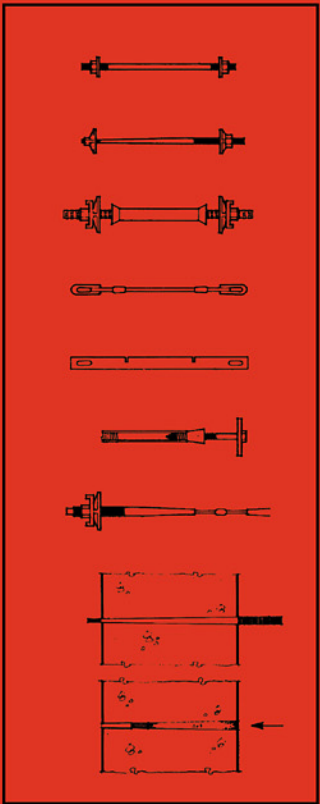
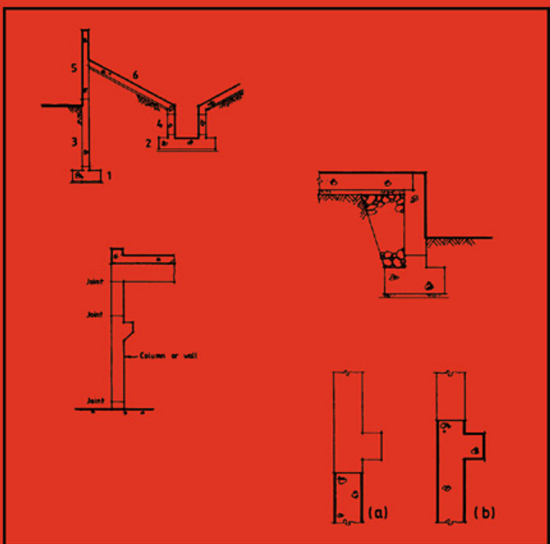


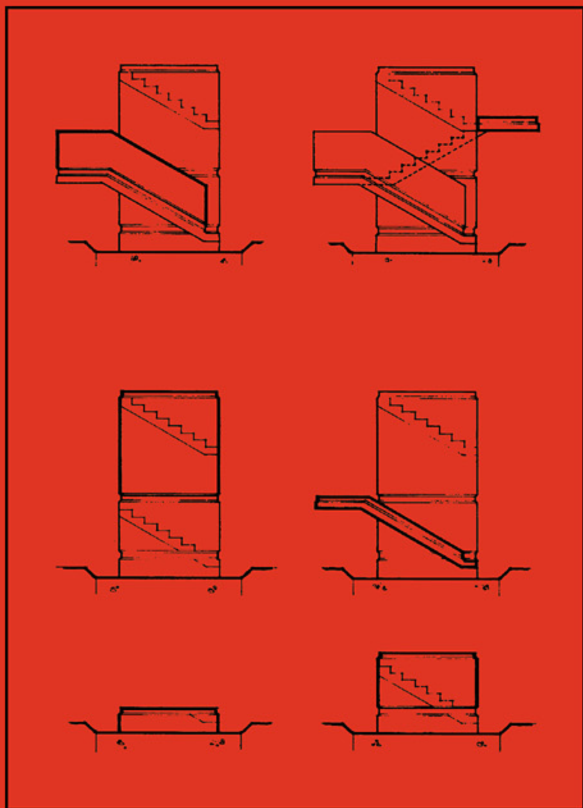
Supervision of concrete construction

VOLUME 1

by

JOHN G RICHARDSON





A Viewpoint Publication

Supervision of concrete construction

J.G.Richardson, MIWM, MICT

A Viewpoint Publication

VIEWPOINT PUBLICATIONS

Books published in the VIEWPOINT PUBLICATIONS series deal with all practical aspects of concrete, concrete technology and allied subjects in relation to civil and structural engineering, building and architecture.

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Contents

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 specifie British Standard or Code of Practice, it is advisable to check the status of such information with the BSI Catalogue—an annual publication, or by telephoning the British Standards Institution.

The author is indebted to the British Standards Institution for permision to reproduce those parts of Codes used in this publication.

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 workmanlike 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 ForrestHolden for all the assistance received in the preparation of the book.

J G Richardson
April 1986

1. Introduction

The author, John Richardson, has written this book with the intention of providing useful and informative material for the supervisor in the construction industry who needs to "know about concrete". Like John's other books in the VIEWPOINT PUBLICATIONS series, *Precast concrete production* and *Formwork construction and practice,* this book is intended as a practical guide for the man who must take charge of and be responsible for a particular part of the construction task, in this instance, construction using concrete.

This book is not intended as a textbook or reference work, and equally is not intended as a do-it-yourself instruction manual. It is intended as an introduction to a number of facets of concrete construction with which the supervisor will become involved when he undertakes decision-making in the planning and execution of concrete work. Where possible, the use of figures and calculations has been avoided, except where essential to the supervisor. The book sets down general principles of construction methods and outlines proven techniques. The material contained herein is based upon information gathered during the course of more than 30 years involvement within the concrete construction industry. The author has worked as an army engineer, a draughtsman, formwork designer/supervisor, concrete supervisor and construction manager and latterly as a lecturer on construction topics with the Cement and Concrete Association. At the Training and Conference Centre of the Cement and Concrete Association, John organises courses on various aspects of formwork and precast concrete.

Practical material discussed in this publication results from the author's involvement with tradesmen and operatives as well as professional engineers and architects in the construction of structures including chimneys, shafts, dams, silos, multi-storey construction and civil engineering works. The technical information on concrete has been largely derived during the author's employ with the Cement and Concrete Association and contact with lecturers and research personnel. John gratefully acknowledges the continuous input of ideas and information which he receives from the 3000 or more people, craftsmen, students, technicians and professionals such as architects and engineers, with whom he works each year in the course of training events at Fulmer Grange, and in companies within the United Kingdom and overseas. The practices described are, in many instances, based on traditional construction techniques. There is some mention of continually developing technology of concrete. Space is also devoted to statistics and, for those whose schooling has been left far behind, there is some basic mathematics (calculator batteries do sometimes fail!).

The author has concentrated on those aspects of concrete construction where he has the most to offer, where in his own experience he met with certain difficulties and where points arise which may be of assistance to others in the same situation. Most chapters are accompanied by a summary of key points and/or a checklist for the supervisor.

The whole, it is hoped, will provide a basic, easy to follow discussion of concrete construction, and the control of concrete operations with sufficient technical and technological background to set these activities into perspective. Armed with the book, the supervisor who comes into concrete from a trades background, from the drawing office, the services or any other of the diverse routes by which supervisors do develop, will have what is virtually a ready-reckoner, an "aide-memoire" to which he can turn for assistance when in need. It is the author's hope too, that the book will prove helpful to those students who, having completed the City and Guilds of London Institute Course *Concrete Practice* are studying for their Certificates in Concrete Technology and Construction, *General Principles* and *Practical Applications*. Here it has been borne in mind that the student often comes from some specialist employment yet must gain a general knowledge of construction principles.

On reading the book, the reader may become aware of different styles of writing from various other writers, specialists in their own particular fields, who have been invited to contribute towards this publication. The author wishes to thank his colleagues at the Cement and Concrete Association for help and advice so freely given, in particular Mr Chris Harris and Mr Bob Wilson. Mention must also be made of those chapters in the book written by Mr R Lavery, Mr Philip Owens, Mr Geo S Richardson, Mr D Wilshere and Mr Bob Wilson, who have contributed on specialist topics.

2.
Drawings and documentation

The supervisor commencing control of concrete construction, whether as a senior person in charge of the main construction or as a section supervisor responsible only for the activities relating to the concrete element (steel reinforcement, formwork and concrete handling, placement, compaction and curing), must be conversant with the detail, specification and commercial considerations governing that part of the contract. All information received, including drawing and detail, schedules for steel reinforcement and inclusions such as fixings, specification and construction programme, must be recorded and, whilst this will probably be carried out as part of the overall contract procedure, the supervisor would be well advised to keep his own local records, entries in a diary for instance, in much the same way as would a Clerk of Works. Such records are of immense value throughout the course of operations right up to the stage of preparing final accounts.

Specification

The supervisor must make himself conversant with local specifications and take time to study the various references made in the local specification to British Standards Institution Codes of Practice and Specifications. Much has been written on the topic of specifications and, in recent years, specifications have improved considerably. In the past, specifications were other than specific to a particular task and were written using a jargon which, on examination, proved to be irrelevant, uninformative and, in some instances, misleading. Phrases such as “all true to line and level” and “of the best quality” are quite meaningless and can lead to argument and upset. Today, specifications generally establish acceptable quality in terms of British Standard requirements or in terms of locally established standards exhibited in site examples, trial panels and the like. Attempts to improve a specification have resulted in various degrees of success. In terms of the attribute of external appearance, it is current practice to nominate existing samples or to set aside money within the Bill of Quantities for the provision of sample panels of sufficient size to allow the establishment of what is an acceptable standard.

With regard to the specification governing concrete, the supervisor will be concerned with the problems of achieving not only quantity of concrete output, but also with the maintenance of quality and accuracy. The specification may, in the case of *method*-type presentation, set down in detail the steps to be carried out in form preparation, casting of concrete, curing and so on.

Where the specification is set down in *performance* terms, then only the outcome in terms of appearance, accuracy and other physical properties will be noted.

The following commentary on requirements of typical clauses from a standard specification is intended for the guidance of the concrete supervisor in preparing and organising his approach to the concreting operation:

Points covered in Specification clause	*Points of supervision*
Schedule of finishes; means of achieving finishes; provision of samples	Ensure that requirements are clearly understood—know where samples are and how samples were prepared. Check drawings to ensure that the finishes for each part of the job are clearly indicated. Inspect samples and consider any particular problems arising such as maintenance of consistency, access for tooling, and timing of operations. View priced samples if not on current contract. Study publications giving recommendations on achieving finishes. Make any samples called for by contract, ensuring that these are representative of attainable standards.
Accuracy clauses	The supervisor should familiarise himself with the specific requirements for the contract and ensure necessary arrangements are made in form construction to avoid abrupt irregularities, ensure continuity of line, the location of building elements within the limits of the permissible deviations regarding level and plumb, and the control of sheathing joints and construction joints to avoid lips, fins and dislocation due to deflections.
Construction joint location relative to length and areas of concrete	Check that formwork system and specified joint locations are compatible and the locations allow gainful work for all trades. Discuss in detail with engineers.
Cleanliness of joints and surface preparation	Recommend up-to-date techniques, wash and brush, grit blast and similar preparation.
Location of inserts, holes and chases	Ascertain the purpose of the various details. Ensure characteristic accuracy to be expected from the concrete method will provide adequate clearances, accuracy and so on.
Type of release agent and retarders	Ensure that method of use, application and special instruction regarding mixing, storage and so on, are established and observed.
Provide drawing and calculations for formwork and falsework	Seek special instruction regarding rate of fill. Ensure where admixtures are to be used that designer is aware of implications. Study

	requirements regarding footings and foundations, lacing, bracing and tie arrangements.
Cambers	Devise means of setting up forms and measuring in-built camber, study implications in terms of service installation, attachment, and so on.
Form ties	Be familiar with available equipment and realise the problems of concrete operations where through ties are not allowed. Devise means of making good tie holes. This may require special attention if the holes are to be an integral part of the design aesthetics.
Surface treatments	Understand various available materials and be familiar with means of application to achieve consistency of finish.
Striking times	Check that proposed methods comply with specification, discuss variations and propose means of determining reduced striking times (through accelerated curing, strength assessment, maturity and so on).

Further specification clauses covering placing and compaction, curing and protection of concrete, and so on, are dealt with in greater depth elsewhere in this publication.

Bill of Quantities

Produced by professional quantity surveyors, the Bill of Quantities forms a part of the contract documents and establishes for contract purposes the amount of the input by the contractor, his sub-contractors and specialist suppliers of materials, labour and services. In what is known as the "preliminary" clauses of the Bill, the facilities required to enable this input are noted in terms of supervision, accommodation, welfare facilities and so on. Reference will be made in the preliminaries to such items as curing, which are not measured but are required by the specification covering the works.

Bills of Quantities are priced by the estimator and the figures established form the basis of the quotation or tender by the contractor in his bid to obtain the work. It is usual for the site manager to have access to a priced Bill of Quantity for guidance and in most cases a surveyor works closely with management in placement of orders for materials and services, negotiating to obtain favourable prices.

Bills of Quantities can be misleading in a number of ways and the supervisor should be careful in interpreting the figures which he may see on the priced Bill:

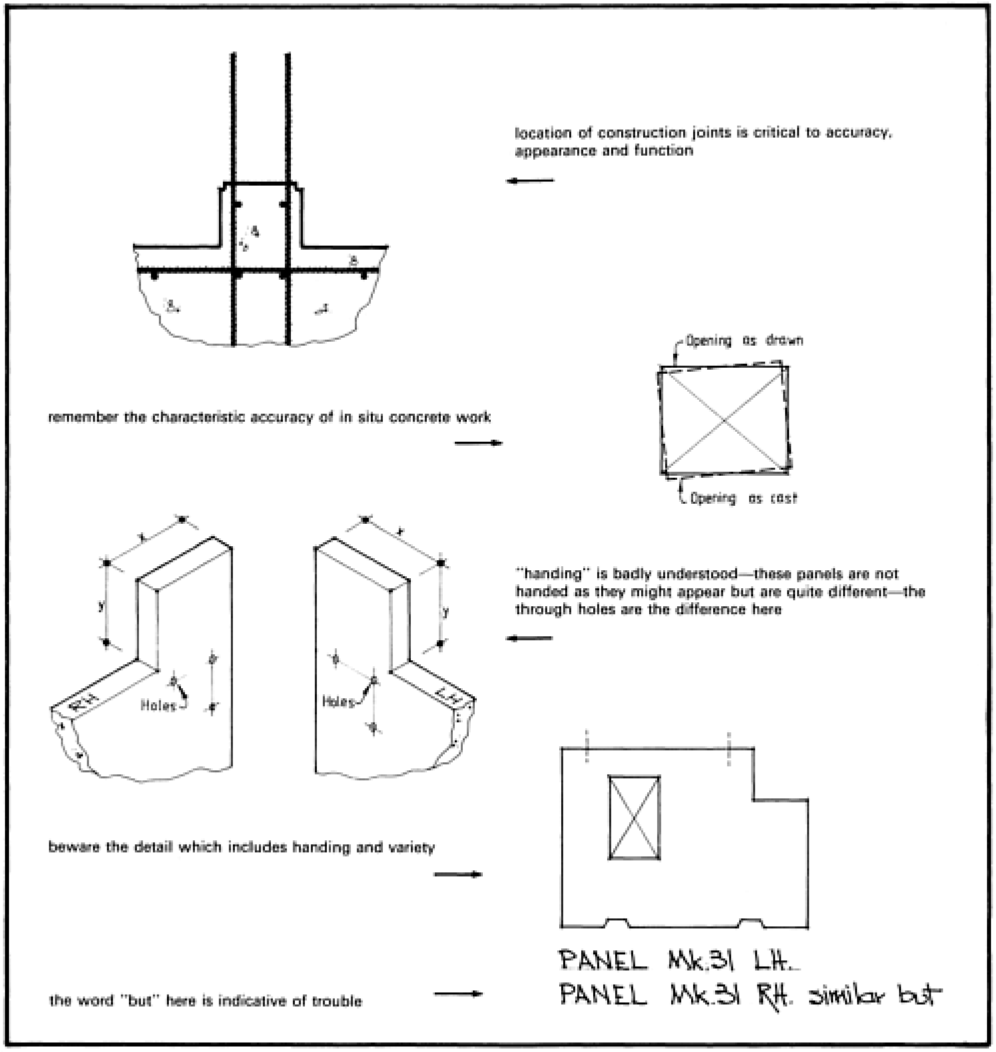
1. The rates are probably weighted in such a way that cash flow, payment for work done, is regulated to the contractors advantage.
2. The rates which have been published may have been modified by negotiation with suppliers at the time of placing sub-contracts.
3. The methods of measurement do not always directly reflect the amount to be paid for individual items of work—many rates are of an average nature such that the cost of complex forms, for example, are balanced out by straightforward work elsewhere—detailed breakdowns of cost used in preparing

tenders are the only way of establishing the true allowances for specific items and the estimator's advice must be sought when establishing methods.

The supervisor must bear in mind that his company has contracted to construct a particular structure to some established standard of workmanship and that this must happen. The fact that the Bill rates may not appear to allow the work to be carried out profitably cannot be allowed to affect the overall outcome of the contract.

There are, however, a number of points of supervision which emerge. Where, for example, some vagueness in description and specification may cause doubt as to the contract requirement, this should be cleared up prior to proceeding with the work. Where variations are made to the published detail, these must be recorded and a note made of consequential costs (such as hire of extra equipment, access scaffold and such like), and the information must be formally passed to the contractor's surveyor. Records should be maintained of attendance at site of nominated sub-contractors, particularly the unloading and positioning of equipment, provision of special access facilities, and so on.

The question of expertise arises and in many instances conditions of contract attempt to lay the onus of sound construction on the contractor rather than the designer. In the event, if in the opinion of the experienced supervisor the illustrations or drawings guiding construction are unlikely to produce satisfactory results, then this must be discussed with management or a suitably qualified surveyor. In general terms, whilst variation orders (more commonly known as Architects Instructions or AIs) must be obtained to cover alterations in construction once a method has been established, costed and set into motion on a contract, changes can become expensive in the short term by delay and upset and, in the long term, in

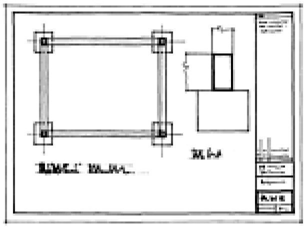


the settlement of accounts between contractor and client.

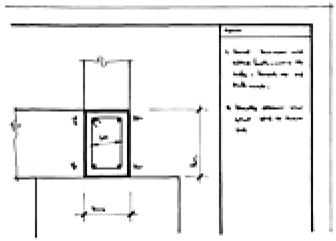
The following are some typical areas covered by Bills of Quantities, the implications are indicated by way of guidance for the supervisor:

"Approved" or "Approval" shall mean approved by or approval of the architect or engineer in writing	The supervisor must ensure that materials and services are provided by approved sub-contractors and suppliers. Substitution in the event of delay or emergency, whilst wellintentioned, could result in subsequent rejection and additional cost. The approval does not relieve the contractor of his

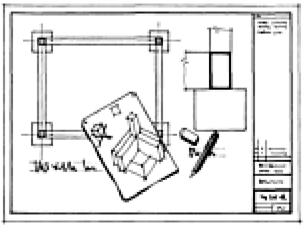
	contractual responsibilities for quality and standards of work.
Precast concrete and specialist supplies	Ensure that the architect has access to newly manufactured units and production facilities.
Concrete mixes	Trends are towards the use of BS 5328 in specification of concrete. There will be items in the Bill to cover the cost of trial mixes in establishing appropriate concrete to meet strength criteria.
Readymixed concrete	The supervisor must ensure readymixed concrete has been approved and should check the status of the supplier in terms of acknowledged Quality Assurance schemes.



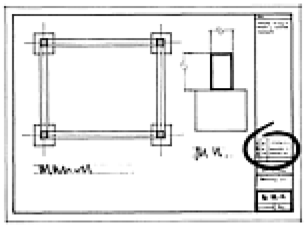
drawings should be scrutinised for errors, also to ensure that revisions are noted and revised drawings are correctly circulated



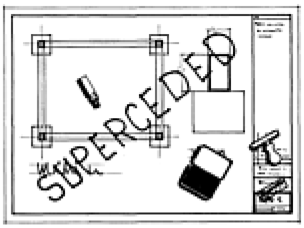
do not be misled by local sections—always check for changes in section and hidden geometry



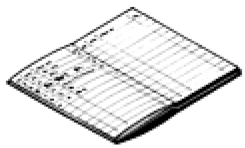
to check a drawing for full information try to sketch the element from the information given



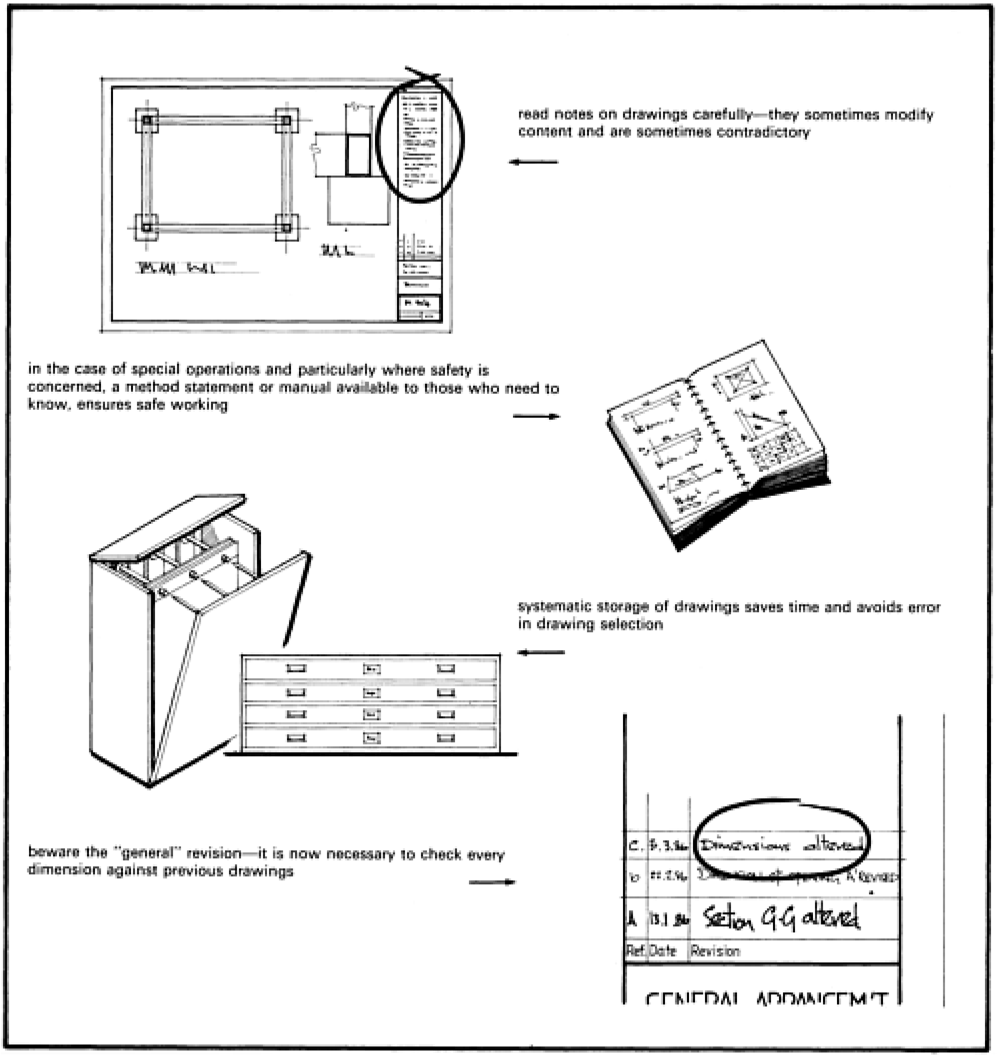
ensure that the drawing in use is the latest revision available



mark all revised drawings—retain one copy for reference purposes



drawings constitute contract documents—always maintain a drawing register, recording dates received, revisions, distribution and so on



Storage of materials	Appropriate sums will be set aside for the proper storage of aggregate, cement, steel and so on, and the supervisor should ensure that the actual standards of storage are adequate and acceptable.
Final preparation and inspection	The supervisor must ensure that required notice is given to allow inspection of steel, fixings and detail before concrete is placed.
Curing concrete in extreme conditions	The supervisor must ensure suitable arrangements are made to protect concrete and prevent drying out and similar shocks when fresh.

Drawings and schedules

In the case of incoming drawing and detail, a careful note should be kept of the status of the drawing, revision number and date. It is very important that outdated or superseded drawings be withdrawn and destroyed, but one cancelled copy should be stored for future reference. Most contracts involve the multiple issue of drawings to various sections of work, various sub-contractors and suppliers, and it is vital when a revision is necessary that the information is made available to all parties concerned to ensure that different people do not find themselves in possession of outdated and different information.

Where concrete is concerned, although the architect's drawings are useful in keying the various items of information, the structural engineer's drawings govern the concrete profile, location of steel, openings, sections and so on. Sub-contractor's drawings, such as those for services, lift installations and such like, are specific to particular locations of those services, but the structural engineer's drawings invariably note that the specialist supplier's drawings should form the basis of the detail here. The supervisor will be well advised to spend time familiarising himself with the initial issue of structural drawings and then carefully study all further issues of drawings, particularly revisions. The latter should be checked to ensure that changes in section and, for example, additional features which become necessary as the details of the structure evolve, are noted and incorporated in the actual structure. The designer has, with good intent, produced initial outline detail upon which the tender and programme has been based, but unfortunately in most instances this has to be revised as work proceeds due to changed needs of the client or the emerging requirements of specialists, such as the fixing or cladding supplier. In general terms various revisions which *reduce* sections or change the position of openings in the concrete can be simply incorporated up to the stage of closing the formwork, requiring as they do some alteration to steel location or the inclusion of a box or stool. Revisions which *increase* sections, floor thickness, or call for the incorporation of projecting nibs, corbels or steel reinforcement are troublesome and often expensive to include.

As part of the checking procedure of incoming drawings involves contact with the Clerk of Works or Resident Engineer and may affect the overall financial arrangements in terms of extra payments, for example, this contact should be formalised and alterations documented in terms of written instruction from these authorities. It should be noted that any alteration emanating from the Clerk of Works, for example, will be on the written instruction of the architect. The Clerk of Works is not empowered to initiate alterations without that prior consent.

In the process of familiarising himself with detail, the supervisor will find that sketches and even simple models will be helpful in the visualisation of the concrete components of the structure. Models are particularly useful in assessing the geometry involved, as well as assisting in planning the sequence of operations, determining crane movements and similar details which are difficult to visualise. Simple block models of each lift or bay of a complicated structure are helpful in all aspects of planning and allow discussion of problems with all concerned.

Steel reinforcement details and schedules

The structural drawings for the concrete element of the contract will indicate the exact location of all steel in the construction. These drawings must be read in conjunction with the reinforcement schedules which describe every piece of steel in terms of shape as set down in appropriate British Standards.

It should be appreciated that the simple lines indicated in the structural drawings can be misleading. A simple line indicating a link or stirrup bar in a corbel is easy to include on the drawing board. However, a line has little thickness and to actually include the substantial bar of steel, bent to BS shape recommendations, that the line represents within the concrete profile, often proves difficult and sometimes impossible. At the ends of prestressed beams, considerable reinforcement is included to contain the bursting forces, for example—again, these steel bars can be simply drawn and yet when translated into actual bars in three dimensional form, extreme congestion often results, almost to the point in some instances where it may prove difficult to place concrete and, moreover, to introduce a poker vibrator to compact the concrete.

Many inserts and inclusions are incorporated into structural concrete in the form of inserts for fixings, fastenings, bearing plates and billets at connections, projecting bars and dowels for connections between precast elements or between in situ and precast concrete. These inclusions must be detailed and scheduled, as must the specialist's inclusions for lift fixings, control gear, plant installation and the like. Omission of any of these fixings can prove expensive, requiring as they may plant and equipment for subsequent installation. The supervisor should familiarise himself with the various types of fixing and fastening which will be used on the contract and ensure that he and the joiner or carpentry supervisor are quite clear on the location and method of installation of such fixings, fastenings and inclusions.

