cut-off curtains or grouted piers. It is available in this country from GKN Keller Foundations Limited only. The process depends on a special piece of equipment, the triple tube, which combines excavating jet, air lift to remove soil slurry, and grouting tremie. It also relies on the different densities of soil slurry and cement grout. Before describing the process in detail, it is necessary to understand the likely applications. In most piling/geotechnical processes, the excavation starts at the ground surface, whereas with jet grouting, except for the initial boreholes, the excavation proceeds from the bottom towards the surface. Panels or circular piers can be formed, but will be in unreinforced grout and both are unsuitable in situations where bending and therefore, tension stress develops. However, as groundwater cut off diaphragm or as directly-loaded piers, jet grouted structures will perform well.

Initially a series of normal boreholes are drilled. These will be at the centre of the piers or at the end of each panel and may be cased temporarily if the ground is liable to collapse. The triple-tube is lowered into an unlined borehole and air and water switched on. The water jets out of a nozzle and excavates the soil into a slurry; the compressed air and the borehole work like an air lift (see diagram on page 000) and the excavated slurry is sucked/blown out of the borehole for disposal. At this stage a small cavity has been formed, which will probably collapse if nothing more were done. While the excavation is proceeding, however, the lower portion of the chamber being formed is being filled with grout. Since this is denser than the soil slurry, the slurry floats on top of the grout and doesn't mix with it. Each pier or panel is formed from the bottom upwards by raising the triple-tube. The faster the tube is lifted, the smaller the reach of the water jet, since it must excavate from the borehole outwards. By rotating the triple-tube a cylindrical cavity is formed, and one of the features of the triple-tube is a special three-way rotating head. A diagrammatical representation of the triple-tube is shown on page 000. The compressed air is also used to concentrate the water jet as it



emerges through a ring of air. The grout would be similar to that used for grouted piles and similar batching facilities could be used. Alternatively, a coloidal mill could be used.

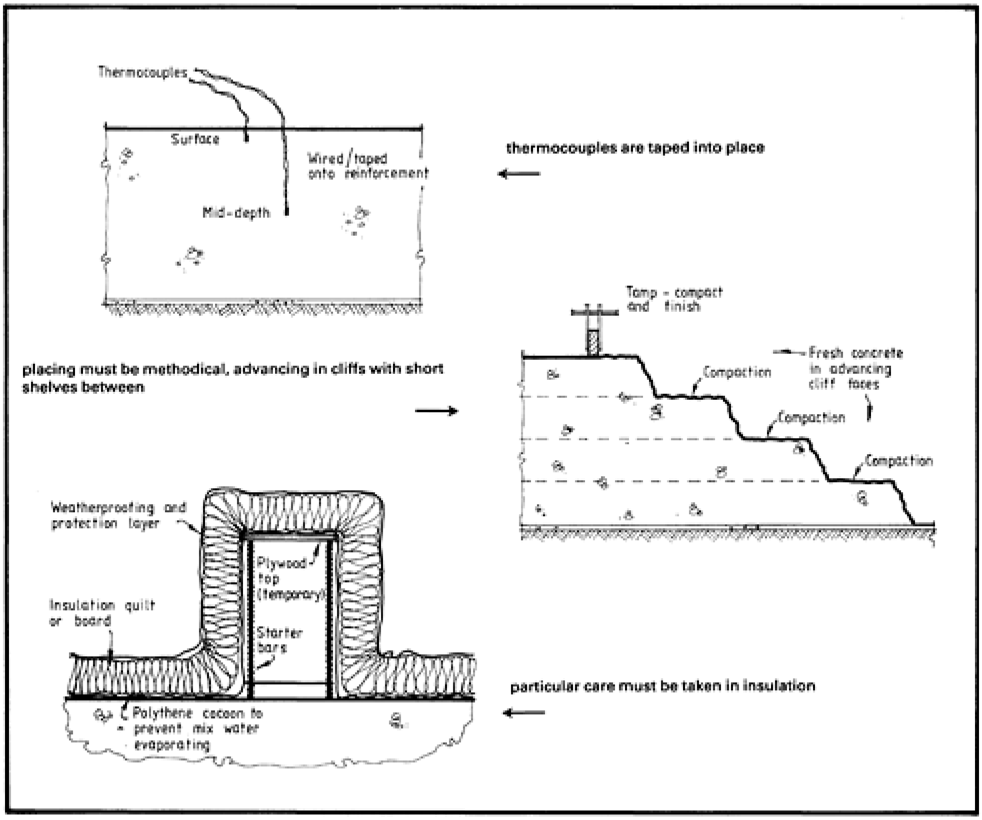
Large volume pours

To reduce construction time, eliminate construction joints and cope with difficult reinforcement arrangements, it has increasingly become the practice to construct basement slabs and similar large volumes of concrete in one continuous pour. The base under a building core area, for example, might require 800 m^3 of concrete, and this could be poured between 08.00 hours and 15.00 hours on the same day, leaving enough time to finish and clean up. Clearly there are logistical problems, such as supply of the required volume concrete (two batching/mixing plants may need to be employed and a small fleet of agitator trucks organised). Mealtimes, spare equipment, such as vibrators, sufficient cube moulds for the day's sampling and thermal quilting will all need to be pre-planned. However, these problems are probably no more complicated than the regular planning of any large scale engineering project. The supervisor needs to know that the planning has been thoroughly carried out. Large volume pours do involve extra supervisory tasks, one of which involves the heat generated by the chemical reaction of the setting cement and the expansion of the still plastic mass of concrete. As the reaction reduces, less heat is generated and the whole mass of hardening concrete begins to cool down. The temperature of the core, or centre, of the mass is highest and can be estimated as 12°C for every 100 kg of cement batched per m^3 (12°C/100 kg cement/m^3). If a mix were to have 360 kg of cement/m^3, the estimated core temperature would be $3.6 \times 12 = 43.2°C$ *plus* whatever temperature the concrete had when poured into place, which may be 5°C higher than the air temperature. So, on a summer day the core temperature might rise to:

$$\underset{\text{hydration heat}}{\underset{\uparrow}{43.2}} + \underset{\text{air temperature}}{\underset{\uparrow}{20}} + 5 = 68.2°C$$

However, the surface temperature will be close to the air temperature, say 25°C. The amount of expansion of the concrete for a temperature rise of 68°C is obviously much more than for only 25°C, so that when the hardened concrete starts to cool down, the core tries to move back a greater dimension than the concrete surface. This differential movement, caused by differential temperatures, generates differential tensile stresses. With the concrete being so young, it has not had time to mature and develop reasonable tensile strength and so the differential thermal tensile stresses tear the mass apart causing cracks. This, of course, is only where the concrete has not been properly cured. Thermal curing controls temperature differentials and prevents cracking. Using quilting the heat loss at the surface is controlled and the surface temperature kept closer to the core temperature. The differential thermal tensile stresses are limited and the maturing concrete is able to accept them. The general procedure is to estimate the core temperature. The concrete surface temperature may be allowed to be 20°C cooler. Sufficient quilting or other insulation must cover the concrete surface to keep the temperature at this level. Calculations are complex and rely on a number of assumptions. The quantity of quilting is usually arrived at empirically (by experience). Where the surface/air temperature differential lies between 0–19°C, either 12 mm of insulating board or 25 mm of compressible quilting should be sufficient. At 20°C differential or greater, double thickness will be required (i.e., 25 mm insulating board or 50 mm compressible quilting). These are minimum recommendations, if thicker material is available then control will be greater.

With the foundation reinforcement in place, thermocouples are taped into position. Several are necessary in case of accidental damage. Several thermocouples should be located at mid thickness and a similar number above the first layer just below the surface. Additional thermocouples may be inserted for research purposes or at places of special interest, such as lift-pit areas. The concrete is often pumped into place and should have a 50–75 mm slump. Placing must be methodical, usually in layers of about 1000 mm depth, advancing over the base area from the starting side as a series of "cliffs" with short shelves between them. Compaction is carried out on the "shelf" concrete. Finishing is traditional and usually tamped. The finished surface is directly covered with overlapping polythene sheet to form a water-retaining cocoon. The quilting or other insulation is laid on the polythene cocoon and this in turn is covered with weatherproofing. Particular care should be taken to insulate between starter bars, in lift-pits and similar places, where convection currents or heat loss could occur.



A regular programme of measuring temperatures should be established. The 20°C differential between the core and the concrete surface is controlled by adding or removing insulation. It may take several weeks before the allowable concrete surface temperature reaches the ambient air temperature. Do not be tempted to "hurry things along". If the quilting is protected there is no restriction on work being continued in the area, for example, fixing reinforcement to the starter bars. Eventually the quilting can be removed and temperature control discontinued. Temperature measurement is done with a pocket electronic digital thermometer. Each thermocouple has a small two-pin plug fitted to the free end which is plugged into the thermometer for each reading. A neat set of records will help to control the cooling procedure.

Points of supervision

Gunite

1. Reinforcement
2. Materials
3. Plant layout and working gang
4. Work in progress

a) correct distance from face
b) clearance of rebound material
c) gunite consistency—not too wet and not too dry
d) screed boards/tensioned wires to guide nozzleman
e) construction joints

5. Prevent rebound pockets, sand pockets and sand layering
6. Samples for testing

Concreting underwater or bentonite

1. Sludge-free base
2. Materials and distribution
3. Placing method
4. Deal with displaced water
5. Plan the cut-off level for minimum work later
6. Keep the end of the tremie in the concrete at all times

Grouting techniques

Underbase grouting

1. Support base level with shims, packs and wedges
2. Prepare a suitable grout
3. Enclose area to be grouted
4. Grout poured from one side—flows under base and fills holding-down bolt tubes
5. Trim and cure underbase grout

Grout-filled bags

1. Assembly of bags and installation
2. Check no tears or unnecessary wrinkles
3. Check zip fasteners
4. Check bank-top fastening
5. Check grout frequently to ensure consistent production
6. Check bag filling—the process should naturally fill the bag without voids, but wrinkles, etc., might cause problems
7. Check top edge of finished work against details on drawings

Grouting leaking drains

1. Rod and flush pipeline before commencing grouting
2. Check piston working efficiently and snug fit in pipeline
3. Check grout mixing

4. If television survey available, locate piston at damaged parts, if no survey, grout whole pipeline
5. Keep piston cavity filled with liquid grout at all times—especially when retracting the plunger
6. Careful measurement of each piston position ensures minimum overlap and prevents sections being missed
7. Do not use pipeline until grout has hardened
8. Confirm effectiveness of treatment with water (or air) test

Grouted piles

1. Access for drilling rig, area for grout batching plant and basic setting out
2. Reasonably level working area with working platform of hardcore
3. Know the pile lengths
4. Before drilling plug end of grout pipe
5. Batching and mixing—check consistency and right quantity of admixture if used
6. Wet-mix tank of sufficient capacity
7. Not too long a delay between mixing and using the grout
8. Blowing the plug
9. Grouting the pile—watch pressure—remove soil
10. Have reinforcing cage ready
11. Suspend (hang) reinforcing cage in place

Jet grouting

1. Relationship between soil and borehole spacing is important—be prepared to vary borehole spacing as ground conditions vary
2. Considerable quantities of water required and similar quantities of slurry produced, for which disposal must be pre-planned
3. If panels are required the water jet must be carefully lined up
4. The rate of lifting the triple-tube and rotating, if required, have an important effect on range/size of excavation and hence on finished panel or pier
5. Confirm process with test panels and records of “grout take”

Large volume pours

1. Detailed planning of operation from access, through concrete supply to finishing
2. Estimate core temperature, hence surface temperature. Guess air temperature for days after casting, therefore estimate quantity and thickness of quilting required—and order same
3. Insert thermocouples and test
4. Ensure methodical placing of concrete with full compaction—beware plastic cracking
5. Finish surface and lay polythene cocoon
6. Overlay with quilting and weatherproofing
7. Monitor temperatures and record—remove quilting as concrete cools—replace quilting if cooling too rapid.

26. Repairs to concrete

Repairs may be required at various stages in the life of a concrete element or structure. Rather than to simply repair a fault, however, it is advisable to make a serious study of the cause of the defect and take steps to avoid any recurrence. In certain cases, prevention is an integral part of the repair procedure, such as where steel is treated to avoid further corrosion. Where the defect arises from some other cause, such as bad detailing of the structure, necessary alterations must be carried out at the same time as the remedial work. Inprocess damage can be simply checked, instructions on a revised method of handling being issued to avoid further incidence of damage arising from form striking, unit handling and similar problems, or at least to reduce the likelihood of future damage. However, where, for example in a bridge deck, concrete elements are being damaged by aggressive salts percolating through the structure, the remedy will become more difficult to achieve. Early action on damage will reduce the cost of remedial work. Steps taken to revise methods can ensure that certain types of damage are limited to the earlier operations of a particular sequence, but it is important that the cause of the damage is clearly established and that information on avoidance of *further* damage is fed to the team producing the work. Equally important is the assurance that previous substandard work built to the same detail is corrected and repaired whilst suitable labour skills, access and equipment are still on site.

Repair and remedial work may be required for a variety of reasons, such as:

inherent problems with materials;
poor concrete placement techniques;
lack of compaction;
bad curing;
weathering and attack from aggressive agents;
movements between elements of the structure, caused by local high stresses within the element, due to temperature shrinkage, settlement and so on;
form displacement;
striking damage and damage resulting from poor handling techniques;
local damage due to overstressing during construction, either as a result of loading with materials or equipment;
fire damage;
impact damage.

The more invidious forms of damage are those caused by aggressive attack from the environment, surrounding land or from within due to the misuse of accelerators. The damage resulting from these causes often goes unnoticed until dangerous proportions are reached.

Repair and remedial work is expensive and generally the work is carried out after completion of the contract proper and during the maintenance period. Repair work frequently costs more than the original work, due to such factors as:

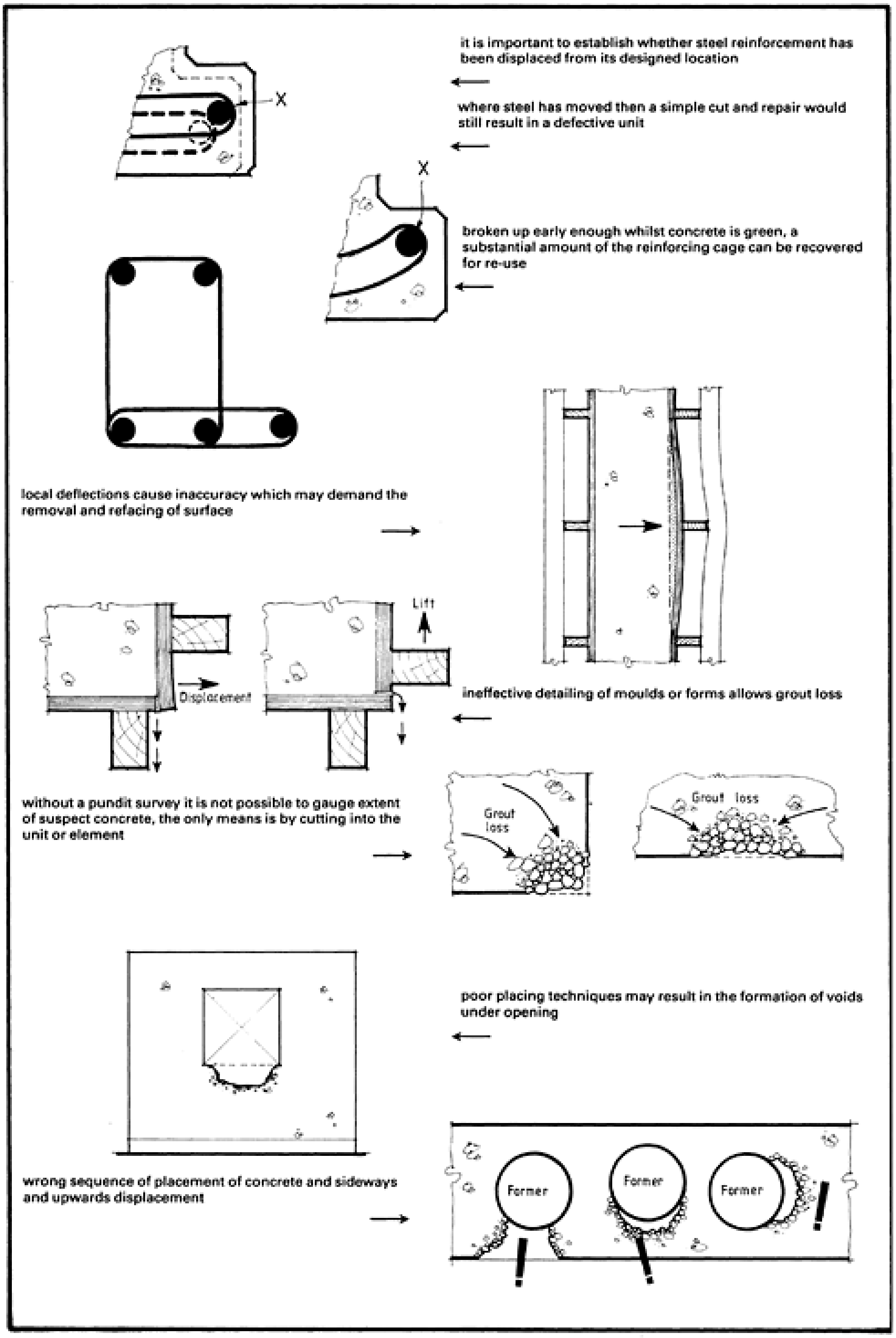
the cost of surveys to establish the extent of the problem;
the provision of access scaffold, cradles and so on;
special equipment costs and the provision of services such as air, electricity and so on;
high material costs where resins and special materials are used;
the necessary timing of remedial work to suit client or occupier (often demanding abnormal hours to be worked by the supervisor and site operatives);
the detached nature of much of the work together with the costs of transport to and from site;
the cost of inspection and supervision.

Common causes of damage on site

Damage due to formwork movement and deflection

Movement or deflection generally result from inadequate design, bad selection of materials or poor concreting techniques. Communication problems may result in too rapid placement of concrete and poor control may allow localised dumping of concrete within the formwork with resulting form deflection or displacement. A more recent problem has arisen with the use of admixtures which have caused retardation of the stiffening process, thus increasing the pressures with resultant excessive deflection. Movements can be identified and checked during the concreting operation provided that a continuous watch is kept for loosening of wedges, ties in distress and so on. Unfortunately, deflection and movement often go unnoticed until the time of striking when local form movement and leakage at joints with kickers and previous bays or lifts become apparent. The most obvious first step is to check the form design and establish whether the formwork and temporary works designer's recommendations were met and whether the methods of placement and rate of placement catered for the workability and stiffening rate of the particular concrete mix in use. Weather conditions often affect the speed of working, the rate of stiffening and thus the pressures developed at the form face. Moisture and humidity affect the perormance of timber forms-deflections tend to increase as form materials become saturated and subjected to pressures combined with heat from the exotherm of the cement. Adjustments made to forms or method should be monitored to ascertain whether the result of the revision is satisfactory. Where massive deflections occur or where, for example stopend members are considerably displaced, obvious steps must be taken to prevent further sub-standard work. It should, however, be borne in mind that movements generally result from more than one cause, so that a continuous check is essential.

Reverting to the actual concrete defect, it is important to establish when determining contract arrangements, whether remedial work is allowed. The economies of repair vs. the demolition of a bay of concrete or the breaking up of a precast element whilst in its *green* state must be examined, not only in terms of direct cost, but also in respect of the delay or upset to succeeding operations, whether they be further concrete work, re-use of forms, or the installation of services or ancilliary equipment. Major factors in reaching a decision will be the position of the steel relative to the surface of the concrete and, of course, the ability of the concrete to perform its designed function. The steel reinforcement can be surveyed as regards cover and location using a covermeter. Provided that the steel is still in its correct position, cutting or planing may be used to correct the inaccuracy. If the steel has been displaced in such a way that incorrect cover will result


it is important to establish whether steel reinforcement has been displaced from its designed location
where steel has moved then a simple cut and repair would still result in a defective unit
X
X
broken up early enough whilst concrete is green, a substantial amount of the reinforcing cage can be recovered for re-use
local deflections cause inaccuracy which may demand the removal and refacing of surface
Lift
Displacement
ineffective detailing of moulds or forms allows grout loss
without a pundit survey it is not possible to gauge extent of suspect concrete, the only means is by cutting into the unit or element
Grout loss
Grout loss
poor placing techniques may result in the formation of voids under opening
wrong sequence of placement of concrete and sideways and upwards displacement
Former
Former
Former

from repair, there is every likelihood that local demolition and recasting will prove to be the most economic solution. Provided that the Specification requirements will be achieved after a planing and remedial operation, it is likely, consistent with the achievement of an acceptable appearance, that remedial work will prove economic. Any minor exceptions to the required cover may be dealt with by coating the steel with a rust inhibitor or the use of a resin-based rather than cement-based repair. A suitably qualified person should advise on the remedial action to be taken and standards should be set for the appearance as described earlier. The remedial work can then be carried out as described, using cementbased or polymer modified mortar or a simple concrete repair if appropriate.