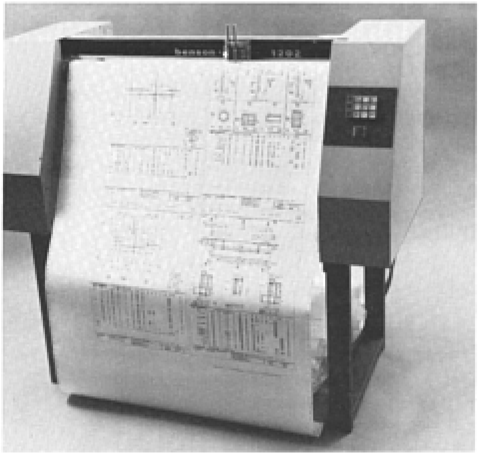
The supervisor should be aware of the recommendations of BS 8110 (CP 110, CP 114, CP 115 and CP 116) regarding the accuracy of location of the steel reinforcement within the concrete section with particular reference to the less obvious requirements of end cover and the maintenance of location and stressing ducts within specified limits.

Drawings and details prepared by the contractor

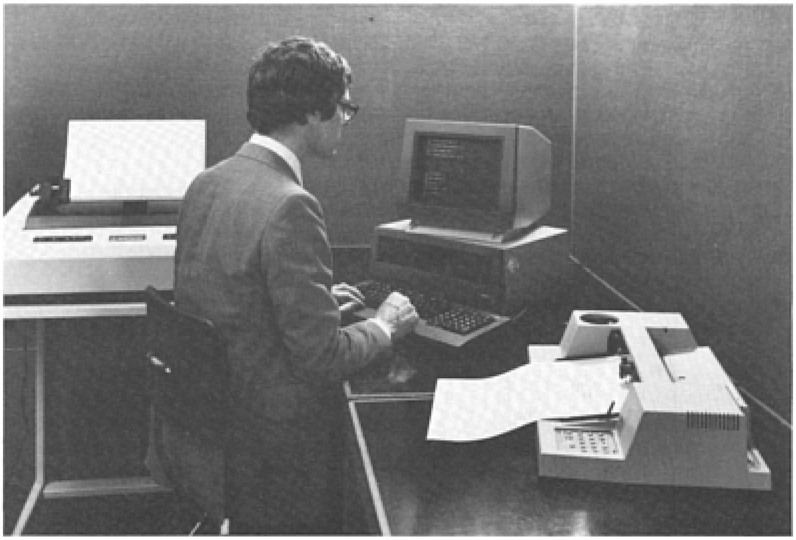
As part of the contract procedure it is normal for the contractor to provide drawings of special aspects of the work, falsework and formwork detail and drawings, indicating specialised aspects of the construction, such as method and sequence of groundworks, excavation, supporting works and so on. The supervisor must interest himself in all these matters with a view to obtaining the best possible understanding of the way in which his work dovetails into the overall effort of construction.

Programmes, pre-tender, long and short term, are generally presented to the authorities. Often as part of the contract requirement, the contractor produces programmes in bar form and latterly in the form of a network diagram illustrating the dependencies of each activity upon others in the construction. It is not unknown for contracts to be let on the basis of the network or programme—particularly where the work duration is critical. Whilst governed by the long term plan, the supervisor concerned with the concrete frame or structure is most affected by mid-and short-term programmes, particularly those concerning falsework and temporary works and the interaction between these activities and those of handling, placing, compacting and curing the concrete. Study of the various programmes often facilitiates the identification at an early stage in construction of problem areas and dependencies which may not have been apparent to the estimators or planners. Care taken in the discussion of problems which arise and choice of solution which is promotional to the contractor's method and timing can make a major contribution to speed and simplification of work. The capable supervisor has a natural feeling for what is likely to be the most straightforward approach to the concreting operation and can be helpful to the detailer in simplifying detail, ensuring adequate access for placement and compaction of the concrete section and so on. Such simplification must bring improvements in the long term in terms of output and must make useful contributions to the reduction of programme time for a particular operation.

Where the tender is based upon a method specification, the supervisor must ensure that he is familiar with the proposed method. This will be apparent from method statements and, in the case of more complex work, there will be drawings to assimilate. It is important to check that the proposed method is likely, in the light of experience, to provide the required results. Where subcontractor's drawings are being submitted to the authorities, the supervisor should, if possible, have sight of these drawings which will perhaps relate to



Output on a Benson Plotter combines drawing detail and bending schedule for column, beam and slab construction



Plotters and VDU equipment in use in the process of computer aided design and detail

support systems, access scaffolds, and so on, and which are, of course, vital to the supervisor in the performance of his own tasks.

Apart from the general site and plant layouts produced by the contractor, the most critical site detail is probably that of crane layout. Here the concrete supervisor must be aware of the implications of location of the crane relative to the most critical sections of his works. Crane layout will undoubtedly have been planned with regard to the overall requirements for handling and placing materials and elements about the site and the supervisor should ensure that the proposed location caters for his specific requirements in terms of provision for critical activities, such as striking of cross wall or table forms, where handling aspects of the activity are influenced by the presence of the newly placed concrete and, for instance, by the presence of projecting reinforcing steel starter bars and such like.

Checklist

Is drawing register up-to-date?
Do we have the latest revisions?
Are the structural drawings available?
Are specialist's drawings (services, lift engineers, etc) available?
Are schedules and Bills of Quantities available?
What does Specification say?
Have samples and standards been established?
What are key features regarding finish and accuracy?
Do we have details of inclusions, cast in connections, etc?
Can we modify detail to ease construction?
What drawings must we submit?
What methods are specified?
How does Specification affect construction techniques, timing of operations and so on?
What are the established lines and datums?

3.
Planning the construction process

All contracts involve programme consideration. Whilst the contract period is often determined by the client prior to invitations to tender, the contractor is frequently required to quote a specific completion date for the contract. The contractor must, as a condition of contract, submit detailed programmes for the works and it is not uncommon these days for a network to be required as a part of the contract documents.

The estimator, in consultation with contract management and specialists, produces a form of method statement which relies on a sound assessment of timing and sequence of the construction operations. This method will be adopted once the contract is secured and, whilst the overall programme and construction time established is a matter of policy and the province of senior management, much of the short term planning of operations must be instigated by site management and supervision.

In the case of the larger building and civil engineering contract, the overall planning and selection of method is likely to be carried out by skilled planning and method engineers employing sophisticated techniques, often involving the use of a computer together with basic data established from previous contracts. Planning engineers working in conjunction with such specialists as plant engineers, mechanical heating and ventilating engineers, specialists in service installations, and formwork and falsework designers, produce the final working method statement supported by site layouts, plant layouts and formwork and falsework drawings. Schedules of target outputs are prepared which will be used to set target labour rates and to establish incentives. The whole of this effort is directed toward the establishment of a programme which, if met, ensures that whilst satisfying the requirements of the specification, the work yields the returns required to cover overheads and to provide a margin of profit consistent with the financial risks involved.

Planning processes vary from the highly sophisticated analysis and plan produced by computer to the simple bar chart or histogram used to convey instructions and information at site level. The methods discussed in this chapter can all be advantageously employed by the supervisor in his role of instructing men and co-ordinating and controlling them at work. Planning involves visualisation or simulation carried out methodically by people who have a sound knowledge of the activities involved and assists in the day-to-day processes of construction with which the supervisor is concerned, by:

permitting forward ordering of plant and materials;

promoting sensible use of resources such as skills and expensive plant and equipment;

providing dynamic control of processes by setting targets against which actual progress can be measured;

improving communications by providing a central reference or datum by which all parties to the contract can regulate their efforts;

ensuring the availability of design detail and schedules at the appropriate time;
ensuring the co-ordination of work carried out by specialists;
providing an opportunity for review and comparison of various available processes.

The achievement of these objectives depends upon programmes being presented in such a manner that they can be simply up-dated when necessary and that when updated they will emphasise alterations in demand or resources, pin-pointing specific activities critical to the duration of the work. If the programme is to be successful it must be realistic, based upon targets established in the light of experience. Whilst programmed outputs may be greater than those previously achieved, they must be feasible in the light of the best information on advances in techniques and developments regarding method available at the time. Other detail used in planning must be based upon specific surveys, samples, trial batches, mock assemblies and similar research.

The supervisor and those under his control ultimately determine the degree of success achieved in the planning. Successful planning will involve provision with the programme of lead times, time for contingencies and "float time", or time in which the start and finish of activities may be adjusted without upset to the overall progress of the contract. In other words, room to manoeuvre, to consider options and to organise the work in a dynamic fashion. Whilst planners allow for such variants as weather, holidays and similar interruptions to production, it should be remembered that weather, for example, may dictate the introduction of additional or special plant and equipment to ensure continuity of construction. Such eventualities cannot be planned. Arrangements can, however, be made to accommodate necessary changes to a well planned programme.

For programmes to be successfully implemented they must include means of measuring progress as well as comparison between programmed and actual production. The plan as presented at supervisory level and trade level must be such that using it the supervisor can measure progress in the short term and can be sufficiently informed to be able to adjust his method of working or resources to maintain the required outputs. The plan must also be sufficiently detailed to allow take-off of materials and ordering of plant for discrete sections of the work as well as establishment of labour and resources demands by section and by trade. The following are some of the better known planning techniques used within the construction industry, which have proved helpful in control and assessment of outputs.

Graphs

Whilst graphs can be used to allow a review of information and provide an indication of trends and comparison of targets against output, they are not particularly valuable to the planner. Unfortunately graphs have been abused in the past, particularly by the media, where distorted scales and the use of false origins have been used to mislead the reader. Graphs of results from tests, of labour turnover and of outputs resulting from various methods can be useful, although more recent charting techniques such as the cusum technique, have more to offer in that they clearly identify trends and can assist in decision making. Graphs and cusums are covered in detail in other chapters within this book. They provide a useful means of storage and retrieval of basic data on outputs and so on, and allow instant comparison by superimposing the results of one technique onto the results of another.

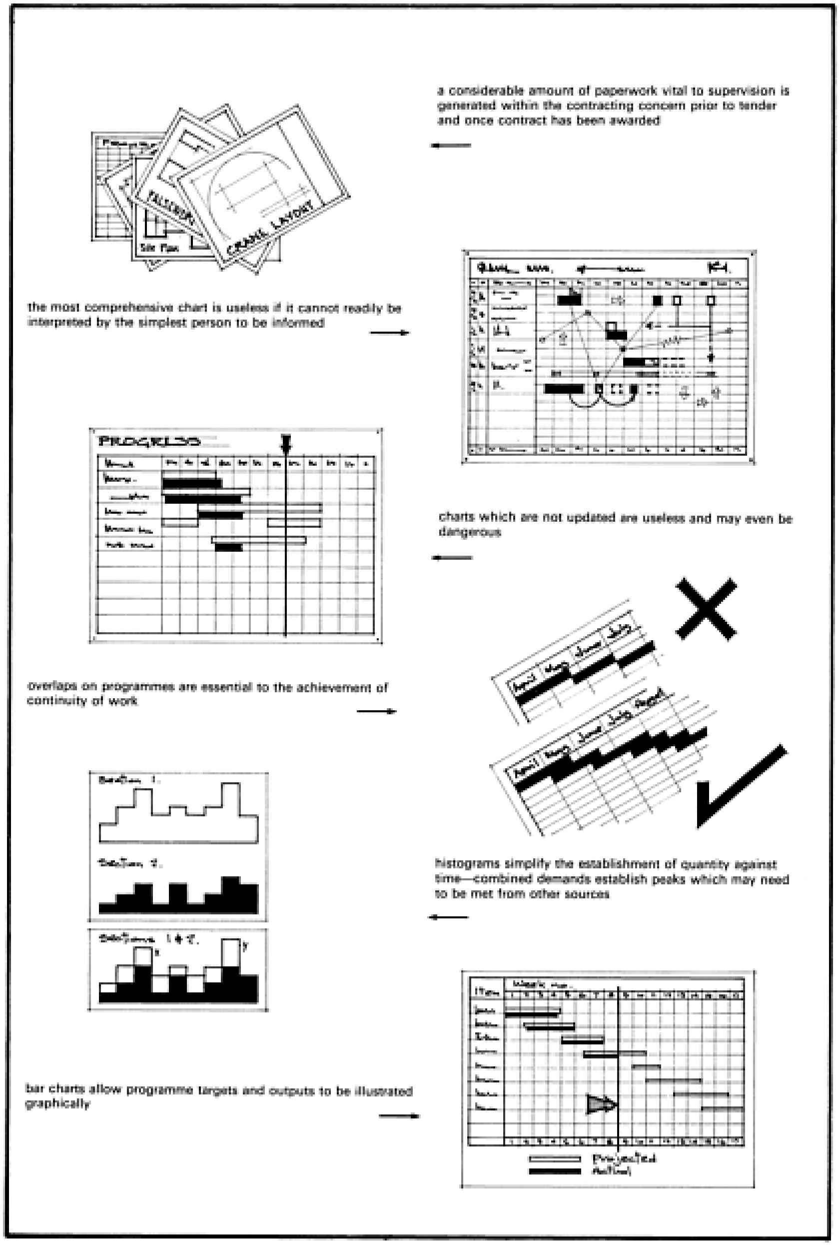
Histograms

Histograms, or frequency distribution charts, are prepared by first clearly establishing the data to be plotted. Typical applications include labour requirements, materials requirements, output from equipment and situations where frequency or demand is to be set against time. For example, consider a situation where several sections of a contract are to place demands on a site batching plant. Forthcoming demands can be established from projected programmes and quantity when plotted against time in weeks, days or hours. The varying demands can be superimposed one upon the other so that peaks can be identified. The overall demand can then be compared with the available supply and decisions can be taken regarding smoothing of the demand by reprogramming certain activities or by introducing further supplies of concrete from a readymixed concrete supplier. From the illustrations it can be seen that the combined demand clearly exceeds available supply on three occasions and marginally on one occasion. It may be possible, by replanning the activities causing peak *x* to avoid any need to import materials from the readymixed supplier and speeding operations by some addition of resources may avoid the problems at *y*. This pictorial representation of fact is extremely helpful when rapid assimilation of information is required, such as when schemes are being outlined in planning conferences and site meetings. Histograms can simply be produced by computer and adjustments made by programmed techniques.

Bar charts

The time honoured programming technique of bar charting is without doubt the best known means of illustrating projected production and providing a visual means of assessing actual output and progress. In recent years adaptations of bar charting, which indicate dependencies of one activity or part of the work upon another, have made the bar chart a powerful planning tool. Unfortunately, bar charting allows only limited amounts of information to be displayed, although the use of computers with their immense capability for data storage and retrieval allows the preparations of very meaningful charts for specific parts of the work.

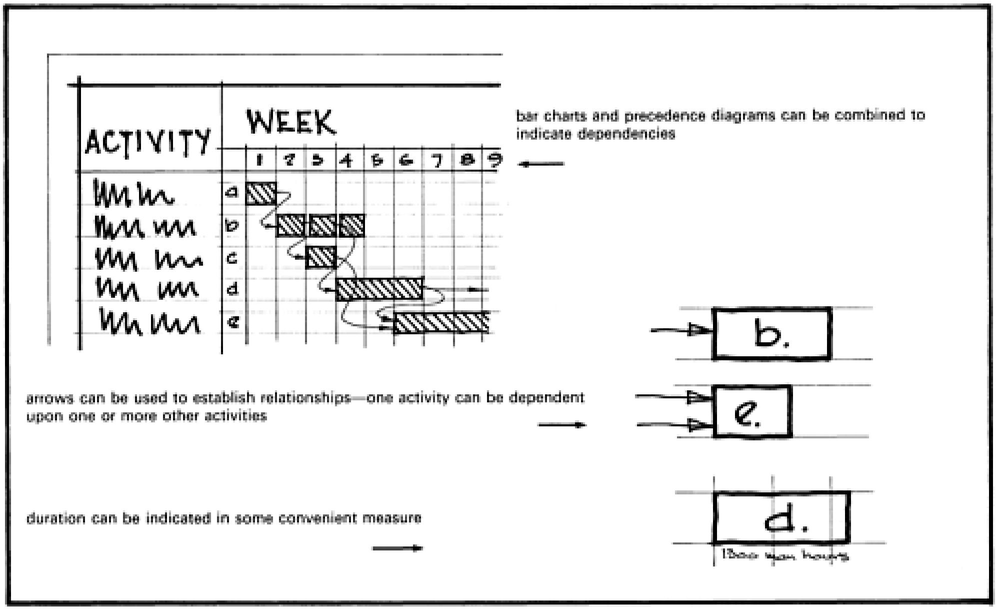
The bar chart is valuable in indicating overall intention and, as with a histogram, can be used to compare the relationship between various parts of the work and the demands on resources. It is vital, if the charting is to be used as a control measure, that the charts be kept up-todate—many charts on display on construction sites are often difficult to understand and/or out-of-date. It should be mentioned here that, if they are to be really useful, charts must be simple enough to be understood by the least qualified of persons who will be required to make use of them. The charts indicate, in the simplest terms, using lines or bars, the period of time allocated for a given task and where that period is within the overall programme for all tasks in that part of the construction. The chart can simply display target dates and key points in time, although secondary information can be incorporated using additional bars or lines to indicate actual progress, resources allocated, and so on. Where the purpose of the chart is such that apart from showing the projected time and actual progress, it is to be used as a dynamic tool in the planning of the work and to allow the interrelation of parts of the work to be assessed, then it is essential that the dependencies are indicated and that the float or permissible variation in timing and time allocation of tasks becomes clearly evident. This arrangement, *precedence planning* as it is known, ensures that the effort expended in preparing charts and diagrams is repaid by ease of planning and economies achieved through careful resource allocation.



Programme charts which show each operation commencing on completion of a previous activity are evidence of lack of understanding of work content and pattern of construction. Equally, charts indicating a large number of discrete operations are not generally helpful, nor are charts containing a mass of details of meaning only to the planner. A chart should indicate the projected programme and the progress made to date—simply and in a way in which it can be understood by everyone.

Precedence diagrams

To assess the interrelationship between various activities and the importance of specific tasks (which may change daily or even hourly as work proceeds), a precedence diagram may be produced, whereby each activity is represented by a box (replacing the bar of the simple bar chart). Arrowed lines joining the boxes are used to



indicate the relationship between the different activities. The arrows can be used to show dependency on more than one preceeding activity and also to indicate absence of any dependency on a previous activity. It is usual in precedence diagrams to indicate the duration of activities using some standard measurement such as man hours, machine hours, and so on, with the same unit being used for every activity. By taking the available sequences or paths through the precedence diagram, the total duration of each series of dependent operations can be established. The sequence of those operations presenting the largest total duration will determine the minimum overall contract period. That sequence with the largest total duration is known as the *critical sequence* or *critical path,* the duration of which is the shortest time in which the total programme can be completed.

A combination of bar chart and precedence diagram can be produced in which the start and finish of activities critical to the overall duration must be coincident in time and will, theoretically, be located one above the other on the chart. The critical series of operations can be clearly identified by hatching or colouring and by reference to this critical path, the float or free time of other activities can be gauged. Arrows can be used to establish relationships between various activities. An activity can be dependent upon one or more other activities. Duration of activity can be indicated in some standard measurement such as man hours. The overall duration can be established by summing durations of the activities on the critical path. The establishment of precedence allows the planner to adjust the timing of activities in such a way as to optimise his available resources.

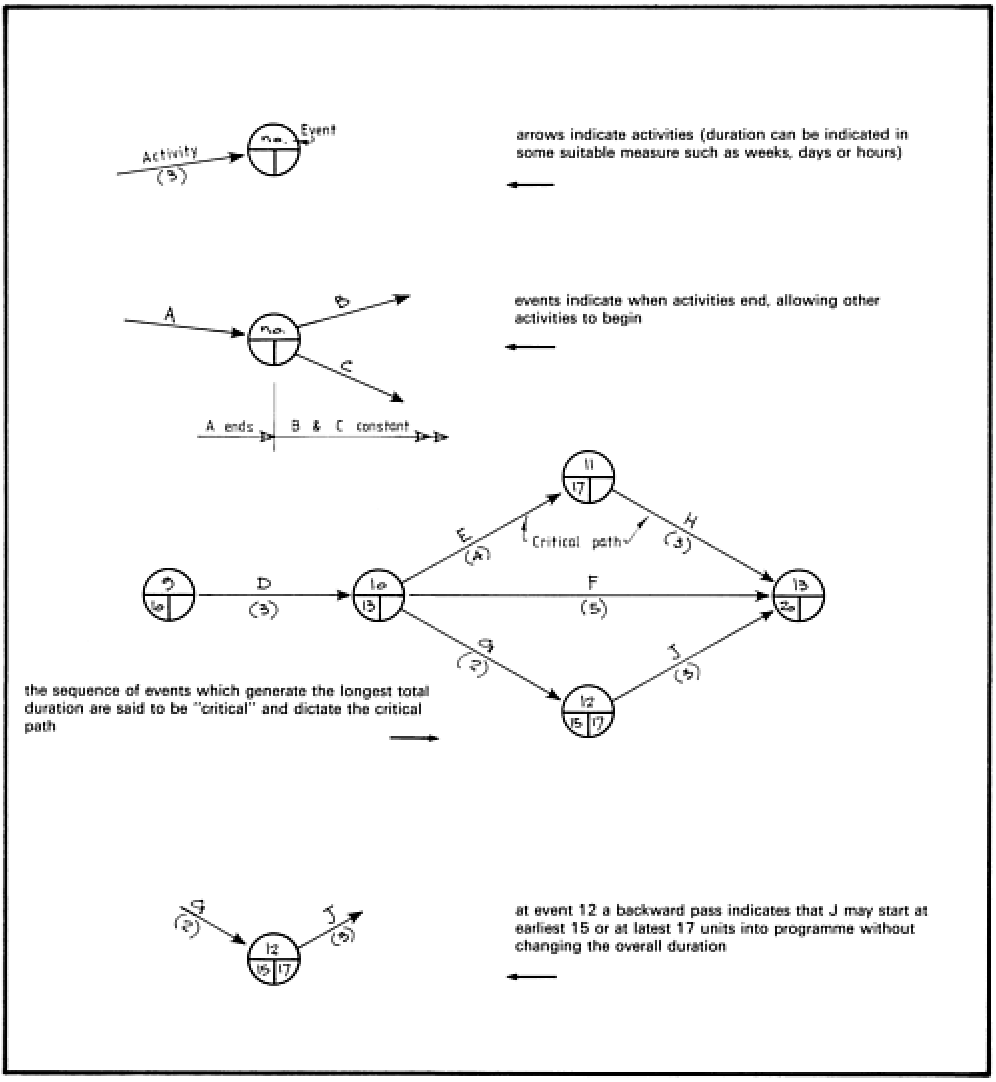
It must be emphasised that these techniques are of value not only in the planning stages but also as a control measure as work proceeds and progress is made in the various activities. The emphasis on, or importance of, the various stages may change as the work proceeds and as more or less progress is achieved in other parts of the construction. The critical path may change many times in the course of a contract due to contingencies, delay or exceptional progress.

Networks

Network, or planned evaluation and review techniques, are extremely powerful means of planning, programming and controlling the construction process. Produced by a person skilled in the process and with a sound knowledge of the construction task, they provide a means of examining the logic of the proposed method of construction and sequence. The system and form of presentation of networks vary, but they all provide opportunities for the assessment of the probabilities of success in meeting the projected dates, allowing for dynamic adjustment to method, whilst they can be produced simply and by manual means. Where the networker has access to a computer, then the updating of information and adjustment of the structure of the network can be carried out daily, even hourly, and almost certainly on demand.

Most planning tools are a means of presenting information such that dependencies are highlighted and, perhaps more important, the logic of the proposed sequence of construction is tested. Networks allow the relationships of activities to be established and adjustments to programme to be made in a dynamic fashion as work proceeds. A considerable range of network techniques has now been developed. These systems indicate the programme by activities using arrow (critical path) methods or can be event orientated (planning, evaluation and review technique), the latter method being used in calculating the probability of completion at the targetted time.

Taking the simple critical path method, which can be prepared for most site operations, the actual network or illustration provides a helpful visual indicator of the logic of the series of activities involved. The diagram uses arrows to indicate activities. At the node points of the network there are boxes or some suitable indicator into which information can be entered as work proceeds. The network illustrates the logic of the process only. The arrows and node indicator are not intended to exhibit any geographical or time relationship. Activities are discrete parts of the process which require resources of time, labour or equipment. Events are points in the process where one or more of the activities end, thus allowing the commencement of successive activities. By working through the various paths, it is possible to determine the earliest times at which certain activities may be commenced taking into account their dependence on preceding activities. This is termed a *forward pass*. The total time established by following the logical dependencies through the network is termed the *duration* and the series of activities which determined the overall duration are said to lie on the critical path. Having determined the duration by making a forward pass, the float or leeway on start or finish time for activities can be determined by making a *backward pass* through the network. This float can be used to advantage in reallocation of resources. Activities can be scheduled over an extended period, or other periods of time made available to enable reduction and rescheduling of activities on the critical path. It becomes

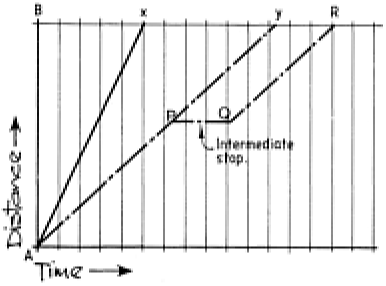


apparent that the critical path can thus be altered, the emphasis or urgency being transferred from one to another of the activities in the network at will. The planner must constantly watch for such changes of emphasis which may emerge as he changes his approach to planning a particular contract. Of course, during the progress of the contract these changes become involuntary, being dictated by output achieved, contingencies arising and such like. During the course of the construction, progress can be maintained using the network. Changes in outputs and thus duration of activities can be entered into the system and the resultant changes in emphasis noted. Computer planning programmes allow almost instant rescheduling and provide a dynamic source of management information. These days networks are frequently used as part of the contract documents.

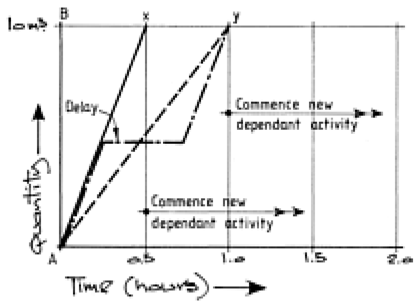
Line of balance

The technique employed in line of balance planning and programming is that of plotting projected outputs against time. Line of balance techniques allow the best of outputs for each section of the construction task to be achieved and the start and finish times for the various activities to be so arranged that interruption and upset between the activities is minimised. Most supervisors can plan informally (in their head, as it were) the activities of a small team of operatives or the activities of several trades involved in a particular task. Line of balance techniques formalise these arrangements and allow them to be set down, manually or by computer, in such a way that a clear picture of relationships and dependencies emerges.

A simple form of line of balance is used in the preparation of transport timetables, where time is set against distance travelled. In the illustration, the solid line *Ax* is the plot of a fast train travelling from *A* to *B*. The chain line *Ay* is evidently the result of slower progress over the same distance. Should there be some interruption to progress, then time will elapse without distance being travelled and a horizontal line will represent this situation *[PQ]*. Once progress recommences the line will revert to

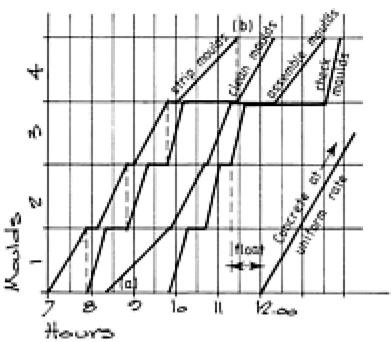


Ax—fast train
Ay—slow train
APQR—stopping train



placing concrete—Ax—non-stop into 10 m³ bay at the rate of 20 m³/hour, Ay—at 10 m³/hour (dotted), and Ay—at 20 m³/hour with delay (chain-dotted)

horizontal line indicates delay



line of balance plot for four moulds—stripping continues to b whilst assembly can commence at a, so new team is required—horizontal lines indicate when teams are free for other activities the appropriate slope indicating progress.