Damage in striking

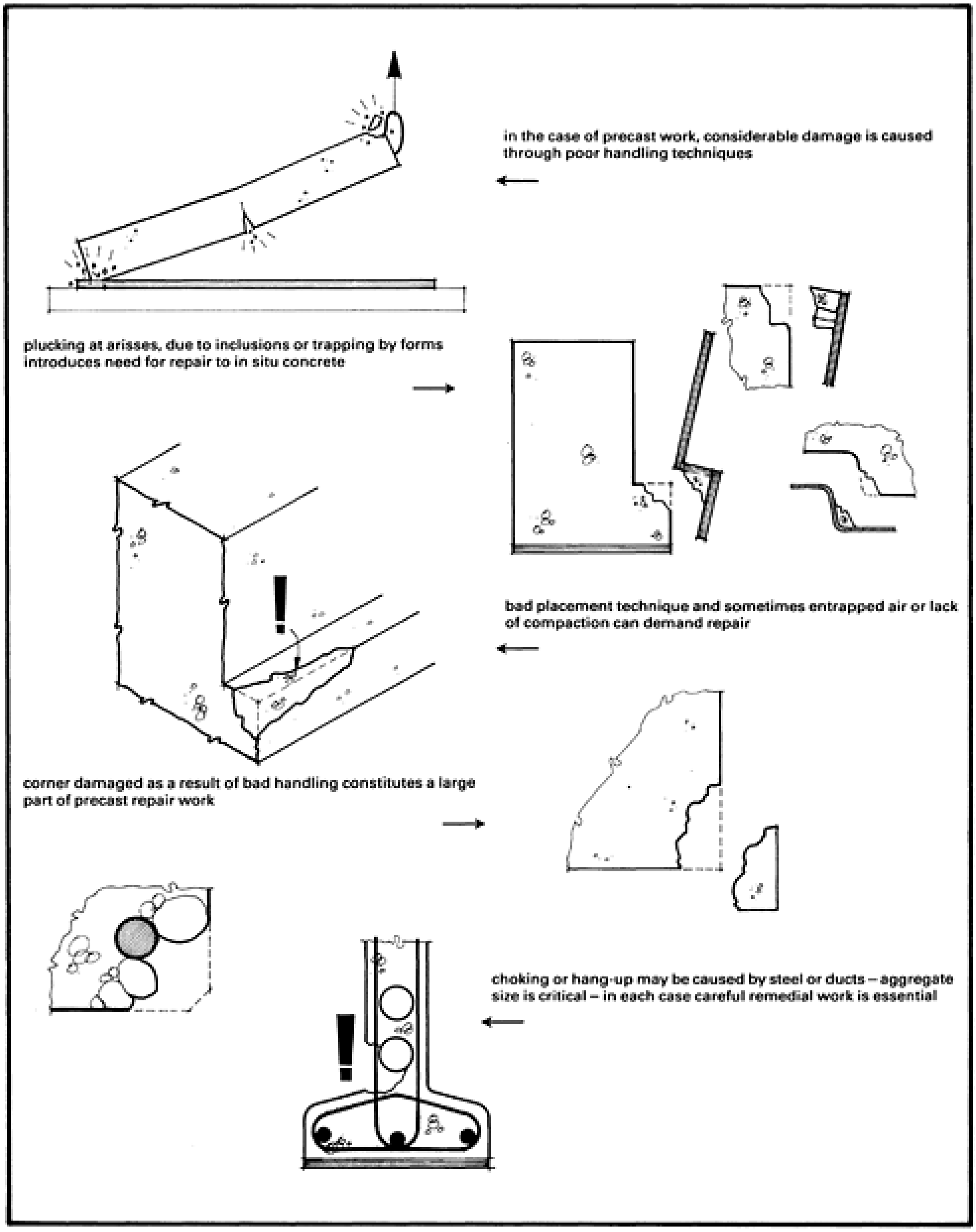
A considerable amount of damage occurs unnecessarily at the time of striking forms, although much of this type of damage originates from omissions in the earlier stages of architectural and structural design and form construction, where possibly insufficient attention has been paid to lead and draw. Details of the nibs and corbels are often such that they cause trapping of the formwork. Features are often of such slender section that without special care in provision of striking fillets and similar form arrangements, the feature is torn from the face of the concrete at striking. Poorly detailed and badly positioned drips and grooves also cause difficulties and attention is required to the size and location of such detail. Where particularly slender sections and fine detail are concerned it may be necessary to discuss changes in the mix proportions and aggregate size to ensure placement and adequate compaction of the concrete. Poor attention to selection of mould oil and parting agent, and the omission of a suitable barrier paint or treatment, all adversely affect the striking of a form and are all areas requiring investigation at the commencement of remedial operations.

Where damage is obviously the result of form detail, immediate action to revise the detail is essential. Fillets must be stripped out and replaced as damage and wear can cause formation of fins of grout which, in their turn, will cause further damage both to the form and the concrete at the time of striking. A watchful eye should be maintained on certain dubious practices in the construction process. For instance, crane striking of formwork and crash striking of soffit formwork in particular are both extremely dangerous practices as well as being responsible for a considerable amount of damage which may only become apparent when the structure is actually in service. The *green* concrete is subjected to forces far beyond those for which it is designed and critical points, such as the construction joint between kicker and wall, are subjected to strain. Crash striking of soffit formwork results in impact loading on the preceding floor, causing deflections and possibly cracking which will detract from the performance of the element in service.

Damage from vibrator

Poker vibrators are a constant source of damage to surfaces. Burns or dents in the form face allow the formation of nibs or excrescences which, at the time of striking, tear further portions off the form face. In this instance, an essential part of the remedial action is to take positive steps to educate the operatives working the pokers in the avoidance of burns and especially in the control of the poker to prevent it penetrating between steel and form face, the main cause of such burns. Rubber tips and rubber rings for attachment to pokers can assist in reducing the incidence of such damage. The supervisor must dispel the doubt which exists in most operatives minds about “over vibration” and the length of time during which concrete should be vibrated to achieve good compaction, and must ensure that the vibratory effort is applied for a sensible period of time relative to workability, concrete section and such like.

Damage or defects resulting from under vibration generally take the form of pockets of entrapped air or water or voids where concrete has been trapped and restrained by steel reinforcement or cast in components. Each of these defects may require treatment varying from simple "bagging in" through patching with mortar, to a full scale cutting and re-concreting operation. Care and attention to the concreting



method and instruction to operatives regarding the sequence of placement and compaction will do much to reduce problems.

Damage after casting

Concrete is often cast correct to profile and to the required standard of finish but then damaged or even destroyed by careless actions during successive operations. The attachment of battens to prevent damage to arrisses, the installation of ply or hardboard pads to prevent scour on stair treads and risers due to construction traffic and similar precautions can prevent the need for difficult repairs. It is equally important to cover face work to avoid splashes of muddy water con-taminating finished surfaces. Other materials which cause problems are oil from plant, for example, and acid from acid-etching being carried out on other surfaces. Concrete surfaces are often stained by mud or clay splashes caused by vehicles or workmen on site and covering down vulnerable surfaces with polythene film after stripping will save expensive remedial work as well as ensuring adequate curing for the concrete.

Small repairs using mortar

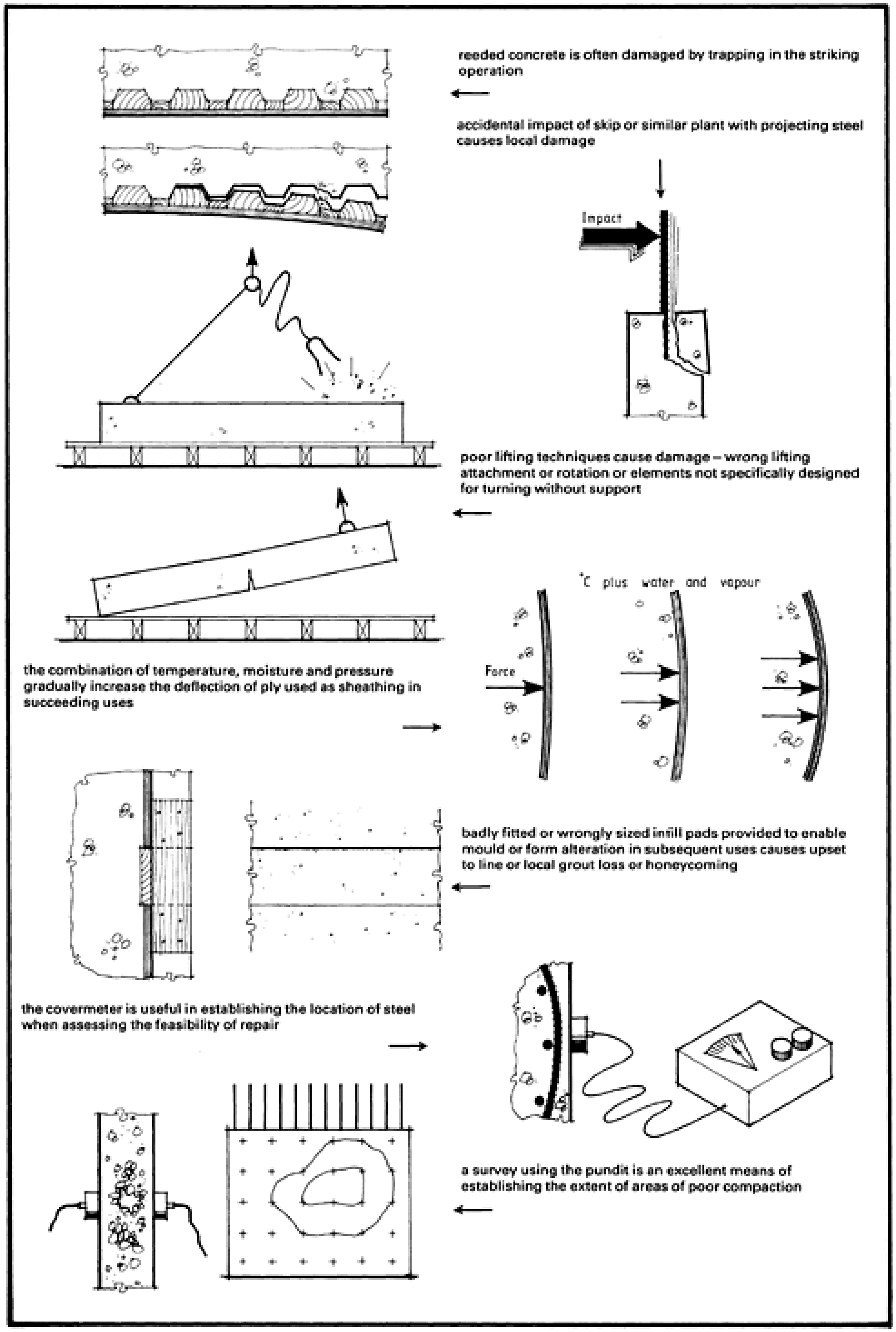
Small repairs of a visual nature are best carried out using concrete, mortar and cement-based mixes. These are generally the most economic and can be carried out on site using readily available materials, labour and skills. Much of the repair immediately required is concerned with improvement of the appearance of the concrete which has been marred by small defects, caused by air and water trapped during the casting operations, honeycombing caused by grout loss at joints and similar minor problems. Provided that it is established by ultrasonic survey, for example, that the problems are only of a visual nature, and that the structural integrity of the concrete is not in doubt, these are best filled with a mixture of fine sand and cement used in the concrete mix. The sand should be sieved to provide very fine particles which, when applied by brush, cloth or stone, will be worked into the minute cavities in the concrete face. The addition of a small amount of white cement to normal grey OPC used in the repair mix will assist in matching the colour of the base concrete, which gets lighter in appearance with age.

The texture of the finished repair will depend on the tools used to smooth the cement/sand paste into the face of the concrete. A skilled concrete finisher uses a variety of tools such as wooden, marble or cement floats, carborundum stone, hessian pads and steel floats. The wooden float and hessian pad give quite open textured surfaces. The use of steel, marble and cement floats give a tight, extremely smooth surface. Cement floats are made by casting pats of cement/fine sand mixture onto plate glass, curing them by soaking in water and then using them to rub in the finishing material. Both the marble float and the cement float are “sacrificial” in that the float wears away in use, the extremely fine particles serving to “tighten” the surface. The steel float polishes the surface and closes the capilliary system. Unfortunately, excessive use of the steel float can lead to the production of a surface prone to minute cracking and/or crazing.

The texture of the repair is important as an open texture tends to gather dirt as the concrete weathers. It does, however, match certain as-cast concrete finishes and is appropriate in these cases. The aim in colour and texture matching should be to achieve a surface which is acceptable when seen from the normal viewing distance.

The supervisor must take care that damage to arrisses and corners is properly repaired using concrete or modified mortars and that the use of sand/cement “finishing stuff” is avoided, the latter being prone to shrinkage if used in any great quantity.

When the repair material has stiffened, the final dressing operation is carried out, care being taken to smooth the surface. This process is not intended to be used to build up a surface but merely to fill visual defects, small blowholes and so on. The surface must be cured using a clean damp cloth for at least 24 hours, although in most cases protection from drying wind and sun should result in an acceptable finish free from crazing and shrinkage cracking.


reeded concrete is often damaged by trapping in the striking operation
accidental impact of skip or similar plant with projecting steel causes local damage
Impact
poor lifting techniques cause damage – wrong lifting attachment or rotation or elements not specifically designed for turning without support
°C plus water and vapour
the combination of temperature, moisture and pressure gradually increase the deflection of ply used as sheathing in succeeding uses
Force
badly fitted or wrongly sized infill pads provided to enable mould or form alteration in subsequent uses causes upset to line or local grout loss or honeycoming
the covermeter is useful in establishing the location of steel when assessing the feasibility of repair
a survey using the pundit is an excellent means of establishing the extent of areas of poor compaction

Major repairs using concrete

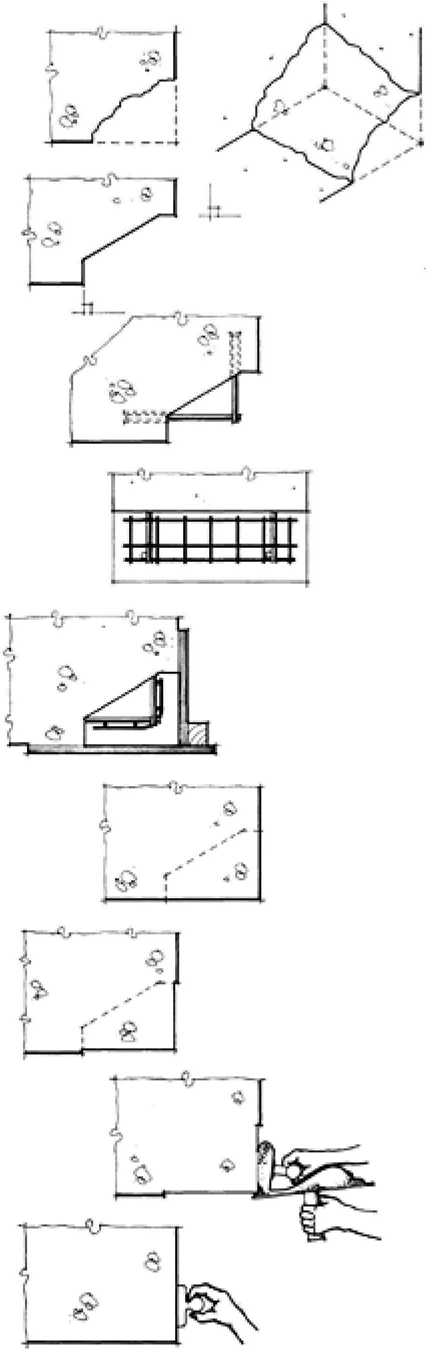
Where substantial amounts of damage are evident, such as corners or arrisses have broken away, steel is exposed and where there is evidence of cracking around the damaged area, careful exploratory work will be carried out in conjunction with an engineer. This exploratory work may become a major operation in the event of serious structural damage. Where there is any doubt as to the extent of the problem, for example, if there is extensive honeycombing or signs of cracking, it may be necessary to employ such means as ultrasonics or radiography to determine the extent of the damage properly. These tests are covered in the section of this publication dealing with problems arising when, for example, cube tests yield unsatisfactory results and some action must be taken to prove the integrity of the concrete in the structure *(Chapter 22: Quality control of site concrete).*

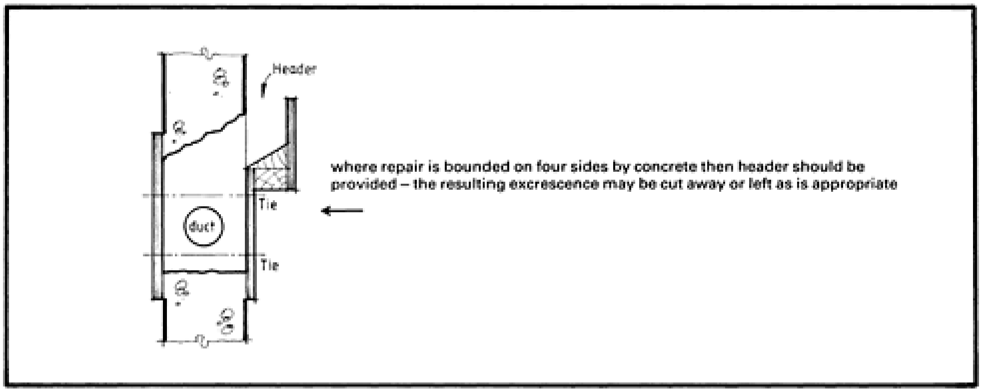
The spalled concrete can be carefully cut away and the area sounded out using blows from a hammer. Cleaning and clearance should be continued until all the loose particles are removed. It may be necessary to introduce local support under beams or slabs, which can be provided using telescopic props placed under timber bearers, thus avoiding damage to the surface where the prop bears against the concrete. It will be necessary to cut away sufficient concrete to allow the insertion of additional steel if required and so that any rust can be brushed away from the reinforcement (rust may have formed during the period between damage and repair), as loose rust particles would prevent the formation of a sound bond between the fresh concrete used in the repair and the steel. Corrosion inhibitors such as phosphoric acid or a coating of epoxy coal tar paint may be used if approved by the engineer. Formwork is positioned around the area, the surface of the concrete is wetted down and repair concrete is then placed and compacted in the normal way. Where the repair does not terminate in an open upper face onto which concrete can be placed or into which a tamping bar or poker vibrator can be placed, the form work must be so arranged as to provide a header or container for the fresh concrete. This ensures that under the influence of vibration or tamping the concrete mix will completely fill the void. It also ensures that the laitance or workability fines flow to the top of the header rather than remain to spoil the joint between old and fresh concrete. In the case of visual concrete, it may be necessary to cut away the header and then repair the surface as a subsequent operation. Whether or not a header is used, it will be advisable to cut the top of the opening to a splayed profile to allow air and water to escape as the repair material is compacted into the void. Where repairs are exposed to view it is advisable to cast the repair slightly undersized by inclusion of a filler of hardboard or ply within the form. This will allow dressing to be carried out as previously described.

Repairs using mortar

Where repairs require a layer of mortar to reinstate the surface, it may be advisable to use a bonding agent which may be some form of polymer. In this case, after cleaning the concrete and any exposed steel of small particles and rust, the bonding agent is applied overall. The repair mortar is then applied. The water/cement ratio of all patching mortars must be kept as low as possible consistent with achieving sufficient workability to allow the mortar to be trowelled into place. Battens can be fixed around the site of the repair to ensure maintenance of line and to give the operative a profile into which the mortar can be "punched" using a wooden float.

Regarding the insertion of additional steel reinforcement, after consultation with the designer, it may be advisable to insert "whiskers" of steel, using drill anchors or resin anchors, which can be bent as required after insertion to form loops capable of retaining or reinforcing the repair. Where there is any doubt regarding adequacy of cover, the additional reinforcement should be stainless steel or phosphor bronze to combat the likelihood of corrosion. To avoid excessive shrinkage and differential movement causing


to repair corner damage or areas of bad compaction
cut back to sound concrete leaving square edges and clean surfaces
introduce additional steel in the case of a substantial repair, chemically fixed dowels are useful also mesh – rules of cover must be observed
saturate the surfaces and allow surface to dry – fix formwork (oiled)
caulk in repair material and then cure repair
hardboard set inside the formwork can be used for form recess for subsequent visual repair
having stippled in a bonding agent, a mortar mix of material passing the 600 micrcon sieve in the proportion 1/2.5 cement sand is then applied
the surface is dressed to a tight finish using a marble or cement float



cracking between base concrete and repair concrete, careful curing is required, the curing carried out using wet hessian covered with polythene sheet. This will also reduce the permeability of the repair concrete.

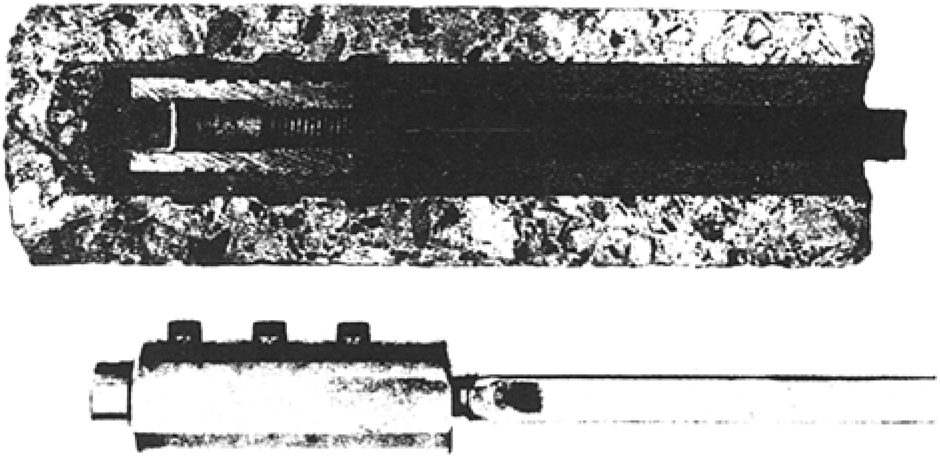
Repairs using specialised materials

In special circumstances, such as water-retaining locations, concrete structures in extreme conditions of exposure, where the concrete will be stressed in some manner when the structure is loaded and where structures or surfaces must be rapidly repaired for return to service, the repairs may be made using polymers. It should be stressed that the repair materials must be approved by the design engineer or some other responsible person.

Polymers are mainly used in concrete repairs either to modify cementitious systems or in the form of thermosetting resins, epoxy and unsaturated polyester resins, and unsaturated acrylic resin systems. Considering the first group of materials where polymers are used as admixtures to cementitious materials, these are generally supplied in the form of dispersions in water. The latex is mixed with repair materials as part of the water or as a water replacement. The presence of the latex in the repair material ensures improved bond with base material, reduces the permeability of the repair mortar and, because it acts to some degree as a water-reducing agent, reduces the shrinkage of the repair. The quality of the repair depends to a large extent on the quality of the sand used in the mix, the proportioning and the workmanship in mixing. Trends are towards the use of pre-packed polymers, factory mixed with sand and cement, which can be used simply with the application of measured amounts of water on site. Polymers used as admixtures include polyvinyl acetates (PVA) and styrene butadiene (SBR).