The line of balance between work rate and a specific task is indicated in a similar fashion. As shown, the overall task (or part of the task) involves the placement of 10 m^3 of concrete. The line *Ax* indicates the progress where placement is carried out at a rate of 20 m^3/hour and *Ay* where 10 m^3/hour is achieved. Clearly it would not be possible to commence an activity dependent upon activity *AB* until point *x* or *y* had been reached, i.e., 0·5 hours or one hour into the programme, depending upon rate of progress. A delay in the progress would be indicated by a horizontal line, in which case the work is proceeding at the rate of 10 m^3/hour and will still be completed in one hour.

An illustration of simple application of line balance techniques is that where a series of interdependent activities have to be carried out, for example, in the casting shop within a precast works where several similar moulds must be stripped, units removed, moulds cleaned, steel reinforcement assembled and mould re-assembled ready for filling. Evidently each of the tasks will be completed at differing rates and the production engineer must establish the best programme, taking advantage of free time to fetch equipment from the stores, take refreshment breaks and so on. For the purpose of explanation each of the four activities illustrated is being carried out by a different team of operatives, and it can be seen that some delay occurs in each case on completion of every mould. This time can be utilised in fetching subassemblies, steel and such like. As planned, because commencement of re-assembly of mould 1 (shown as point *a*) occurs before completion of stripping of mould 4 (point *b*) [dependencies are established by the vertical projection of points onto the time axis], it would not be possible to use the stripping team for the re-assembly task if concrete were intended to commence mould by mould immediately on completion of re-assembly. Adjustment in the timing of activities, either by speeding stripping or delaying the start of concreting by inserting what would be a necessary inspection of assembly, would allow the stripping team to proceed with concreting and ensure an economic flow of work. Where tasks are complex and a number of trades or skilled operatives are involved, the line of balance technique is particularly useful.

Planning procedures for a small concreting operation

Basic data should be consulted and the method intended in pre-tender plan established.

Specialist activities, plant and equipment, should be discussed and the most recent structural drawings obtained.

Consultation with trades involved, such as formworkers, steel fixers, and a check against unwanted geometry follow.

Quality and accuracy requirements of local specification must now be considered, also restraints, bay sizes, lift heights and any repetitive module.

Reinforcing detail should be studied with a view to prefabrication.

Check storey height versus prop heights (remembering carcassing depth).

Look for optimum section, devise formwork to cater for sensible range of sections with minimum alteration.

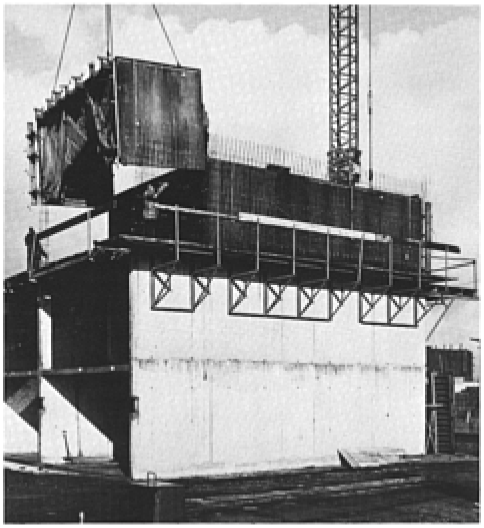
Examine sections for uplift and air entrapment problems.

Remember formwork provides a template and working platform.

Consider pre-and post-concrete conditions, after placing formwork must be extracted from around and below cast concrete.

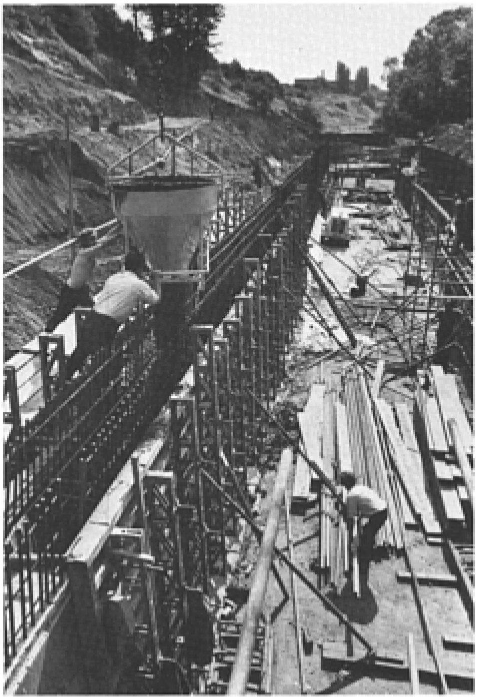
Concreting method should be established as well as rate

Concreting proceeds around the previously fixed reinforcing steel. Formwork and reinforcement should be considered jointly when planning the construction



Tunnel form techniques combined with accelerated curing reduce cycle times in cross wall construction (Uni-Form Shuttering Systems Ltd)

The use of large span double-tee beams reduces the need for falsework and formwork (Dow-Mac Concrete Ltd)



The construction sequence can be clearly identified in this illustration of wall construction. Toe boards should be installed on working platforms

of fill/placement of concrete.

Reinforcement should be investigated to determine whether continuity of placement can be achieved. Joints, day joints, construction joints and such like should be examined.

Dependencies should be identified.

The inclusion of admixtures in the concrete should be questioned and their effects anticipated.

Excessive amounts of cast in fixings must be avoided and time allocated for installation and checking of same.

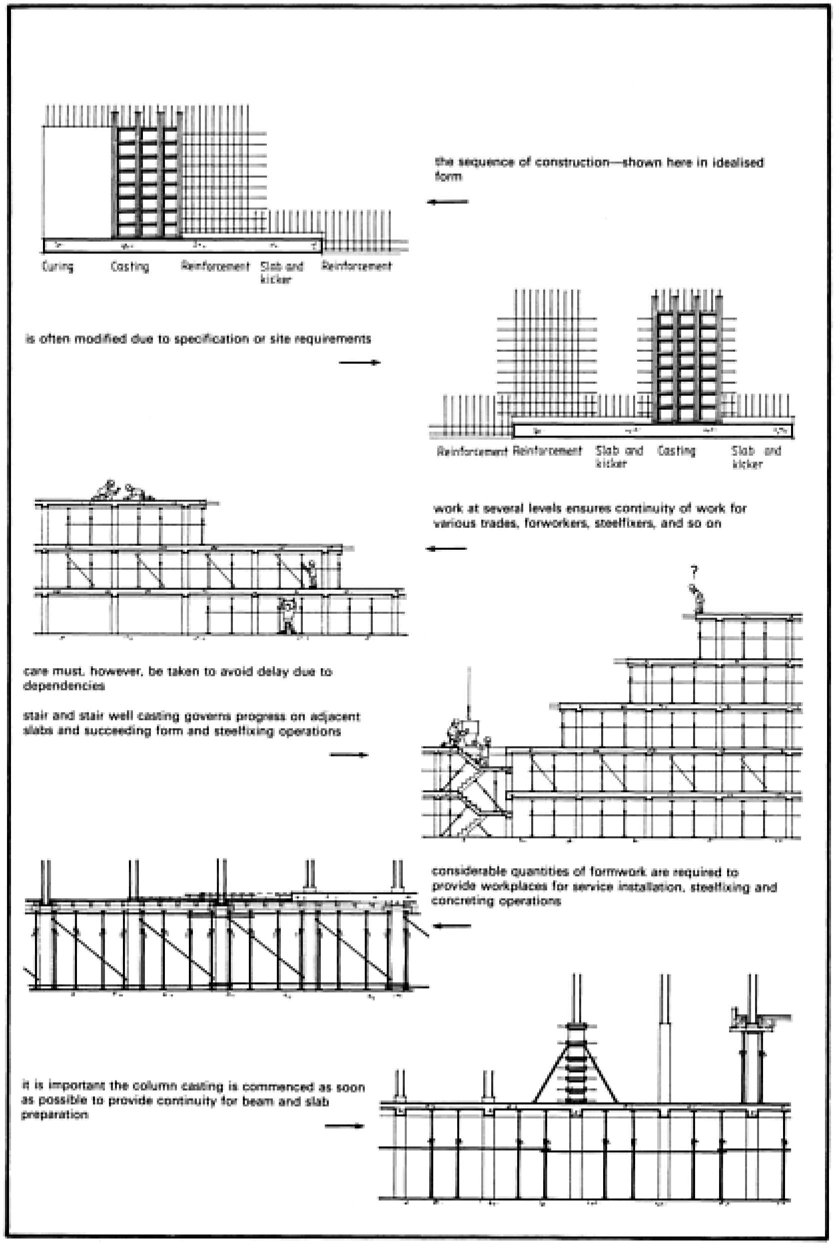
Previous supervisory experience and trades skill must be established and consideration given to any necessary training.

Type and location of ties must be examined to establish the simplest tieing and supporting system.

Striking arrangements must also be considered and a means of maintaining accuracy and continuity of support devised.

Information, in the best manner suited to the job in hand (bar charts, histograms, networks, line of balance plots, and so on) should be produced as well as method statements incorporating checklist.

Orders, cutting lists, requisitions, drawings and other necessary aids should be provided.



The system should be installed and check made that it can be used as intended.
It is essential to record results at all stages of construction.

Planning for pumping operations

Consideration must be given to the scale of concrete and frequency of concreting operations.

A suitable mix must be approved.

Mixes of known flow characteristics should be used, which may involve some considerable effort in trial mixing and, in extreme cases, pumping trials.

The availability of concrete in quantities required must be ensured.

Size of pump must be determined and availability of suitable equipment established in consultation with equipment supplier.

Pump positions should be clearly established as well as space and access for delivery vehicles.

Pipeline routing must be co-ordinated with concreting sequence such that pipelines are removed and cleaned as placing proceeds from the furthest part of each bay of concrete.

Suitable stooling must be provided to prevent displacement of reinforcement or formwork during pumping operations and care taken to avoid the introduction of impulse loading onto scaffolds or formwork during pumping operations.

Communication must be established between pump/ boom control and point of placing.

Materials should be provided to insulate pipelines to extreme weather conditions.

Site layout

The positioning and establishment of the concreting plant, batching plant and mixer forms an important part of the overall process of site layout. The location of the static plant will be determined by a number of factors, which include:

1. Scale of operations—available space, etc;
2. Quantities of aggregate, cement, etc;
3. Site access
4. Position of buildings on site, height of structure;
5. Location of largest bulk of concrete;
6. Duration of concreting operations;
7. Means of transporting concrete on site.

As regards the scale of operations, these will have a bearing on the size of plant, size of aggregate storage areas, silo space, and so on. A decision will have been made early in the planning stages regarding the optimum output of concrete required for the plant and perhaps a decision taken to buy-in quantities in excess of this optimum from a readymixed supplier. Once the figure for demand has been established, a histogram can be used to determine this optimum amount.

From the demand figure the quantities of aggregates, cement and so on, to be stored, can be calculated and after allowance has been made for a number of days' supply to be stocked, allowing standardisation and drain down of aggregates, space between bin dividers at ground level or the capacity of overhead bins and thus the area required can be calculated. It is usual to use silo storage of cement in the UK although for work abroad the area required for storage in bags must be established.

The siting of plant must be related to the means of site transportation. When a tower crane is the prime means of handling employed on site, then the batching plant must be positioned such that skips can be picked from bogeys running from below the mixer discharge.

Other means of transport such as pumping, transit by truck, dumper or similar means, permit a more detached location of the plant and thus the routes by which the concrete is to be distributed around the site may influence the eventual location of the plant. Monorails provide considerable flexibility of route and can cope with varying levels as discussed in the chapter covering placement and handling (Volume 2).

It is, of course, essential that large vehicles making deliveries of aggregate and cement have easy access without blocking public roads adjacent to the site. The vehicles need sound access ways of concrete, well compacted hardcore, sleepers or pierced steel planks providing substantial roadways. A delivery truck, axle deep in the site access, part way through a large pour is not conducive to good concrete practice!

Where a site is particularly congested it may be necessary to establish the batching plant in the basement or foundation area initially, moving the plant once a suitable hardstanding has been constructed at ground floor level. This arrangement may call for quite substantial temporary works to provide vehicular access for delivery of materials.

Where, as in civil engineering, there is one particular area of the site where the heaviest sections or greatest amount of concrete is required, then it may be advisable to set up a plant for that section of the work. This plant, although temporary, will need to have the same careful attention regarding bin separation, and so on as will the eventual plant set up to serve the complete site. In civil engineering work the demand for concrete is often sporadic but the allocation of a plant able to discharge directly into the formwork can provide an extremely economic means of concrete supply. The standard of plant erection will be governed by the period of the contract although good work can be done using sleepers and scrap concrete in bin dividers, hardstanding for the mixer and so on. It will be advisable to produce a proper drawing for the plant to ensure that discharge height is appropriate to the means of transport, to ensure that drainage of aggregates is maintained and such like. The provision of adequate shelter at the control position will ensure that the operator can work effectively throughout any inclement weather. Provision must also be made for the storage of cube moulds, slump cone or compacting factor equipment and it is often convenient to provide a site hut which can be used as a simple QC laboratory as well as for storage of samples, admixtures and so on.

The majority of concrete plant available today is of the "one man" type whereby one man is able to maintain aggregate supplies using a boom scraper in conjunction with receiving hoppers for example. Where aggregates are stored in hoppers, then this man can control an elevator, or can co-operate with a man driving a crane equipped with a grab. Hoppers make for compact layout of batching plant but, of course, the elevator arrangement calls for care in location. Crane and grab operations can be carried out in quite restricted areas, although the stand-off distance at which the crane must work relative to the height of the storage bins must be carefully considered. Remember also the area behind the crane swept by the projecting Kentledge or balance weight.

It is possible, on occasion, to take advantage of the slope of a site to provide sufficient elevation of the discharge for placement into dumpers. Failing this some mixers need to be set up on bunkers or grillages of sleepers to provide suitable discharge.

The plant should always be located in such a position that delivery of concrete is made downhill. This generally ensures that full dumpers, and so on, run freely loaded and only journey uphill when empty. Where skips are used in conjunction with a tower crane the bogeys used to transport the skips under the plant for the purposes of receiving concrete should run on track so arranged that empty skips are pushed up a slight incline. This ensures that the full skips will be easy to extract running downhill from under the plant. To ensure continuity of supply when two skips are in use, two tracks can be arranged to intersect at one point below the discharge.

The sequence of construction for the precast concrete caissons is evident from this illustration of the site casting yard. The gantry is used to lift slipform equipment and to handle the completed caisson. Tower cranes handle steel and concrete (Taylor Woodrow Construction Ltd)

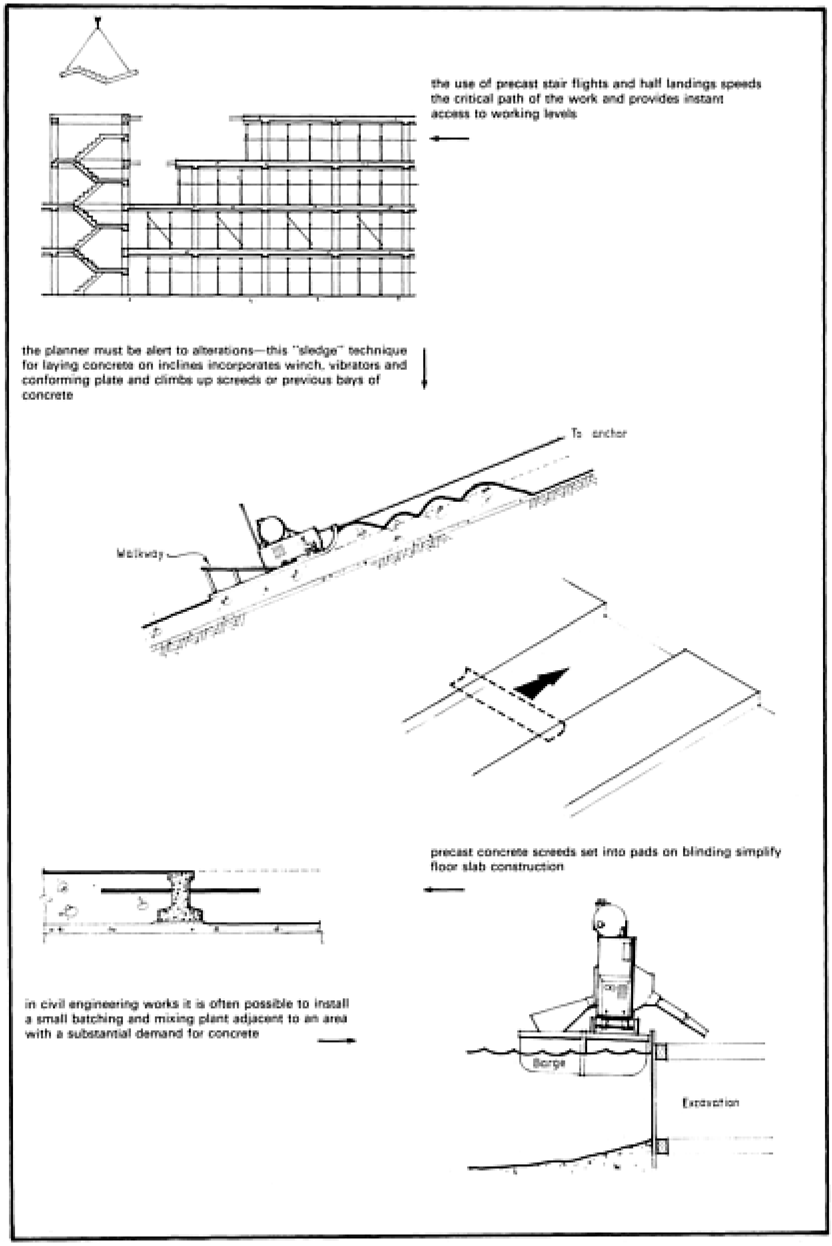
Regarding services, water and electricity can be run to the plant from the main supply, proper care being taken to mark the cable and pipe routes as demanded by the safety regulations or conditions of the statutory undertakings. Location of supply is generally a minor consideration in the siting of the plant, the foregoing considerations of place of maximum demand on site and site geography being more important. One cable or pipe trench may appear to be an expensive item, but when compared with the endless journeys involving a dumper or similar piece of concrete handling equipment, the cost of taking a supply to the plant is really quite small. The main concern is to economise where the best economy can be made and to locate the plant where the gross handling can be reduced.

The maintenance of a clean plant requires an ample supply of water for washing down and provision should be made to dispose of this water. Where a plant is to be long standing, then a system of weirs in the drainage channel will provide for the settling out of cement and fine aggregate which otherwise form a wasteful and time consuming crust over the surrounding ground. Provision of wash down facilities are essential where large trucks, rotating drum trucks and similar plant are used in concrete transportation, although the average dumper truck driver can use enormous quantities of water if not given sensible instruction.

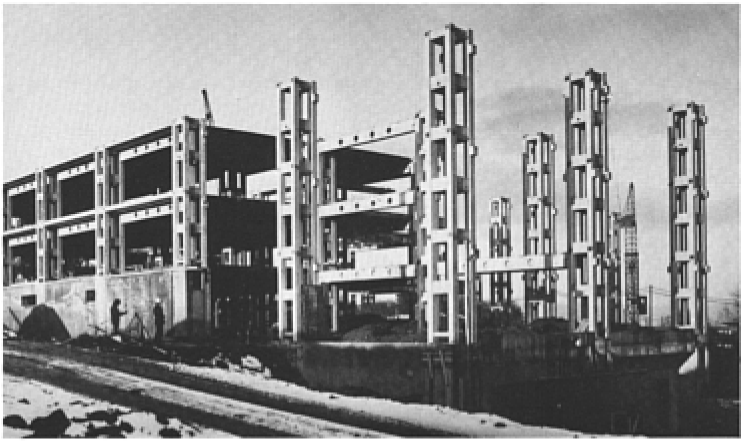
Precast site or works layout

In precast works the layout is dependent upon the type of production. Pile production demands a different layout to that for the production of cladding—the first being linear by nature, requiring long cages or long runs of wire stressed down a production bed and long travel cranes or gantries to handled cages, concrete and finished product along the floor. Cladding production, or the production of structural elements, is generally more localised—most trades and installation being carried out around fixed moulds in set places in the workshop. Linear layouts, therefore, include pile production, lintels, beams, flooring and armour units and localised layouts include the facilities for panels, frames, cladding and such like.

The supply of concrete may be by “bullet” or fast skip from batching place to point of placement, or by a combination of skip and crane handling. Conveyors and pumps have both been used successfully in conveying high volumes of concrete for mechanised production of items such as armour units on battery cast walls. Most

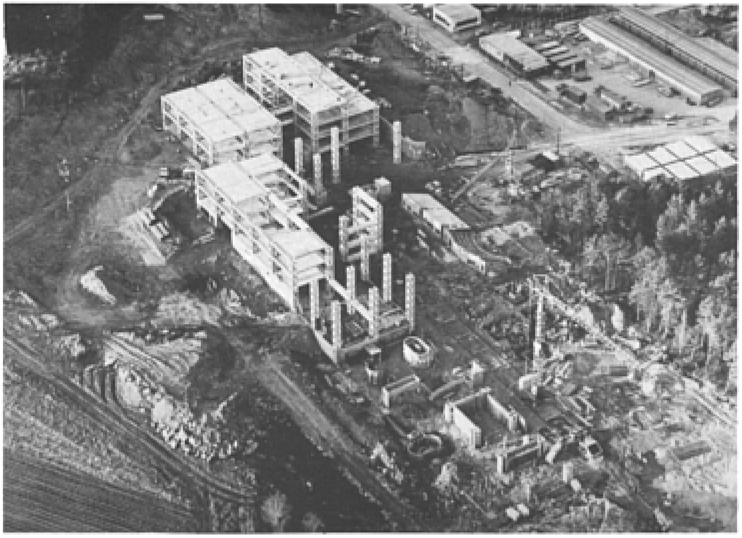


Earnest discussion in the early stages of post-tensioning in situ concrete beams (South West Water Authority)



Close-up of the structure shown overleaf indicating the columns designed to provide service access (Nordlanske Spenbetong AS)

precasters employ several batching plants distributed about their works with the capability of serving more than one production centre to cover breakdown. Where special mixes using exotic aggregates are involved, small batching plants, some semi-automated with multiple storage for a variety of aggregates, are sited adjacent to the appropriate production centre.



The construction sequence from ground work to frame erection is illustrated in the construction of this university building (Nordlanske Spenbetong AS)

Location of stores and services

Security plays a large part in the location of stores buildings on a contract although, of course, the stores must be readily accessible both for site personnel and outside suppliers' vehicles making deliveries.

Contractors are tending to put certain items on free issue. Items such as mould oils and parting agents, tieing wire and certain materials in constant use. Certain building materials are, however, extremely valuable such as special steel supplies, cast in fittings in phosphor bronze, aluminium bronze and so on, and these must be kept secure in stores and issued against a requisition prepared by a supervisor. Certain items of stores need to be carefully controlled for health reasons, for safety reasons and for reasons of quality, as in the case of admixtures, where overdosing could result in a substandard concrete product.

Planning for the use of cranes

In practice, crane allocations are frequently made on the basis of greatest demand, the need of some trades being neglected. In cyclic construction it is a fairly straightforward matter to allocate crane times and crane commitment to such activities as hoisting steel and handling forms, and concrete can be incorporated into the programme, initially on the basis of estimates taken from previous data and experience based upon actual outputs achieved at site. Contingencies will, of course, arise and such items as unscheduled arrival of a steel delivery or several loads of bricks or pipes may call for local adjustments. The supervisor should maintain an intelligent sequence of operations in conjunction with trades and section supervisors and arrange for the most gainful application of equipment.

Tower cranes have revolutionised construction with their ability to reach and service large areas of the site. Now, at a signal, a man in the workplace can have a massive form or heavy skip moved from one place to another accurately and can have supplies and equipment brought to the work level and inspection or working platforms handled in substantial pieces. Unfortunately a large number of activities on site have been allowed to become crane-dependent, and often the crane becomes the cause of bottlenecks in production.

Ideally a programme is developed which caters for the constraints imposed by crane availability, hoisting time and so on, with time set aside for extending masts and allowing for proper maintenance. It may become necessary to impose disciplines on deliveries, to put drivers onto shift working and to take special action such as instituting overtime, working at night and during weekends, to ensure the optimum use of craneage. A clear policy must be established regarding precedence of various activities and a responsible person put in charge of controlling crane operations. Banksmen, whilst having special skills and ability in securing loads, are not always best suited to controlling crane activities.

It has become practice on many sites to employ a supervisor to control cranes and their use and maintenance. Even with capable supervision, forward notice of casting operations, movement of cages and handling of steel is essential. Lifting beams, chains and slings must be readily available and even duplicated if necessary to prevent time being wasted in backtracking to pick up gear for a particular operation. Radio communication is an important tool in controlling equipment, indeed the radio link between banskman, supervisor and operatives, may be advantageously monitored by the site supervisor or manager, when priorities can be allocated in the event of upset or delay.

Key factors concerning the planner are those of crane capacity at various radii and reach, swept areas (in the case of rail-mounted cranes), access and ground conditions where mobile cranes are involved and weather conditions likely to be encountered, as well as the means of dismantling the crane (which may range from use of a massive truck mounted crane to the use of helicopters), and stagger arrangements where more than one crane is available. In the case of mobile cranes, standing space, clearance for kentledge, outriggers, ground rigs and the like must be considered. The stand-off distance when reaching over construction and into a structure needs to be carefully examined, as does the location of the crane at various times in the construction processes. Arrangements must be made to allow the crane to work its way out of a frame and provision made for the withdrawal and transporting away of the crane after use.

Ancillary equipment

An important aspect of all planning for the use of cranes and indeed handling operations in general, is that of the provision of lifting beams, rigs and attachments necessary to facilitate the movement of materials, structural elements and the like. Stringent safety precautions must be maintained and all special equipment tested and marked with its safe working load. Examples of such equipment are the frames used for extracting table forms at the time of striking and for the handling of the precast elements in standard and special operations.

The use of derrick cranes

For years the derrick crane was the major tool of the civil engineer. Some derrick cranes have, however, been used in building construction and considerable use has been made of them in precasting. Whether static or railmounted on gabbards, derrick cranes are extremely reliable and have the advantage of considerable capacity over the swept area. In mobile form, derrick cranes can be arranged to cover greater areas and in pairs the coverage is comprehensive.

Checklist

What is the agreed programme time?
On what plant methods and techniques was the estimated duration based?
What are the restraints imposed by phasing, handover times, subcontractors?
What are the activities critical to the duration?
Can modifications to plant, equipment or method ease the tasks?
Are the appropriate skills available?
How do contracts for supply affect the overall programme?
Can sub-letting assist in balancing the duration of operations?
Can hire or purchase of plant assist in achieving programme?
What controls can we install to achieve feedback on progress?
Will a study of critical activities yield returns in time/ labour saving?
Can we impart experience from other contracts?
Is the equipment for production and placing matched as regards capacity?
Can the various activities be uncoupled to avoid delay?
Has advice been taken from in-company specialists and service personnel?
Have processes been discussed with engineers and supervisors?
Has advantage been taken of “free” consultancy with suppliers, manufacturers, trade associations and so on?

4.
Safety and health in the construction industry

Common Law rights

The supervisor, in conjunction with his safety officer and safety representative(s), is responsible for the safe operation of the construction site. An important aspect of safety in any industry is an understanding of the Common Law rights. These *rights* are clearly defined responsibilities in terms of activities of various people and, when considered in conjunction with Statute Law, provide a sensible guide for the supervisor. The Common Law rights apply to everyone. Every employee has rights which must be observed by the employer and supervisor. In return the employer has certain rights which the operative is bound to observe.

The employee's basic rights are:

the right to a safe place of work
the right to a safe method of work
the right to safe fellow workers
indemnity for liability whilst acting on the employer's behalf
reward as agreed in the contract between employer and operative

A contract is said to exist after an offer has been made, considered and subsequently accepted. All that has been agreed prior to acceptance is considered part of the contract. The contract between employer and operative also binds the operative to observe the employer's rights which consist of:

personal service
careful service
obedient service
loyal service

These terms may sound quaint, but of course they imply that the employee cannot sub-let his work or send another to do it, that he must observe the employer's responsibility for the safety of others, that he must carry out lawful instructions, that he must not disclose details of the employer's business to others and that he must at all times have regard to the employers liability to others.

To revert to the rights of the employee, the supervisor will see how important these rights are in terms of site safety, particularly where concreting operations are concerned. Examining each in turn, the following points can be clearly established:

The right to a safe place of work covers all aspects of site conditions, access to place of work, working platforms and protection from hazard caused by other operations being carried out on site. The implications are obvious and demand from the supervisor and the employer a great deal of care and attention.

The right to a safe method of work deals with the requirement on the supervisor to instruct (and where necessary, train) the operatives in the task which, under the terms of their contract, they are required to perform on site. The implications here in terms of plant, equipment, tools, protective clothing and such like, are obvious and the importance of clearly defined job specification and method statement will be evident. It should be mentioned that Common Law rights exist in all situations but where considered in terms of the Law of Master and Servant governing employment, a much higher degree of care is implied.

The right to safe fellow workers is also very important. Where operatives are skilled and carrying out specialist (albeit simple) operations, it is the supervisor's responsibility to ensure that those employees which he sets to work together are capable of operating in such a manner as to avoid danger, a typical example of such a hazard may become evident if there is a language barrier between employees.

Statute Law

Where Statute Law is concerned, this is established in a two tier fashion in terms of Enabling Acts, the Factories Act 1961 and the Health and Safety at Work, etc, Act 1974 and other regulations. The Acts allow for making of the "second tier" regulations which set down mandatory details and requirements for particular cases such as Regulation 49 of the Construction Regulations (General Provisions) 1961, which would cover failure of falsework, scaffold collapse or instability, and so on. The construction supervisor will be particularly concerned with four sets of regulations: *General provisions; Lifting operations; Work places* and *Health and welfare*. Other regulations deal with abrasive wheels, asbestos, wood-working machinery, electricity, compressed air, protection of eyes, diving and the use of radioactive (ionising) substances. The supervisor should avail himself of the guidance and assistance available in these matters from the safety officers and the Health and Safety Executive. If the supervisor is to be responsible for the activities of others his training should include instruction in the maintenance of the statutory registers, such as those concerning accidents, lifting equipment, access scaffold and so on. The supervisor should study the requirements of *The Factories Act, Notification of Accidents and Dangerous Occurrences, Regulations, 1981* and must ensure that certain occurrences, such as personal injury or death, collapse of falsework, formwork, structures and scaffolds, or over-turning of a crane, bursting of a revolving wheel (maybe a grinding wheel), and similar incidents are reported, and he must understand and follow the methods of reporting. The supervisor would be well advised to take instruction in the form of a recognised course, such as that for industrial supervisors and industrial managers, where this topic will be covered in detail. Whatever his experience, the supervisor should consult his company safety officer, the Site Agent or Site Manager, or the person nominated by his company to be responsible for matters of safety.

There are, of course, other requirements to be met by the employer regarding the publication on site of abstracts of The Factories Act, Electricity Regulations and Woodworking Machinery Regulations. These must be displayed prominently in a location where every person entitled to access to the site or workplace may read them. There are very strict regulations governing welfare facilities, such as toilets, changing and drying rooms, first aid and similar amenities. These are covered in detail in the *Bibliography*. The experienced supervisor will, in the course of his normal working day, be busy with planning, organising, co-ordinating and controlling work. As he devises methods and arranges for plant and equipment to be delivered and installed in the back of his mind must always be the question "What hazard does this method/ equipment introduce?" Safety and economy cannot be divorced. The safest method may not be the most economic in the short term but in the long term, when the cost of accident delay and damage to moral is calculated, there can be little doubt that the safest method will prove to be the most economic. Indeed, the safest method is the only method to be adopted in any circumstances. Apart from the humane aspects, such as injury or loss of life, the damage caused to output and relationships following an accident is enormous. After an accident, shock and upset cause delays and uncertainty, which may well introduce other hazards to the work. The supervisor must do all within his power to get things back to normal as soon as possible. The supervisor should attempt to visualise any problems which may arise by implementation of a certain method of work. Initially, known hazards, such as inadequate access, poor guarding of tools and equipment, the use of electrical equipment, must all be considered. Further, less predictable hazards must then be foreseen, including operative error, machine malfunction, breakage of apparently safe lifting gear and so on. With experience possible hazards become known and safety precautions, such as further training for operatives and careful preparation of job instruction, can be taken by the supervisor.

Defining an accident

Before moving onto more specific matters of site safety, it is worthwhile imparting a clear understanding of what is meant by the term *accident*. This has been examined and re-examined in the establishment of case law and the following may be helpful in the discussion of accidents and accident hazards:

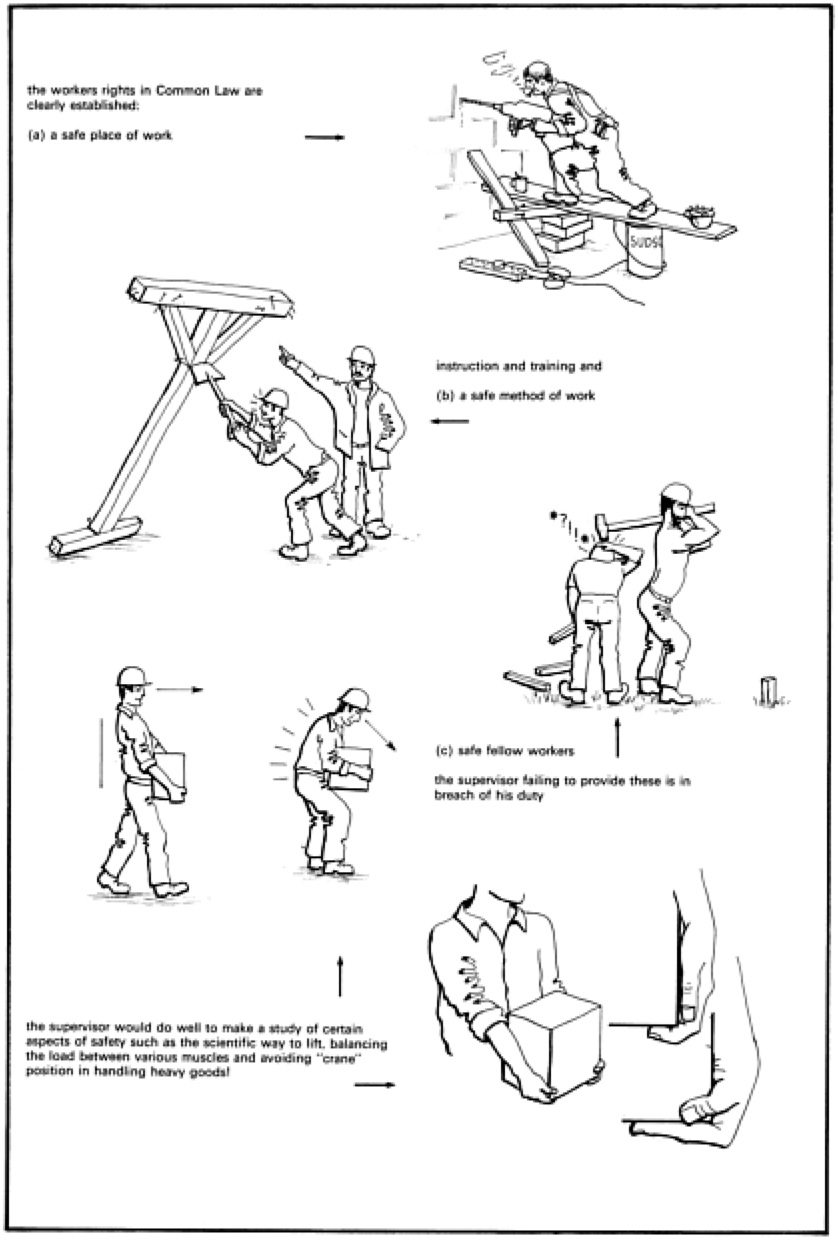
> *An accident is the result of an unplanned and unintended series of events which, once set in motion, cannot be interrupted. An accident results in damage to people or property.*

Action in the event of an accident

In the unfortunate event of an accident, the supervisor must ensure that first aid and medical attention are administered immediately and that any injured persons are taken to hospital. Registers and notices, as required by law, must be completed. A *notifiable* accident is one involving death or major injury resulting in more than three days absence from the place of work, or any injury sustained by a person not employed on or occupying the site. Details of the accident/dangerous occurrence must be entered in the record books. Form 2509 may be used for this purpose. Within seven days a written report or Form 2508 (available from Health and Safety Executive officers) must be sent to the enforcing authority. This form should be used to report all accidents causing fatal or major injury and notifiable dangerous occurrences. H.S.E. form HSE 11 gives details of accident reporting as required by *The Notification of Accidents and Dangerous Occurrences Regulations, 1981*. In the event of a notifiable accident, it is wise to take statements from witnesses as soon as possible—descriptions of events soon become garbled and subjective and early recording of details will ensure the greatest accuracy. It is essential that the union representative of the injured party be given access to the witnesses. Care must be taken in the event of a fatality to ensure that none of the equipment involved is altered or removed and the location in which the accident occurred is not disturbed.

The problems facing supervision

The construction worker is, by nature, extremely versatile and all too often considers that he has an ability to improvise—this in itself is a danger, as makeshift arrangements, such as planks for access, a wire to activate a switch or a wedge to retain a latch, can present real danger. Improvised access arrangements are responsible for a number of accidents, as is the temporary tie used to lift a form or the chain sling shortened by a bolt or tie. The good intention on the part of the worker to get on with the job often later results in disaster. Some men seem more accident-prone than others and are more likely to take risks—these men call for special supervision as not only are they likely to damage themselves or their equipment, but they also constitute a considerable risk of danger to their fellow workers. If, in exercising firm control of the men, the supervisor makes it clear that he has the safety and well-being of the workers at heart, he can generally count on the support of all concerned, particularly the representatives of the trades unions involved.



On larger construction sites, the contractor or major sub-contractor often sets up units which would elsewhere in industry be regarded as quite large factories, such as the steel yard, with craneage, cutting and bending machines, the formwork compounds with saws, planers and drilling machines and the plant compound stores with all the facilities of a garage or a light/heavy engineering workshop. For each of these units there are relevant safety regulations, and the supervisor should familiarise himself with the general requirements of these regulations. It is possible that during the construction process he will utilise the services of men from these units and he should be able to do so, and to control their activities with safety borne in mind. Checklists accompanying Chapters 13: *Formwork* and 12: *Falsework and temporary works* provide information concerning risks in these areas. The list appended hereto covers aspects of steel fixing and concreting activities. Where formwork, steel fixing and concreting operations are concerned the problem areas are generally associated with such matters as access, support, bracing and ties, handling operations and equipment, and the use of power tools. The supervisor can be prepared to overcome the risk of accidents in a number of ways:

prepare a careful method statement;

clearly establish whether drawings exist for such items as formwork, falsework and temporary works;

consult suppliers of materials, substances and equipment and refer to relevant handbooks and manuals;

prepare sketches and written instructions on working methods to be adopted;

consult service departments within the employing organisation;

consult the Health and Safety Executive;

ensure that equipment is properly maintained and is complete with necessary guards, fences and so on.

Hazards in construction

Construction, by its very nature, presents numerous hazards for operatives in handling heavy weights, placing large quantities of plastic concrete, working at heights and operating in all weather conditions. The following are a few aspects of accident hazard which have been encountered by the author. This is not intended as a comprehensive list but as a pointer to the problems likely to be encountered and requiring resolution by the supervisor.

There are occasions when, on changing from designed methods, loads on formwork become greater than those envisaged by the formwork designer. An example would be where forms, originally intended to be filled by crane and skip, are filled by pumping. The pressures which result from filling by crane and skip at normal wall filling rates of 2 m rise/hour can easily exceed those for which the formwork was designed with disastrous consequences. Equally disastrous events will ensue if a readymixed concrete truck is used to discharge direct into a wall form originally intended to be filled by crane and skip. Full head situations can result within 3 to 5 minutes from commencement of fill. With regard to craneage, there are a number of hazards peculiar to the concreting operation. A concrete skip of the roll-over variety is a massive piece of plant and if this weight was neglected, the total load of the skip and concrete may cause problems with reach and overbalance. Impact resulting from several tonnes of concrete and skip can overturn forms, access scaffold and even demolish previously cast concrete. Where the work centre is not visible to a crane driver, he must operate under the control of a banksman using established signal code, by wireless or by telephone communication. Concrete pump rigs are much akin to cranes and demand all the precautions observed with the crane. An added hazard is that of dynamic load which can be transmitted into formwork or scaffold by the pipeline as it oscillates due to the surge of concrete within it.

On no account should attempts be made to use a crane to strip formwork. Cranes are principally designed for raising and lowering loads—the practice of using the mass of hook and block to free forms from a concrete face is extremely dangerous, both to the persons concerned and to the concrete from which the form is being struck. There have been instances where slender walls have been demolished by this method of striking.

Access platforms, whether tube and fitting, system scaffold or attached to formwork, must be complete. Men working concreting plant must be able to move about freely without the possibility of falling from an incomplete arrangement, through a missing board or where a toe board or guard rail has been omitted or removed.

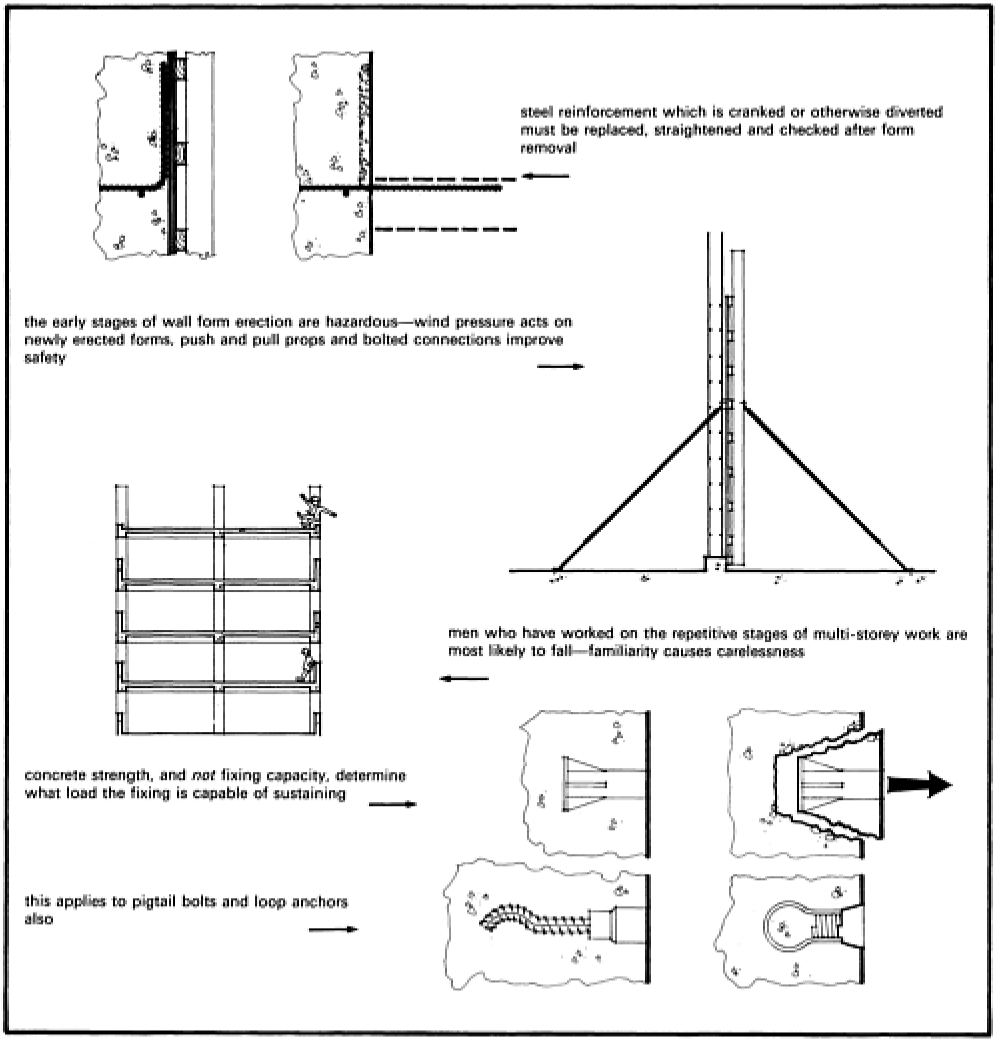
The load on a formwork system alters as the concrete is placed—local settlement may allow props to slip from their intended location and uplift may develop or sideways thrust on formers may occur. The supervisor should discuss the concreting operation with the formwork designer to obtain an understanding of the problems likely to be encountered. Load patterns on formwork or falsework arrangements are likely to change as an element is prestressed using post-tensioning techniques. The load changes from one of uniformly distributed to one of point load at, or adjacent to, the supports, which could result in overloading of the temporary supports with dire consequences. Again, where some new technique or a different application of an existing arrangement is encountered, the supervisor should discuss the work with a suitable authority, such as the designer or qualified engineer.

Operatives engaged in other work near temporary support systems or formwork, may be tempted to *borrow* lacing tubes or braces with every intention of replacing them on completion of their own task. Failure to reinstate such members has resulted in serious consequences. Partially completed work, both forms and scaffold, have been loaded in the course of a succeeding shift with resulting collapse.

Where steel has been diverted or bent into the wall to allow the simplification of formwork operations, failure to reinstate such steel correctly has resulted in subsequent structural failure. There have been serious accidents resulting from a misunderstanding of the load capacity of embedded steel fixings, fastenings and lifting equipment. The capacity of any such embedded member to sustain load is a function of the concrete strength at the time that the load is applied. A 7 *tonne fixing* is only capable of sustaining 7 tonnes when the concrete reaches a specified characteristic strength.

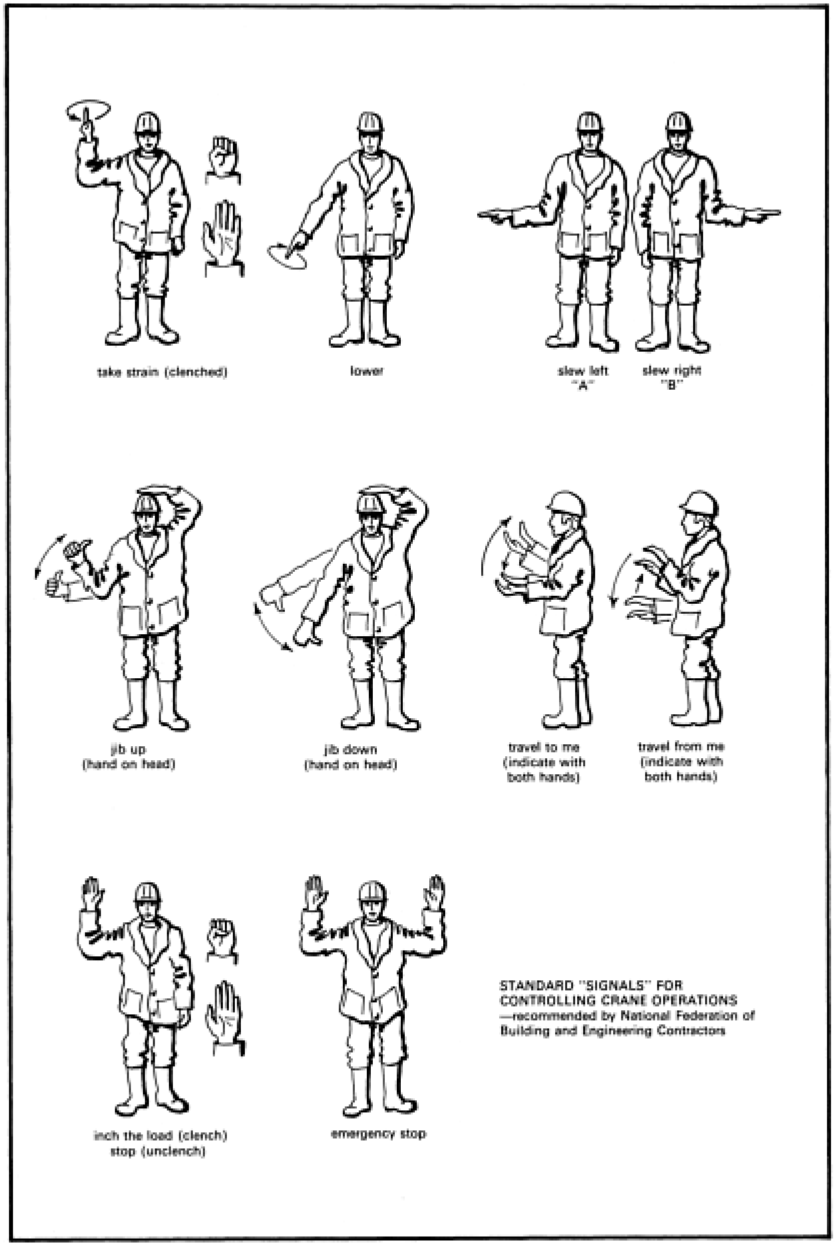
Innumerable accidents are caused by men jamming, wedging or tieing back safety fences, hoist gates, crane overload safety devices and the like. Frequently the operative intends to improve outputs and believes he is doing the right thing by his fellow workers, but many such actions go unnoticed and unchecked and remain hazardous for all involved in the construction and on site.

Equipment left lying around on site deteriorates, parts



are lost or damaged and, where maintenance is omitted, rust presents difficulties in use and often causes jamming. Slinging of such equipment is often carried out using chains or slings which are subjected to incorrect usage or are strained by wrong application of load. Both equipment and slings are then liable to further failure during later use. Misuse of equipment, such as the forcible striking of formwork, causes damage both to the slinging equipment and the formwork as well as providing hazards for the man employed in the operation.

When accidents do happen, they are made all the more serious by failure to use safety equipment, such as goggles, helmets, boots and similar. Grit in the eyes or damage to the head and scalp, or a nail in the foot all cause loss of time as well as upset at the workplace. Projecting steel reinforcement has also been responsible for accidents involving the eyes, while nails from blocks can cause serious lacerations, with putlogs projecting from scaffold and similar projections all resulting in hazards which cause endless hours of lost time due to accident or injury. The largest number of accidents on the construction site, however, are due to people falling or having things falling on them. Tools, equipment, tubes and fittings left on access ways cause terrible damage should they accidentally become dislodged. Unfortunately this type of accident is not limited to those working within the construction site and there are numerous cases where equipment has fallen in public access ways and space. Timber or ply falling from a height such as a multistorey block or bridge deck, tend to sail on the wind until they are travelling at high speed just above ground level— the resulting damage can be considerable.



STANDARD "SIGNALS" FOR CONTROLLING CRANE OPERATIONS —recommended by National Federation of Building and Engineering Contractors

Avoiding hazards in construction

From the foregoing it becomes evident that special problems arise in connection with the concreting process. There is always some new problem to be solved, none are insoluble and most can be resolved by careful planning. The safety aspects of the works are probably the most demanding of the supervisory tasks and are certainly an area of the supervisor's work where co-operation with others can be a major contribution towards success. *If in doubt ask* is an excellent motto, *if in doubt don't do it* is probably as excellent a piece of advice!

One further aspect of safety is that the actual placement of the concrete changes the whole sytem. Once concreting is commenced, forms become working containers, thrusts and loads develop, noise upsets communication, equipment is set working and a considerable tonnage of material starts to be moved. This is when all the care and attention to the planning of the working method comes to a peak, where training and experience mean the difference between safe working and dangerous working. When the concrete is hardened, it changes the task completely, because where forms could easily be located in early stages of the construction, they must now be extracted from around and under the hardened concrete. Methods must be devised to counter these environmental hazards and it is most important that all concerned be given the opportunity to contribute to the method adopted.

It is always interesting to read the statistics issued by the Health and Safety Executive, which are issued annually in the form of a handbook outlining typical accident hazards, most of which are instantly recognisable to the supervisor. Figures for a typical year (1979) in construction (as follow) underline the hazardous nature of the construction process, where much of the activity concerns access and movement of men and materials, movement of heavy plant and work in the ground. The temporary nature of much of the access scaffold and supporting works must have a bearing on the result. With regard to frequency of accidents, a recently released statistic revealed that one person was killed or injured every 2½ minutes in falls in the construction industry! The capable supervisor tends, during his normal work, to visualise possible hazards and plan to avoid them. In his work on and about the site, the supervisor should remain alert, watching always for the instances where the handrail or toe board has been omitted from an otherwise safe scaffold, where a ladder has been hastily erected and is being used untied. Unfortunately, these and many other hazardous details often go unnoticed in the effort to produce work on schedule in difficult conditions of location and extremes of weather.

Causes of accidents in construction (1979)

Falls of persons	51%
Falls of material	12%
Non-rail transport	9%
Excavators	7%
Lifting equipment	6%
Electrical	4%
Machinery	4%
Tunnelling, poison, gassing and other	7%

The Health and Safety Inspector

If an Inspector discovers a contravention of one of the provisions of *existing* Acts or Regulations, or (after April 1975) a contravention of a provision of the new Act (known as a *relevant statutory provision*), he can:

1. ISSUE A PROHIBITION NOTICE if there is a risk of serious personal injury, to prohibit the carrying on of the activity giving rise to this risk, until the remedial action specified in the notice has been taken. This notice can be issued whether or not there is a legal contravention and can take effect immediately or at a later time specified on it. The notice can be served on the person undertaking the activity, or on a person in control of it at the time notice is served.
2. ISSUE AN IMPROVEMENT NOTICE if there is a legal contravention of any of the relevant statutory provisions, requiring that the matters contained in the notice be remedied within the time specified in it. This notice will be served on the person who is deemed to be contravening this legal provision. A notice can be served on any person on whom responsibilities are placed, whether he is an employer, employed person, or, for example, a supplier of equipment or materials.
3. PROSECUTE any person contravening a relevant statutory provision—instead of or in addition to serving a notice. Contravention of some of the requirements can lead to prosecution, summarily in the Magistrates' Court (in England and Wales) or Sheriff Court (in Scotland). Contravention of other provisions can result in prosecution either summarily or on indictment in the Crown Court (England and Wales) or Sheriff Court (Scotland). The maximum fine, on summary conviction, for most offences will be £400. There is no limit on the fine for prosecution on indictment and, in addition to or instead of a fine, imprisonment for up to two years can be awarded for certain offences. In addition to any other penalty the Court can make an order requiring the remedying of the matters concerned in the case.
4. SEIZE, RENDER HARMLESS OR DESTROY any substance or article that he considers to be a cause of imminent danger or serious personal injury.

If a person on whom an improvement notice or prohibition notice is served, fails to comply with it, he is liable to prosecution either summarily or on an indictment and failure to comply with a prohibition notice could lead to imprisonment. A person upon whom a notice is served may appeal against the notice, or any of the terms of it, to an Industrial Tribunal. The procedure for doing this is given in the notice.