The second group of materials, thermosetting resins, include epoxy resins and polyester resins. These are classified as thermosetting because when set, unlike thermoplastic materials, they do not melt or flow when heated, although there may be some loss in strength. These materials are supplied in the form of two or three part packs and proportioning or mixing is extremely important to the success of the repair. Thermosetting resins do shrink at some stage during the curing process and the supplier carefully formulates materials to minimise effects in terms of loss of bond to the base material. It is this shrinkage movement which determines the manufacturer's recommendations on the thickness of the repair.

It must be borne in mind that any admixture used to modify the behaviour of a concrete mix may result in some competely different characteristics in the concrete, differences in the rate of thermal movement being extremely critical. The supervisor intending to use polymers in repair work should, therefore, carefully select a reputable supplier. There are several major suppliers of polymers providing massive technical support for their products, which are the result of years of careful development, testing and research.



The ankerbonder improves the surface of a cored hole to ensure bond between grout or resin and cast in fixing—air driven cutters produce profile/ key in cored hole (John Macdonald and Company Limited)

Approval having been given for the use of special products and having studied suppliers literature, provided the activities of preparation, mixing, application and curing are all carefully supervised, a successful result should be achieved.

The following points, relevant to all materials presently supplied for repair purposes, have at some stage resulted in substandard repairs:

badly measured quantities or wrong proportioning of materials;
the use of volume measurement instead of weighed quantities (and *vice versa*);
failure to observe recommendations regarding surface condition, the application or primer or tack coats;
use of materials on surfaces which are either too wet or too dry.

Curing conditions must be controlled and avoidance of contamination of the freshly cast repair and that of the raw materials is important in achieving success. The exotherm developing during the curing process may, in some extreme cases, rupture the repair material and the manufacturer's instructions regarding appropriate formulation for use in extremely low or high temperatures must be closely observed.

Repairing cracks in concrete

As in the case of more general damage, it is essential, before even attempting to repair a crack, to determine the cause and, as far as possible, eliminate further cracking. Apart from the visual aspect, it is generally desirable to repair cracks in concrete because they may allow ingress of moisture or vapour which attack reinforcement and cause further damage. Some cracks detract from the structural value of an element and others may allow the passage of sufficient water or fluid to render the structure unsatisfactory for its intended use. Cracks which harbour dust and dirt are obviously undesirable in most structures, whether the concrete is visual or purely structural. Where the strength of an element in a structure is impaired by a crack and the approval of a responsible engineer has been sought, thermosetting resin can be injected into the crack through injection nipples fixed at intervals along the crack which is otherwise surface sealed. The process as described is best carried out by specialists, and subcontractors are available who undertake such repairs. Emulsions and latex whilst sealing cracks make little or no contribution to the strength of the concrete element. The repair materials are generally poured into a dam of clay and penetrate the crack by gravity. The very simplicity of this technique often leads to its adoption where, perhaps, other more complex techniques should be used. Large cracks can be filled using cement-based materials. Here the preparation work is similar to that previously described in the case of general damage to concrete. In extreme cases this involves supporting the element as required, cutting out or enlarging the crack, preparing the surfaces and then punching in an earth dry mortar mix, where once again curing by maintaining a moist condition is essential to development of strength.

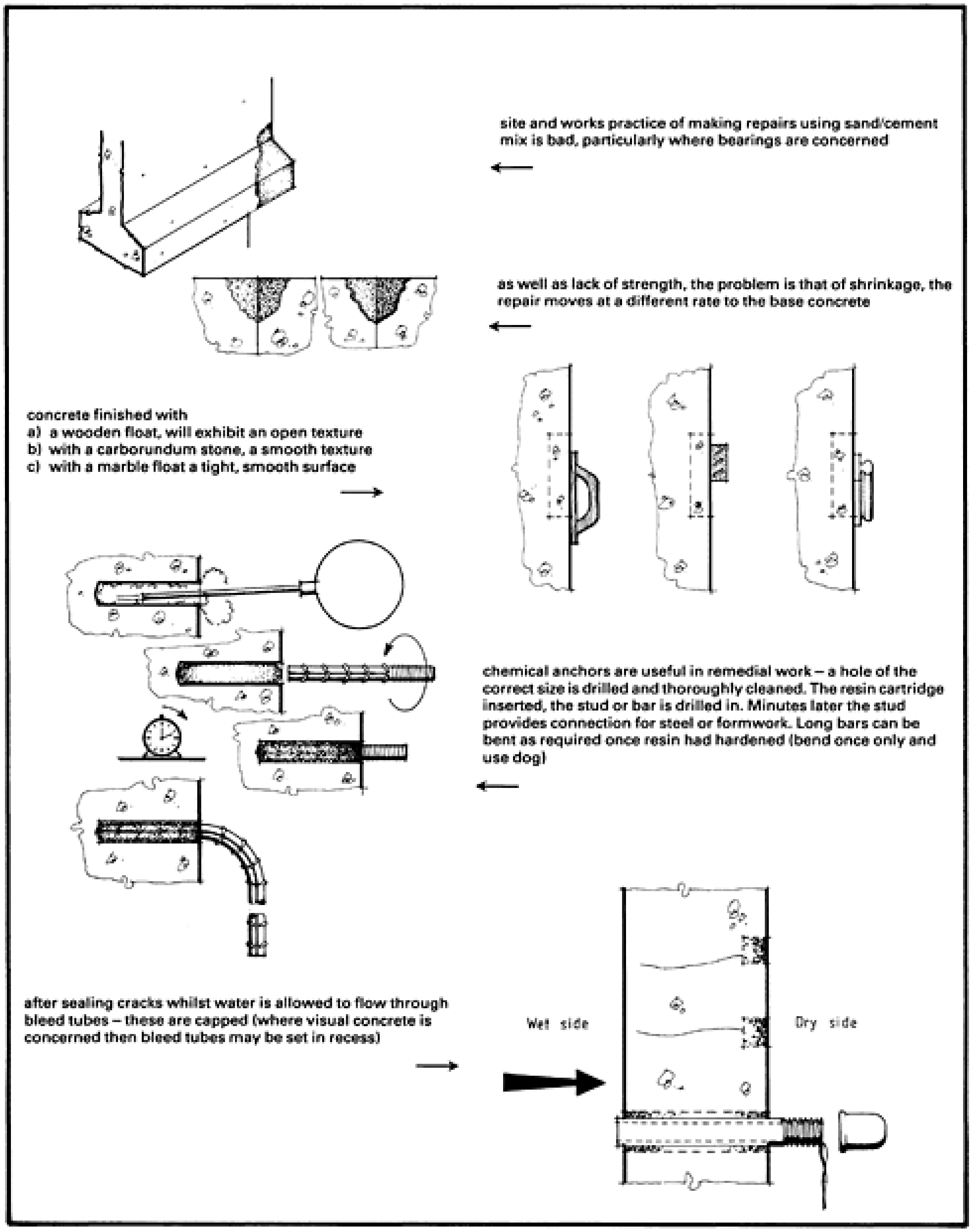
The use of vacuum in repair

Problems are always encountered when an attempt is made to introduce very low viscosity materials into cracks of any great depth. For years vacuum techniques have been used in industry in lifting and handling precast elements and also in dewatering processes, as in the case of road and floor slab construction. In the repair context, vacuum is used to promote the ingress of grout or resin. Cracks evident at the face are sealed, injection and excavation nipples are inserted at intervals and resin is then introduced, working from some low point in the crack system. An advantage claimed for this system is that dust and minute debris become incorporated as filler in the repair medium.

Where massive remedial work is required, the whole of a pier or a column or structural element can be shrouded with an impervious enclosure, a vacuum set up and the repair material introduced to penetrate through the crack system. A useful extension which uses the vacuum system combines slabjacking and the introduction of the repair medium. In this case a vacuum mat is used in conjunction with a lifting facility capable of raising a bay of a settled slab ready for grout. Alternatively the slab is raised by chemical anchors in conjunction with a lattice beam which bears on sound work, either at the side or end of the bay under repair. With the slab raised to its normal position, polymer modified grout can be drawn into the void below the slab to affect a permanent repair. This technique, using the fast curing time of the polymer, results in speedy repair often necessary in the case of motorways, airport runways and so on.

Sprayed concrete repair

Where there is any considerable amount of damage to be repaired, where concrete has spalled extensively due to corrosion of the steel or fire damage, for instance, it may prove economic to affect repairs by sprayed concrete techniques. It will be necessary to survey the damage by sounding, the use of ultrasonics and, where necessary, by exploratory cuts and cores into the concrete element. Steel which is damaged, distorted or excessively corroded, should be treated or replaced and the surface cut back to present a sound concrete base for repair. It is usual to fix a light gauge mesh to the steel reinforcement or by shot-fired fixing into sound concrete. The spray concrete coating is then applied, normally by specialist contractors working to an approved specification. The layers of sprayed concrete will normally be built up in 25 mm coats, the spray action ensuring proper compaction of the material. The resulting repair will be of slightly greater strength than normal concrete due to the low water/ cement ratio. This results in a low permeability which is advantageous where water resistance or water proofing are required.



Repair of leaking concrete

Where water is penetrating a wall, one of two things will generally occur:

damp areas will become evident;

local concentrations of leakage will be apparent.

In the case of damp areas, the cause must be established. This may happen where access to both faces of the wall is possible and may result from a build up of water in the ground or by driven rain. The penetration may be via permeable concrete or through a crack, and ideally the repair should be made on the wet face. Where driven rain is the cause, some suitable coating can be applied, silicone based materials generally providing adequate protection. In the case of substantial quantities of water being present at the wet face, then any one of a wide range of materials may be used. Cement render may offer a solution but it is essential that a good bond is achieved with the base material. Special renders containing chemicals which promote crystal growth (thus blocking the pores of the concrete) can be supplied and applied by specialists. One further approach is where a compound is applied which builds into a continuous elastic membrane and is capable of accommodating some movement and considerable pressure. These materials can be reinforced and where large local movements are anticipated, debonding may be desirable.

Where concentrated leaks are evident a quite different approach is called for. The water will usually be allowed to flow whilst the apparently leaking area is opened up. A tube or pipe with a valve is inserted, the size consistent with the flow and the whole made good with concrete, whilst the water is still allowed to flow. The pipes are then plugged and made good using quick setting materials. Where leaks occur in more than one location it may be necessary to seal them progressively. Unfortunately in this situation, where there is any real pressure, the water tends to seek another path through the concrete and repairs must be monitored to ensure that solving the initial problem does not present complications elsewhere in the structure.

Points of supervision

Before commencing repairs, ensure that the cause is known and further damage can be avoided

Damaged concrete is best repaired using concrete

Avoid the use of “finishing materials”—sand/cement repairs

Match base colour by the addition of white cement

Treat all steel to prevent corrosion

Insert additional steel to ensure monolithic repair

Consult a suitably qualified authority regarding details of repair

Ensure all materials are properly proportioned and *thoroughly* mixed

Cure the repair carefully using damp hessian or a curing membrane.

27.
Mathematics
By G.S.RICHARDSON

For many supervisors, school days are long gone. Concrete and concrete technology, however, do make some demands in terms of figures and calcualation and trends are such that mathematics and statistics become essential tools. The modern calculator (scientific) and microcomputer find their place on many supervisors desks, although it is occasionally necessary to resort to first principles. With this in mind, this chapter revises the mathematics essential to the constructor. Examples of addition, subtraction, multiplication and division of whole numbers have been omitted, but fractions and decimals, met in concrete mix design as well as in mix proportioning for concrete and repair materials, provide an introduction to the topic.

Fractions

Any quantity less than unity (one) is a fraction. A fraction can be expressed in (a) numerical or (b) decimal form:

(a) The numerical form of a fraction consists of a numerator divided by a denominator, arranged as:

$$\frac{\text{numerator}}{\text{denominator}}$$

The denominator indicates the number of parts into which the whole has been divided. The numerator indicates how many of these parts are contained in the fraction.

The fractional quantity ¾ means that the whole quantity has been divided into four parts, and three of these parts form the fraction.

(b) The decimal form of a fraction consists of a series of numbers indicating the size of the fraction in tenths, hundredths, etc.

0.5 means five tenths of the whole;
0.75 means seven tenths plus five hundredths of the whole;
0.375 means three tenths plus seven hundredths plus 5 thousandths of the whole.

Decimal fractions can be converted to numerical fractions by writing the decimal in the form of a fraction and by cancelling out similar numbers above, and below the line, arriving at the simplest fraction:

$$0.5 = \tfrac{5}{10} = \tfrac{1}{2}$$

$$0.75 = \frac{75}{100} = \frac{3 \times 25}{4 \times 25} = \tfrac{3}{4}$$

$$0.375 = \frac{375}{1000} = \frac{3 \times 125}{8 \times 125} = \tfrac{3}{8}$$

Numerical fractions can also be converted into decimal fractions by dividing the numerator by the denominator:

$$\tfrac{1}{2} = 1 \text{ divided by } 2 = 0.5$$

$$\tfrac{3}{4} = 3 \text{ divided by } 4 = 0.75$$

$$\tfrac{3}{8} = 3 \text{ divided by } 8 = 0.375$$

If a whole number preceeds the fraction, then convert it into a vulgar fraction and divided as before:

$$1\tfrac{1}{2} = 3 \text{ divided by } 2 = 1.5$$

$$2\tfrac{3}{4} = 11 \text{ divided by } 4 = 2.75$$

$$12\tfrac{3}{8} = \tfrac{99}{8} = 99 \text{ divided by } 8 = 12.375$$

Numerical fractions: Addition

$$\tfrac{3}{8} + \tfrac{5}{6} + \tfrac{2}{3}$$

To add these fractions the common denominator is found by factorising:

$$8 = 2 \times 2 \times 2$$
$$6 = 3 \times 2$$
$$3 = 3 \times 1$$

The common denominator is the lowest number containing all the above factors: $3 \times 2 \times 2 \times 2 \times 1 = 24$ so that:

$$\tfrac{3}{8} = \tfrac{9}{24} \qquad \tfrac{5}{6} = \tfrac{20}{24} \qquad \tfrac{2}{3} = \tfrac{16}{24}$$

The fractions can now be added by adding the numerators:

$$\tfrac{3}{8} + \tfrac{5}{6} + \tfrac{2}{3} = \frac{9+20+16}{24} = \tfrac{45}{24} = 1\tfrac{21}{24} = 1\tfrac{7}{8}$$

and similarly

$$\tfrac{1}{4} + \tfrac{5}{8} + \tfrac{3}{5} = \frac{10+25+24}{40} = \tfrac{59}{40} = 1\tfrac{19}{40}$$

and, where whole numbers precede the fraction:

$$1\tfrac{2}{3} + 2\tfrac{3}{4} + 3\tfrac{4}{9} = \tfrac{5}{3} + \tfrac{11}{4} + \tfrac{31}{9} = \frac{60+99+124}{36} = \frac{283}{36} = 7\tfrac{31}{36}$$

Numerical fractions: Subtraction

Fractions may be subtracted by converting them to common denominator then subtracting the numerators:

$$\frac{15}{16}-\frac{7}{8}=\frac{15-14}{16}=\frac{1}{16}$$

$$\frac{5}{9}-\frac{5}{12}=\frac{20-15}{36}=\frac{5}{36}$$

$$2\frac{5}{8}-1\frac{3}{4}=\frac{21}{8}-\frac{7}{4}=\frac{21-14}{8}=\frac{7}{8}$$

Numerical fractions: Multiplication

Fractions are multiplied by multiplying all the numerators, then multiplying all the denominators and reducing the resulting fraction to its lowest form:

$$\frac{5}{16}\times\frac{3}{4}=\frac{5\times 3}{16\times 4}=\frac{15}{64}$$

$$\frac{3}{4}\times\frac{7}{8}\times\frac{1}{3}=\frac{3\times 7\times 1}{4\times 8\times 3}=\frac{21}{96}=\frac{7}{32}$$

$$1\frac{1}{2}\times 2\frac{1}{4}\times 3\frac{1}{8}=\frac{3\times 9\times 25}{2\times 4\times 8}=\frac{675}{64}=10\frac{35}{64}$$

Numerical fractions: Division

Fractions are divided by inverting the divisor, multiplying the numerators, and then the denominators, and expressing the resulting fraction in its lowest form:

$$\frac{1}{6}\div\frac{1}{3}=\frac{1}{6}\times\frac{3}{1}=\frac{3}{6}=\frac{1}{2}$$

$$1\frac{1}{2}\div\frac{4}{7}=\frac{3}{2}\times\frac{7}{4}=\frac{21}{8}=2\frac{5}{8}$$

$$2\frac{1}{4}\div\frac{4}{7}\div\frac{2}{5} \qquad \frac{9}{4}\times\frac{7}{4}\times\frac{5}{2}=\frac{315}{32}=9\frac{27}{32}$$

Decimal fractions: Addition

Decimals should be arranged in order about the decimal point.

$$\begin{array}{r} 0.0061 \\ 0.1061 \; + \\ 0.0131 \\ \hline 0.1253 \\ \hline\hline \end{array} \qquad \begin{array}{r} 26.87 \\ 31.26 \; + \\ 118.04 \\ \hline 176.17 \\ \hline\hline \end{array} \qquad \begin{array}{r} 106.870 \\ 7.800 \; + \\ 0.946 \\ \hline 115.616 \\ \hline\hline \end{array}$$

Decimal fractions: Subtraction

$$\begin{array}{r} 16.09 \\ 7.91 \; - \\ \hline 8.18 \\ \hline\hline \end{array} \qquad \begin{array}{r} 0.3052 \\ 0.0667 \; - \\ \hline 0.2385 \\ \hline\hline \end{array} \qquad \begin{array}{r} 95.1070 \\ 0.9648 \; - \\ \hline 94.1422 \\ \hline\hline \end{array}$$

That gives: 3087 ÷ 1260   1260) 3087

1260 will divide into 3087 twice. Place digit 2 above 7 and multiply 1260 by 2 = 2520. Subtract 2520 from 3087, 567.

```
        2
1260) 3087
      2520
       567
```

Bring down a zero, when 1260 will divide into 5670 four times. Place digit 4

```
        2.4
1260) 3087
```

Multiply numerator and denominator by 100 by moving the decimal point two places right. That gives: 7000 ÷ 56

Divide out as previous example.

```
     125
56) 7000
    56
    140
    112
     280
     280
```

Therefore: 70 ÷ 0.56 = 125.

6.45 ÷ 0.015

Multiply both numbers by 1000 by moving the decimal point three places right. That gives: 6450 ÷ 15.

Divide out as previous example.

Therefore: 6.45 ÷ 0.015 = 430.

```
     430
15) 6450
    60
     45
     45
```

Ratios

The numerical relationship that exists between two or more quantities is known as a ratio. It is the numerical way of expressing their relative proportions in either weight, size, area, volume, density or cost. Mix proportions are a good example of ratios. In the past it was usual to specify concrete by the proportions, or ratios, of its constituent parts, either by weight or volume. With the adoption of the SI system, and in keeping with the practice of the Common Market countries, and also in America, mix design is now expressed in terms of the quantity of materials per unit volume required to produce one cubic metre of concrete.

Mix Number 1

Assuming the weight of the fresh concrete to be 2400 kg/m^3, and the following to be the mix quantities:

320 kg cement
640 kg sand
1280 kg coarse aggregate
160 kg water

Then the mix proportions expressed as a ratio will be 1:2:4 with a water content of 160 kg. (This is sometimes expressed as a water/cement ratio of 0.5).

Mix Number 2

Again assuming the weight of the concrete to be 2400 kg/m^3, and the following to be the mix quantities:

400 kg cement
600 kg sand
1200 kg coarse aggregate
200 kg water

The mix proportions expressed as a ratio will be: 1:1½:3, with a water/cement ratio of 0.5.

The aggregate/cement ratio is also of interest to the concrete technologist. In the case of *Mix Number 1* it is 6:1 and in *Mix Number 2* it is 4½:1.

Percentages (symbol %)

Per cent means per hundred. 5% of a quantity implies five hundredths (5/100) of that quantity, 95% means 95 hundredths (95/100) of that quantity and 105% means that quantity plus five hundredths (1 5/100) of that quantity.

Percentage gain

$$\text{Percentage gain} = \frac{\text{Increase in value}}{\text{Original value}} \times 100$$

If the 7-day strength of a sample of concrete was 30 N/mm^2, and its strength at 28-days rose to 40 N/ mm^2, calculate the percentage gain in strength during the last 21 days:

$$\text{Percentage gain} = \frac{\text{Increase in strength}}{\text{Original strength}} \times 100$$

$$= \frac{40-30}{30} \times 100 = 33.3\%$$

Percentage loss

$$\text{Percentage loss} = \frac{\text{Amount of loss}}{\text{Original amount}} \times 100$$

If a sample of 20 kg of coarse aggregate, after being oven dried and re-weighed, indicates a loss of 1 kg, calculate the percentage loss:

$$\text{Percentage loss} = \frac{\text{Loss of weight}}{\text{Original weight}} \times 100$$

$$= \frac{20-19}{20} \times 100 = 5\%$$

Percentage error

$$\text{Percentage error} = \frac{\text{Amount of error}}{\text{True value}} \times 100$$

The length of a steel test piece was 250 mm, but when measured by a student using a micrometer screw gauge, a reading of 250.35 mm was recorded. Calculate the percentage error:

$$\text{Percentage error} = \frac{\text{Amount of error}}{\text{True value}} \times 100$$
$$= \frac{250.35 - 250.00}{250.00} \times 100$$
$$= \frac{0.35}{250} = 0.14\%$$

Interpretation of simple mathematical expressions

The shorthand of mathematics consists of numbers, letters and symbols forming an expression that might represent a fact, a law, a relationship or a formula. Some of the more commonly used symbols are:

$=$	equal to
$\neq$	not equal to
$>$	greater than
$\ngtr$	not greater than
$<$	less than
$\nless$	not less than
Σ	the sum of
$\sqrt{\ }$	the square root of

Simple equations

A simple equation merely expresses the fact that two quantities are equal, for example: 6×4=24; 12=2 (3×2); 24=32–8.