Checklist

Materials: receipt, batching and mixing

Are receiving hoppers fitted with gates or grilles?
Is conveyor/elevator guarded?
Is the isolating switch clearly visible?
Is the area covered by the boom scraper adequately fenced or identified?
Are wire bonds and hoist ropes in good condition?
Do operatives know which parts move?
Are accessible moving parts guarded?
Are rams guarded?
Are inspection covers intact?
Is pan intact and guarded?
Can drives be isolated (and locked off)?
Are filters regularly cleaned?

Skips, conveyors and handling equipment

Do doors operate freely?
Is door mechanism guarded?
Are purpose-made lifting arrangements installed?
Are stands, supports and rails complete?
Do skips locate securely on bogeys or trucks?
Has truck driver a clear view of tracks?

Vibration

Are electrics of correct voltage?
Are connections sound mechanically and electrically?
Are motors guarded and drives in good condition?
Are external vibrators adequately secured to forms?

Pumps and placers

Is driver competent and trained in equipment usage?
Are pipelines in good condition and securely clamped?
Are pipelines supported and independent of scaffold and formwork?
If secured to scaffold, has this been checked with an engineer?
Is vehicle boom clear of overhead wires?
Is vehicle correctly maintained?
Are outriggers soundly supported and on good ground?
Is there a recognised system of control signals?
Are forms designed with pumping and placing in mind?

Falsework

See *Checklist* to Chapter 12: *Falsework and temporary works.*

Formwork

See *Checklist* to Chapter 13: *Formwork.*

All operations

Is adequate lighting available?
Are operatives supplied with weather protection and safety gear?
Is there a preferred method of working and has that method been published?
Are spanners and keys of correct sizes available?
Is equipment appropriate to the work in hand as regards capacity, temperature, weather, location and so on?

5.
Reinforced concrete

Concrete is an extremely versatile construction material. Compared with other construction materials it is relatively cheap to produce using natural constituents available in quantity in most parts of the world. Provided that suitable control is maintained over selection of the constituent materials, the way in which they are batched and mixed, and as long as handling, placing, compaction and curing are properly carried out, the concrete will be capable of sustaining considerable loading in demanding situations. Concrete in its fresh state is a plastic material, the flow characteristics of which can be simply controlled. Initially the gain in strength is rapid, measured in hours, but concrete continues to harden throughout a number of years. For convenience, concrete strength is measured using 28 days at a constant temperature (20°C in Britain) as a reference point.

Concrete can be used unreinforced in massive construction works such as dams, foundations and similar applications. Unreinforced concrete has considerable resistance to compressive stresses and a dense and durable concrete has much to offer in simple loadbearing uses above and below ground level and in water. Where forces other than direct compression are to be sustained, it becomes desirable to reinforce the concrete with some further material which can provide much greater resistance to tensile and shear forces. Reinforcement may take the forms of bars of steel, strands of steel or wires, although in those countries where steel is expensive, alternative materials, such as bamboo or coir, may be used. Indeed, any material which offers good resistance to tensile forces without an excessive tendency to stretch can be used provided that it will not be affected by the alkaline environment of the concrete mass.

The supervisor responsible for the production or construction of concrete structural elements, whether in situ or precast, should have an understanding of the way in which the component functions mechanically. Just as one can learn to drive a car without understanding how the gearbox works, so one can construct without a knowledge of design, although the more involved one becomes in supervision, the more necessary it is to understand the rudiments of design. This understanding ensures better control of the *key activities* and permits the supervisor to enter usefully into discussion regarding such details as construction joint location, steel location, cover to steel and so on.

In this Chapter some Code recommendations and the more important physical characteristics of the materials are reviewed to provide a framework which the supervisor may supplement with further reading.

Concrete

The storage, handling, batching and mixing of concrete materials has been covered in Chapters 16, 17 and 18 in Volume 2. Chapter 28: *Statistics* (Volume 2), examines the term *characteristic strength* in terms of its application to quality control procedures. The usual criterion for the strength of concrete is its characteristic

28-day compressive strength, measured in N/mm^2, also known as the *Grade* of the concrete. Specimens, generally cube specimens in the UK, are made in accurate moulds of 150 mm or 100 mm cube size. The concrete is compacted using a standard tamping bar 25 mm square, weighing 1·8 kg, or using a vibrator. BS 1881:100 series: 1983, sets down curing conditions for site and laboratory. In UK practice it is usual to assess strength by crushing cubes of standard dimension, made and cured in compliance with BS 1881, in a reliable compression testing machine. Specifications set down the criteria by which sets of results should be judged to establish compliance with the requirements of the structural designer.

TABLE 5.1
Curing test cubes

SPECIMENS MADE IN LABORATORY:

Store in vibration-free location in moist air at least 90% humidity at temperature 20°C±2°C for 16–24 hours.

Demould at 24 hours, mark for identification. Submerge in curing tank, temperature 20°C±1°C. Remove just prior to test.*

SPECIMENS MADE ON SITE!

Store in vibration-free location. Cover with damp material under polythene sheeting. Temperature 20°C±5°C for 16–24 hours.

Demould. Mark for identification. Submerge in tank until transported to test laboratory, at not less than 3 days nor more than 7 days old.

Pack in damp sand or wet sacks, enclose in polythene bag or sealed container, to arrive at laboratory in damp condition, not less than 24 hours before time of test.

Store on arrival in tank at 20°C±1°C.*

* In neither case must specimens be allowed to become dry at any time until they are tested.

Attention to making, curing and testing procedures is an essential part of the work of the supervisor. Poor results will cause delay and possibly expense when time and effort is required to validate the concrete in the structure. In the event of non-complying cubes, discussion and further testing will need to follow. Chapter 22: *Quality control* (Volume 2), sets down some recommendations which the supervisor should find helpful in these circumstances. The required concrete strength can be achieved by selecting and blending the correct proportions of cement, fine and coarse aggregate and water. Sometimes, where specifications so allow, admixtures may be used to accelerate, retard or otherwise alter characteristics of the concrete with regard to flow, stiffening time, rate of hardening, and so on.

Special cements, such as sulphate-resisting cement and cements which have a modified chemical composition, can be used in stringent conditions, such as where sulphate salts may otherwise attack the surface of the concrete, when the products of the chemical reaction between the sulphates and the cement paste occupy a greater volume than the paste in its normal state before the attack. The expansion at the surface causes the concrete to be so weakened that it softens and can be crumbled away in the fingers.

The Code of Practice for the structural use of concrete, BS 8110:1985, lays down the following *Grades* of concrete for reinforced, pre-tensioned and post-tensioned concrete:

Minimum Grade	Characteristic strength at 28 days	Use
15	15 N/mm^2	Reinforced concrete with lightweight aggregate
20	20 N/mm^2	Reinforced concrete with dense aggregate
30	30 N/mm^2	Concrete with post-tensioned tendons

Minimum Grade	Characteristic strength at 28 days	Use
40	40 N/mm^2	Concrete with pre-tensioned tendons

BS 5328:1981 *Methods of specifying concrete,* the standard now in general use by specifying authorities, describes further mixes for other purposes.

Thermal movements

Most structural materials expand when they are heated, and steel and concrete are no exceptions. The coefficient of thermal expansion is the increase per unit length of the material per degree centrigrade rise in its temperatu has a coefficient of approximately 11×10^{-6}, which means that when heated its length increases by $\frac{11}{1\,000\,000}$ per degree increase in temperature in °C. In practical terms, a bar of reinforcing steel 10 m long will increase in length by 1·76 mm if its temperature is raised by 16°C, from say 5°C to 21°C. The change in length may be calculated as follows:

Change in length	=	length(m)×change in temperature (°C)×coefficient of thermal expansion for the material
	=	10m×(21°C−5°C)×(11×10^{-6})
	=	10000×16×(11×10^{-6})
	=	1·76 mm

The thermal coefficient of concrete is governed chiefly by the mix proportions, the characteristics of the mix constituents, the curing regime, the relative humidity of the area in which it is being used, the way in which concrete expands and contracts, and the moisture content at the time of change in temperature. For general purposes the coefficient of thermal expansion of concrete can be taken as lying between 7×10^{-6} and 14×10^{-6} (limestone to flint aggregate).

The similarity between the behaviour of steel and concrete in changing thermal conditions is sufficient for the designer to be sure that the bond between steel and concrete is not broken as it would be were the two materials to change length in a dramatically different fashion. As far as temperature change and the resulting movements are concerned, steel of various types and in various forms, provide an eminently suitable material for use in reinforcing concrete for structural purposes.

Strain

The relative change in length of a material cause, amongst other things* by application or force, is termed strain. Strain is expressed in terms of the ratio of change in length (due to the application of force) to the original length of the member:

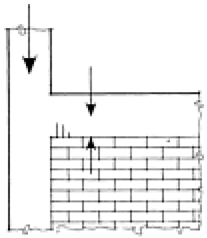
$$\text{Strain} = \frac{\text{change in length}}{\text{original length}}$$

Elastic strain is wholly recoverable on the removal of force. Whereas concrete has a very limited strain capacity, say 100–200 μ, steel is capable of sustaining considerably greater strain before cracking, say 2000 μ, and much greater forces, say 8 times greater, at a similar strain to the concrete. This means that considerable resistance to tensile forces can be achieved by the inclusion of steel in the concrete. In structural reinforced concrete the concrete supports the compressive forces whilst providing a protective environment for the steel. Carefully located steel reinforcement deals with the tensile and shear forces which would otherwise cause excessive cracking and eventual failure under load.

Creep and drying shrinkage

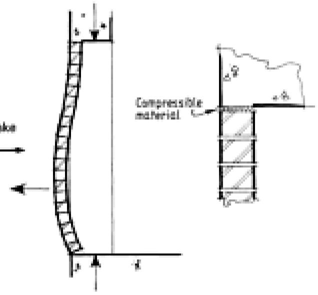
As previously explained, when a material is subject to stress due to application of a load, a change in length occurs. Where concrete is concerned, strain under load can be identified as being made up of initial immediate strain followed by creep movement whilst the load is maintained. On removal of the load the concrete exhibits some degree of elastic recovery, but there will always be the irrecoverable element of creep. In the time between loading and unloading, further hydration of the cement in the matrix will have resulted in the formation of hydration products which, in simple terms, lock up a certain amount of strain in the material. Thus it can be seen that if, for example, an exceptional load is applied to a beam or slab soon after removal of the formwork, the downward

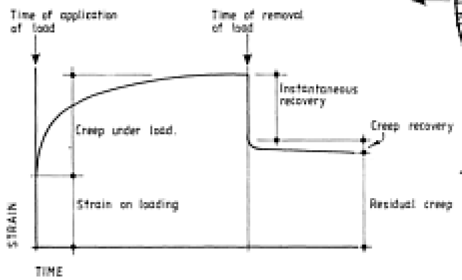
* Other types of strain include temperature strain, creep strain and shrinkage strain



restraints (unintended) caused by masonry when coupled with creep movement of the concrete frame have caused cracking in the structural element

shrinkage and creep in the concrete frame coupled with expansion of (clay) brick panel has caused brick panel failure—inclusion of a compressible material at the head of the panel allows movements to take place

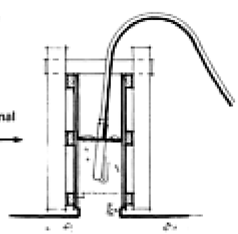


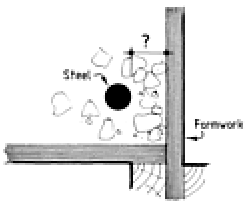


after removal of load whilst strain is reduced by instantaneous and creep recovery, residual creep remains

concrete must be capable of being compacted using poker, immersion or external vibratory equipment

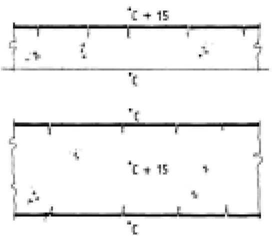
1% voids (unwanted entrapped air and water) means 5% loss of strength—5% voids means 30% loss of strength

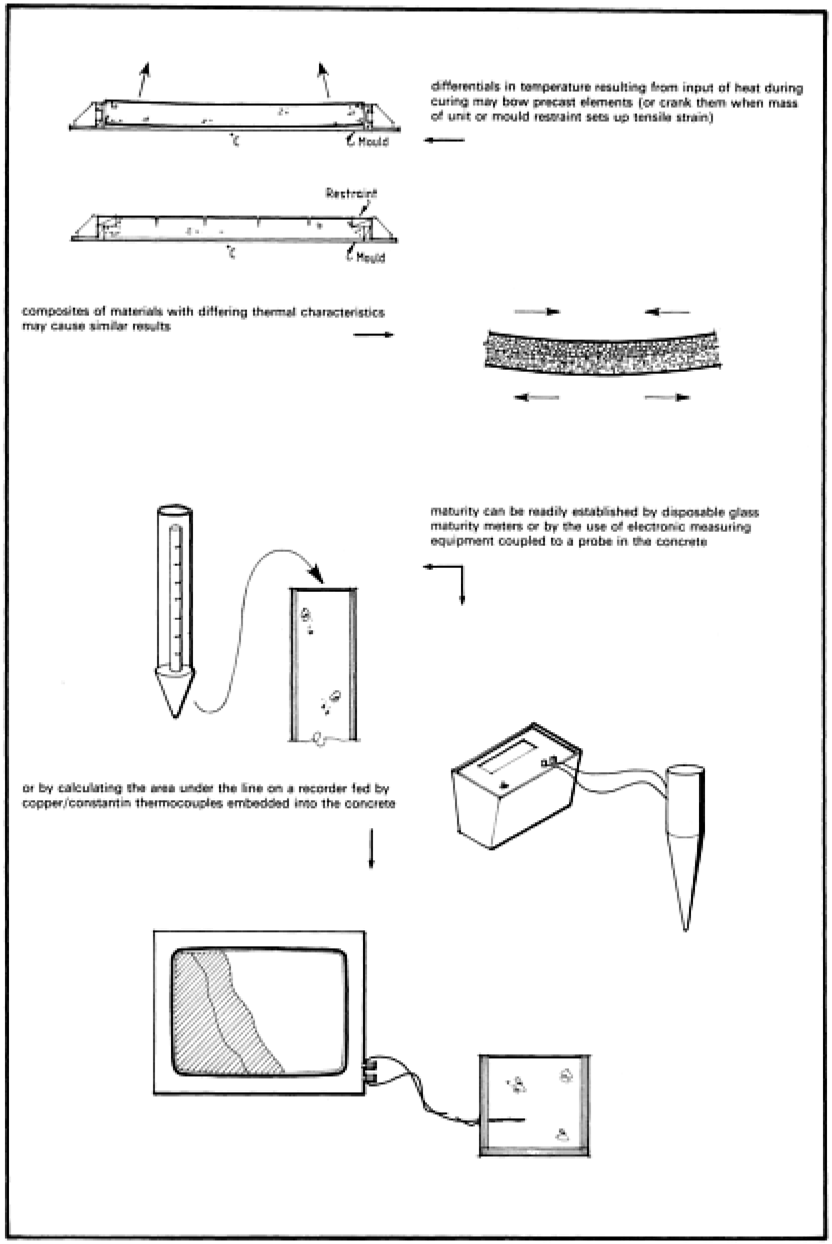




aggregate size must be related to steel spacing and cover if concrete is to be placed satisfactorily

temperature gradients across a unit can cause differential movements which, if restrained, cause cracking, as do differences between core and face (one hazard of accelerated curing techniques)





deflection will become locked into the structure. This is one of the reasons some engineers require camber to be built into formwork. Early age constructional loads should be avoided and care must be taken to ensure the support of concrete slabs by the retention of standing supports during the time in which the concrete is gaining strength.

It should be borne in mind that whether subjected to load or not, concrete contracts in 3 dimensions on drying. The change is quite independent of the stress in the concrete and is termed *drying shrinkage*. Both shrinkage and creep may be restrained by reinforcement although if the bond between the concrete and reinforcement is reduced by poor curing, poor compaction, rapid, excessive or premature loading or incorrect reinforcement, this may result in the development of cracks of greater width than permissible. Creep movement may benefit the structure by affecting a gradual relief of local high stresses, but generally where deflections increase or prestressing force is lost due to creep, the elements in the structure will be adversely affected. When designing a structure, the engineer estimates the changes which result from creep and shrinkage. These changes, often resulting in an increase in deflection or a change in length of an element with time, are calculated with reference to a number of factors, each of which play a part in determining the resulting movement. These factors include:

1. The effect of drying, low temperatures and low relative humidity increases both drying shrinkage and creep
2. The *maturity* at loading in terms of age and temperature, more mature concrete will creep less but shrinkage may not be affected
3. The amount and quality of the cement paste, i.e. the water/cement ratio and cement content, more water means more creep and shrinkage
4. The size and shape of the element which will affect the rate of drying, a thinner element will move more in a given time
5. The time under load or drying, including the delaying effect of large sections
6. The aggregate type, if the water absorption is greater than 3% in 24 hours the designer will normally be taking precautions to minimise the effect of creep and drying shrinkage

Many of these factors are pre-determined by location, rate of construction, mix and specification. In some instances these items are the direct responsibility of the construction supervisor in his control of mix proportion and water content, curing conditions, time of application of load, formwork striking operations, and loading of the structure, and can have a marked effect on the way in which the concrete behaves. Such matters as the provision of standing supports under beams and slabs, which remain in position after removal of the formwork, are part of the construction process which the supervisor can rigidly control. Failure to provide such support means that early, sometimes *shock* loading, will adversely affect the structure by allowing considerable deflections due to self and imposed weights.

Swelling and plastic shrinkage

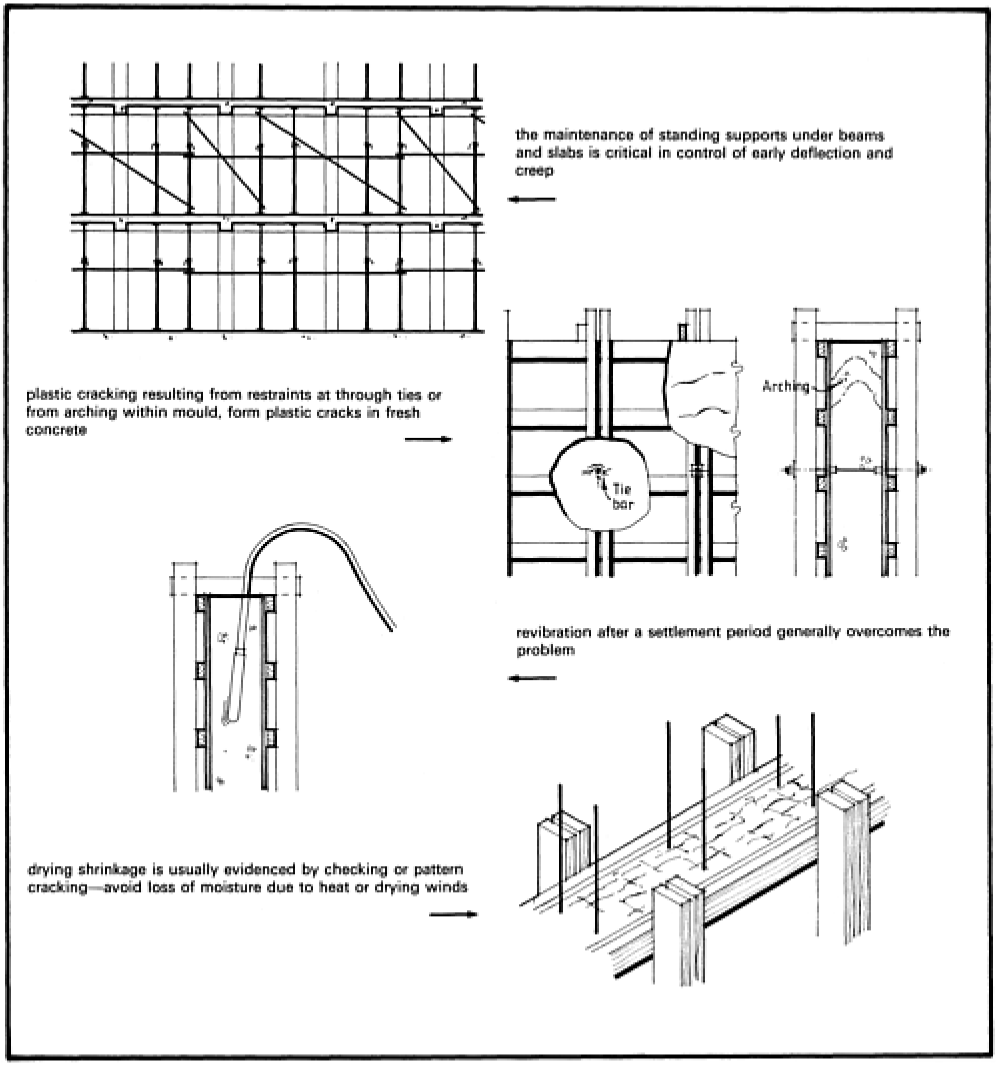
Swelling of concrete normally only occurs in continuously wet conditions and does not generally cause problems in construction. The increase in volume when it does occur is relatively small and takes place over a long period. Very little swelling takes place after 6–12 months from casting. This behaviour is very different from that of bricks which do swell after being brought out of the kiln, a characteristic of bricks which has caused considerable and serious construction problems, particularly when they are used in infill panels. Gain in volume and thus length and height of the panel has caused bellying-out or bulging of brick panels restrained at the sides or top by concrete columns or beams which will probably be shortening or deflecting under load due to creep. The supervisor should check that suitable expansion joints are incorporated into the details for such work.

The first type of plastic shrinkage encountered in the construction process is that of plastic settlement (that is chiefly vertical). Fresh concrete consists of suspension of solids in water. After being placed in a form and compacted, further settlement takes place, bleeding occurs where water rises to the surface in differing quantities, depending upon water content, the temperature and grading of the particles comprising the mix, and some settlement results. Where such settlement is restrained by very stiff reinforcement, mould or form profiles and tie bolts, then *plastic settlement cracking* occurs. The resulting cracks can generally be closed by revibration or further trowelling of the surface as the mix stiffens. The re-introduction of the poker vibrator or switching on of external vibrators for a further period during the time whilst concrete is still in its plastic state (i.e., having some workability), will allow further compaction, the locally fluidised concrete flowing around and below the obstructions.

The second type of plastic shrinkage, *plastic drying shrinkage* (which is chiefly horizontal) may be encountered as a result of poor curing technique. Attention to protection of the fresh concrete, shading from the sun and drying winds, will reduce this form of shrinkage, while prevention of moisture loss will eliminate it completely, allowing the concrete to develop strength and resist early age cracking.

Heat of hydration

One of the most important aspects of the hydration process of cement is the heat resulting from the exothermic chemical reaction. In massive concrete pours, 2 m or thicker, 12°C will be generated per 100 kg/ m^3 of cement. The concrete is warmed by the heat so generated which, in turn, further promotes the chemical reaction. The heat does, however, have the disadvantage that it varies throughout the mass of the concrete and, being initially greater in the centre of the mass, expansion takes place there, tending to disrupt the surrounding concrete. The curing process is ideally arranged to reduce differential temperatures and maintain them within some reasonable range. In extreme cases it may be necessary to insulate



formwork so that the outer part of a substantial mass does not lose its heat too rapidly. Generally in the UK sufficient insulation is provided by timber formwork, although where steel forms are used in exposed positions, the heat from sunshine and the cooling effect of wind occasionally present problems, with cracking developing at the surface of the concrete or at changes of section, where the concrete is restrained by the formwork or by adjacent or underlying older concrete.

Durability

The durability of a material is that quality which ensures that the material can function as intended by the designer during its designed life in the conditions envisaged at the design stage. Concrete satisfying these requirements would be described as durable. The durability of concrete is adversely affected by the following:

1. *High permeability* of concrete due to inadequate specification or construction allowing aggressive moisture to percolate through the concrete facilitating corrosion of the steel reinforcement.
2. *Excessive cracking* from inadequate specification, design or construction permitting the ingress of acid laden fumes or aciduous moisture which will eventually set up electrolytic action and corrosion of reinforcement.
3. *Repeated wetting and drying,* particularly by salty or sea water.
4. *Surface disintegration* chiefly brought about by freezing and thawing of saturated concrete without air entrainment.
5. *Heavy trafficking* of roads and running surfaces and damage to slabs through movement of heavy loads.
6. *Cavitation* due to fast flowing water in conduits, culverts and at bridge piers
7. *Acidic liquids* such as moorland water dissolving components in the paste causing loss of aggregate and appearing like erosion.
8. *Fire damage* where the surface of the concrete is heated differential temperatures cause cracking and spalling.
9. *Alkali-aggregate reaction* under damp conditions which may cause formation of expansive products within the concrete mass so that cracking and distortion take place with ugly staining (the structure may not, however, prove unsound, even after years of reaction).

Durability is dependent on a wide range of factors, including materials selection, mix design, steel location, surface finish and the adequacy of compaction and curing techniques. Permeability and porosity are not the same thing—*porosity* is a measure of the amount of pore space whereas *permeability* depends upon the form which the pores take, their distribution and whether or not they are continuous, thus controlling moisture and vapour movement. Permeability decreases as the processes of hydration and gel development proceed. The aggregate content and type has an effect on permeability as it affects the area through which moisture or vapour may flow. Curing concrete in a suitably moist environment, essentially above 75% relative humidity, reduces permeability by promoting the adequate growth of hydration products.

Apart from the requirements of strength and durability, the concrete must meet certain criteria whilst in its freshly mixed state: It must be capable of being handled between the mixing plant and the point of placement without separation and it must be of a suitable consistency to enable compaction to be achieved within the form and around the steel. The concrete can only protect the embedded steel satisfactorily if it can be compacted to exclude unwanted entrapped air and water, thus providing an impermeable coating to resist the aggressive acids and moisture in the atmosphere which corrode steel and embedded metal. The concrete should, when vibrated with the available equipment on site, flow into position around the steel and into the details and features of the forms in such a way that on removal of forms the finished face of the concrete will meet the requirements of the specification.

Cracking

A number of factors affect the concrete element in a manner likely to cause cracking. Cracking may result from the application of an external force, such as when a member is loaded, or from internal causes, such as excessive temperature gradients within the concrete mass causing differential strains in the material. As has been discussed elsewhere, early cracking, plastic cracking and drying shrinkage cracking may arise due to placement or curing method, although these can be remedied whilst the fresh concrete remains plastic. Cracks may appear in concrete due to differential temperatures arising from the curing technique, and in instances where composite members are constructed using aggregates having different thermal characteristics. Concrete restrained from movement also cracks. Restraint problems also arise where formers and cast-in components restrict the movements resulting from the normal thermal shrinkage of concrete. Cracking has been observed, for example, in in situ concrete where steel drainage tubes cast into the concrete acted as stress raisers as the concrete contracted. What is in fact taking place in these circumstances is a "race" between the development of tensile strength and the increase of tensile *stress* due to the restraint of shrinkage by the steel member.

Sudden thermal shock cooling by the application of cold water to a concrete mass, warm from the exothermic reaction between cement and water, causes shrinkage movement likely to be in excess of the capacity of the fresh concrete at that stage. Regarding cracking due to thermal gradients, these can, for example, develop in larger pours where the centre of the concrete mass is warm and still expanding whilst the outer faces are cooling and contracting. The remedy is to monitor and control the temperature in such a way as to reduce differentials, for example, by additional insulation to supplement the ability of the formwork to retain heat in the concrete adjacent to the face.

The principal problem arising from cracked concrete is that steel reinforcement loses its protection and becomes liable to corrosion. Loading and deflection cause cracking, particularly shock loading at early stages. Due to the nature of concrete, cracking is to be expected and the designer locates steel reinforcement at such positions as will ensure that crack widths are acceptable.

Whilst cracking is a semi-random feature of concrete, it is impossible to calculate absolute maximum crack widths and a few cracks may exceed the calculated width. *All visible cracking should be reported* and the time after casting noted, this applies particularly where cracking becomes evident as the construction process continues, where, for example, creep movement in one part of the structure causes excessive loading in other less substantial sections.

One cause of cracking which has created problems in both in situ and precast concrete operations has been that where water which has lodged either in drainage tubes in in situ concrete or in lifting eye sockets in precast concrete, has frozen and split a column in the case of in situ concrete or spalled off concrete from beams where precast elements are concerned. In winter it is wise to ensure that voids, tubes or even recesses in concrete, are drained or plugged with a material such as expanded polystyrene, which allows the ice to expand without generating sufficient force to crack the surrounding concrete.

High water/cement ratio and high water content both drastically affect the tendency of concrete towards cracking, the high water/cement ratio by reducing the strength of the concrete and the high water content by rendering the paste more likely to shrink. Careful curing and a planned approach to control of temperature including differentials is essential to the production of durable concrete.

Maturity of concrete

In recent years considerable attention has been focussed upon the maturity concept which, in its simplest terms, is a measure of the combined age and temperature history of concrete. Maturity is measured in °C/hours. The maturity concept assumes that for a given concrete it will have the same strength for given opportunity however that maturity is achieved. A number of different formulae have been published from which maturity can be calculated. Strength can be estimated for any planned heating cycle. Measurements of maturity can be a simple matter using, for example, meters which give a direct reading in °Chours. Maturity can be compared with strength as measured by others means, such as the standard compression test on cubes, and a graph of strength for various maturities drawn.

Estimates can be made of maturity from temperature measurement. These estimates can be compared with strength measurement taken by some standardised process and a close correlation obtained in most cases between the two sets of results. The maturity value for a concrete can be obtained by plotting a curve of temperature against time, −10°C being used as the base temperature. A typical example, taken from an accelerated curing situation, is illustrated in CP 110. In this instance the reference is made to concrete cured according to the cycle illustrated, having a maturity equivalent to that of concrete cured for 48 hours at 18° C. The formula used gives an approximation of maturity, it overestimates greatly the temperature needed in accelerated curing and also overestimates the actual strength of concrete by 50% at temperatures below 5° C.

The maturity concept will be of assistance in determining striking times for formwork where agreement can be reached upon some acceptable strength criteria for the concrete in the structure based upon the maturity. Temperature recording or a maturity meter can then be used to determine when the concrete in the structural element has achieved sufficient strength to combat the stresses which will be encountered during and after striking. A number of researchers have examined the maturity concept and have devised their own formulae which give different values for maturity calculated from temperature and time. It will be apparent that mix proportions and aggregate characteristics do indeed affect the rate of gain in strength in differing amounts as well as the type of heat applied and conditions of humidity.

The best advice available recommends some experimental work and selection of a formula which best matches the results obtained from tests.

Admixtures

The supervisor must acquaint himself with the basic rules regarding the use of admixtures, which are becoming a more acceptable and established part of the materials used in making concrete for use in the construction process. Admixtures can be obtained which modify the concrete in a number of ways:

to accelerate strength development of the mix;
to delay stiffening of the mix;
to reduce water required for a given degree of workability;
to increase workability;
to enable concrete to flow;
to increase frost resistance of the hardened concrete;
to minimise bleed water and hence plastic settlement.

Admixtures require careful handling to avoid wrong dosage, which will cause production of sub-standard concrete. Admixtures must be introduced into the concrete in exact quantities as specified by the manufacturer. They should be introduced using metering dispensers set up in such a way that double-dosing is impossible. Once introduced into the concrete, the mixing must be thoroughly carried out to avoid local pockets of what are sometimes sticky substances and which, if allowed to agglomerate, will cause strength or appearance problems. Particular care must be taken with powder type admixtures (rarely supplied) that they cannot be confused with cement and that mixing is long enough to obtain good dispersal. Containers in which liquid admixtures are delivered must be clearly marked in such a way that they can be identified, even if paper labels are washed or scoured away, and preferably should be used in order of delivery. The admixture supplier will often give valuable information and advice on when the admixture should be added to the mix, combining admixtures without problems and optimum materials dosages.

The supervisor is advised to take particular care that he understands the local specification, as many specifications do not allow the use of particular types of admixture. Where they are allowed it is vital that only tried, tested and approved materials are used. Any admixtures advertised as being "anti-freeze" or "frost proof" should be avoided, unless the chloride content is below the stringent and extremely low limit given in most specifications.

BS 5075: Part 1 covers accelerating, retarding and water-reducing admixtures, Part 2 covers air-entraining admixtures and Part 3 deals with superplasticising admixtures.

PFA (fly-ash)

Fly-ash is a by-product of the generation of electricity. It is used as an admixture to concrete in the form of a partial replacement for Portland cements and of the fine aggregates. It offers improvements upon properties of concrete as follows:

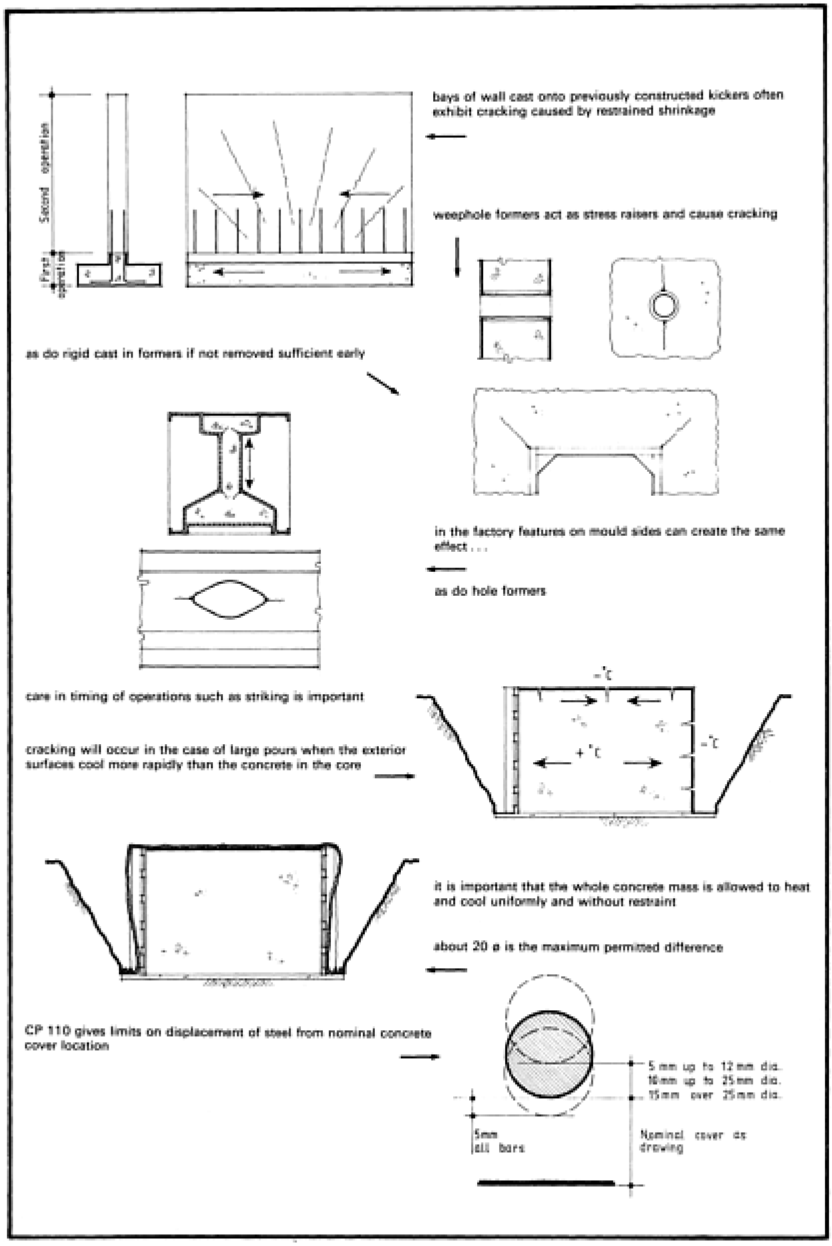
there is a reduction in water demand, the required workability being achieved with reduced quantities of water;

permeability and porosity are reduced;

drying shrinkage and the normal tendency to bleeding are reduced;

the concrete mix exhibits greater cohesion as the fines content of the mix is increased, and fly-ash can be used to compensate for deficiency in fines, improving the fines distribution;

the addition of pfa as "finer fines" assists in achieving concrete which can be easily pumped—this increase in

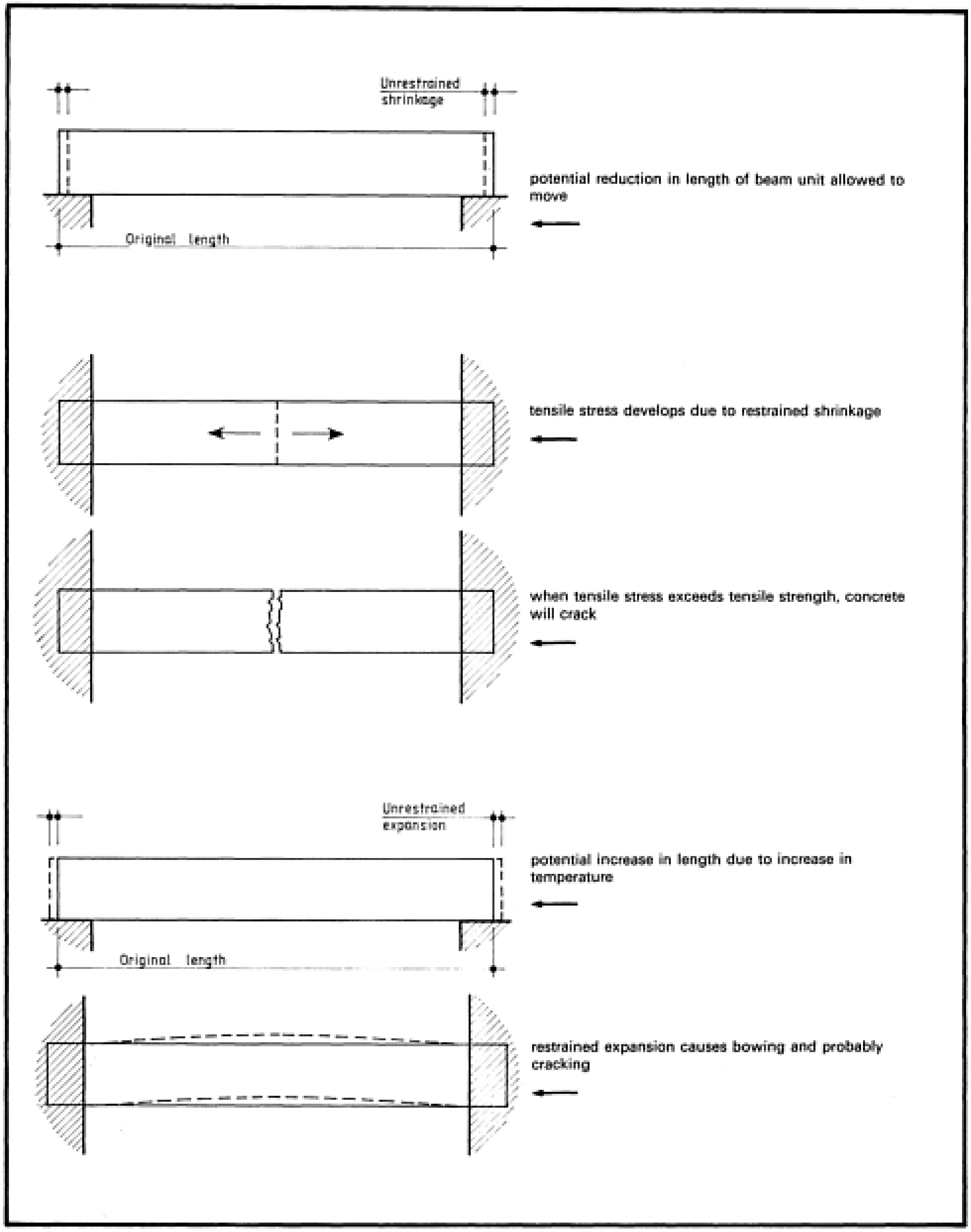


fines content also combats any tendency towards segregation when the concrete is worked in its fresh state;

there is a chemical reaction involved and fly-ash reacts with the lime in the mix to make a contribution to strength throughout the life of the concrete mix, both at early and later ages, but chiefly at 28 days;

the admixture assists in developing the sulphateresistance of the concrete as well as reducing the heat of hydration;

efflorescence is also reduced and the admixture is beneficial in improving the durability of the concrete.


Unrestrained shrinkage
potential reduction in length of beam unit allowed to move
Original length
tensile stress develops due to restrained shrinkage
when tensile stress exceeds tensile strength, concrete will crack
Unrestrained expansion
potential increase in length due to increase in temperature
Original length
restrained expansion causes bowing and probably cracking

Steel reinforcement

The properties of the steel used in reinforced concrete are clearly set out in various British Standards, as follows:

BS 4449:1978	*Hot rolled steel bars for the reinforcement of concrete*
BS 4461:1978	*Cold worked steel bars for the reinforcement of concrete*
BS 4483:1969	*Steel fabric for the reinforcement of concrete*

The BSI publication, BS 4466:1969 *Bending dimensions and scheduling of bars for the reinforcement of concrete,* sets out preferred shapes and gives guidance on cutting and bending tolerances. British Standard Code of Practice BS 8110:1985 *The structural use of concrete,* Part 1: *Design, materials and construction,* contains recommendations for cover to bars, permissible deviations and the stresses to which the designer may work.

The supervisor responsible for concrete work is advised to acquaint himself with the key points in these various documents in order that he has better control of work on site. He will find that the publications are clearly worded to avoid ambiguity. He should, in case of doubt, not make assumptions and should consult with a suitably qualified person in case of problems arising over steel type, location or cover.

Bond strength

The bond between the concrete and embedded steel develops during the hardening of the concrete which, as it shrinks, grips the steel. This grip is known as bond strength and is a measure of the force which would have to be applied to the contact surface to cause a significant movement between the steel and the concrete. The strength of the bond is improve if the reinforcement is deformed, having ribs or indentations on its surface. The bond strength may be reduced if the surface of the reinforcement is painted, oily or badly rusted. Loose scale would reduce the bond strength in a marked fashion and must, therefore, be avoided. Sometimes poor galvanizing or other treatment to prevent rust may reduce bond. In uncracked concrete there must be no movement between the hardened concrete and the steel. The total force in the steel is the product of the bond stress and the effective area of contact between the steel and the concrete.

BS 8110 sets out recommendations regarding the way in which bars are lapped and anchored to allow the transmission of force from one bar to another and into the concrete where the bar terminates. BS 4466 specifies hook and bend configurations. Bars can be grouped together and, although the area of contact is reduced when this is done, the bobs (right angle bends) or hooks provide additional anchorage and thus supplement the bond where there is not sufficient length of bar in contact with concrete for the stresses to be adequately distributed.

Cover to reinforcement

The thickness of concrete cover over the embedded reinforcement depends upon the type and grade of concrete used, the fire resistance requirement and the environment in which the structure must fulfil the design requirements. Cover is measured as the minimum distance between the outside of the reinforcement (including ties and stirrups) and the nearest external surface of the concrete (excluding any subsequent rendering). The durability of reinforced concrete depends on adequate protection for the reinforcement and there being sufficient concrete around each bar to maintain the necessary bond between steel and concrete.

The thickness of cover lies between, the values given in Table 5.2 quoted from the more detailed tables in BS 8110:1985: Part 1 *Design, materials and workmanship.*

TABLE 5.2
Norminal cover to all reinforcement (including links) to meet durability requirements (see note).
(This table relates to normal weight aggregate of 20 mm maximum)

Conditions of exposure	Nominal cover				
Mild	25	20	20	20	20
Moderate		35	30	25	20
Severe			40	30	25
Very severe			50	40	30
Extreme				60	50
Lowest grade of concrete	C30	C35	C40	C45	C50
Maximum free water/cement ratio	0·65	0·60	0·55	0·50	0·45
Minimum cement content (kg/m^3)	275	300	325	350	400

It should be noted that BS 8110 goes on to quote nominal cover to all reinforcement (including links) to meet specified periods of fire resistance.

The exposure conditions noted are defined as follows:

Mild Concrete surfaces protected against weather or aggressive conditions

Moderate Concrete surfaces sheltered from severe rain or freezing whilst wet.
Concrete subject to condensation.
Concrete surfaces continually underwater.
Concrete in contact with non-aggressive soil.

Severe Concrete surfaces exposed to driving rain, alternate wetting and drying or occasional freezing or severe condensation.

Very severe Concrete surfaces exposed to seawater spray or de-icing salts, directly or indirectly,
or corrosive fumes,
or severe freezing conditions while wet.

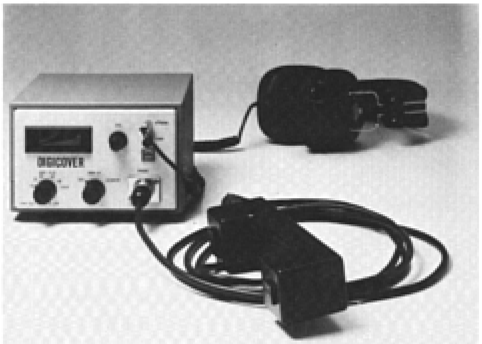
Extreme Concrete surfaces exposed to abrasive action, for example, seawater carrying solids,
or flowing water with pH<4·5,
or machinery or vehicles.

BS 8110 recommendations regarding tolerances on steel location, unless otherwise specified, are as follows:

1. The actual cover should not be less than the required nominal cover minus 5 mm.
2. Where reinforcement is located in relation to only one face of a member (i.e., a straight bar in a slab), the actual cover should not be more than the required nominal cover, plus:

5 mm on bars up to and including 12 mm size,
10 mm on bars up to and including 25 mm size,
15 mm on bars over 25 mm size.

The pundit reading indicates the transit time in microseconds of a pulse over the distance between probes. The distance in mm divided by the transit time gives pulse velocity which can be related to concrete strength (C.N.S. Electronics Ltd)

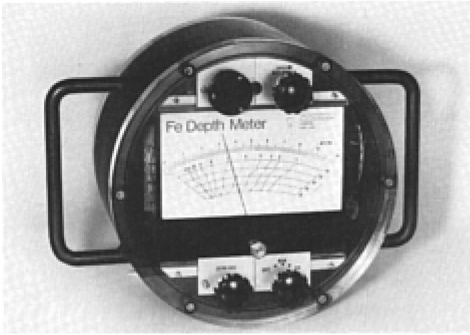


The world's first digital covermeter capable of determining cover by comparison with calibrated spacers at ±3 mm to a depth of 120 mm maximum (C.N.S. Electronics Ltd)

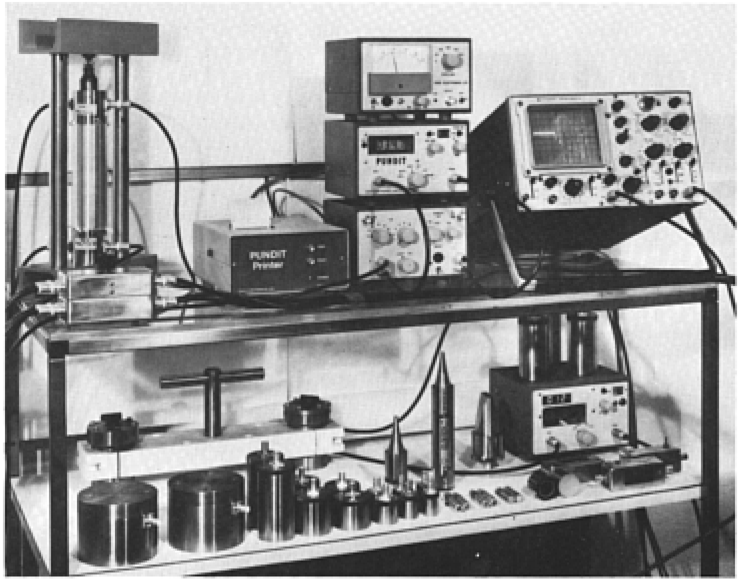
Where the question of cover arises on the construction site, whether in situ or precast concrete, the use of covermeter will establish orientation, depth and even the diameter of the reinforcing steel.

Corrosion

A reinforcement bar surrounded by concrete is normally protected from corrosion by the alkaline nature of the concrete. Cement paste has pores and concrete has voids which combine to increase the permeability of the concrete permitting the ingress of moisture and oxygen, both of which are needed for corrosion. Corrosion is an electrolytic process and as the film of oxide on the surface of a bar is slowly destroyed by aggressive attack, the bar at that point becomes an anodic area while the adjacent protected surface of the bar becomes a cathodic area. Ions flow from the cathode through the concrete to the anode where they form corrosion products. The rate at which the corrosion takes place depends on the electrical resistance of the concrete and the availability of oxygen at the cathode. The electrical resistance is greatly reduced (×100) by the presence of chloride ions and high moisture content, only (×10) by lower grades of concrete strength. Corrosion almost always starts at points of internal stress within the metal and results from incorrect (insufficient) cover, from porous or badly compacted concrete, and unfortunately the process is self-perpetuating unless, in some particular circumstances, a state of passivity is arrived at and the corrosion



For use in marine works, this meter can be used to a depth of 100 m to etablish cover to steel (C.N.S. Electronics)



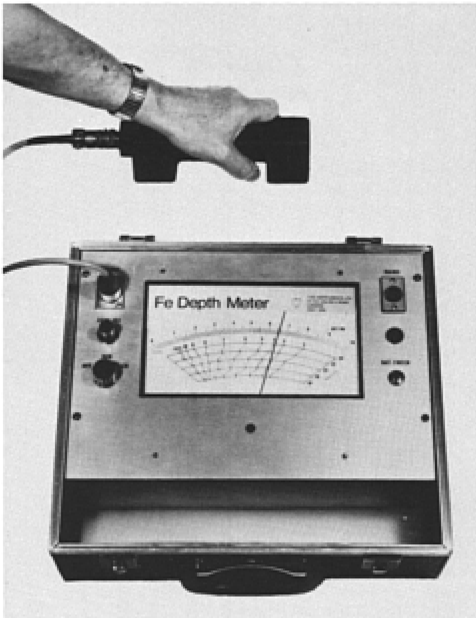
Ultrasonic testing equipment under test prior to delivery (C.N.S. Electronics Ltd)

process halted. Expansive products of corrosion often generate sufficient force to spall off the concrete locally, thus exposing steel to further, more rapid attack.

Carbonation

Concrete used for structural purposes which has been properly batched and mixed, carefully placed, compacted and cured and which has been formed in such a way as to retain the total fines content, provides an alkaline environment which inhibits rusting or corrosion of the embedded steel.

Where carbon dioxide from the air reacts with the concrete, when for example it is carried in solution, it combines with the lime (calcium hydroxide) in the Portland cement concrete to make calcium carbonate (chalk) and water.



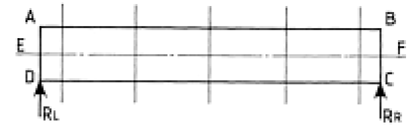
The depthmeter is an invaluable aid in the maintenance and control of quality where steel location is concerned (C.N.S. Electronics Ltd)

This carbonation process increases in depth with age, the concrete ceasing to provide the required protection to the steel. The designer, by careful detailing and specification, and the constructor, maintaining cover and ensuring good quality, well compacted concrete, but above all curing for the specified period, can ensure that the depth of carbonated material does not increase at such a rate that the steel corrosion will be initiated within the normal life of the structure.

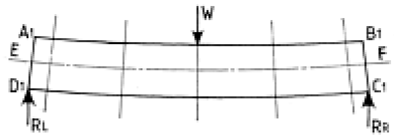
Structural mechanics

The cross sectional areas of steel and concrete are governed by the need to ensure that the structure will be serviceable at working loads, have an adequate safety factor against failure and will resist fire. The moment of resistance of each element in the structure must exceed the ultimate bending moment resulting from the live and imposed loads and, where applicable, the wind loadings. The moment of resistance is equal to the couple formed by the compressive force in the concrete and the tensile force in the steel. The ultimate compressive force in the concrete is a function of the characteristic strength of concrete, the breadth and depth of the stress block, b and x as illustrated. The depth, x, depends on the effective depth of the structural member.

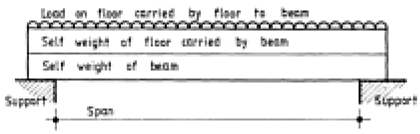
The tensile force of the steel is a function of the characteristic strength of steel and its area. For a specific characteristic strength of steel, the area of the steel is determined by the force it has to sustain. Thus the grade and dimensions of the concrete and the grade and location of steel reinforcement are critical to the satisfactory performance of the structure. When designing a structure the engineer will arrange the location and quantity of reinforcing steel in such a way that in the extreme case elements give warning of imminent failure and do not fail abruptly. The designer applies a factor of safety to his design, which is determined by the probability of overloading, the danger to life in the event of failure and the economical consequences of failure. Recommendations are made in the various Codes of Practice and Building Regulations regarding the appropriate safety factors. The structural designer, also guided by Code recommendations, incorporates a safety factor into his design which guards against the effects of expected variations in materials and workmanship. However, no designer can economically allow for *substandard* materials and workmanship. *It is most important that defects in*



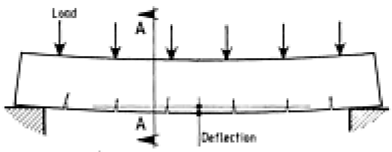
elevation of simply supported beam in unloaded state



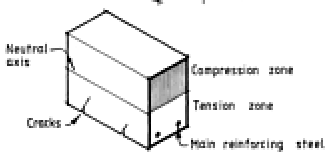
after the beam has been loaded, the top of the beam has been shortened by compressive force and the bottom has been stretched by tension, the neutral axis is the same length as before



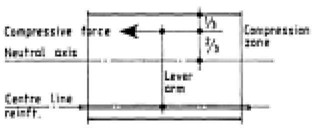
definition of loads in a beam—beam carries own weight plus weight of floor plus load applied to floor—note, selfweight includes finishes to floor and ceiling and often an allowance for services



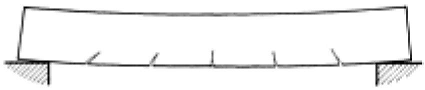
behaviour of beam under load



section on AA

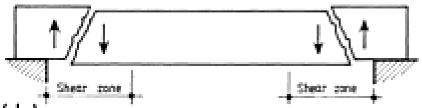


the strength of the beam is equal to the (tensile or compressive) force × lever arm



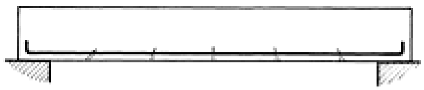
(a)

the load in a beam has two separate effects on that beam:
(a) bending (stretching and compressing the outer faces of the beam)

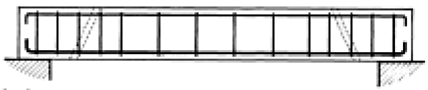


(b)

(b) shear, in which part of the beam tries to slide past another part (shear is greatest near the ends of beams)



reinforcing against tensile cracking under load

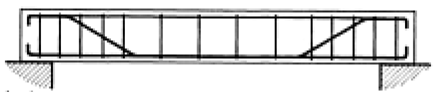


(a)

three methods may be used to reinforce against shear:
(a) additional stirrups

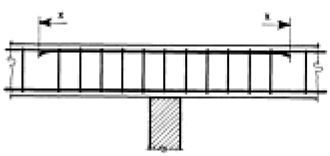
(b)

(b) bent up bars

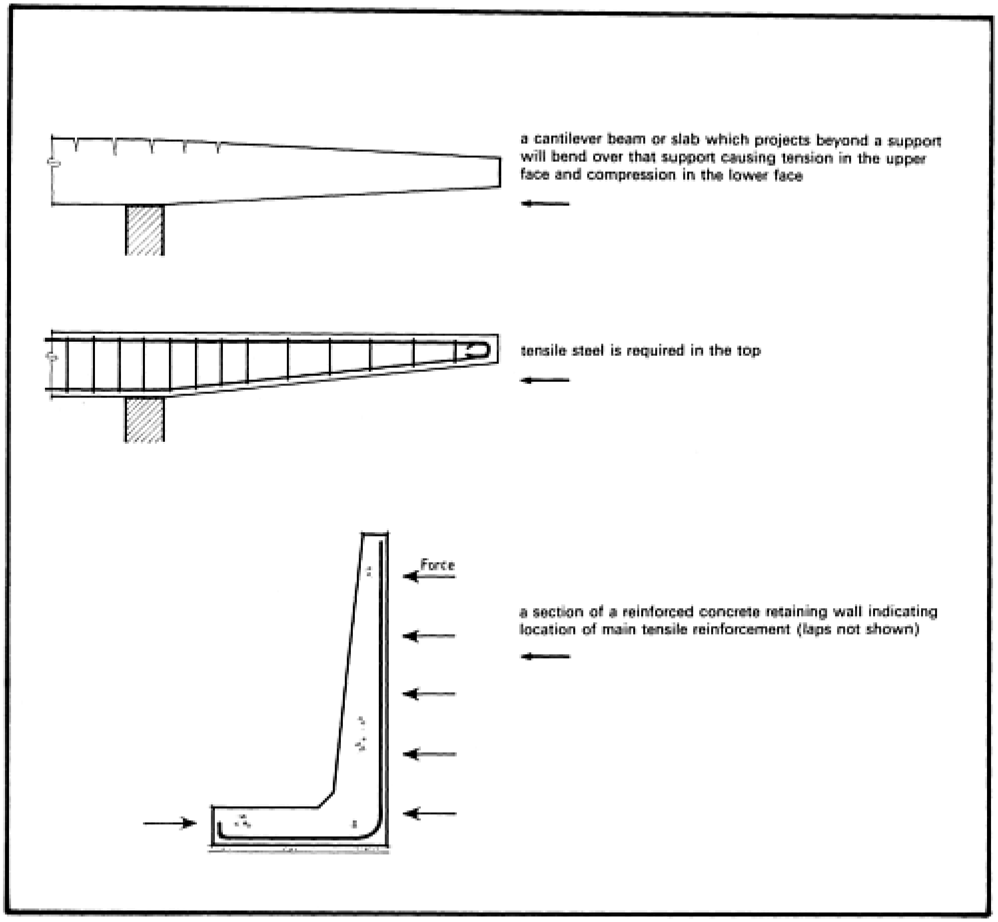


(c)

(c) a combination of (a) and (b) to avoid congestion



where a beam is continuous over a support, additional steel will be introduced to deal with tension developing over the support



site workmanship, the maintenance of correct section, correct location of steel, and so on, do not make inroads into these safety factors.