An equation is a statement of fact which has been established by measurement or calculation. Equations may be manipulated without altering their meaning but allowing easier calculation. The following rules, however, must be followed:

1. Equal quantities may be added to both sides of the equation.
2. Equal quantities may be subtracted from both sides of the equation.
3. Each side may be multiplied by the same quantity.
4. Each side may be divided by the same quantity.

Then, considering transposition of formula using these rules, if it is required to find the value of b when the other factors are known, re-arrange the equation to make b the subject of the formula as follows:

(a) $y=mx+b$
(b) subtract mx from both sides of the equation: $y-mx=b$
(c) reverse the equation so that b is on the left: $b=y-mx$

Example: Calculate the value of b if $x=6$, $y=15$ and $m=1.5$.

$$b=y-mx$$
$$b=15-(1.5\times 6)=6.$$

The letter x is usually used to denote a quantity to be calculated and is placed on the left hand side of the equation. Known information then makes up the right hand side of the equation. Finding the value of x is termed "solving the equation".

Example: Given $h=35$ metres

then, if

$$x=0.7h$$
$$x=0.7\times 35=24.5 \text{ metres}$$

The formula $A_S=\rho.b.d$ is used when determining the area of steel required for a singly reinforced rectangular concrete beam, where:

A_s= area of steel reinforcement (mm^2),
ρ= ratio of the area of steel to the effective area of the concrete beam.
b= width of beam (mm).
d= effective depth of beam (mm).

Transpose the formula to make ρ the subject:

(a) $A_s=\rho.b.d$
(b) divide both sides of the equation by $b.d$

$$\frac{A_s}{b.d}=\rho$$

(c) reverse the equation so that ρ is on the left:

$$\rho=\frac{A_s}{b.d}$$

The formula $z=d-k_2x$ may be used to determine the length of the lever arm of a rectangular beam, where:

z= length of lever arm (mm)
d= effective depth of beam (mm)
k_2= a decimal factor related to the cube strength of concrete
x= depth of the neutral axis (mm).

Transpose the formula to make x the subject:

(a) $z = d - k_2 x$
(b) add k_2x to both sides of the equation:

$$z + k_2 x = d$$

(c) subtract z from both sides of the equation:

$$k_2 x = d - z$$

(d) divide both side of the eqation by k_2:

$$x = \frac{d - z}{k_2}$$

The tensile strength of concrete is given by the formula:

$$f_{ct} = 0.0431\ f_{cu} + 0.465$$

where:
f_{ct}=tensile strength of concrete (N/mm2)
f_{cu}=28-day strength of concrete (N/mm2).
Transpose the formula to make f_{cu} the subject:

(a) $f_{ct} = 0.0431\ f_{cu} + 0.465$.
(b) subtract 0.465 from both sides of the equation:

$$f_{ct} - 0.465 = 0.0431\ f_{cu}$$

(c) divide both sides of the equation by 0.0431:

$$\frac{f_{ct} - 0.465}{0.0431} = f_{cu}$$

(d) reverse the equation so that f_{cu} becomes the subject:

$$f_{cu} = \frac{f_{ct} - 0.465}{0.0431}$$

If high yield steel is used to singly reinforce a rectangular concrete beam, the area of steel should not be less than 0.15% of the effective area of the beam $(b \times d)$. This can be expressed as the formula:

$$A_s = 0.0015\ bd$$

where:

A_s=	area of steel (mm^2)
b=	breadth of beam (mm)
d=	effective depth of beam (mm)

If the area of steel is 400 mm^2, and d=720 mm, calculate the breadth of the beam:

(a) A_s=0.0015 bd
(b) divide both sides of the equation by 0.0015 d:

$$\frac{A_s}{0.0015\,d}=b$$

(c) reverse the equation so that b is the subject:

$$b=\frac{A_s}{0.0015\,d}$$

(d) substitute known values:

$$b=\frac{400}{0.0015\times 720}$$

$$b=370\text{ mm}$$

Reference to the bar chart will show that two 16 mm diameter bars would be required.

Algebraic expressions

In arithmetical statements quantities are represented by numbers, which may be subjected to addition, subtraction, multiplication or division. In algebraic statements, quantities are represented by letters and may also be added, subtracted, multiplied or divided.

Rules for addition, subtraction, multiplication and division

Addition

(a) Letters with like signs

Add similar letters with like signs and prefix them with that sign:

$$2a+3b+3a+4b=5a+7b$$

(Note: when the sign prefixing the first letter is plus, the sign is omitted).

Statements in algebra will not be true unless they are true when different numbers are substituted for different letters. To check the two following statements, let $a=1$, $b=2$, $c=3$:

$$a+b+a+c+a+b=3a+2b+c$$

Check: $1+2+1+3+1+2=10=3+4+3=10$

$$2a+3b+4a+c+a=7a+3b+c$$

Check: $2+6+4+3+1=16=7+6+3=16$

(b) Letters with unlike signs

Collect letters with the same signs, find their difference, and prefix the answer with the sign of the greater quantity:

$$6a-2a-3a+a=7a-5a=2a$$

$$-6a+2a+3a-a=-7a+5a=-2a$$

$$\text{Add } (3a+2b) \text{ and } (2a+b)=5a+3b$$

$$\text{Add } (5a+4b) \text{ and } (-2a-3b)=3a+b$$

Subtraction

Place the expressions in brackets with a minus sign in front of the bracketed terms to be subtracted. Change the signs inside the brackets following the minus sign. Remove the brackets and add all the terms:

From $8a+2b$ *subtract* $3a+b$

$$(8a+2b)-(3a+b)=8a+2b-3a-b=5a+b$$

From $-8a-2b$ subtract $-3a-b$

$$(-8a-2b)-(-3a-b)=-8a-2b+3a-b=-5a-b$$

From $12a-6b$ subtract $8a-3b$

$$(12a-6b)-(8a-3b)=12a-6b-8a+3b=4a-3b$$

Multiplication and division

If the two quantities have the same sign, the result is a positive quantity. If the two quantities have different signs, the result is a negative quantity.

Multiplication

$$a\times b=ab$$

$$a\times -b=-ab$$

$$-a\times -b=ab$$

$$a\times a=a^2$$

$$a\times -a=-a^2$$

$$-a\times -a=a^2$$

a+b multiplied by a+b can be wirtten: *(a+b)(a+b)* and can be multiplied out as follows:

$$\begin{array}{l} a+b \\ \underline{a+b} \\ a^2+ab \end{array}$$

Multiply the top line by the first term in the second line

$$\begin{array}{r} \underline{+ab+b^2} \\ \underline{a^2+2ab+b^2} \end{array}$$

Multiply the top line by the second term in the second line. Add the answers.

$a+b$ multiplied by $a-b$ can be written: $(a+b)(a-b)$ and can be multiplied out as follows:

$$\begin{array}{l} a+b \\ \underline{a-b} \\ a^2+ab \\ \quad \underline{-ab-b^2} \\ \underline{a^2 \quad - \quad b^2} \end{array}$$

$-a+b$ multiplied by $a+b$ can be written:

$$(-a+b)(a+b)$$

and can be multiplied out as follows:

$$\begin{array}{l} -a+b \\ \underline{\quad a+b} \\ -a^2+ab \\ \quad \underline{-ab+b^2} \\ \underline{-a^2 \quad +b^2} \end{array}$$

Division

$$\frac{a}{a}=1 \qquad \frac{a}{-a} = -1 \qquad \frac{-a}{-a}=1$$

$$\frac{25a}{-5a}=-5 \qquad \frac{-20a}{4a}=5 \qquad \frac{15a}{5a}=3$$

Algebraic fractions

Addition

$$\frac{a}{x}+\frac{b}{y}=\frac{ay+bx}{xy}$$

$$\frac{2a}{x}+\frac{3b}{y}=\frac{2ay+3bx}{xy}$$

Subtraction

$$\frac{a}{b}-\frac{c}{d}=\frac{ad-bc}{bd}$$

$$\frac{5x}{y}-\frac{3a}{b}=\frac{5bx-3ay}{by}$$

Multiplication

$$\frac{a}{x}\times\frac{b}{y}=\frac{ab}{xy}$$

$$\frac{3a}{x}\times\frac{2b}{3y}=\frac{6ab}{3xy}=\frac{2ab}{xy}$$

Division

$$\frac{x}{y}\div\frac{a}{b}=\frac{x}{y}\times\frac{b}{a}=\frac{bx}{ay}$$

$$\frac{x}{3a}\div\frac{3b}{5y}=\frac{x}{3a}\times\frac{5y}{3b}=\frac{5xy}{9ab}$$

Substitution of numerical values in algebraic expressions

In the following examples, let: $a=-2$, $b=4$, $x=3$, $y=-5$.

1. $a+b \quad =-2+4=2$
2. $2a+2b \quad =-4+8=4$
3. $-3a+6b \quad =6+24=30$
4. $x+y^2 \quad =3+25=28$
5. $x^2+y \quad =9-5=4$
6. $x+xy \quad =3-15=-12$
7. $x^2-xy \quad =9+15=24$
8. $x^2+xy+y=9+(-15)-5=9-20=-11$
9. $x^2+y^2 \quad =9+25=34$
10. $x^2-y^2 \quad =9-(+25)=9-25=-16$

TABLE 27.1
Perimeters and areas

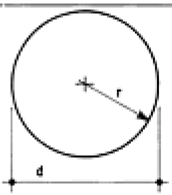
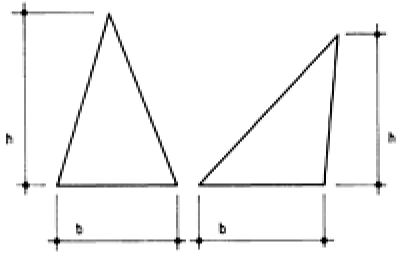
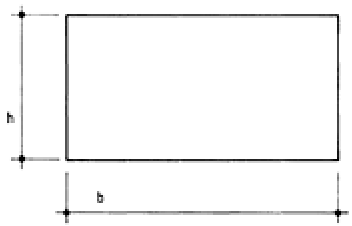
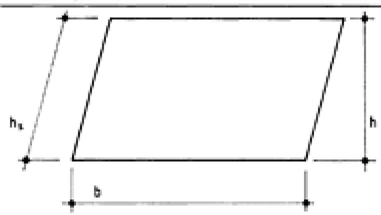
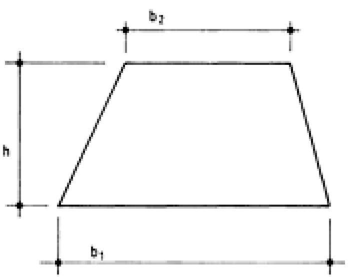
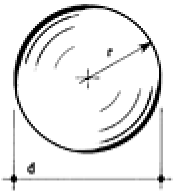
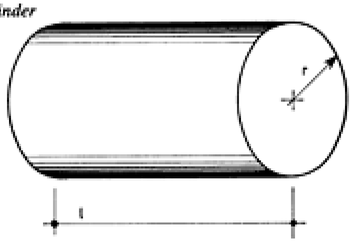
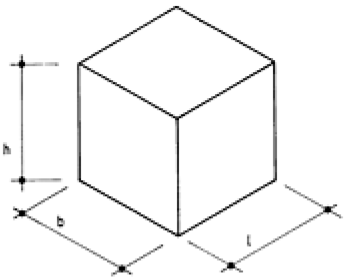
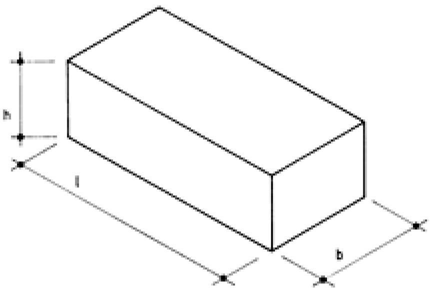
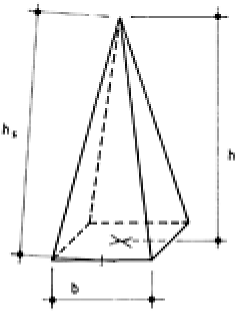
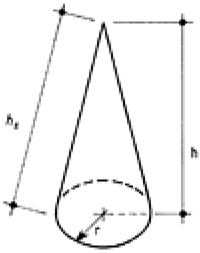
Shape	Perimeter	Area
Circle 	$2\pi r$ or πd	πr^2 or $0.7854\,d^2$
Triangle 	$\Sigma(s_1, s_2, s_3)$	$\frac{bh}{2}$
Rectangle 	$2(b+h)$	$b \times h$
Parallelogram 	$2(b+h_s)$	$b \times h$
Trapezium 	$\Sigma(s_1, s_2, s_3, s_4)$	$\frac{1}{2}$ sum of parallel sides × height $\frac{h(b_1+b_2)}{2}$

TABLE 27.2

Surface areas and volumes

Shape	Surface area	Volume
Sphere 	$4\pi r^2$ or πd^2	$\frac{4\pi r^3}{3}$ or $\frac{\pi d^3}{6}$
Solid cylinder 	$2\pi r(r+l)$	$\pi r^2 l$ or $0.7854\, d^2 l$
Cube 	$6b^2$	area of one face × length b^3

Shape	Surface area	Volume
Rectangular prism 	$2(lb+lh+bh)$	area of rectangular end × length bhl
Pyramid (square base) 	$2h_s b+b^2$	$\frac{1}{3}$ area of base × height $\frac{b^2h}{3}$
Cone (circular base) 	$\pi r(h_s+r)$	$\frac{1}{3}$ area of circular base × height $\frac{\pi r^2 h}{3}$ or $0.2618d^2h$

Perimeters, areas and volumes

The units employed in the measurement of geometrical shapes are derived from the measurement of length:

$$\text{Area} = \text{length} \times \text{width } (\text{m}^2 \text{ or mm}^2)$$
$$\text{Volume} = \text{length} \times \text{width} \times \text{height } (\text{m}^3 \text{ or mm}^3)$$

The *perimeter* of a plane surface is the length of the boundary line enclosing the space, expressed in linear units. The *area* of a plane surface is the extent of the surface contained within the boundary lines, expressed in square units. The *volume* of an object is the measure of the space occupied by that body, expressed in cubic units. The symbols used in calculating the above measurements are:

b= width
d= diameter

h= height
h_s= slant height
l= length
r= radius
s= length of one side
Σ= the sum of
π= the circumference of a circle divided by the length of its radius=3.142.

The expressions used to calculate the perimeter, area and volume of some common geometrical shapes are given in Tables 27.1 and 27.2.

Examples based on common shapes

What is the volume of concrete required to make each of the following sets of items?

(a) 46 cylindrical posts with a diameter 300 mm, length 2m.
(b) 93 rectangular beams, width 250 mm, depth 450 mm, length 2 m.

$$\text{(a) Volume} = 46\ (0.7854\ d^2\ \text{l}) = 46 \times 0.7854 \times 0.3^2 \times 2 = 6.5\ \text{m}^3\text{, say } 7\ \text{m}^3$$

$$\text{(b) Volume} = 93\ (b.d.\text{l}) = 93 \times 0.25 \times 0.45 \times 2 \times 20.9\ \text{m}^3\text{, say } 21\ \text{m}^3$$

What are the volumes of the following measured in cubic millimetres and cubic metres?

(a) a 100 mm test cube
(b) a 150 mm test cube
(c) a test cylinder, diameter 150 mm, length 300 mm.

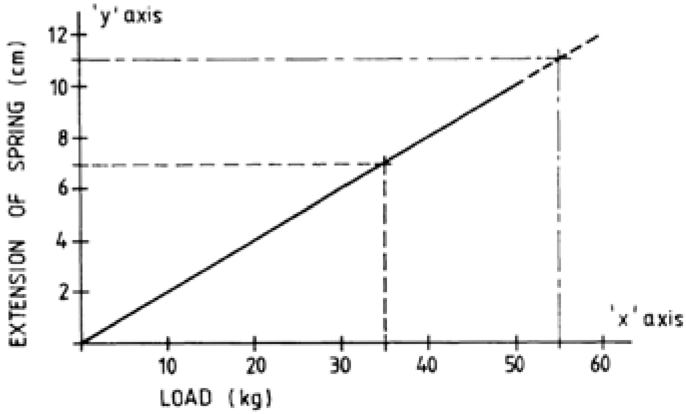
$$\text{(a) Volume} = 100^3 = 1000000\ \text{mm}^3 = 0.001\ \text{m}^3$$

$$\text{(b) Volume} = 150^3 = 3375000\ \text{mm}^3 = 0.003375\ \text{m}^3$$

$$\text{(c) Volume} = \text{area} \times \text{length} = 0.7854\ d^2 \times \text{length} = 0.7854 \times 150^2 \times 300 = 5301450\ \text{mm}^3 = 0.0053\ \text{m}^3$$

Areas and volumes determined by graphical means

The graph is the pictorial representation of the relationship between two quantities, drawn to a suitable scale. A simple graph consists of two lines drawn at right angles to one another and meeting at the point of origin (0). The horizontal line is known as the "x" axis and the vertical line as the "y" axis. Each line is divided



into a number of equal parts. A simple graph can be drawn by taking the results of a test of the extension of the spring of a weighing machine, as shown in the following table:

Load (kg)	10	20	30	40	50
Extension of spring (cm)	2	4	6	8	10

The graph showing this relationship is indicated below:
This graph is known as a linear, or straight line, graph. Further information, not given in the data, can be obtained from the graph. For example, the extension of the spring due to an intermediate value of the load, say 35 kg, can be found by drawing a vertical line up from the 35 kg point on the "x" axis to the graph line, then projecting a horizontal line from that point to the "y" axis, where the value of 7 cm will be read. This is known as *interpolation*. If the extension of the spring due to a load above the values given in the data is required, the graph line may be extended to include, say 55 kg. By the same process as previously described, an extension value of 11 cm will be read. This is known as *extrapolation*.

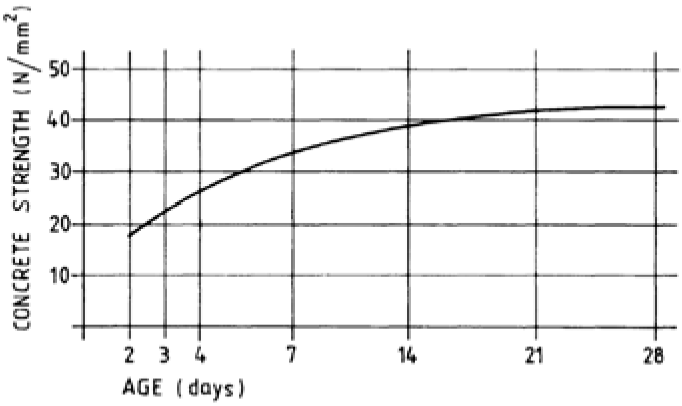
Some graphs are non-linear, or curved, an example being the graph of the increase in the strength of concrete with age. Typical values are as follows:

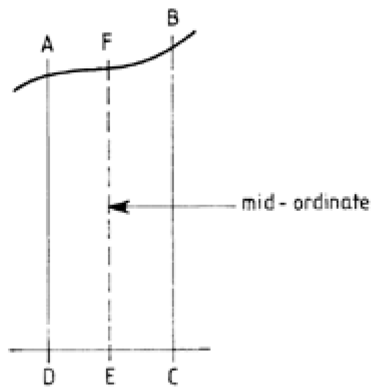
Age (days)	2	3	4	7	14	21	28
Strength (N/mm^2)	17	22	25	32	38	41	43

The graph of these values is as follows:
Again, intermediate and out of range values of concrete strength may be obtained by interpolation and extrapolation respectively.

Graphical methods may be employed to estimate the areas and volumes of irregular shapes. To determine the area between a curve and a straight line, the midordinate method is used. If it is required to find the area between part of the curve *AB* as shown and the straight line *DC,* draw two parallel straight lines *AD* and *BC* perpendicular to the line *CD*. Take the mid-point *(E)* of the line *CD* and draw a perpendicular line to reach the curve at *F*. The height *EF* can be taken as the average height of the curved lined *AB*. Therefore, the approximate area of the irregular shape *ABCD*= length of the base *DC*×average height *EF* (in units^2).

To estimate the area of the irregular shape now shown, mark off the "x" and "y" axes in equal intervals of length. Project the "x" axis divisions up to the top surface of the figure, thus dividing it into 5 sections.
Draw in the mid-ordinates, find their average length:



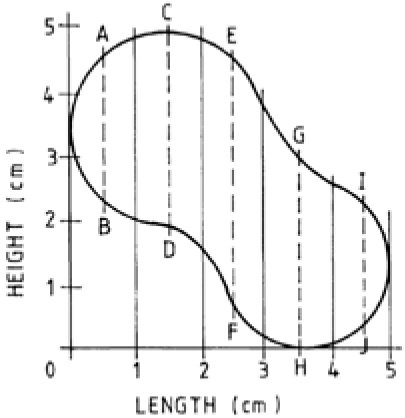


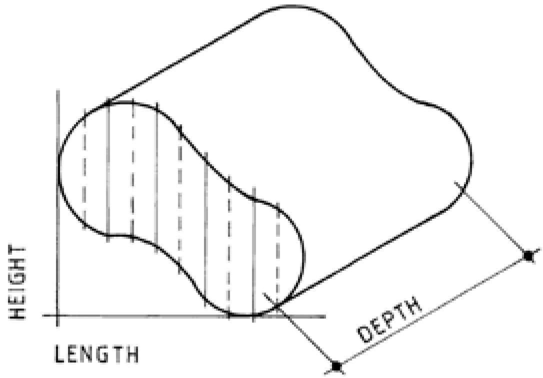
$$\frac{AB+CD+EF+GH+IJ}{5}$$

which will give the approximate height of the figure. Multiply the height by the length to give the approximate area of the irregular shape. If the shape is three dimensional, as shown here, its volume can be estimated by calculating the area of the side by using the mid-ordinate rule, then multiplying the area by its depth to give the approximate value in cubic units.

Simpson's rule

Simpson's Rule is an extension of the mid-ordinate method previously described and can be used to calculate the approximate volume of an irregular shape. For example, if it is required to determine the volume of earth to be removed from an excavation 12 m wide at the top, 10 m long, and having a cross section as shown in the figure, the volume of the excavation can be calculated from:





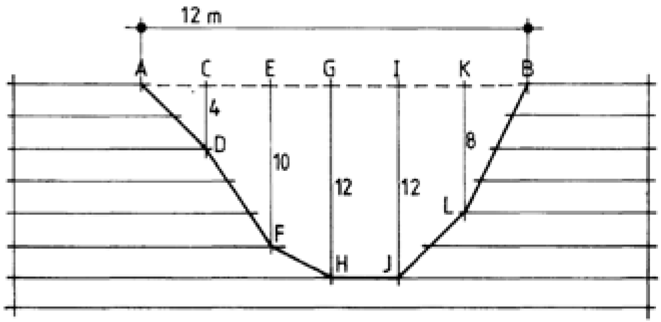
Volume (V) = the sum of the first and last ordinates plus four times the sum of the even ordinates, plus twice the sum of the odd ordinates, multiplied by the length of each division, multiplied by the length of the excavation, all divided by three.

using the figures given in the illustration, therefore:

$$V=\frac{(0+0)+4(4+12+8)+2(10+12)\times 2\times 10}{3}$$

$$=\frac{(0+96+44)\times 20}{3}$$

$$=933.3\ \text{m}^3$$



We know that $3 \times 3 = 9$, can be written $3^2 = 9$. The digit 3 is the square root of 9, written $\sqrt{9} = 3$. Also: $\sqrt{36} = 6$, $\sqrt{144} = 12$, $\sqrt{10000} = 100$ and $\sqrt{1000000} = 1000$.

In some construction calculations it is necessary to find the square root of an expression. For example, a concrete column has to have an area of 30625 mm^2. Calculate the width using the following formula: where:

$$b = \sqrt{A}$$

where:

b = width of column (mm)
A = area of column (mm^2)

substituting known values:

$$b = \sqrt{A} = \sqrt{30625} = 175 \text{ mm}$$

A square shaped building site has an area of half a hectare (5000 m^2). Calculate the length of one side of the site from the following formula:

$$L = \sqrt{A} = \sqrt{5000} = 70.71 \text{ m}$$

For those familiar with the use of logarithms, the square root of a number is equal to the antilogarithm of half the logarithm, as the following examples demonstrate:

Books of logarithmic tables often contain tables of the square roots of numbers from 1–100, to an accuracy of three decimal places. The 64th line in a square root table reads as follows:

	.0	.1	.2	.3	.4	.6	.6	.7	.8	.9
64	8.000	8.006	8.012	8.019	8.025	8.031	8.037	8.044	8.050	8.056

Therefore: $\sqrt{64} = 8.0$; $\sqrt{64.3} = 8.019$; $\sqrt{64.9} = 8.056$.

A much slower but basic method of finding the square root of a number is as follows:

To find the square root of 5.29

(a) the number is written with a line above it and half a bracket in front $\quad) \overline{5.29}$

(b) the first divisor is the highest whole number whose square is less than 5 (viz 2)

```
   2
2) 5.29
```

(c) this is divided into 5 to give a quotient of 2, placed in front of the bracket and above the line over the figure 5

```
   2
2) 5.29
```

(d) 29 is now brought down, converting the 1 into 129

```
   2
2) 5.29
   4
   129
```

(e) the quotient 2 above the line is now doubled and made the first figure of the new divisor

```
   2.
2) 5.29
   4
4) 129
```

(f) the divisor is now completed by adding a digit that is the highest whole number which when added to 40 and multiplied by it will give 129 (43×3 =129). The digit 3 is placed over the line above the digits 29.

```
     2.3
 2)  5.29
     4
43)  129
     129
```

This gives: $\sqrt{5.29} = 2.3$.

When finding the square root of numbers with a greater number of digits than shown above, it is usual to set out that number in pairs of digits to the left and the right of the decimal point. For example:

12.6 is written as 12.60
24.961 is written as 24.96 10
1638.386 is written as 16 38.38 60

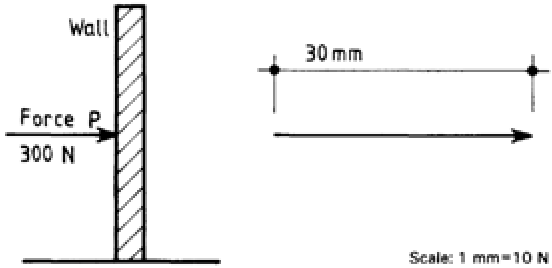
The following examples illustrate this method of square rooting:

Find the square root of 0.1296

```
     0.  3  6
 3)  0. 12 96
        9
66)     396
        396
        ...
```

$\sqrt{0.1296} = 0.36$

Find the square root of 1936




```
      4  4
  4) 19 36
     16
 84)  336
      336
      ...
```

$\sqrt{1936} = 44$

Find the square root of 6740.41

```
        8   2.  1
   8)  67  40. 41
       64
 162)   340
        324
1641)    1641
         1641
          ...
```

$\sqrt{6740.41} = 82.1$

Resolution of forces graphically and by resolution

All designers are faced with the problem of force, whether they are designing a mortice lock or a multistorey office block. The unit of force is the Newton (N), not to be confused with the unit of mass, the kilogramme (kg). Forces can be added or combined by the use of vectors. A vector is a straight line which represents the magnitude and direction of a force drawn to some suitable scale.

(a) *A single force acting at a point.*

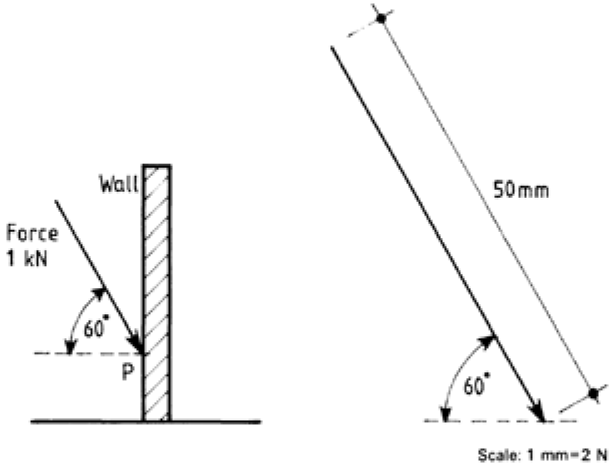
If a force of 300 N acts at right angles to a wall at point *P,* it can be represented thus:

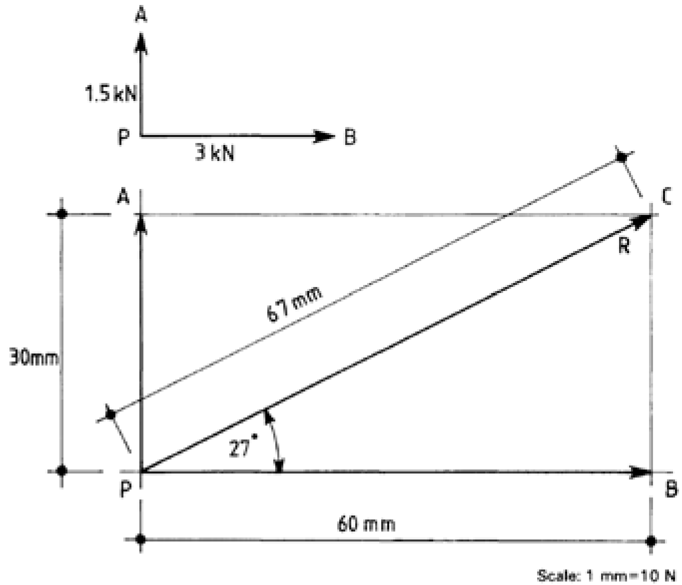
If a force of 1 kN acts at 60° to the horizontal at point *P* on a wall, it can be represented thus:

(b) *Two forces acting at a point.*

If two forces acting at right angles to one another at a point *P* are represented by vectors, the resultant force *(R)* can be found by drawing the vectors as adjacent sides of a parallelogram of forces, to some suitable scale, and measuring the magnitude and direction of the diagonal to give the value of the resultant force.

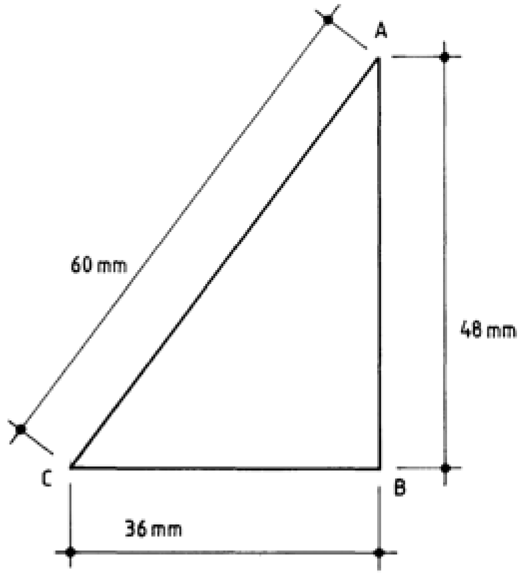
The resultant *(PC)* measure 67 mm which represents:

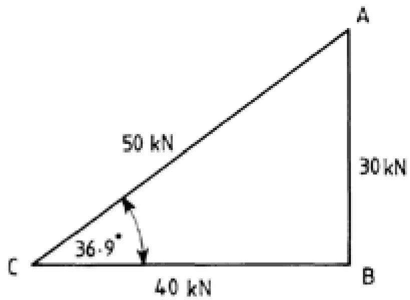




$$\frac{67\times 50}{1000}=3.35\text{ kN force at an angle of }27°\text{ to the 3 kN force }(PB)$$

This demonstrates that the forces *PA* and *PB* can be replaced by a single force *PC,* or vector *PA* plus vector *PB*=vector *PC*. It should be noted that the triangle *PCB* formed by the diagonal is a right angled triangle, and that the resultant *(R)* is the hypotenuse. A quicker method of solving this example is to apply the Theorem of Pythagoras relating to right angled triangles.





Theorem

In a right angled triangle the square on the hypotenuse is equal to the sum of the squares on the other two sides. This applies either to the length of the sides or to the forces they represent. For example, considering length, in the right angle triangle *ABC, AB*=48 mm and *BC*=36 mm. Find the length of the hypotenuse *(AC):*

$$AC^2 = AB^2 + BC^2 \text{ (Pythagoras)}$$

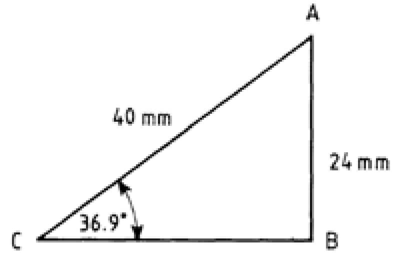
Taking the square root of both sides:

$$AC = \sqrt{AB^2 + BC^2}$$

Substituting the values given in the question:

$$AC = \sqrt{48^2 + 36^2} = \sqrt{2304 + 1296} = \sqrt{3600} = 60 \text{ mm}$$

When applied to two forces acting at right angles, determine the resultant force of forces of 30 kN and 40 kN acting at right angles to one another at point *B:*



$$AC^2 = AB^2 + BC^2$$
$$AC = \sqrt{AB^2 + BC^2}$$
$$= \sqrt{30^2 + 40^2}$$
$$= \sqrt{900 + 1600} = \sqrt{2500} = 50\ \text{kN}$$

The resultant force of 50 kN acts at 36.9° to the 40 kN force. To avoid measuring the angle $A\hat{C}B$, a trigonometrical ratio known as the sine of the angle may be used. The sine of either of the acute angles of a right angled triangle is equal to the length of the side opposite the angle divided by the length of the hypotenuse. The sine value for every minute of angle from 0°–90° have been tabulated, usually to four decimal places. The values can be found in most books of mathematical tables and when using the tables it is not necessary to draw the figure to scale, a rough sketch is sufficient to indicate the angle concerned.
Let the Greek symbol θ° (Theta degrees) equal the value of the angle $A\hat{C}B$.

Side AB = opposite side = 24 mm
Side CB = adjacent side = 32 mm
Side AC = the hypotenuse = 40 mm

$$\text{Then sine } \theta^\circ = \frac{\text{opposite side}}{\text{hypotenuse}} = \frac{AB}{AC} = \frac{24}{40} = 0.6$$

Reference to the sine tables shows that an angle whose sine is 0.6 is 36.9°.

Resolution of forces

In some problems the resultant force is known, and it is necessary to calculate the two component forces acting at right angles which produce this resultant force. This is known as a resolving force.

If a force of 600 N is acting at a point *P* 36° to the horizontal, resolve this force into its horizontal and vertical components graphically.
Draw a vector of the 600 N force to some suitable scale.

Draw a perpendicular line from point *A* to meet the horizontal from *P* at *B*.

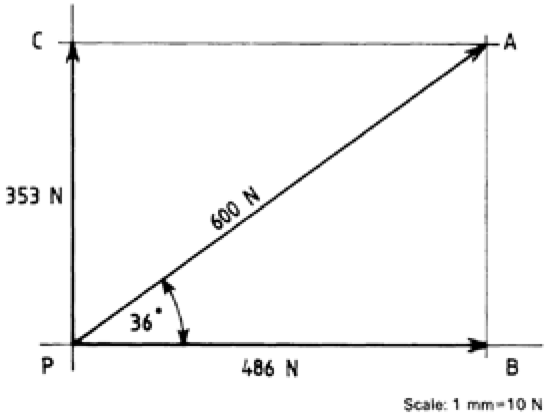
Draw a horizontal line from point *A* to meet the vertical axis at *C*.

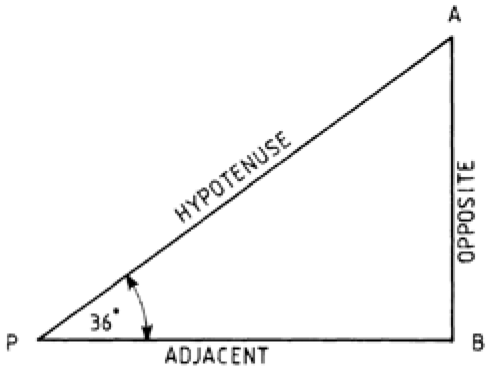
For future reference note *PC*=*BA*.

Measure *PB*=48.6 mm=486 N=horizontal component.

Measure *PC*=35.3 mm=353 N=vertical component.

With the aid of another trigonometrical ratio, the tangent, the previous example can be checked by calculation. The tangent of an acute angle of a right angled triangle is equal to the length of the opposite side divided by the length of the adjacent side. A mathematical book of trigonometrical tables will contain the required values.

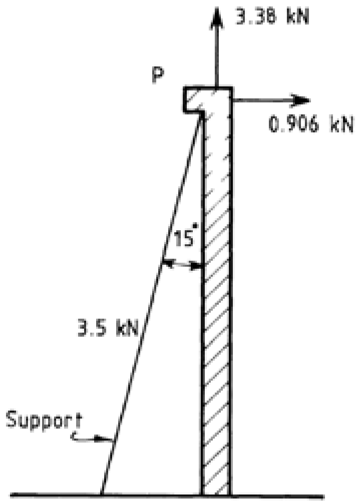




$$\text{Check: } \frac{\text{side opposite}}{\text{side adjacent}} = \tan 36°$$

$$\frac{353}{486} = 0.726 = \tan 36°$$

The resolution of forces mentioned can be obtained without measurement to scale. Draw an unsealed sketch of the 600 N resultant laying between the horizontal and vertical axes. Mark the angle *APB* as 36°.



$$\frac{\text{opposite}}{\text{hypotenuse}} = \sin 36°$$

$$\text{opposite} = \text{hypotenuse} \times \sin 36°$$

$$= 600 \times 0.588 = 353 \text{ N vertical component}$$

$$\frac{\text{opposite}}{\text{adjacent}} = \tan 36°$$

$$\text{adjacent} = \frac{\text{opposite}}{\tan 36°}$$

$$= \frac{353}{0.7265} = 486 \text{ N horizontal component}$$

A temporary support to a vertical wall makes an angle of 15° to the wall. If the load on the support is 3.5 kN, what are its vertical and horizontal components at point *P*?

horizontal component opposite =opposite side
=hypotenuse×sin 15°
= 3.5×0.2588=0.906 kN

vertical component adjacent =adjacent side
=hypotenuse×cos 15°
=3.5×0.0659=3.38 kN

Information which may be found in most books of mathematical tables

The square of numbers

The table of numbers from 1–9.9 are made up as follows:

The first column contains the number, to one decimal place, which is to be squared.
The second column gives the square of that number.
The third to eleventh columns give the square of the number to three, and later two, decimal places (the digit at the head of each column is the second decimal place of the number to be squared).

If the number to be squared has three decimal places, then one of the last nine columns has to be used, and the numbers at the head of these columns represent the value of the third decimal place, and the digits under that number have to be added to the answer. For example, taking the line commencing with 2.5:

	0	1	2	3	4	5	6	7	8	9
2.5	6.250	6.300	6.350	6.401	6.452	6.503	6.554	6.605	6.656	6.708

Mean differences

1	2	3	4	5	6	7	8	9
5	10	15	20	25	31	36	41	47

From the table:

$$2.5^2 = 6.250 \quad ANS$$
$$2.52^2 = 6.350 \quad ANS$$
$$2.526^2 = 6.350 + 0.031 = 6.381 \quad ANS$$
$$2.589^2 = 6.656 + 0.047 = 6.703 \quad ANS$$

The square root of numbers

The square root tables are usually divided into (a) the square root of numbers between 1–9.9 and (b) between 10–99.

(a) *Square roots between 1–9.9.*
The first column contains the number, to one decimal place, which is to be square rooted. The second column gives the square root of that number. The third column gives the square root of the number to three decimal places. The digit at the head of each column is the second decimal place of the number to be squared. If the number to be square rooted has three places of decimals, then the last nine columns have to be used. The numbers at the head of these columns represent the value of the third decimal place and the digits under that number have to be added to the answer.
For example, taking the line commencing with 6.5:

	0	1	2	3	4	5	6	7	8	9
6. 5	2. 55 0	2. 55 1	2. 55 3	2. 55 5	2. 55 7	2. 55 9	2. 56 1	2. 56 3	2. 56 5	2. 56 7

Mean differences								
1	2	3	4	5	6	7	8	9
0	0	1	1	1	1	1	2	2

From the table:

$$\sqrt{6.5} = 2.550$$
$$\sqrt{6.52} = 2.553$$
$$\sqrt{6.523} = 2.554$$
$$\sqrt{6.529} = 2.555$$

(b) *Square roots between 10–99.*

Square roots between 10–99 are dealt with in a similar manner as the square roots between 1–9.9.

Reciprocals of numbers from 1–9.9

The reciprocal of a number is equal to that number divided into 1. The use of reciprocal tables is similar to the use of the tables previously considered, with the major difference that the digits in the mean difference columns are subtracted and not added. For example, taking the line commencing with 5.5:

	0	1	2	3	4	5	6	7	8	9
5.5	.1818	.1815	.1812	.1808	.1805	.1802	.1799	.1795	.1792	.1789

Mean differences								
1	2	3	4	5	6	7	8	9
0	1	1	1	2	2	2	3	3

From the table:

$$5.5 = 0.1818$$
$$5.53 = 0.1808$$
$$5.539 = 0.1805$$

Logarithm tables (logs)

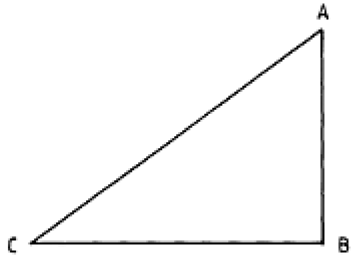
A logarithm consists of two parts:

1. The characteristic or whole number part, and since:

$$10^0 = 1 \quad \log 1 = 0$$
$$10^1 = 10 \quad \log 10 = 1$$
$$10^2 = 100 \quad \log 100 = 2$$
$$10^3 = 1000 \quad \log 1000 = 3$$

so that,

for numbers between 0–10 the characteristic is 0;
for numbers between 10–100 the characteristic is 1;
for numbers between 100–1000 the characteristic is 2.



As an *aide memoire* the characteristic is always one less than the number of digits in the whole number part of the number. Thus the characteristic is determined by inspection, and is not given in the log tables.

2. The decimal part of the log is called the *mantissa* and is usually calculated in the tables to four deci mal places. It is useful to remember that the numbers having the same significant figures have the same *mantissa,* for example:

$$\begin{aligned} \text{The log of } 2468.0 &= 3.3923 \\ 246.8 &= 2.3923 \\ 24.68 &= 1.3923 \\ 2.468 &= 0.3923 \\ 0.2468 &= \bar{1}.3923 \\ 0.02468 &= \bar{2}.3923 \end{aligned}$$

Antilogarithm tables (antilogs)

These tables are similar in form to log tables, but the *mantissa* of the log only is given, and the position of the decimal point must be fixed as previously explained. For example:

Log		*Antilog*		*Number*
2.4312	=	2699	=	269.9
1.4312	=	2699	=	26.99
0.4312	=	2699	=	2.699
$\bar{1}$.4312	=	2699	=	0.2699

Sine tables

The sine of an acute angle of a right angled triangle is equal to the length of the side opposite the angle divided by the length of the hypotenuse. Consider the triangle *ABC:*

$$\text{sine } A\hat{C}B = \frac{AB}{AC}$$

$$\text{or} \qquad AB = AC \times \text{sine } A\hat{C}B$$

$$\text{or} \qquad AC = \frac{AB}{\text{sine } A\hat{C}B}$$

Sine tables are usually calculated to four decimal places. For example, taking the line commencing with 55°:

	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′
	0°.0	0°.1	0°.2	0°.3	0°.4	0°.5	0°.6	0°.7	0°.8	0°.9
55°	.8192	.8202	.8211	.8221	.8231	.8241	.8251	.8261	.8271	.8281

Mean differences

1	2	3	4	5
2	3	5	7	8

From the table:

Sine 55°	=0.8192
Sine 55°.5=55°30′	=0.8241
Sine 55°.54=55°32′	=0.8245

Cosine tables

The cosine (cos) of an acute angle of a right angled triangle is equal to the length of the adjacent side divided by the length of the hypotenuse. Consider the triangle *ABC:*

$$\cos A\hat{C}B = \frac{BC}{AC}$$

$$\text{or} \quad BC = AC \times \cos A\hat{C}B$$

$$\text{or} \quad AC = \frac{BC}{\cos A\hat{C}B}$$

Cos tables are normally calculated to four decimal places. For example, taking the line commencing with 75° (and remembering that with the cosine tables the numbers in the mean difference columns are subtracted and not added):

	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′
	0°.0	0°.1	0°.2	0°.3	0°.4	0°.5	0°.6	0°.7	0°.8	0°.9
75°	.2588	.2571	.2554	.2538	.2521	.2504	.2487	.2470	.2453	.2436

Mean differences

1	2	3	4	5
3	6	8	11	14

From the table:

Cos 75°	=0.2588
Cos 75°.3 =75°18′	= 0.2538
Cos 75°.36=75°22′	=0.2527

Tangent tables

The tangent (tan) of an acute angle of a right angled triangle is equal to the length of the opposite side divided by the length of the adjacent side. Consider the triangle *ABC:*

$$\tan A\hat{C}B = \frac{AB}{BC}$$

$$\text{or} \quad AB = BC \times \tan A\hat{C}B$$

$$\text{or} \quad BC = \frac{AB}{\tan A\hat{C}B}$$

Tan tables are usually calculated to four decimal places.