In the limit state approach to design, the philosophy recommended in BS 8110, the designer considers the stage at which a structure becomes unfit for its envisaged usage in the light of seven limit states (collapse, local damage, deflection and cracking, vibration, fatigue, durability and fire resistance), and in all of these the supervisor will recognise the importance of his role and that of the workers for whose activities he is responsible.

Compression and tension

The forces set up within a simple rectangular beam under load are illustrated. A rectangular beam freely supported at R_L and R_R, has a number of equidistant vertical lines ruled upon it. Length *AB* represents the length at the top of the beam, *CD* the length at the bottom. Length *EF* represents the length at about the middle of the beam. As the beam is not loaded, *AB*=*CD*=*EF*. When the beam is subjected to a concentrated load, *W,* at its centre point it will be seen that the vertical lines are no longer vertical or parallel. The top of the beam has shortened under compression and the bottom has lengthened under tension, but the line at or about the middle will have neither lengthened nor shortened, so that the length *A B* is shorter than *AB,* length *C D* is longer than *CD* and length *E F* is equal to *EF*. The vertical location of *E F* will vary depending upon the shape of the section of the beam, and on the location of any reinforcement incorporated into the beam. The part of the beam which undergoes no change in length on loading is called the *neutral axis*.

When visualising the location of steel reinforcement within an element, it helps to consider the pattern of tensile cracking of the element under load. Thus, taking the simple case outlined above, it would be necessary to introduce steel to carry the tensile forces in the bottom of the unit at the middle of the span. The tendency of failure in shear, diagonal cracking induced by the combination of stresses along and downwards through the beam adjacent to the support, can be combatted by steel located diagonally across the likely shear plane or by stirrups being placed closer together in the shear zone. In deep beams a combination of the two methods may be necessary. In general practice the smaller diameter bars incorporated in the top of the beam are mainly of use in caging or assembling the steel and are termed lacers or lacing bars. Where the member under consideration is continuous over a number of supports then steel will be introduced over the supports to deal with the tension which will develop there.

The point of contraflexion is the name given to the theoretical position in the beam where tension ceases to exist in the bottom face and changes over to the top face. Where special configurations of concrete are considered, such as cantilevers, it is again helpful to visualise the probable mode of failure when the means of combatting the forces becomes apparent, i.e. by locating steel in the top of the element particularly at the last point of support. A similar configuration exists where retaining walls are concerned, and it is simple to visualise where the reinforcement should be positioned to take the tension.

Of course the accurate location of the steel within the concrete is essential and this is achieved using chairs, spacers and in certain situations, welded connections, to ensure that the reinforcing cage remains in the correct location throughout the stages of formwork erection, concrete placement and compaction. BS 8110 recommends minimum quantities of steel required in different types of structural element when drying shrinkage cracking has to be minimised as well as for the expected loading.

Prestressed concrete

Economic large span construction can be achieved using prestressed concrete. Indeed, a combination of high strength concrete and high tensile steel has much to offer in terms of economy in the production of linear products, poles, piles, sleepers, pipes, floor slabs and similar structural elements.

Reverting to the location of steel in reinforced concrete as previously discussed, it is essential to visualise how high tensile tendons, accurately located within the section, and in some instances supplemented by simple reinforcement, can be used to achieve the benefits of long spans and light section while taking advantage of improved resistance to fire and the fact that prestressed concrete elements do not crack under normal working load. The application of force into concrete via prestressing tendons, either using pre-tensioning and post-tensioning techniques, ensures a *reserve* of compressive force being built into the unit. A freely supported beam would, after casting and before introduction of initial prestress, appear as illustrated.

It is convenient to visualise equally spaced vertical lines marked upon the surface of the concrete. On application of prestress the concrete element would alter in shape— there would be a shortening of length of line *CD* due to the introduction of compressive force and the beam would lift or camber as a result of this shortening. The length *AB* would, in most instances, remain unaltered on loading. Some part of the camber would be lost. Whilst *AB* lengthens there would be no cracking under normal working load because of the inbuilt compressive force. Cracking would occur under an excessive load but the cracks would be uniformly distributed along *AB* and would close and disappear on removal of the load.

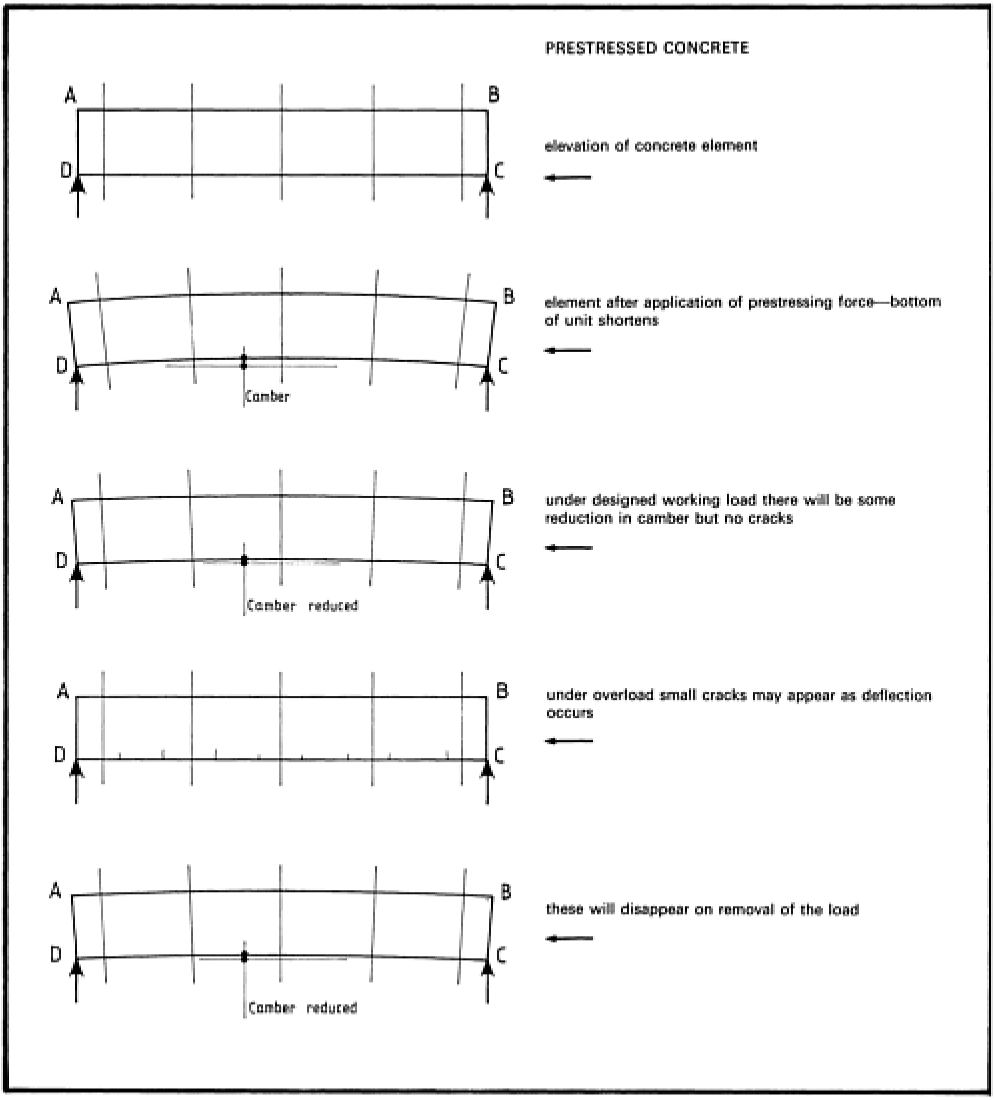
Taking linear prestressed products (piles, beams, poles, floor slabs, and so on), the initial prestressing force can be introduced exactly where required by careful location of the tendons or groups of tendons. The tendons are supplemented by mild steel or high yield high bond stirrups, lacers and links adjacent to points of shear, bursting and so on.

In the case of pre-tensioned concrete the force is transmitted by the bond between steel and concrete. In some cases crimped or indented wire is used to enhance bond. In the case of post-tensioned concrete the force is transmitted via anchorages and bearing plates into end blocks or anchorage blocks. The location of the tendons within the structure of the element can be so arranged that they deal with shear forces as well as the normal tensile forces. Indeed the concrete may, in the case of large sections, be prestressed in several directions, say, horizontally, transversely *and* vertically. Prestressing using posttensioning techniques can be applied to silos, tanks and similar enclosures where substantial tensile forces must be sustained. Latterly, segmental construction has become an economical means of constructing large span bridge beams and similar constructions. In segmental construction transverse joints are introduced into the structure, in situ elements or precast elements are then post-tensioned together to form the completed structure.

Concrete for prestressing

High strength concrete with suitable workability is essential to the prestressing operation. The workability must be such that the concrete can be compacted around the tendon and into all parts of the member, although the mould or form may be congested by ducts, anchorages and other cast in fittings and reinforcement. A high degree of quality control is essential to ensure that the required concrete strength to permit transfer of force is achieved at the appropriate time in the construction process. Careful mix design and control is required to ensure that higher shrinkage and creep from lower strength concrete do not reduce the prestressing force below the designed value.

BS 8110 gives guidance on concrete grade and strength for prestressing purposes, ranging from 30 Grade to 60 Grade. It is usual to require sample cubes, cured using a similar regime to that employed in curing the product, to achieve a compressive strength of, say, 40 N/mm^2 prior to the transfer of the prestressing force into the unit. In some instances, the tendons may be partially prestressed to allow early removal from the casting bed. In this case the designer will stipulate a minimum concrete compressive strength as represented by the cube specimen prior to the introduction of the prestressing force. Prestressing elements are, to some extent, self-testing. Unsatisfactory concrete, badly compacted areas of concrete, misplaced tendons and similar defects will be revealed by excessive unintended camber or distortion at the time of introduction of initial force.

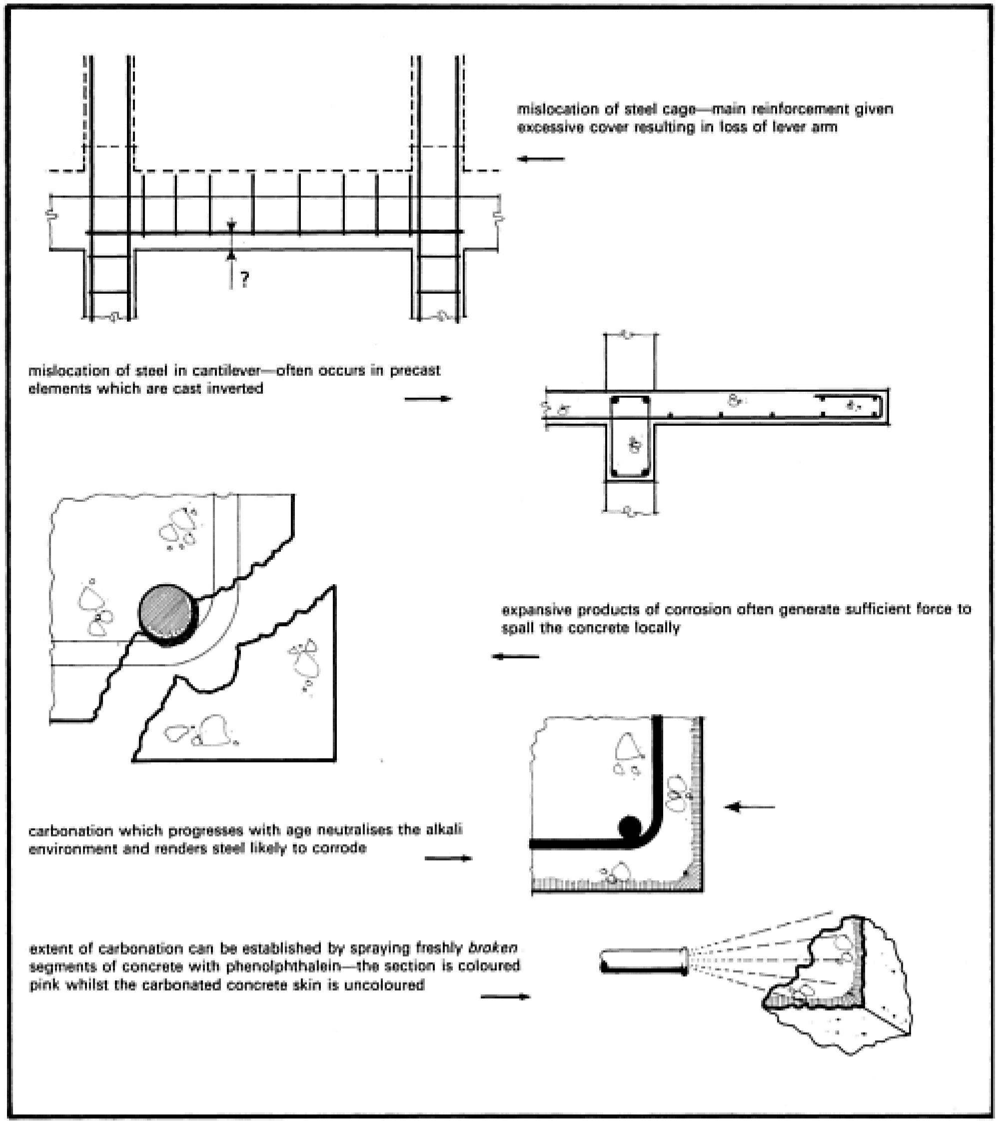


Fire resistance of reinforced and prestressed concrete

The supervisor will observe from the drawings supplied by the architect and structural engineer, certain provisions to prevent the spread of fire in the structure, ventilators to remove smoke, and so on. It is important where concrete construction is concerned to have a knowledge of the way in which reinforced concrete behaves when exposed to extreme heat, as in a fire. This will assist in understanding the methods of designers in combatting problems by adjusting cover, reinforcement locations and by incorporating further fabric.

The concrete within the structure expands upon intense heating and the concrete at the face dries, shrinks and cracks. The outer face being hotter than the core, differences in the rate of expansion cause excessive strain in the concrete. The concrete tends to spall away from the steel and may, if it is very wet and heated very rapidly, be forced off by steam. Spalling allows the further heat to reach the steel, causing greater expansion.

The heat penetration depends on the materials from which the concrete is made. Lightweight concrete, for example, reduces the heat flow rate into the elements. The type of reinforcing steel and the stress in the steel also govern its resistance to fire damage. In the design process, engineers improve the resistance to fire damage of the structure by introducing chamfers at the corners of the undersides of beams and at column heads and by increasing the cover of concrete to the steel, in which case



the additional cover may have to be retained by the incorporation of a wrapping mesh.

When a survey of fire damage is carried out, the inspecting engineer may recommend that all that is required is for the damaged concrete to be hacked away and replaced by sprayed concrete or a resin mortar coating. In cases where prestressing beams have been subjected to intense heat, massive deflections may require their replacement.

Lightweight concrete

Lightweight concrete is manufactured using clinker and ash, expanded slag, clays and shales, sintered pulverisedfuel ash and a variety of more recently introduced materials, such as plastic particles. Pumice has, of course, been in use since Roman times.

Lightweight concrete has good thermal properties due to its lowered density which, for general purposes, may be taken as being below 1850 kg/m^3. The lightest concretes with densities between 300–800 kg/m^3 are normally used in non-structural applications, lightweight concrete with a density between 800–1850 kg/m^3 being used in reinforced and prestressed structural applications.

Aerated concretes (a lightweight concrete product of 350–550 kg/m^3 density) are produced using gas or air and are used in block form or as sprayed or flowed materials in screed or insulating applications. Some products include reinforcement, although care has to be taken over the location and protection of the units to avoid corrosion of embedded steel.

As discussed in the section on cover, where lightweight concrete is used in a structural role, the cover to embedded reinforcement should be increased to the largest nominal aggregate size due to greater porosity of the concrete. Lightweight concrete, because of its good insulating properties and low thermal movement, is more resistant to fire damage and offers better protection to the steel. The aggregates themselves are produced in the main by processes involving high temperatures and are thus less liable to damage and disruption by heat.

Applications of lightweight concrete

The supervisor will encounter lightweight concrete in loadbearing and non-loadbearing blockwork. This has become a specialised area of construction and the supervisor is referred to the *Bibliography* for further reading. Prestressed lightweight concrete is becoming increasingly popular, the lightness of weight offering economies in large span members and where considerable cantilever is desirable.

Air-entrained concrete

Air-entrained concrete, or concrete into which air in the form of minute bubbles has been purposely incorporated, has improved properties of frost resistance. BS 8110 recommends the use of air-entrained concrete where concrete of Grade 40 or lower is required to resist attack by salt used for de-icing. The inclusion of air in carefully controlled quantities as *entrained air,* as distinct from *entrapped air,* also improves the characteristics of the fresh concrete. Also, the workability of air-entrained concrete is greater than plain concrete and bleed of water from the fresh concrete is reduced, the mix is thus less prone to plastic settlement problems. With regard to the resistance to frost attack, it is likely that the minute bubbles provide space into which the water in the pores can expand by about 10% when it freezes.

Whist air-entrainment reduces the concrete strength, unless the cement content is slightly increased, the opportunity to reduce the water content presented by the increased workability resulting from the entrainment offsets the loss to a large extent. Use of an air-entraining agent can overcome the problem of harshness in the lightweight concrete mixes, the minute bubbles acting as a weightless fine aggregate and supplementing the fines components for the mix. The supervisor must ensure that a proper dispenser is used to measure the quantities of airentraining agent as such minute quantities are required in a dose that small errors can make considerable variation to the properties of the concrete. The air meter test is described in BS 1881:100 series. If air-entrained lightweight concrete is tested, the apparent air content of a non-entrained mix should also be measured. This value deducted from the results obtained from the air-entrained concrete, will give the quantity of entrained air.

6.
Supervisory skills

The main elements of supervision are those of:

planning
organising
motivating
co-ordinating
controlling the work and the workers

Although basically self-explanatory, a few words of explanation covering each of these elements may prove helpful. In the instance of planning, the supervisor is mainly concerned with the communication of long term plans and the execution of short term planning as indicated by the programmes. Senior supervisors are frequently involved in the preparation of programmes, devising methods of working, and are then well placed to ensure that the methods are installed and maintained at the workplace once the contract is underway. Many supervisors in construction develop specialisations, and the "concrete frame supervisor" is a recognised expert in this particular field. The frame supervisor generally commences work in the ground then supervises basement construction and the reinforced superstructure through to the completion of the construction. At this stage a finishing supervisor will take over and deal with the installation of services, control of mechanical/electrical trades and other finishing trades. The frame supervior then has the responsibility of arranging the supply of concrete (or receipt of readymixed concrete), the means of handling using a variety of plant which will have been ordered in conjunction with the plant manager or suppliers, organisation of the workplace, particularly the arrangements for gangs of formworkers, steel fixers, concreters, finishers and so on. All this demands an intimate knowledge of the skills involved. In this context a considerable amount of liaison is required with both those who have planned the overall operation, selected methods and produced cost comparisons, and those who control the allied trades—carpenters, steel fixers, electrical and mechanical services, and so on.

Motivation and encouragement of the workforce to produce according to the programme forms a vital part of the supervisory duties. Here a knowledge of the capabilities of each individual in the team and something of their personal circumstances is important to aid successful motivation. The supervisor must understand the policies of the company regarding incentives and reward and, of course, must ensure that the quality of production is maintained as well as the quantity being attained. The establishment and maintenance of standards for his workforce is an important part of supervision.

The activities of co-ordination are especially important and on the construction site with detached working locations, often bad working conditions and with problems of communication, the supervisor is often hard pressed to achieve the necessary degree of co-ordination. The employment of sub-contractors who are controlled by a mobile supervisor can cause further difficulty. Coordination is, of course, essential and the provision of the correct equipment and materials as well as suitable labour and service personnel is difficult to achieve, particularly in the early stages of a contract. Co-ordination improves as all concerned learn their particular tasks and an important part of the co-ordination aspect is that of training and instructing the various members of the teams in the importance of their contribution. Careful programming, a better knowledge of the task and, especially, a greater amount of mechanical plant and aides to communication, such as VHF radio, have done much to ease the tasks of co-ordination for the supervisor.

Regarding the element of control, the supervisor in concrete construction can best achieve sound control by actual involvement, being in on the work, taking part in tests and trial casting and getting involved in the establishment of method and the incorporation of day-to-day alterations resulting from feedback of results. As a rider to control, there must be a further element—that of maintenance of the preferred system. All too often systems are devised and installed at considerable expense in terms of professional input, the time and effort of method engineers, programmers and so on, only for the system to fall into disrepair as the work proceeds. The supervisor should be constantly alert to “unofficial” changes in method or failure to use plant which has been specifically purchased at considerable expense. Maintenance of the system must, however, be carried out with a sensible approach to revision in the light of results and the supervisor has an important role here in the process of communicating results and possible improvements to the specialists, such as plant engineers, formwork and falsework designers, and then installing and maintaining alterations to the sytem from these sources.

The following commentary has been prepared as a result of the author’s involvement in concrete construction at site and in the provision of services—formwork and precast concrete. It is incorporated here to expand on and supplement the five key activities of the supervisor as previously mentioned.

The role of the supervisor within the construction industry

The supervisor/operative relationship

The author holds a firm belief that considerable gains in productivity and standards of achievement are to be obtained from improved attention to the training of supervisors in matters of communication and human relationships. In this commentary the functions of supervision are examined and training topics discussed. The problems vitally affecting the construction industry at this point in time—rising costs, shortage of skilled labour and difficulties in maintaining standards of workmanship— make demands upon the skill of the supervisor.

The supervisor's management role

Management organise and set targets, initiate systems and provide facilities for a particular task to be carried out by the workforce, and whilst they can co-ordinate the efforts of the section supervisor and control resources, the actual drive and encouragement required to motivate the individual operative can only be provided by the immediate supervisor at the place of work.

Particular requirements of the construction industry

The supervisor in the construction industry has particular difficulties to contend with. Inclement weather and the difficult working conditions under which a contract is carried out, coupled with the continual effort in carrying through the work programme on time, make exceptional demands upon the physical and mental abilities of the supervisor. These demands, together with the manual nature of much of the work, call for men of stamina and temperament suited to the tasks and used to adapting themselves and their methods to daily variations in conditions.

The supervisor's basic skills

It is the personality of the supervisor, his skill in encouraging his section to maintain the required levels of performance as regards output and quality, which will eventually be reflected in the suitability of the completed work. Successful supervision will present a finished job such that the manufacturer retains the goodwill of the client, the architect and appropriate authorities, and thus will have the opportunity of obtaining further work of a similar nature on subsequent contracts.

The supervisor's skill reflected in the work

In particular aspects of construction, the quality of the supervision concerned can be directly read from the face of the finished work. A simple concrete wall unit which is to be left exposed on completion of the contract will present an extremely accurate record of the skill and experience of the operatives concerned in the manufacturing process but, more specifically, the product will provide a commentary upon the ability of those concerned with organising and supervising the work.

Modern methods

As the component becomes more complicated in manufacture or construction, so will the finish attained more directly reflect the degree of supervisory skill incorporated, and as many of the present functional applications of modern materials will allow little opportunity for postmanufacture remedial work to cope with defects resulting from poor workmanship or bad supervision, there are obvious gains to the architect and engineer to be obtained as a result of firm supervisory training programmes being maintained by the contractor.

Cost of supervisory training related to other capital outlay

Relatively small investment in the selection and training of supervisors will give substantial returns in the productivity of the firm through maintenance and improvement of standards. Provided that the supervisor can be retained by the firm and find suitable advancement within the structure of its organisation, the money invested will be amply repaid as the supervisor builds upon his training by experience and progresses into management or specialist sections of the concern. The benefits of similar sums of money invested in plant or equipment will long have been written off and the benefits dissipated while the trained supervisor will progress and, in turn, develop his subordinates in the light of the training and experience he was given.

Understanding the demands of the work

The operative will expect the supervisor to be able to appreciate the effects on his work of changes in operating efficiency of his tools, also the effect of changes in temperature and climate, and here again the supervisor will need a clear understanding of the work to appreciate these points.

Demands on the supervisor

Where training methods are concerned, the critical examination of the supervisor's responsibilities and the factors affecting his performance will assist in establishing the matters around which the training should centre. It is extremely desirable to make an appraisal of what is expected of the supervisor by the various people with whom he has contact during the course of his activities, both by his sub-ordinates and those who control his efforts within the firm.

The demands of the operative

Firstly then, an examination of the views held by the subordinate whose daily work will be subject to continual scrutiny by the supervisor. The sub-ordinate's livelihood will depend, in some cases, upon the ability of his supervisor to control the work flow and maintain a suitable workplace environment in which he can operate successfully with access to the services and assistance which he may require. He will thus hold very exact views on what he requires of his supervisor.