For example, taking the line commencing with 20°:

	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′
	0°.0	0°.1	0°.2	0°.3	0°.4	0°.5	0°.6	0°.7	0°.8	0°.9
20°	.3640	.3659	.3679	.3699	.3719	.3739	.3759	.3779	.3799	.3819

Mean differences

1	2	3	4	5
3	7	10	13	17

From the tables:

Tan 20°	=0.3640
Tan20°.8=20°48′	=0.3799
Tan 20°.88–20°53′	=0.3816

Nomograms

A nomogram is an alignment charge, arranged so that the value of a variable can be found without calculation from the values of one or two known variables. A simple nomogram will give the area of a triangle if the length of the base and the vertical height are known. A straight edge is placed across the nomogram connecting the length of the base on the left hand side to the height of the triangle on the right hand side, whilst the area is read from the centre line.

Another example of a nomogram could give the strain in a reinforcement tendon, if the original length and the extension of the tendon are known. A straight edge is placed across the nomogram connecting the original length on the left hand side to the amount of extension on the right hand side, whilst the strain is read off the centre line (assuming that the area of the tendon remains constant).

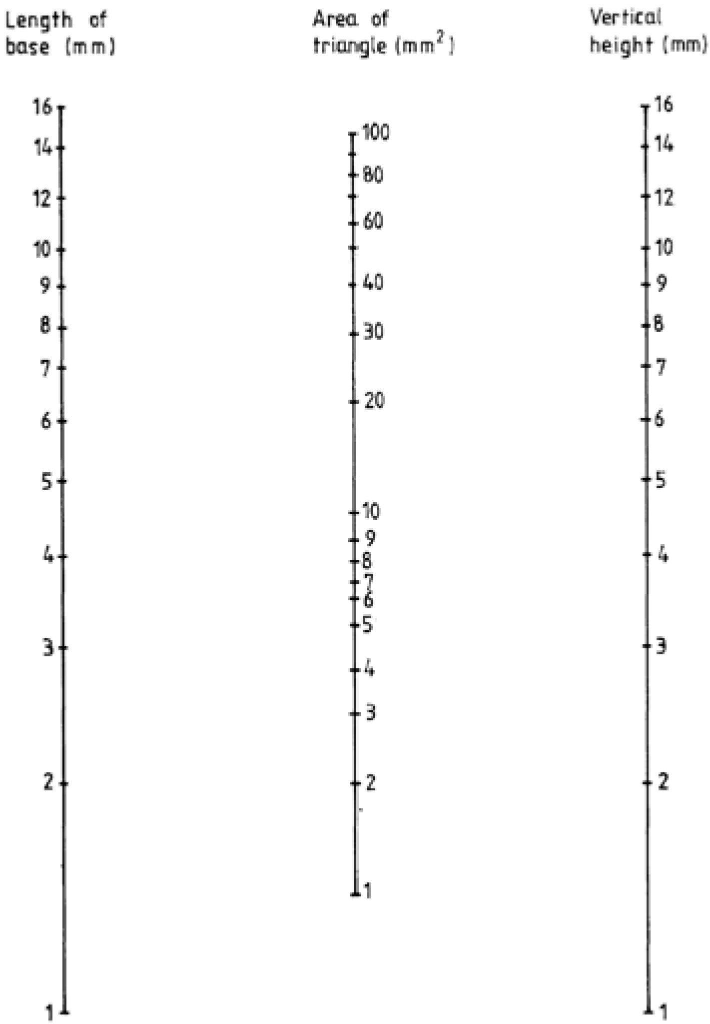
Data obtainable from graphs and charts

Graphs

A graph is a diagram depicting the relationship between two or more variables, and consists of two axes of reference. The horizontal axis, OX, is drawn at right angles to the vertical axis, OY, and they meet at the point of origin, O. In most graphs, one quantity depends for its value on the other, this quantity being the *dependent variable,* and is plotted on the “y” axis, whilst the *independent variable* is plotted on the “x” axis, thus:

Equations may be presented graphically, for example, the equation $y=mx+b$ is the equation of a straight line graph, where:

Nomogram for finding the area of a triangle when the length of the base, and the vertical height are known



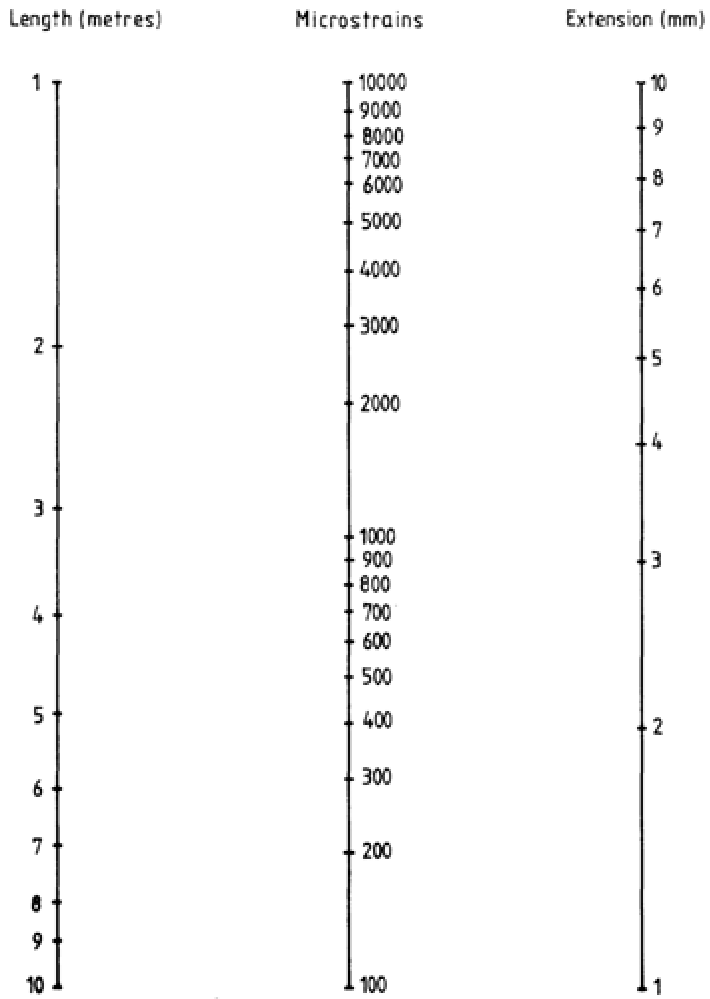
y=the value on the vertical axis of any point *P* on the graph;
x=the value on the horizontal axis of the same point *P;*
m=the slope, or gradient, of the graph line;
b=the value on the vertical axis at the point cut by the graph.
Graph of $y=2x+2$:

From this graph, intermediate values for the quantities represented by the two axes may be measured as indicated at $7y=2.5x$.

It is generally understood that the tensile strength of concrete (f_{ct}) is dependent upon the compressive strength of the concrete (f_{cu}). This information, in chart form, would appear as follows:

f_{cu} (N/mm^2)	20	30	40	50	60	70	80

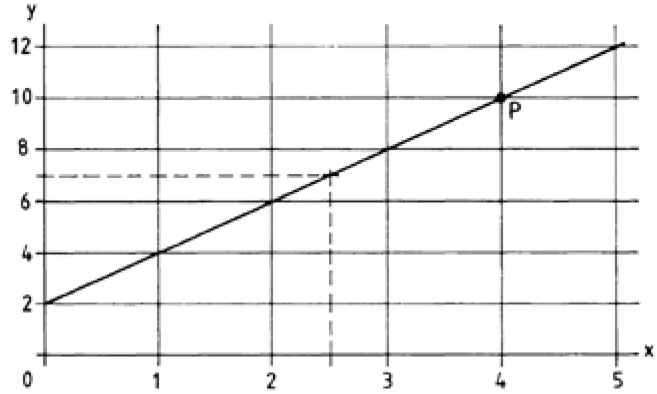
Nomogram for finding the strain in a reinforcement tendon (one microstrain equals an extension of one part in one million)

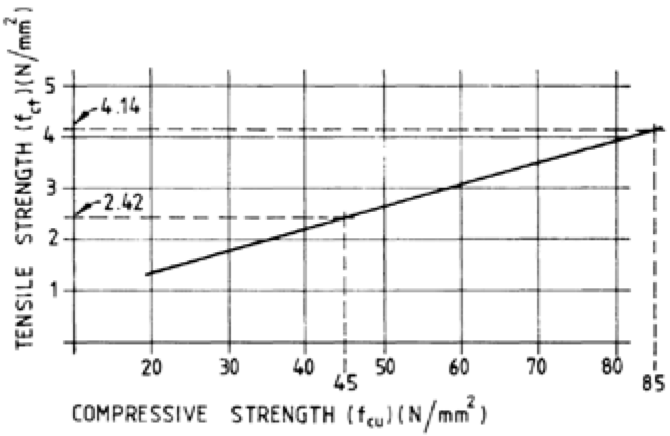


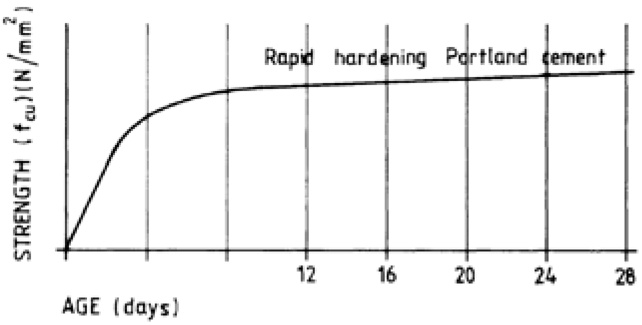
f_{ct} (N/mm^2) 1.34 1.77 2.20 2.63 3.07 3.50 3.93

from which the following graph may be drawn:

As the graph line is a straight line, the relationship between the two variables is said to be linear. If it is required to read an intermediate value, not shown on the chart, it can be read off the graph. For example, the tensile strength corresponding to a compressive strength of 45 N/mm^2 would read 2.42 N/mm^2 (which is known as interpolation). To read a value above the maximum quoted on the chart, the graph line may be extended to include the required value (which is known as extrapolation). For example, the tensile strength corresponding to a compressive strength of 85 N/mm^2 would read 4.14 N/mm^2.

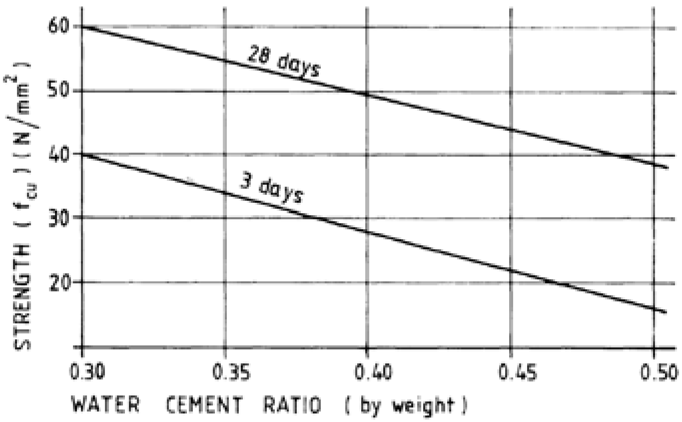






However, not all graphs are linear. For example, in a graph where the compressive strength (f_{cu}) of concrete, which is known to depend on its age (days), plotting a typical strength/age of concrete would be as follows:

Units have not been assigned to the "y" axis as the strength depends on several variables such as type of cement, mix ratio, water/cement ratio and admixtures (if used), but the general graph shape would be as shown. The curved shape of the graph makes the relationship between strength and age non-linear.



The two previous graph lines sloped upwards as the independent quantity increased. Some graph lines slope downwards as shown in the following example. The strength of concrete at a given time depends on the water/cement ratio. Two graph lines are shown, one representing the strength at three days and the other the strength of the same concrete at 28 days.

Charts

In designing a beam to withstand a given bending moment, calculations are made to determine the total area of steel reinforcement required. Reference is then ma de to a bar area chart, which will give the number and size of bars required to meet a calculated steel area. Part of a typical chart for round bars is as follows:

	Area of steel reinforcement (mm^2)								
Number of bars required	Diameter of bars (mm)								
6	8	10	12	16	20	25	32	40	
1	28	50	79	113	201	314	490	804	1257
2	56	100	157	226	402	628	982	1608	2513
3	85	151	236	339	603	943	1472	2413	3770
4	113	201	314	452	804	1257	1964	3217	5026

If an area of 856 mm^2 has been calculated, the nearest area above that on the chart is chosen. In this case an area of 943 mm^2 should be provided with three 20 mm bars. If, however, the calculated area was 1186 mm^2 then reference to the chart would give 1257 mm^2 as the nearest area which would be provided by four 20 mm bars.

Information charts used as advertisements

The publication in the technical press of data is one way in which an advertiser can explain the characteristics of his product. The following table was issued, as an advertisement, by the Central Electricity Generating Board, giving the mix details and test results obtained from mixing pulverised fuel (pfa) with cement (OPC) to make concrete stronger for a water storage reservoir.

Mix constituents (kg/m^3)					Number of cubes tested	Cube results	
OPC	pfa	Aggregates		Water	Strength (N/mm^2)	Standard deviation	
Fine	Coarse						
197	84	697	1297	149	2380	43	4.5
225	110	664	1233	157	2380	50	4.5

The advertiser claimed that as 30% by weight of cement had been replaced by pfa, a significant saving in cost had resulted.

Density

The density of a substance is equal to its mass divided by its volume. The SI derived unit is expressed as kilogrammes per cubic metre (kg/m^3). Three types of concrete have the following densities:

Lightweight (insulating) 400–1200 kg/m^3
Ordinary (Portland) 2200–2600 kg/m^3
Heavy (iron ore aggregate) 3000–3900 kg/m^3

If a block of concrete measures 6m×1.5m×0.5m and weighs 10800 kg, calculate its density:

$$\text{Density} = \frac{\text{mass (kg)}}{\text{volume (m}^3)} = \frac{10800}{6 \times 1.5 \times 0.5} = 2400 \text{ kg/m}^3$$

When aggregate is batched by volume, the weight of the aggregate required to fill a container of unit volume is known as *bulk density,* and is used to convert quantities of aggregate by weight to quantities by volume, including its moisture content. The amount of water absorbed by a particular aggregate can be found by measuring the increase in weight of an oven dried sample after it has been immersed in water for 24 hours.

Specific gravity

The specific gravity of a substance is the ratio of the weight of any volume of the substance to an equal volume of water (at 4°C) and is also numerically equal to its density when expressed in g/cm^3. As the density of water is 1000 kg/m^3, and as this is equivalent to 1 g/cm^3, then the specific gravity of water is 1.0.

If, for example, 1 m^3 of cement weighs 3100 kg/m^3, or 3.1 g/cm^3, then its specific gravity can be said to be 3.1.

28.
Statistics

Statistics and the supervisor

Company policy regarding performance, accuracy and similar criteria governs the standards which the supervisor must attain in the course of the construction process. Certain targets are set by the specifications governing the work, and the level of attainment must be related to these according to the quality policy. To meet the demands made upon him by such quality targets, the management and the client, the supervisor controlling the construction process must know where to aim and how to adjust his aim to meet the targets. The most economic method of working will be to so adjust performance targets that the results just exceed the *minimum* requirements set by specifications. The use of statistical methods in studying results and adjusting the aim accordingly is an extremely powerful tool of supervision.

Here it should be stated that there is a great deal of skill in the establishment of standards in relation to the minimum requirements. The failure probability of individual results increases as the target is set nearer to the minimum, so that the probable cost of rejects and re-working increases, and it is obviously sensible to consider this fact against the cost of maintaining slightly better than minimum quality. It would thus appear that at some point a break-even point can be established for the process or product cost where an economic balance is struck between the two costings.

The use of statistics assists in the control process and enables the supervisor to identify exceptions and changes in performance. Used as a management tool, statistics can ensure economics in construction, particularly where they are used as a quality control measure to ensure dynamic response to change. In maintaining standards, the supervisor will meet specifications which demand special degrees of dimensional accuracy. In certain instances, such as the manufacture and erection of prefabricated components and, for example, in precast work, it is essential that close estimates can be made of the eventual size of manufactured components so that appropriate space can be allowed in the design for them to be fitted into the overall construction. In the case of concrete strength and component sizing, the supervisor will be better placed to understand and meet the requirements of the design if he has an understanding of the pattern of measurements which the manufactured elements are likely to follow. The study of the way in which results and measurements form reasonable patterns is part of the study of statistics. From many years study applied to such measurements and the resulting patterns and groupings which occur naturally, certain basic laws have been derived which can be applied to new situations as they arise. These laws allow certain hypotheses and predictions to be made which in turn can be used as the basis upon which control decisions can be taken. The careful use of past data can provide information and, in particular, can be the basis of an early warning system indicating the need to take action in the control of such things as concrete strength and component sizing by adjustment to process details such as mould size or mix proportions.

The shorthand used in working out statistical examples will, like the algebraic signs mentioned in the previous chapter, reduce the amount of writing necessary when setting down facts. The use of symbols and established formulae also ensures that standardised treatment of results, apart from providing information in the required form, allows ease of checking and review.

At this stage it is considered worth reminding the supervisor that time and care expended in setting down information in a logical and tidy fashion will be amply repaid when it becomes necessary to consult the recorded information at a later date. Whilst the study of statistics is interesting, it is essential to realise that it is not an end in itself—statistical methods merely provide valuable tools for management, measurement and control of process and production.

Terms and symbols used in statistics

When an observation is taken, a test result is obtained or an event is recorded, the symbol used to denote that observation or result is x. A series of such measurements would be grouped thus: x_1, x_2, x_3, x_4, x_5 and so on, until say, x_{10} (in the case of there being ten results in the series). The actual measurements could, for instance, be as follows:

$$x_1 = 13 \quad x_2 = 16 \quad x_3 = 23 \quad x_4 = 19 \quad x_5 = 17$$

$$x_6 = 15 \quad x_7 = 12 \quad x_8 = 11 \quad x_9 = 20 \quad x_{11} = 19$$

The values for x given are added, a total of 165 being obtained in this example. A further sign is used, Σ, which denotes the *sum or total of a series of numbers*. In the example given when summation of the results is 165, this can be written:

$$\Sigma(x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8, x_9, x_{10}) = 165$$

It is convenient in this case, as one type of result is being described, denoted x, to simply state: Σx=165. Where more than one type of result is considered, each type can be allocated a symbol, such as a_1, a_2, a_3, or y_1, y_2, y_3, and so on, for each of which the total can again be expressed as Σa or Σy. The *total number* of events, observations or results is indicated by the letter n. Where there are ten results, this will be expressed as n=10. The *mean figure,* that is the most representative of all the results can be worked out by taking the summation of the results (Σx) and dividing by the total number of results (n), thus: $\Sigma x/n$. This calculation will provide a figure, not necessarily a whole figure, which is most representative of all the other numbers in the series. In the example so far discussed then, it will be:

$$\frac{\Sigma x}{n} = \frac{165}{10} = 16.5.$$

This figure, the mean of the results, is represented by $\bar{x}$ (x bar). The mean is always in the same units as the series of results from which it has been calculated. So now, results can be described in terms of:

results of or individual measurements	x
total sum of measurements	Σx
number of measurements	n
mean of measurements	$\bar{x}$

It is also convenient, when assessing such results, to observe another feature of the group of measurements, the range, w. This range of a group of measurements is obtained by subtracting the lowest value of x from the highest value of x. In the example quoted, 11 is subtracted from 23, giving a range of 12 (w=12). The range is a measurement of the spread of results. At this stage in the study of information or a series of results, it appears that one can establish a fairly clear picture of what is happening, in terms of whether the results, measurements or observations are satisfactory, and indeed for many purposes this is sufficient. Where, however, there is an attempt to forecast what the performance will be in the future or what effect past events are likely to have on future results, it is necessary to establish a more precise picture, especially if action is to be taken upon the information. The supervisor will read in other chapters herein how histograms, for example, can be used to clarify resources needed in the course of production and how often something is done or is required to be done in a given process. This is described as the frequency (f) of that event. So now another factor can be studied and recorded from the emerging results, being the frequency (f) with which they occur.

Normal distribution

A study of a considerable number of results carried out by various scholars in the past has established certain facts about the way in which results or measurements, which are taken in a standard way, conform to certain clearly defined patterns. The pattern to which most measurements or results encountered in construction work conform is a pattern known as the *normal distribution*. For the purpose of supervision, it is sufficient to visualise a histogram of normal distribution as illustrated. The illustration shows a number of results plotted above a base line which is marked with a scale suited to the measurements or results under consideration, the symbol • being used to illustrate each result. Taking large numbers of measurements of components manufactured using the same labour, equipment and controls or taking large numbers of results from tests conducted by the same people using particular test equipment in given conditions, a pattern such as that illustrated would emerge when the plot of the results was complete. This is a frequency distribution pattern (a histogram). Smoothing the outline would result in a bell-shaped curve. Of course, for different types of test or different products measured, the curve would take differing profiles, but would still be bell shaped with the majority of the measurements grouped around the mean, $\bar{x}$.

According to the degree of control applied to the process of test or manufacture, the range of results would change as illustrated, with flat curves for loose control or steep curves for close control. As the shape of the curve or some description of the curve clearly conveys the affect of applied controls, the importance of the distribution of the results becomes readily apparent. As additional results are reported and introduced into the histogram, the profile of the curve alters. Knowing the required profile and its relationship to the mean, action can be taken to determine what factors control the pattern and to then make the necessary arrangements to achieve a more desirable shape of the distribution of results. Considering the normal distribution illustrated, it will be noted that whilst, as expected, many of the results are grouped closely around the average, a spread of results exists. The frequency of results generally decreases as the value of individual results varies from the mean. Again, this is a fact which has been proven over years of study and indeed the distribution of the results can be accurately described using established mathematical rules. It must be borne in mind that the greater the number of results, the more likely is the pattern to conform to the pattern described as *normal distribution*.

The sample

When numbers sampled are governed by some specific requirement such as very high strength, or extremely stringent requirements of accuracy, then the frequency distribution diagram may take on some new appearance, such as the skew apparent in the illustration. At this stage it is necessary to examine further terms which will assist in the description and discussion of results and the pattern which they represent. When considering results or measurements these are viewed as a *sample,* representative of all the possible results or measurements. The greater the number of results in a sample the more accurately will the sample represent the whole. The sample is thus part of the whole, the statistician says, part of the *population*. It is essential to remember that it is generally impossible or impractical to deal with every item in such a population, it being impossible to test the strength of every skipful of concrete, for instance, and so a sample size or number of tests is agreed as being representative of the population. The greater the number of elements measured out of perhaps 1000 elements (i.e., the greater the sample taken), the more of those measurements will represent the actual measurements of the 1000 elements. The sample size is important and has a bearing on the accuracy of the estimates or predictions based upon it, and any action which will be taken in the light of a study of that sample.

Equally as important as the number of results in a sample is the way in which the results are obtained. Standards of testing and measurement are set down in Codes of Practice governing the work. At all times care must be taken to ensure that where, for instance, materials or products are being sampled, the random nature of the sample is maintained. In the instance of concrete in a structure or readymixed in a truck, the sampling system is covered by specification and Codes of Practice. A sound means of achieving a random pattern of sampling is the use of a table of random numbers. This table will consist of values all of which are independent of any other value in the table. The size of sample is determined by the risks accepted in any sampling system, and these are:

The producer's risk: the risk that a batch of results which are acceptable, are rejected by a poorly designed sampling system.

The customer's risk: the risk that a batch of results which should have been rejected by a properly adjusted sampling system will actually be accepted.

Although samples can be described in terms of n, Σx, $\bar{x}$ and w, this description still leaves much to be desired. The range and mean of results give some indication of the way in which the results vary but do not convey in any quantitative sense the way in which individual results are distributed about the mean or to what degree the control applied to a process is effective.

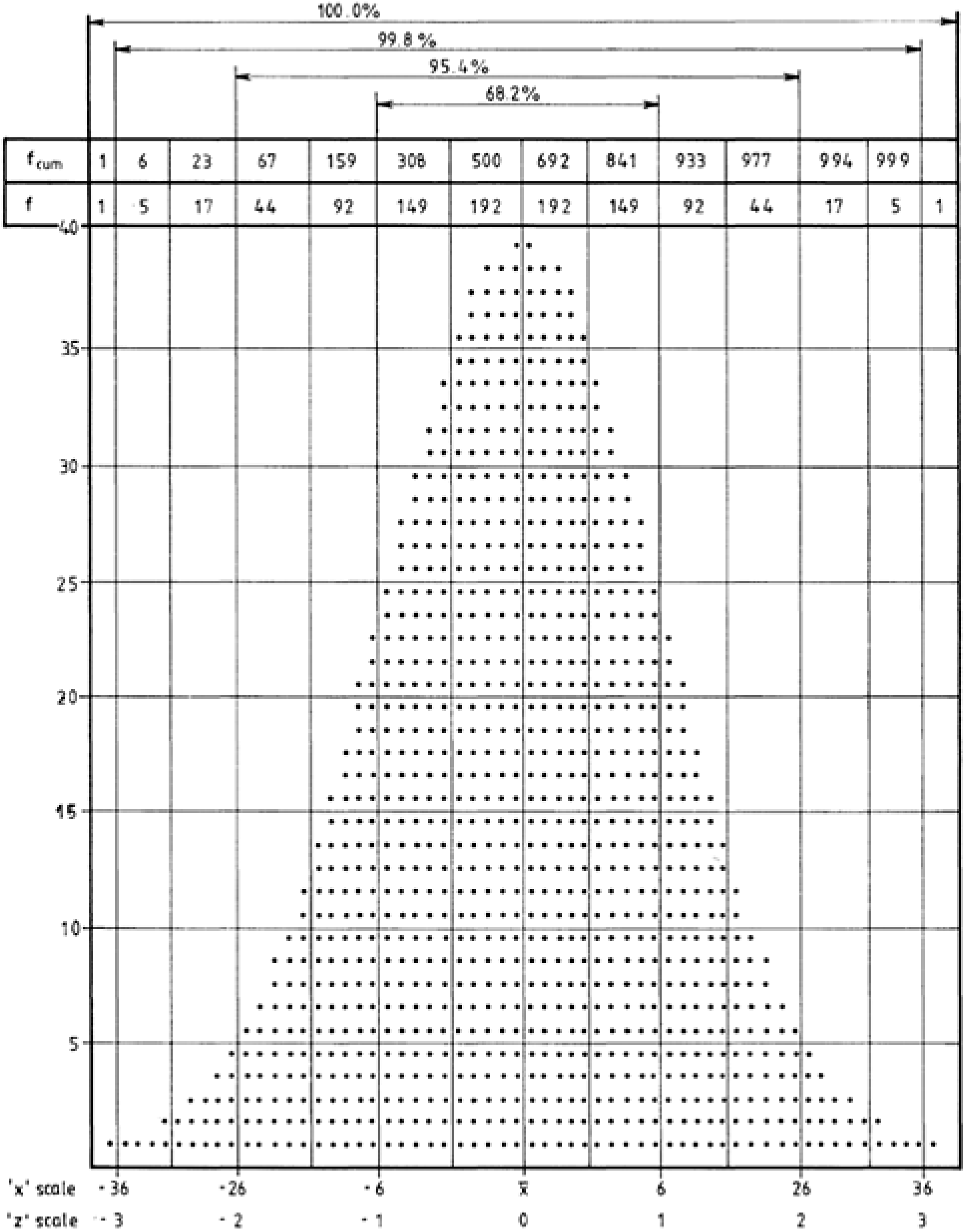
The standard deviation

The use of some fairly straightforward arithmetic allows calculation of a measure of the variability of a set of results which, when used with the values of n and $\bar{x}$, provides a useful description of the variability. This measure is called the *standard deviation* and is abbreviated to s in the case of work with samples and for the whole population. The calculation of standard deviation is carried out using results as they appear from measurement or test to establish mean, summation, and so on, as previously discussed, and then to use these measurements in a way devised by statisticians to calculate s. Care must be taken in the course of calculation to set down the results and various items of information derived from these results in such a way that they can be easily checked and reviewed. Careful setting out of results will also ensure correct working and interpretation.

The standard deviation is a measure of the way in which results are distributed about the mean. Unlike the range, which only describes the differences between the greatest and least results, the standard deviation provides a means of assessing how closely all of the results match established requirements. The calculation of standard deviation is carried out as follows:

The n of individual results are listed under the heading x_i, taking care that the results are those of standard testing carried out under the specified conditions of test. The mean, $\bar{x}$, is calculating using the formula

A normal distribution



$\Sigma x/n = \bar{x}$. By subtracting the mean from each individual result ($x_i - \bar{x}$*) the deviation between results and the mean is established. The deviation is squared, $(x_i - \bar{x})^2$ this process of squaring the result ensures that negative quantities do not appear in further calculations. The square of the deviations is summed, $\Sigma(x_i-\bar{x})^2$ and the result divided by $n-1$ (an adjustment determined by research), giving:

$$\frac{\Sigma(x_i-\bar{x})^2}{n-1}$$

This calculation gives the mean of the square of the deviations of all observations. The square root of the result is now a number, not necessarily a whole number, which provides a measure of the variability of the sample results about the mean. This value then is known as the standard deviation (s), where:

$$s=\sqrt{\frac{\Sigma(x_i-x)^2}{n-1}}$$

Example of calculation of standard deviation

Given the following ten cube test results:

34 30 38 34 37 36 38 40 36 37 (N/mm^2)

and setting out the results as previously described:

x_i	$(x_i-\bar{x})$	$(x_i-\bar{x})^2$
34	−2	4
30	−6	36
38	+2	4
34	−2	4
37	+1	1
36	....	....
38	+2	4
40	+4	16
36	.....	.....
37	+1	1
$\Sigma x_i=360$ so $x=306$	$(x_i-\bar{x})^2=70$	

$$n=10 \quad \bar{x}=\frac{x}{n}=36 \quad s=\sqrt{\frac{\Sigma(x_i-\bar{x})^2}{n-1}}=\sqrt{\frac{70}{9}}=2.79$$

The results of the calculation then are: $n=10$, $\bar{x}=36$ and $s=2.79$, and the use of these results enables an accurate description of the distribution of the results of the samples. Sufficient is known of the normal distribution that these statistics enable the statistician to make certain predictions about the population from which the sample was taken.

The illustration indicates a normal distribution in terms of this new statistic which has been calculated from sample results with reference to the sample mean, $\bar{x}$. other words, the diagram shows the number of results which ought to occur in a normal distribution within multiples of the standard deviation either side of the mean. The area under the curve, if measured, would be representative of the proportion of results out

* Here the notation x_i is a way of indicating the individual result under consideration.

of the total population which would be expected to occur within the given multiple of standard deviation about the mean. In this figure, 68.2% of the results would occur within one standard deviation of the mean, 95.4% within two standard deviations of the mean of 99.8% of results would occur within three standard deviations of the mean. These facts, which apply to the normal or *Gaussion* distribution as it is sometimes known, are of immense value in the establishment and maintenance of standards, and provided that reliable records are kept of such items as compression test results, size of components, timing of operation, distances travelled by plant and equipment and hours worked, and operations carried out by a man or a piece of equipment, then quite accurate estimates can be prepared for use in planning and control of these results and activities.

Samples can now be summarised in terms of n, x, Σx, $\bar{x}$, w, and s. Taking 20 results, the majority of which lie quite closely to the mean as follows:

20 22 23 23 24 24 24 24 25 25 25 25 26 26 26 26 27 27 28 30

these results can be grouped, thus indicating a measure of frequency:

24 25 26
24 25 26
23 24 25 26 27
20 22 23 24 25 26 27 28 30

The mean of the result is 25, the range 10. By calculation the standard deviation can be established:

$$n=20 \quad \bar{x}=25 \quad w=10 \quad s=2.2$$

Taking another 20 results where there is a greater spread:

20 21 22 22 23 23 24 24 25 25 25 25 26 26 27 27 28 28 29 30

these can again be set out to indicate a measure of frequency:

25
25
22 23 24 25 26 27 28
20 21 22 23 24 25 26 27 28 29 30

The mean is 25, the range is 10, but in this case, when the standard deviation is calculated, the result is s=2. 695. Thus two sets of results are obtained which are in many ways very similar:

the number of results is 20
the range of results is 10
the mean of results is 25
the summation of each set is 500

What does differ, however, is the standard deviation which is higher when the results are more widely spread about the mean. The standard deviation gives a quantitative indication of the spread about the mean. Using what are known to be the rules governing the pattern of a normal distribution, it is now possible to determine, using the standard deviation, the manner in which sample results are distributed about the mean.

Alternative methods of determining standard deviation

As well as the direct calculation using the formula

$$s = \sqrt{\frac{\Sigma(x_i - \bar{x})^2}{n-1}},$$

there are two other methods which are useful to the supervisor concerned with such matters as concrete quality:

1. The mean range, $\bar{w}$, of groups of samples can be used to calculate an approximate standard deviation. To use this method results are divided into groups. For example, given 21 results, these can be divided into seven groups of three results each:

	12.5	8.5	13.5	10.5	13.0	12.5	9.0
	11.5	13.5	12.0	11.5	11.0	10.0	11.0
	10.5	8.0	11.0	9.5	10.0	10.5	11.0
w=	2.0	5.5	2.5	2.0	3.0	2.5	2.0

then,

$$\bar{w} = \frac{\Sigma w}{\text{number of groups}} = \frac{19.5}{7} = 2.786$$

then, using factor *d* from Table 28.1, $\bar{w}/d$=estimate of standard deviation, so that

$$\frac{2.786}{1.693} = 1.645.$$

More accurate methods of calculation given an estimated s=1.529.

TABLE 28.1
Factor for converting mean sample range to standard deviation

Number in groups of results	Factor *"d"*
2	1.128
3	1.693
4	2.059
5	2.326
6	2.534
7	2.704
8	2.847
9	2.970
10	3.078

2. The standard deviation can be determined using probability paper for normal distribution, an example of which is illustrated. The method of use of this paper is prepared as follows:

Group intervals are selected and indicated in the appropriate space at the bottom of the page. In the illustration 2 N/mm^2 has been selected. A frequency histogram is plotted, a mark being entered in the appropriate column for each result in the sample. The frequency, *f*, is noted for each column.

The frequency is converted into a cumulative frequency by adding sequentially from left to right the frequency from each column.

The cumulative frequency, expressed as a percentage of the total number of results is now plotted on the graph paper.

A line is drawn to fit these plotted points using a straight edge.

The scale of the chart is so arranged that the mean and standard deviation can be read directly from the plot. The mean can be read on the scale of compressive strength from the intersection between the plotted line and the heavy black line at 50% (percentage of results below stated value), in the case illustrated approximately 34 N/mm^2. The standard deviation can be read as being the interval in N/mm^2 on the compressive strength axis between the intersection of the plotted line and the heavy black lines at 50% and 16% (i.e., the 34% of the population which falls within one standard deviation from the mean). In the case illustrated the standard deviation is 4 N/mm^2. An accurate calculation of the standard deviation of the results illustrated in the figure, gives mean, $\bar{x} = 33.78$ and standard deviation, s=3.99 (two decimal places).

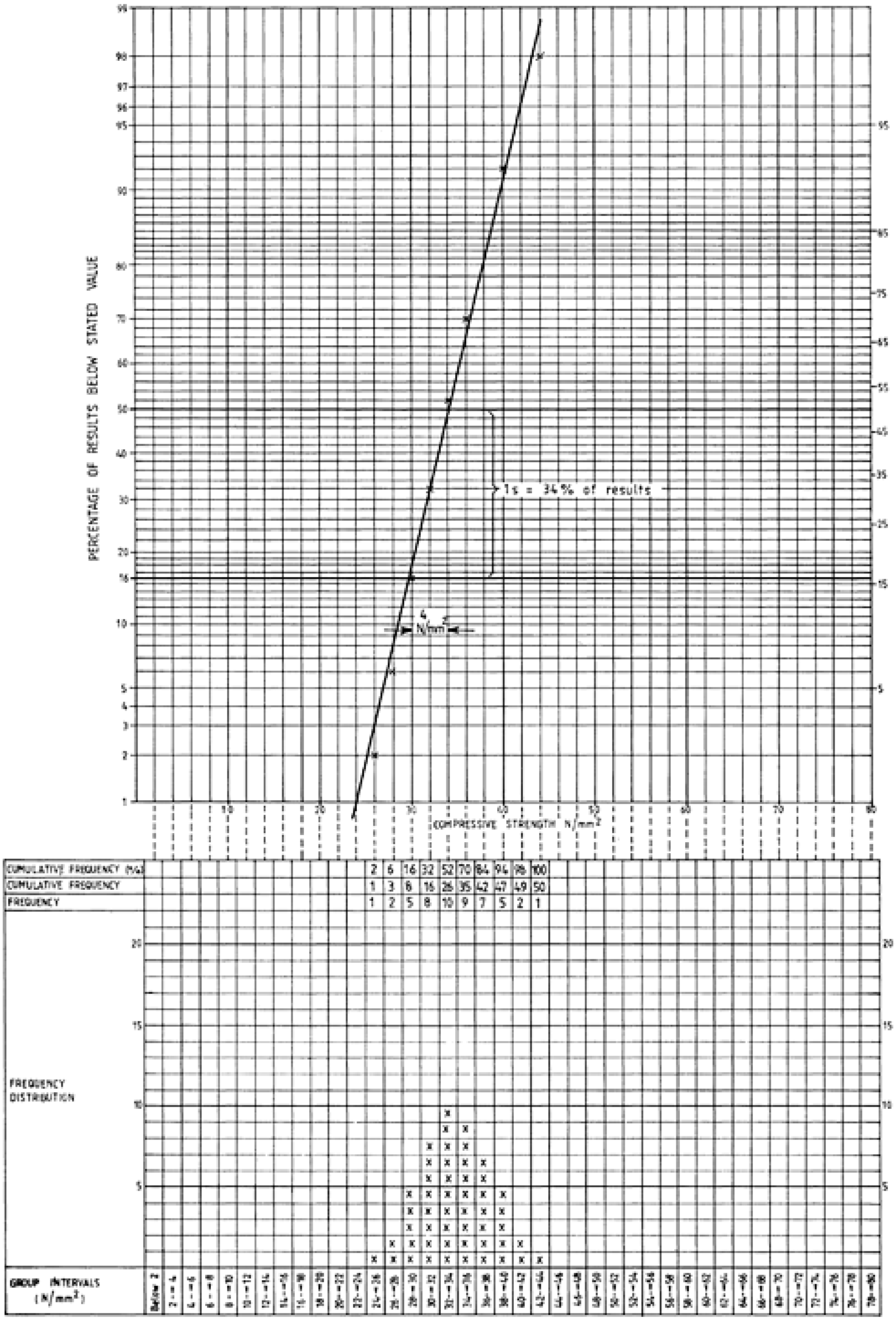
The following worked examples indicate the use of the formula

$$s = \sqrt{\frac{\Sigma(x_i - \bar{x})^2}{n-1}}$$

and the mean range method using values for d taken from Table 28.1.

Example A: Formula method

Result	Result−Mean	Difference squared
x_i	$x_i - \bar{x}$	$(x_i - \bar{x})^2$
37.0	3.22	10.3684
31.5	−2.28	5.1984
32.0	−1.78	3.1684
33.5	−0.28	0.0784
29.5	−4.28	18.3184
43.5	9.72	94.4784
31.0	−2.78	7.7284
35.3	1.72	2.9584
38.5	4.72	22.2784
34.5	0.72	0.5184
35.5	1.72	2.9584
38.0	4.22	17.8084
39.0	5.22	27.2484
36.0	2.22	4.9284
41.0	7.22	52.1284
39.0	5.22	27.2484
27.5	−6.28	39.4384
35.5	1.72	2.9584
30.5	−3.28	10.7584
33.5	−0.28	0.0784
30.5	−3.28	10.7584
35.0	1.22	1.4884


PERCENTAGE OF RESULTS BELOW STATED VALUE
1s = 34% of results
4 N/mm²
COMPRESSIVE STRENGTH N/mm²
CUMULATIVE FREQUENCY (%) 2 6 16 32 52 70 84 94 98 100
CUMULATIVE FREQUENCY 1 3 8 16 26 35 42 47 49 50
FREQUENCY 1 2 5 8 10 9 7 5 2 1
FREQUENCY DISTRIBUTION
GROUP INTERVALS (N/mm²)
Below 2

Result	Result−Mean	Difference squared
x_i	$x_i - \bar{x}$	$(x_i - \bar{x})^2$
31.0	−2.78	7.7284
33.5	−0.28	0.0784
33.0	−0.78	0.6084
37.5	3.72	13.8384
37.0	3.22	10.3684
27.0	−6.78	45.9684
32.5	−1.28	1.6384
34.5	0.72	0.5184
32.0	−1.78	3.1684
31.5	−2.28	5.1984
28.0	−5.78	33.4084
36.5	2.72	7.3984
25.0	−8.78	77.0884
28.5	−5.28	27.8784
41.0	7.22	52.1284
35.0	1.22	1.4884
39.5	5.72	31.7184
37.5	3.72	13.8384
29.0	−4.78	22.8484
29.0	−4.78	22.8484
33.5	−0.28	0.0784
32.5	−1.28	1.6384
30.0	−3.78	14.2884
30.0	−3.78	14.2884
34.0	0.22	0.0484
36.0	2.22	4.9284
34.0	0.22	0.0484
33.0	−0.78	0.06084

$$\sigma x_i = 1689.00$$

$$\Sigma(x_i - \bar{x})^2] = 779.58$$

$$\bar{x} = \frac{\text{sum of all results}}{\text{number of results}}$$

$$= \frac{\Sigma x_i}{n} = \frac{1689}{50} = 33.78 \text{ N/mm}^2$$

$$\text{Standard deviation } s = \sqrt{\frac{\text{sum of differences squared}}{\text{number of results} - 1}}$$

$$= \sqrt{\frac{\Sigma(x_i - \bar{x})^2}{n-1}}$$

$$= \sqrt{\frac{\Sigma(x_i - 33.78)^2}{50-1}} = \sqrt{\frac{779.58}{49}}$$

$$= \sqrt{15.9098}$$

$$= 3.99 \text{ (to two decimal places)}$$

Example B: Mean range method

	1	2	3	4	5
	37.0	33.5	30.5	32.0	29.0
31.5	38.0	35.0	31.5	29.0	
32.0	39.0	31.0	28.0	33.5	
33.5	36.0	33.5	36.5	32.5	
29.5	41.0	33.0	25.0	30.0	
43.5	39.0	37.5	28.5	30.0	
31.0	27.5	37.0	41.0	34.0	
35.5	35.5	27.0	35.0	36.0	
38.5	30.5	32.5	39.5	33.0	
34.0	34.5	33.5	34.5	37.5	
Ranges	14.0	13.5	10.5	16.0	7.0

$$\text{Mean range } \bar{w} = \frac{\text{sum of all the ranges}}{\text{number of ranges}}$$

$$= \frac{\Sigma w_i}{n_w} = \frac{61}{5} = 12.2$$

$$\text{Standard deviation } (s) \triangleq \frac{\text{mean range}}{d} = \frac{\bar{w}}{d}$$

(where d is a factor according to the number of results per group as given in Table 28.1—when the number in each group is 10, d=3.078). Therefore:

$$s \triangleq \frac{12.2}{3.078} \triangleq 3.96 \text{ (to two decimal places)}$$

Example C: A graphical method

From the probability paper illustrated, mean ($\bar{x}$) $\triangleq$ 34 N/mm^2 and standard deviation (s) $\triangleq$ 4. It should be mentioned that the σ arrived at by the mean range method is by coincidence extremely close to that calculated using the formula and that in general practice larger differences may be found.

As has been seen earlier in this Chapter, the normal distribution follows a clearly established pattern. Tables are available which set out details of the distribution. It is convenient to use the standard deviation as a measure of the spread of the distribution about the mean:

68.25% of population of a normal distribution lie within one standard deviation either side of the mean
95.5% of population of a normal distribution lie within two standard deviations either side of the mean
99.75% of population of a normal distribution lie within three standard deviations of the mean

There are some further multiples of standard deviation about the mean which are of interest in quality control. These are $1.64\times\sigma$ each side of the mean and $1.96\times\sigma$. Within these values lies 90% and 95% of the population respectively. These values are encountered in a number of specification clauses in construction.

Coefficient of variation

So far in the examination of variability, emphasis has been toward certain criteria which can be used to define a distribution, using n, x and s. Whilst these measures can be used to convey information regarding the pattern of distribution, they do not provide a means of direct comparison between distributions, for which the coefficient of variation should be used. The coefficient of variation is determined by dividing the standard deviation by the mean, s/x, and expressing as a percentage by multiplying by 100. The result allows comparison with other coefficients of variation from other distributions. The main benefit of the coefficient of variation is that its use allows comparison of the variability of groups with widely differing means.

Specification

Specifications are prepared by specialists in conjunction with the design engineer, and are set according to rules of construction, stating such matters as the accuracy to be achieved in construction, strength of the concrete, type of reinforcement and similar details. Specifications give the manufacturer a measure of the quality required to ensure that the building or construction will function as intended by the designer. Whilst it can be extremely satisfying to produce excellence, in many cases excellence is unnecessary and, indeed, wasteful of labour and materials. The achievement of the appropriate standards which meet the minimum requirements set by the specifying authority can be a difficult matter, because however carefully a job is supervised, some defects may occur which render the whole job or process outside the specification.

Certain areas of specification can be set in quantitative terms. Concrete strength, dimensional accuracy of components and similar attributes of the structure can be categorically stated in the specification. These are the areas where statistics can be used as a tool in the achievement of a given performance in an economic manner. The maintenance of records and the statistical work in quality control cost money. This cost, however, can be offset against savings made in the reduction of materials usage and time which would otherwise be spent in cutting away and replacing defective work. As regards the accuracy of components, increasing the control applied to the manufacturing process can ensure that there will be less variation in element sizes. The installation of the elements will thus be simpler and such details as joint widths will become more standard. Fewer varieties of gaskets, cover fillets and similar items will thus be required and the joint or connection will become more typical of that envisaged by the designer.

Provided that performance has been accurately recorded and accorded to certain test criteria standards, and provided that measurements are taken from items produced in a standard fashion, then not only can the shape of the distribution be established, but forecasts can be made. These forecasts enable establishment of targets which will provide a given probability that a certain defect rate will not be exceeded. Here it should be noted that statistically based specifications are written on the assumption that a certain proportion of the results will be expected to lie below a given level.

Having studied the normal distribution pattern, it is evident that there will always be a proportion of these outlying results. Based upon a knowledge of probability, limits can be set for production quantity, for accuracy, for concrete strength and so on, and with a knowledge of the results obtained for a particular degree of control the contractor or supplier can target his activities to ensure that his work meets the requirements whilst using the most economic control and materials input. If, for example, the specifier states that he will accept a supply of concrete in his structure which, when sampled in a specified manner has only a given number of results falling below a certain strength, then study of the results of trial mixes or records of mix results over some period of time will provide a good indication of where the target should be set to meet such requirements. Here it becomes necessary to examine a concept which has been adopted in construction generally when specifying strength, fit and similar characteristics, for which sample values are obtained as a result of specified routine testing, which is the concept of *characteristic strength* (and, for example, characteristic size).

Characteristic strength

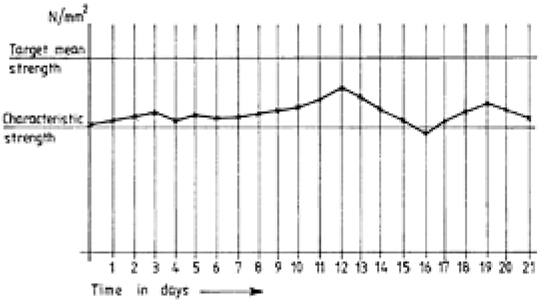
The characteristic strength is defined as the strength below which a given percentage of results of tests are expected to fall (5% in respect of the results of compression tests in cube specimens in BS 8110). Within certain limits present knowledge of statistics enables a target to be set for mean strength to ensure that specified characteristic strength requirements are met, to maintain the maximum of 5% of low results falling below the characteristic strength.

With reference to the information set out in the illustration, it can be seen that the *target mean strength* will need to be 1.64 above the specified characteristic strength. The allowance, or margin, of 1.64 s above the specified characteristic strength is known as the *current margin*. In BS 8110 clauses set out ways of determining the current margin where there is insufficient historical data regarding the results obtained from a particular concrete mix, in which case alternative criteria are stated. In practice, the margin is, of course, dependent upon the standard deviation of the results being achieved. As has been seen, the standard deviation is a measure of the spread of the results about the mean and thus with a greater spread of result (i.e., a higher standard deviation), it will be necessary to set a higher target for mean strength to ensure that only the specified number of results will be less than the specified characteristic strength.

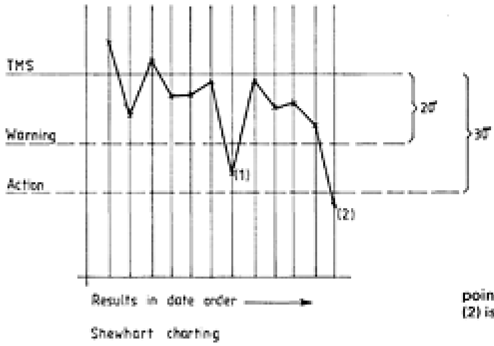
Control of variability

An essential part of the supervisory role in construction is that of control. To control activities the supervisor needs standards and some means of measuring how the production for which he is responsible matches up to those standards. It is easy enough, when cube results fall off for example, to change mix proportions –as a result of such a change, the strengths may well be achieved. A further problem then exists, however, that of establishing just what should be changed and how much of a change should be made.

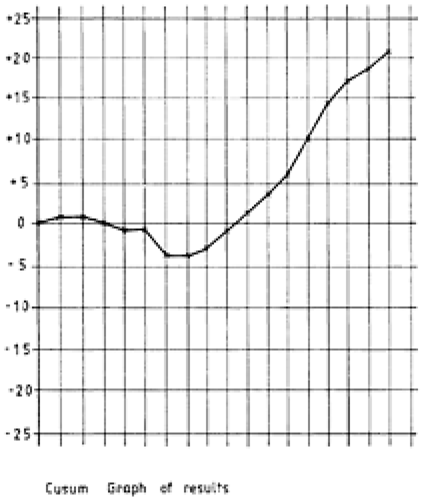
To deal with the first part of the problem of control, of identifying the need to make changes, it becomes necessary to maintain certain records in such a way that changes become apparent. Charts which give indications of the way in which results vary day by day are useful and possibly the simplest chart is of the



this chart shows daily variation but does not indicate possible trends



point (1) is an indication that process needs examination, point (2) is an indication that process may be out of control



the cusum graph for the 18 results

type illustrated, which simply plots results to scale on one axis against dates set out on the other axis. This chart is valuable in that it serves to illustrate at a glance the way in which cube results vary day to day. The gradual increase in strength from day 3 to day 12 is of interest and quite a healthy chart is developing. The results in days 13–17 are a source of some concern, however, and it will be necessary to establish, provided sampling and testing standards have been maintained, what are the possible reasons for the fall off in results, to enable steps to be taken to avoid a continuing decline in results.

The disadvantage of a chart of this type is that little indication is given of *possible* trends and there is no warning of when action needs to be taken. Although in days 13–17 there was a fall off in strength, to have taken action then might have proved wasteful. The lower results may have resulted from some isolated change, for example, in the moisture content of the aggregate, which went undetected or was not allowed for in batching. To enable a sensible control to be established, charts are required which, when plotted systematically, give guidance on when and what action should be taken to maintain the required standards.

Shewhart charts

As has been seen, the traditional charting of strengths obtained from some standard form of testing against target mean strength on a daily or weekly basis includes no control measure or system of warning to take action. The Shewhart chart, however, uses the same information but, because critical levels of results have been calculated and appropriate limit lines entered onto the matrix of the chart, warning is given when results indicate the need for some corrective action. So that the charted results can be used as a control measure, some systematic examination process must be incorporated into the charting technique. Shewhart charts can be constructed in such a way that each result provides a point in a visual display representing variations in the quality of production. Shewhart charts can be set up to review individual sample results (xi), mean of sample results ($\bar{x}$), range (w), mean range ($\bar{w}$), and the standard deviation of samples (s). The charts most frequently used employing Shewhart techniques are those for sample mean and sample mean range. For small samples the range gives a good indication of variability. The test results are divided into group of, say, four results from which the means and ranges are calculated.

Where results of compressive test on concrete cube specimens are being charted using Shewhart techniques, a horizontal line is drawn at the level of target mean strength. Two further horizontal lines are drawn above and below this line, and are called the *warning* and *action* lines. The distance of the warning and action lines from the target mean strength line depends on the degree of control to be maintained. The lines could, for example, be set at distances equivalent to multiples of the standard deviation established from previous testing, or they could be placed at levels indicating different failure tests, say one failure in 20 or one in 40. The lines closer to the centrally placed target mean strength are the warning limits and the outer lines are the action limits. Traditionally, Shewhart charts would use action lines at TMS $\pm 3\sigma$ and warning lines at TMS $\pm 2\sigma$. Where plotted points fall outside the warning lines, the indication is that the production process may be going out of control. If plotted points fall outside the action lines, steps must be taken to establish the cause of the unacceptable variation and remedial action introduced. An essential part of the charting procedure is that the points should be plotted in chronological order. For the purpose of control of concrete quality, results are used from compression testing of specimens tested at either 28 days or, in some instances where the specimens are cured using accelerated curing techniques, 16 hours provides a convenient reference point.

For warning limits the population mean$\pm 1.96\sigma$ (2 sigma) is used and for action limits the population mean $\pm 3.09\sigma$ (3 sigma) is used where σ (sigma) is the estimated standard deviation of the population. From the previous study in statistics it will be obvious that 1 in 40 of the results may be expected to fall outside the warning limits and 1 in 1000 outside the action limits. As the results are entered onto the charts, trends can be identified but as changes in Shewhart charts result from a combination of abrupt and gradual changes, they are difficult to analyse. They do, however, provide valuable indications of when action is necessary.

The interpretation of Shewhart charts, used as a control measure, follows clearly defined rules. If points lie within the minor limit lines the process is said to be in control. If a point lies outside the 1 in 40 limit then this is taken as a warning of likely trouble and suggests that the process should be examined for disturbances or faults. If a point lies outside the 1 in 1000 limit this is taken as an indication that the process may be out of control and a careful check should be made to isolate the reason for the fault. In both cases the succeeding result is plotted and carefully scrutinised. If the next result also falls outside the 1 in 40 limit this indicates a need for action. A second result beyond the 1 in 1000 limit gives a very strong indication that there is some need for action to be taken. Where the result succeeding that which has fallen outside the limits is within the limits, then it can be assumed that the exceptional result is just a 1 in 40 or 1 in 1000 happening and is part of the normal variability to be expected within the process.

Cusum techniques

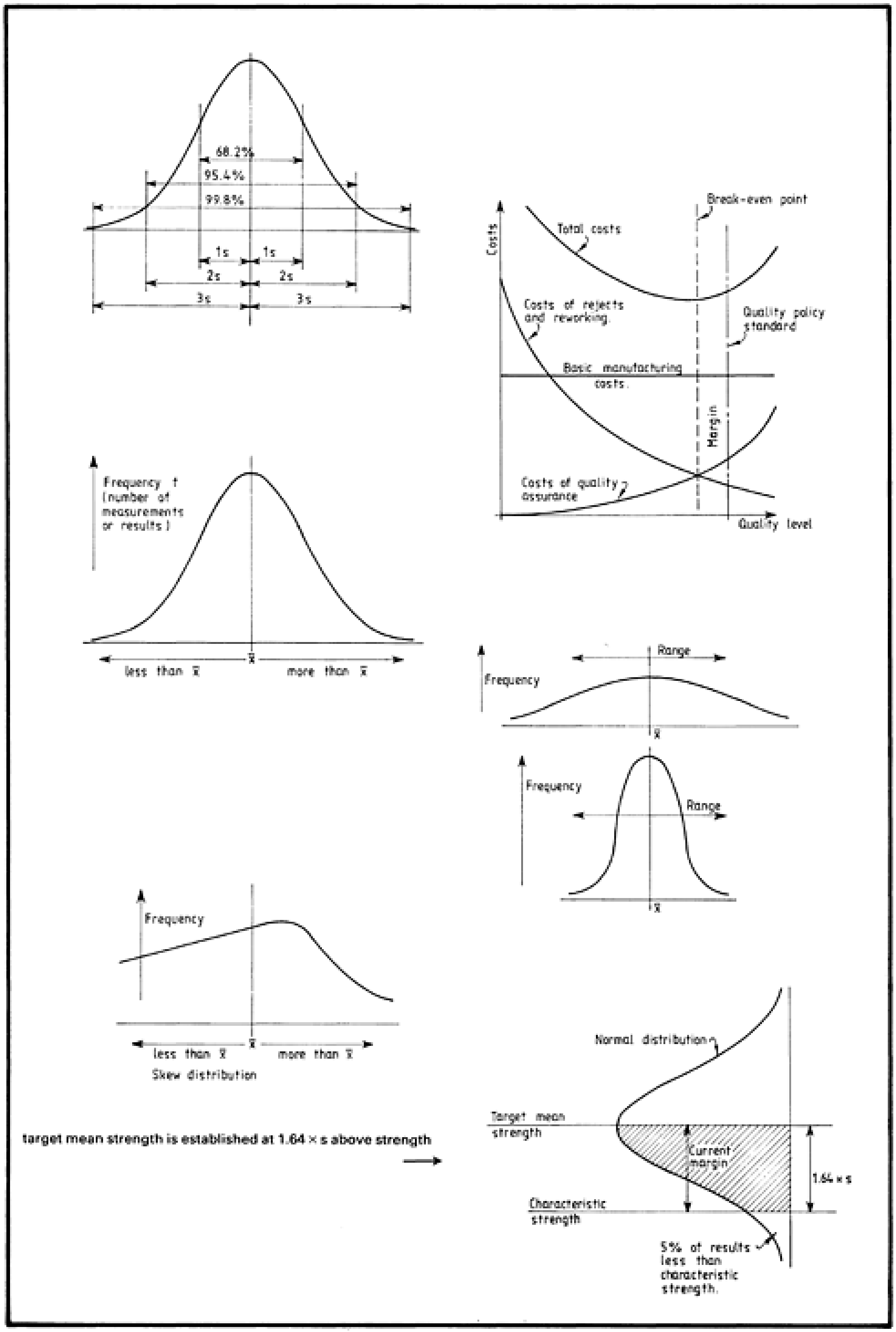
In the case of cusum, or cumulative sum, charts, the results are plotted sequentially on graph paper which has been prepared to a special grid. The cumulative sums of the mean and the range and the correlation between estimated 28-day strength and the result taken from accelerated testing are plotted and control can then be checked in each case by application of a mask or template based upon the same scale as the chart. The accompanying illustrations, reproduced by kind permission of the British Readymixed Concrete Association, indicate the use of cusum techniques in the control of concrete production to a specified standard. This technique has been developed by Ready Mixed Concrete Limited and makes use of copyright charts, masks and graphs.

Cusum (cumulative sum) charts are drawn by plotting the cumulative sum of the differences between the actual results achieved from testing and the target value. Thus, if a horizontal line is produced as the results are plotted, the mean of the results is the same as the target value. Changes, a rise or fall in the plotted line, indicate that the mean value over that period is greater or smaller than the target value. Quite small differences between actual and target can be clearly identified as the slope of the line changes. It will be seen that a cusum chart indicates clearly and continuously as results are entered and records the trend of these results. The simple illustration shows the line which results on a cusum graph from plotting the following results:

26 27 26 25 24 26 23 26 27 28 28 28 29 30 30 29 27 28

These results can be set down thus:

Result	Target	Difference	Cusum
26	26	0	+55
27	26	+1	+1
26	26	0	+1
25	26	−1	0
24	26	−2	−1
26	26	0	−1
23	26	−3	−4
26	26	0	−4


68.2%
95.4%
99.8%
1s
1s
2s
2s
3s
3s
Break-even point
Total costs
Costs
Costs of rejects and reworking.
Quality policy standard
Basic manufacturing costs.
Margin
Costs of quality assurance
Quality level
Frequency f (number of measurements or results)
less than x̄
x̄
more than x̄
Range
Frequency
x̄
Frequency
Range
x̄
Frequency
less than x̄
x̄
more than x̄
Skew distribution
Normal distribution
target mean strength is established at 1.64 × s above strength
Target mean strength
Current margin
1.64 × s
Characteristic strength
5% of results less than characteristic strength.

Result	Target	Difference	Cusum
27	26	+1	−3
28	26	−2	−1
28	26	+2	+1
28	26	+3	+2
29	26	+3	+6
30	26	+4	+10
30	26	+4	+14
29	26	+3	+17
27	26	+1	+18
28	26	+2	+20

and the graph of these results is as illustrated. It will be noted that the shape of the line gives an indication of the extent of the variation, i.e., the steeper the slope, the greater the variation from TMS. From statistical principles, masks can be calculated which, when applied to the plot indicate a need for changes to be introduced to bring the results back within the predetermined limits related to the standard deviation. The approved standard deviation in the case illustrated is 6 N/mm^2 (this would mean that BRMCA members use a factor of 2 rather than 1.64 as their margin between characteristic and target mean strength) and that 33 N/mm^2 is required for a specific characteristic strength of 21 N/mm^2 at 28 days. The ready mixed concrete industry use, as a basis for their quality control measures of known properties, a reference mix with which the results of all other mixes can be compared. The industry also does a considerable amount of testing of specimens using accelerated curing techniques to allow prediction of 28-day results from tests conducted at early ages. The cusum points plotted in the illustration are those of range, mean strength and the correlation between three or seven days or similar approved accelerated results or the way in which these accelerated results related to the 28-day strength test results. This early testing ensures that quality control data is available early in the course of supply. The dotted lines in each case represent the masks which, in illustration, are those for an *s* of 6 N/mm^2. The masks are applied to each cusum point as it is plotted, a watch being kept for coincidence between the sloping lines of the mask and previously plotted cusum points. When some point of coincidence is noted, then action can be taken to correct the trend by changing the quality of cement which is batched for the mix.

Discussion on illustration

When cusum point corresponding to test result number 26 was entered onto the chart for cusum *M,* the mask line (for a 6 N/mm^2 standard deviation) coincided with a point 17 results previous (i.e., on the date when cube number 9 was taken). The coincidence with the mask indicates that a significant change probably occurred and from established data the change in mean strength can be established. In this instance the magnitude of change would be established as a decrease in target mean strength of 2.5 N/mm^2. The action taken to correct the situation would be to increase the cement content of the mix. This is assumed to restore the target mean strength and the plot for the mean strength *only* is restarted from zero.

When cusum point corresponding to cube result number 41 was entered into the chart for cusum R, the mask line (for a 6 N/mm^2 standard deviation) indicated that a significant change probably occurred 31 results earlier, i.e., on the date when the result from cube number 10 was entered from previously established data. The change in the standard deviation can be identified as a decrease. The decrease indicates that the results are grouping more tightly about the mean so that there is scope for reduction in

cube strength whilst maintaining the required design margin between mean strength and characteristic strength. The reduction in cement is made and it is assumed that the reduction in target mean strength maintains the design margin. The standard deviation plot *only* is restarted from zero. Due to the decrease in standard deviation for which the masks are calculated, it will be necessary to use a new mask for further analysis of cusum R and cusum M, and an immediate check must be made on the cusum M chart to detect any changes which may not have been detected previously with the higher standard deviation mask.

It will be noted that the adaption of cusum techniques in conjunction with known standards of production and a knowledge of the changes which can be expected as a result of varying the cement content, a very close control of quality can be maintained. Indeed, where increased control is required, masks of a different shape can be used.

Variability in construction and production

When the result of tests or the outcome of a survey of construction accuracy is considered, variations implicit in the method and those introduced by the operation of the method must be acknowledged. Implicit or process variations are caused by the presence of a number of individually unimportant and possibly immeasurable variations in the controls applied to the process, some of which cancel each other out. Others will affect the product to some extent, although mainly only to a small degree. Implicit variations cannot be completely removed from a process although they must be studied and where necessary some allowance made for them. There are variations known as assignable variations, however, for which reasons can be established and once these reasons are established steps can be taken to remove or adjust their effect. Assignable variations are usually larger than process variations and knowing the probable shape of a normal distribution, it can be stated with differing degrees of confidence, what is the probability of any variation occurring within the distribution. Exceptions can then be identified and isolated, in which case reasons can be sought for the exception and remedial action taken to bring the process back under control.

Bibliography

The following publications provide further, more detailed information on topics covered in the respective chapters of this book and will provide in-depth information vital to the supervisor as he progresses in his career and becomes more involved with the technology of concrete construction. A sound starting place for the supervisor is the *Man on the Job* series of leaflets published by the Cement and Concrete Association, which contain the basic information upon which instruction can be based, highlighting the importance of the operative's contribution to good construction practice. Another important source of information for the supervisor, covering more than 60 construction topics, is The Concrete Society publication, *Current Practice Sheets* (Volume 1).

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