The supervisorÐan extension of management

In the construction industry, with congested sites and complicated components in production, the supervisor will be expected to represent the management and proprietors of the company. Whilst it is evident to the operative that the supervisor does not pay the wages, he takes the supervisor as the representative of management and expects his instructions to be those which would emanate from the management were they, in fact, present in the working area.

Financial and organisational agreements

Promises made by the supervisor, or offers made in respect of payment for services, must be seen to be backed by the firm, and must be seen to represent what the operative comprehends as the intention of the firm. Action must be forthcoming in respect of any promise made strictly in the terms of the initial promise and not modified by any authority not involved in the original agreement.

Company backing

The backing of the firm must be evident in all that the supervisor does and he must be seen by the operative as understanding the requirements and decisions of management.

Instruction in safe and efficient working

The operative will expect to be instructed in methods of working and he will expect the experience of the supervisor to be injected into these methods in such a way that the method outlined becomes safe and leads to successful completion of the work.

Quality consideration

In accepting the effort of the operatives, the supervisor will be expected to accept also the responsibility for the work produced by those efforts and the fact of completion of the work will generally be taken as acceptance of a given standard of performance. The supervisor will then be required to uphold the standard achieved in discussion and dispute with any authority who subsequently checks or modifies the product.

The supervisor representing the operative

The operative will surmise that during the process of planning and discussion, the supervisor will have put forward such information as necessary to ensure that difficulties likely to be encountered by the worker will have been brought to the attention of the management and it will be assumed that the supervisor will have respected the ability of the operative and used his knowledge of the individual concerned to ensure that the task is made acceptable and that it is within the terms of employment of the members of the sections. The supervisor will be expected by the operatives to be able to promote their welfare as well as issue instruction to them.

Obtaining the support of services

The supervisor will be called upon to secure from other departments of the firm the services necessary for completion of the tasks in hand. It must be apparent that a fair share of these services is being obtained, in this regard the supervisor will gain in status in the operative’s opinion if he demonstrates his continued ability to better obtain such services than other of his colleagues.

Aims of gang promoted

By pre-planning and knowledge gained from his experience, the supervisor will be required to promote the interests of his own section, the operative taking pride in the fact that he works for a particular supervisor, and the fact that he works for a popular supervisor (or even manages to satisfy an unpopular supervisor!), will improve the job satisfaction of the operative within a given section.

Rights of gang maintained

Sometimes rights and facilities achieved by the team in the past, working areas, storage places, precedence with canteen facilities and similar informal arrangements which enhance the work in the section from the point of view of the workmen, will need to be defended against other sections and management changes.

Understanding of management aims

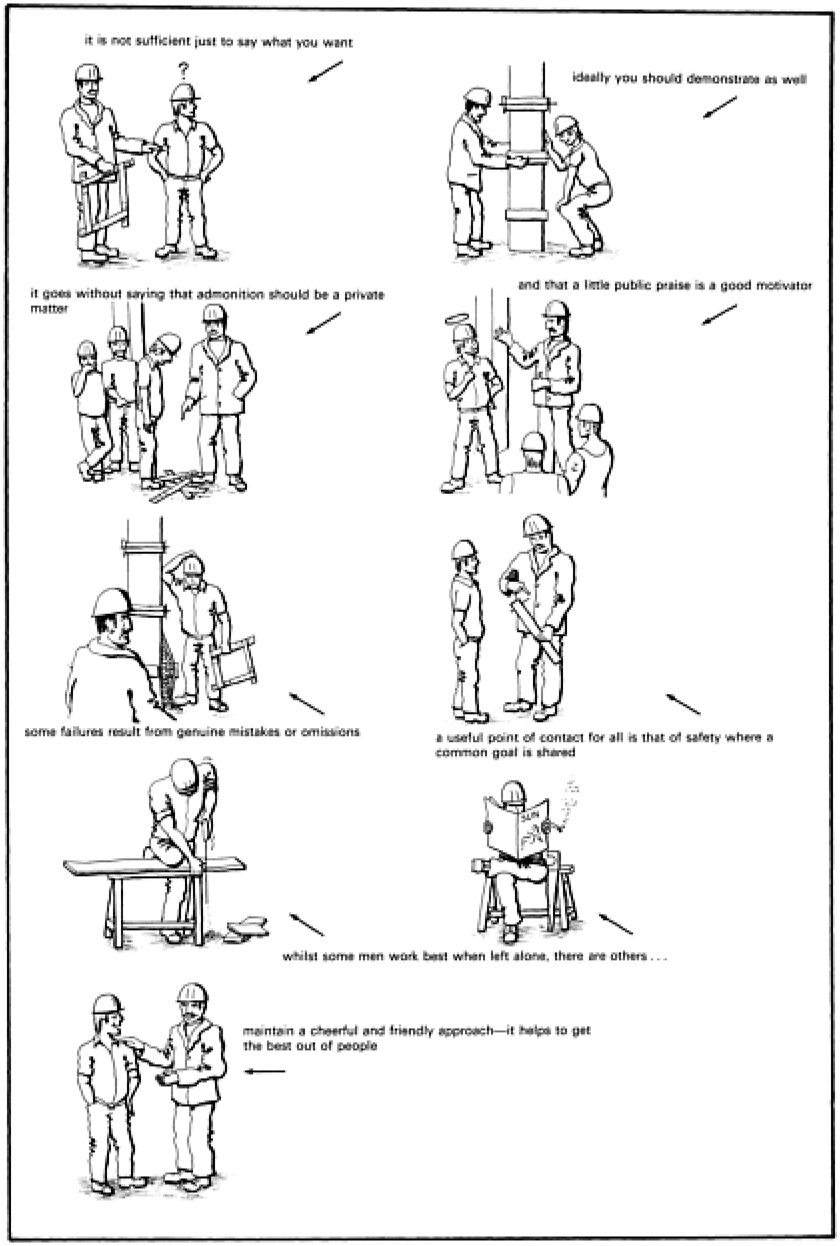
The supervisor will be called upon to explain the motives of management in changes in organisation, re-allocation of tasks and work places, and he will be expected to identify people within the firm and be able to outline their responsibilities and explain how their actions can affect those working in his own section.

Assistance with pay problems

Problems of pay and bonus of incentive schemes will be brought to the supervisor and he will be expected to be able to provide satisfactory answers to queries and ensure that his men obtain their rightful reward for work done. The supervisor will be expected to have time available to deal with all matters and must have respect for the high priority accorded to the matter in the mind of the man concerned. Rarely will delay on such matters be tolerated and redirection to the department concerned will not generally be satisfactory. The operative will expect to be able to demand the interest of the supervisor and be sure of assistance with his problem.

Supervisor's understanding of the work

The operative will not generally expect that his supervisor should be able to do the work which he, the operative, will be set to do, nor will he demand that the supervisor should previously have done similar work. He will, however, expect that the supervisor will have a complete understanding of the tasks in which he is employed. This understanding will be necessary in estimating and controlling the amount of effort which each operative is applying to a task and in assessing the effectiveness of the operative’s application to the task.


it is not sufficient just to say what you want
?
ideally you should demonstrate as well
it goes without saying that admonition should be a private matter
and that a little public praise is a good motivator
some failures result from genuine mistakes or omissions
a useful point of contact for all is that of safety where a common goal is shared
whilst some men work best when left alone, there are others . . .
maintain a cheerful and friendly approach—it helps to get the best out of people

Assistance with personal matters

Personal matters will occasionally present problems which the supervisor will be invited to solve—possibly minor matters such as how to deal with insurance, schooling and such like, in which assistance can be given in the light of the supervisor's own affairs. The supervisors will be consulted in confidence, and must respect this confidence in any subsequent situation which may arise.

Accessibility of the supervisor

The supervisor must be available at all times to receive and discuss grievances, to ensure equal distribution of work and look after the safety of the operative. The operative will expect to receive criticism from the supervisor during the course of the work, criticism and encouragement are essential to control. The supervisor will need to be quick to praise advances and improvements and equally quick in dealing with defects and poor workmanship. The supervisor who allows things to be accepted which are acknowledged within the section to be substandard, discards the authority which he would need to deal with subsequent defective work of a similar nature.

Maintenance of job disciplines

The operative may tend to cut corners and may even feel that it is his prerogative to find short cuts, he will certainly lose respect for a supervisor who fails to check and eliminate such short cuts and loopholes in the system which allow defective work performance. Failure on the part of the supervisor to discipline a section member who repeatedly causes defects in the work or output of the section will cause a fall off in the value of the work of the section as a whole and loss of authority on the part of the supervisor.

Support of hourly paid supervision and juniors

Within the section or department there will be junior grades of supervisor, hourly paid leading hands and similar appointments undertaking the difficult task of leading by example within the group. These men will demand support and instruction in their own efforts, even the informal group and its leader will require acknowledgement and the supervisor will have to be particularly skilful in his arrangements regarding this element.

The informal group

Care must be taken to ensure that the objectives of the group are seen to be in line with those of the section as a whole. When there are differences between the apparent aims of the two, he must carefully adjust the situation such that the company's interests are best served.

Enthusiasm as a part of supervision

At all times the operative will expect a degree of enthusiasm from his supervisor and it might be that distrust will be read into lack of such enthusiasm, labour will take the lead in many ways from the supervisor, and the mantle of gloom cast about a task by an unenthusiastic approach on the part of the supervisor can mar the outcome of the work. Bad humour and a surly approach to work will spread rapidly throughout a section and men affected by such demoralising situations will require considerable encouragement and assistance to regain the frame of mind where tasks are once again tackled in good humour with expectations of successful completion.

Utilising operatives' ideas and suggestions

Encouragement will include consultation with the operative on method to be adopted in carrying out the tasks in hand and building into the selected system the ideas of section members aimed at reducing times and improving outputs.

Interpretation of policy

The supervisor may, in some cases, be expected to interpret rules and methods in a way which favours the interest of the operative. These requirements are obviously grossly unreasonable and the supervisor finding himself in such a situation should immediately discuss the matter with his superior with a view to obtaining a review of suspect rules or arrangements. These comments apply in particular to matters affecting the safety of the worker and his fellows in the section.

Errors

The operative will be prepared to accept the supervisor as a human being and thus a person apt to make mistakes, he cannot forgive error of judgement which affects his income or standing in the eyes of his workmates. Mistakes acknowledged and explained can be erased or compensated for, but mistakes glossed over or wrongly blamed upon circumstances will never be excused and successive errors will adversely affect opportunities of the supervisor to achieve effective results in future operations.

The humour of the supervisor

Minor moods of the supervisor will be humoured by the sub-ordinate but he must know that judgements of his performance are objectively reached based on usual situations and not the result of subjective decisions reached during such periods of depression on the part of the supervisor. The operative can understand that the supervisor has troubles and responsibilities, but he will not excuse a supervisor for moods or bad temper on the grounds of such responsibility bearing heavily. The operative knows that the supervisor accepted the responsibility and possibility of weighty problems when he undertook to carry out the job and the operative therefore expects the supervisor to be able to absorb the pressures of the work and maintain an even tenor of affairs within the section. An operative will express or show some sympathy in situations where the supervisor is under pressure, but can rightly expect that such pressure should be contained by the supervisor at his own level.

Freedom from supervision

The operative will expect the supervisor to know which sections of the work he may be left to complete on his own and without close supervision. Such free work promotes the operative’s sense of job satisfaction and strengthens the co-operation between supervisor and operative in mutual trust.

Human approach

The operative will expect a sympathetic reception of his problems and ideas, he expects a human reaction and above all else desires to be recognised as an individual, a person with something to offer, be it skill, strength or persistence of effort. The supervisor acknowledging the worker's ability, having regard to his responsibilities and domestic situation, will achieve lasting results in his field.

The experience of the supervisor

In the process of supervisory work, the supervisor will gain the respect of the men in his charge and build an experience which can be drawn upon during each successive stage of his development within the firm. At the same time he will be building up the knowledge and skills which are essential to the leader of an enterprise and which result in formal acceptance of the supervisor in a position at the head of a team.

The supervisor and the Trade Unions

The operative will expect the supervisor to acknowledge such parts of the Trade Union structure as effect them both in the course of the working day. He will expect the supervisor to receive the comments of the steward or the gang spokesman and will watch for due consideration to be given to matters discussed. He will expect the supervisor to have a working knowledge of the function of the Trade Union and its aims and it will be the care and attention accorded to details of approach and interpolation at this stage in potential dispute or discussion which will set the tone of negotiation and settlement in the long term. In fact, the supervisor's reaction to a particular problem at this level may set the tenor of subsequent negotiation beyond the scope of the gang or site, throughout the company or, indeed in serious matters, within the industry as a whole

Communication

The foregoing review, although by no means comprehensive, will serve to illustrate how great is the responsibility of the supervisor in matters regarding his relationship with sub-ordinates, many of the problems and situations outlined above clearly being matters of communication and human relationships and upon which training can be given.

Training for the supervisor

We can summarise the main points to be considered when setting up a suitable scheme of supervisory training to deal with the demands upon supervision and the need for firm instruction based upon good principles of job method and relationships. To be successful the supervisor must be given a firm grounding in methods of communication such that not only are his instructions to the operatives clearly given, but the intention behind the instruction and the resultant impact upon the operative become clarified and consolidated during the course of operations. The instruction given to the supervisor should contain sufficient information on current situations and economic considerations to enable the supervisor to give advice on or within the gang upon the position of the operative with regard to welfare and his standing within the community. Finally, the supervisor must be placed in the position where his evident knowledge of its members enables him to meet the operative in the capacity of an effective member of the management team.

The supervisor and his colleagues in supervision

The supervisor exists within a group of supervisors each responsible for other activities within a particular site or production centre. The relationship which he establishes with these men will govern to a great extent the satisfactory performance of his section within the overall effort. In considering the performance of the supervisor it is necessary to examine the expectations of his fellow supervisors and their impact upon each other's operation. Each of the service supervisors will expect the local supervisor to have sufficient knowledge of the work carried out by their tradesmen to enable him to assess the proportion of the problems involved in providing the services required, thus establishing what degree of assistance the other supervisor will be able to render them in carrying out the combined task.

Planning and co-ordination

Supervisors responsible for providing a service will expect due notice of the requirements of the section supervisor to enable them to plan their men's work satisfactorily. They will expect certain arrangements to be made by way of access to enable them to provide the service. Service supervisors with men on detachment will require assistance in maintaining control over such of the operatives for whom they are responsible, although these operatives are away from their normal workshop or service centre. The supervisor responsible for labour in a detached situation such as this will look to the supervisor directly responsible for the work place to assist in maintaining the discipline of his men whilst on his section, and will require assistance in on-the-spot supervision, expecting their service personnel to receive the consideration which they would receive in their normal work place. The service personnel will have commitments throughout the site and time will not allow direct supervision at all times of the working day, thus the local or section supervisor must have sufficient knowledge of the work of such a service department and its standards, to allow such supervision "by proxy".

Safety considerations

Supervisors will expect the section supervisor to care for the safety of their operatives whilst engaged on work in his section, and will require the section supervisor to ensure that relationships between the service and section operatives and tradesmen are maintained at the right tone.

It may be necessary in the instance of detached working for the supervisor to combine a knowledge of certain general skills of the service personnel with a knowledge of trade practice and union matters beyond the normal scope of his daily routine. This will ensure that the best output is obtained and problems regarding demarcation are avoided. A major requirement is that the supervisor should understand the function of the various departments controlled by his colleagues, and he must be fully aware of the company policy covering their work and allocation of tasks between departments. He will be expected to allow other supervisors sufficient scope and flexibility in mutual arrangements regarding timing of operations to allow them to co-ordinate their work with other supervisory staff responsible for other production centres. The service supervisor and those of other sections will expect the section supervisor to consider their standing within the site or the works and, whilst there will undoubtedly be a degree of good humoured competition expected, will wish to have their particular status upheld by the section foreman or supervisor both with his subordinates and their own.

Co-operation

It will be recognised that there is a very delicate relationship between supervisors dependent upon each other for support in progressing within the company on evidence of results. Trust will be essential—each must know that in difficult circumstances they can rely upon the other to assist in maintenance of the programme outputs and objectives. Knowledge of each other's skills and weaknesses will result from periods of co-operation in carrying out work and each will, in time, discover the particular aspects of their joint task in which their colleague will require assistance to provide a satisfactory outcome to their joint efforts.

Where the right spirit has been generated, particularly through successful joint ventures completed in the past, such informal overlap of supervisory responsibility can greatly assist management in maintaining the function of co-ordination. The service supervisor will expect recognition of the fact that he has to satisfy many varied sections of the works, though he will realise that such considerations will not modify the demand made by the section supervisor. The services and associated supervisors will understand the motivation of their colleague and, being subject to much the same pressures, including those of time, shortage of labour and/or absence of suitable labour, will do much to amalgamate the interests of the supervisory group.

Development and competition

Competition will spur on the respective supervisors in their tasks as they strive to obtain recognition for the work which they complete satisfactorily and add to their experience which they are building with a view to promotion and advancement within the firm. The particular aspects of the relationship between supervisors on a site, some of which have been discussed above, present a fairly clear outline of the subjects which must be covered in the training programme devised for the supervisory groups as a whole.

Development of supervisory skills

At this stage it would seem appropriate to examine ways in which the supervisor can improve his supervisory skills. There is little substitute for experience and the supervisor should ensure that he gains experience in the widest possible range of construction activities. This he can achieve by studying all the methods and techniques used on the sites on which he is employed, and here the training manager can prove helpful in making arrangements such that the supervisor is given the opportunity to view new techniques on other of the company's sites. It may be that a request to contract management will provide an opportunity for involvement in jobs which are "out of the ordinary" in that new or different techniques are employed. In the case of the junior supervisor, who has time on his side, it may be necessary to change from one site to another, or even one firm to another, to obtain the required scope of experience. While this may at first sight seem a rather drastic approach, it is often necessary to make such changes to provide an opportunity to earn the wages necessary to maintain the individual lifestyle. There are, of course, less drastic ways of obtaining the information necessary to enlighten supervision—examples of which are noted below. The supervisor can build up a series of sources of reference which will prove helpful in planning operations and the actual process of control. The following are a few suggestions which may prove useful:

1. *Keep a diary:* this is critical in job control. Items such as the recording of timing of activities, weather, reasons for delay, deliveries to site, progress made by subcontractors, and so on, being essential information for contract management, surveyors, technicians, etc. The diary can, of course, be expanded to include notes of outputs achieved by formwork joiners, concretors, floor finishers, and

such like. This information will stand the supervisor in good stead when further work is being planned. This basic data, recorded in a diary, can be valuable even when, in later years, the writer has progressed to senior management, planning or estimating.

2. *Take advantage of sales visits:* numerous representatives and salesmen call on site with various products which they wish to sell to the contractor. Whilst it is not possible for the supervisor to spare time for all these people, he would be wise to meet some each week to find out what is new on the market. Most salesmen are in contact with a number of other sites and have useful comment to make on the way work is being carried out and the way in which their products are performing under various conditions. Whilst many innovative materials and methods (such as "anti freeze") for use with concrete are useless, it is possible to learn of new and useful materials from these visiting representatives and salesmen. Literature concerning admixtures, retarders, formwork systems, weather bars and similar products, should be kept and filed for future reference and at the same time it is worth taking proffered samples and, where possible, experimenting with them on site using the skills and experience of the labour force to help in forming an assessment of their value.
3. *Join an association or society* devoted to some aspect of construction, such as The Concrete Society or the local branch of a professional association. Meeting with other supervisors and controllers forms a useful sounding board for ideas and discussion of topics of common interest and provides opportunities to gather useful background information of one's own and other trades. The Concrete Society, in particular, is open to anyone who has an interest in the use of concrete in construction and technical meetings, discussions and visits to interesting sites, form a useful and informative part of the activities of regional groups and local clubs.
4. *Make a careful study of selected papers and journals:* a considerable amount of information can be gathered from write-ups of concrete projects—many advertisements in technical journals are informative regarding new materials and techniques. An occasional glance at a journai from another country will give an interesting slant on developments there. Certain countries lead the field in concrete technology and new techniques for handling, placing and compacting concrete. An occasional visit to the public library will afford an opportunity to view new technical publications.
5. *Watch for short courses at local technical institutes:* many colleges run courses on specialist topics which can be of value to the supervisor in his everyday work. Recent courses in the writer's local college have included statistics for quality control, formwork for supervisors, foremanship, and so on.
6. *Take up a full course of study* on some particular topic of supervisory or technical value. The courses for City and Guilds of London Institute qualifications in concrete practice, concrete technology and construction, formwork for concrete construction, and so on, generally run for one year terminating in an examination, successful candidates receiving a Certificate of Competence.

Checklist

Has a clear method statement been published?
Are the safety implications understood?
Are the necessary skills available?
Is the method of payment clearly established?
Are the necessary tools and equipment available?
Can emergencies, accidents, power failures, plant breakdown be coped with?
Are the standards of work clearly established?
Have other supervisors been made aware of needs?

Is safety equipment, lighting, heating, etc., prepared?
Is access suitable?
If this is the first operation of this nature, is it possible to have a “dummy run”?
What in-process checks should be made?
Are stand-by services and equipment, etc., available?
What records are required—concrete workability, stressing records, and so on?
If delay is unavoidable, have meals, refreshment, and so on, been reserved for operatives?
Has transport been arranged to/from hostel/local centre and so on?
What are contacts in event of problems with plant, engineering aspects and so on?

7.
The prime mix method of mix design

By PHILIP L.OWENS, HNC, MPhil, MICT

Introduction

Nowadays the practice of mix design depends largely upon the skills of the ready mix or precast concrete technologist who can be, and often is, responsible for the annual production of tens of thousands of cubic metres of concrete. However, although readymixed and precast concrete have become more widespread and are used on both small and large construction projects alike, mix design should not be completely delegated to these producers. On the other hand, the readymixed or precast concrete industries should not be too restricted, in that they should be allowed to make the best use of local materials. As an aid to those directly and indirectly involved with concrete, what follows is, in many respects, an appreciation of the methods used in the proportioning of materials and selection of a mix, and should thus be of considerable help in the communication and perception of data concerning concrete.

The combination of cement with fine and coarse aggregate provides a three component system, enabling the void content and thus the water requirement of a mix to be minimised by the appropriate selection of suitable proportions of the three components. The skill of the mix designer is essentially one of selecting and proportioning the materials to optimise the void content, so that the least amount of water is used to obtain the workability (consistency) required.

The approach to mix proportioning and mix design of concrete used by the industrial technologist differs in principle from many of the well publicised methods. Most of the latter enable the non-skilled to obtain quick but approximate solutions, which can either be used immediately because the results are intentionally overdesigned, or need to be confirmed by trial mixes. Such methods are often considered too slow or inaccurate, particularly when unfamiliar or new materials are proposed for use. Thus, an appreciation of the techniques used by the industrial technologist for concrete mix design is essential to increase confidence in concrete as a material and to understand the data concerned with concrete technology.

The process of mix design

In mix design there are two distinct stages with the common objective of making, with the materials available, an economic and yet consistent quality of concrete for the purpose required:

1. *Mix proportioning* is the estimation of the quantities of each component, usually with the aid of trial mixes, to ensure the correct yield of concrete produced for a complete range of possible mixes.

2. *Mix design* is the calculation, from quality control data, of the most appropriate mix to meet a particular specification.

The main constraints to increasing the cost-effectiveness of concrete are:

1. The specifications may be ambiguous.
2. The equipment for batching and mixing may be too limited in its capacity for either storing or handling different concrete materials.
3. The site or factory conditions for transporting, placing and finishing may be inadequate for the volume and types of concrete to be used.

Each constraint has an effect, and there is generally little point being precise in mix design if the practices surrounding the specification, manufacture, transport and placing, are dubious. This has lead to the recent standard practice of specifying "ordinary prescribed mixes", in that the mix has to be over-designed to take account of the unknown. Such mixes, in terms of mix design, are inefficient and more costly as they inevitably have to use an excessive amount of cement which is the most effective, yet most costly component of the concrete.

The primary rule is to produce a concrete suitable for the job, and not to approach the problem with too many pre-conceived ideas or prejudices, as concrete of regulated quality can be made with most materials and equipment as long as the principles are thoroughly understood. This is why it is possible to design very high strength concretes in excess of 60 N/mm^2 with some lightweight aggregates, which are porous and apparently considerably weaker than most natural aggregates.

Before the formalised process of proportioning and mix selection is commenced, some basic principles of the materials and mix composition of concrete and how the various factors interact, should be considered.

Materials

Cement

Because cement can be supplied in accordance with many specifications (BS 12, BS 146, etc.), the type of cement should be clearly identified from the onset. This involves obtaining information and samples of the cement to be used in the trial mixes. The information most critical to mix design is that related to strength grade of the cement itself. The method of predicting the 28-day strength of concrete to be used here is based on the standard 28-day tests made on the cement by the manufacturers in accordance with BS 4550: *Methods of testing cement,* for compressive strength at 28 days using concrete of 0·60 water/cement ratio. Figure 7.1 relates the grading of cement strength to various water/cement ratios.

The use of cementitious components based on pulverised-fuel ash (pfa) to BS 3892 or ground granulated blastfurnace slag (ggbs) to BS 6699, will increase with availability. The use of either material, in conjunction with cement to BS 12, obviates the use of special cements. Where twin bulk storage silo facilities exist, cementitious components are worthy of consideration, not only on a cost basis but also for increasing the durability of the concrete. Details of their quality and performance are best obtained directly from the manufacturers.

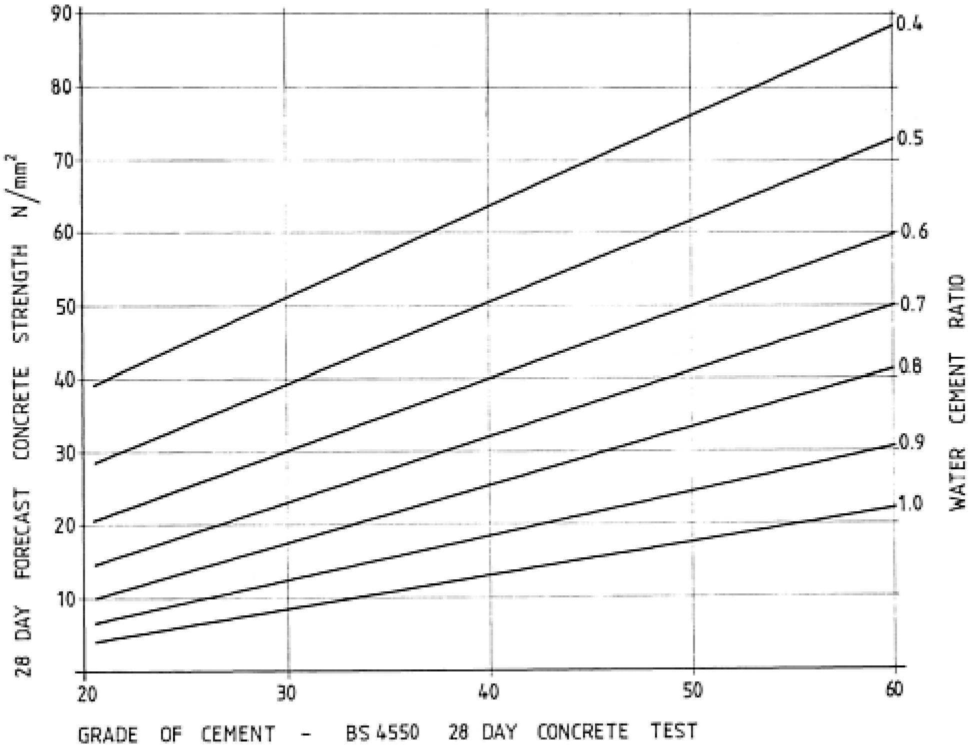


Figure 7.1. Method of strength forecasting using the 28-day strength grading of the cement and water/cement ratio

Water

While water needs to be generally potable, it need not be provided that it is fresh and complies with BS 3148. Generally "soft" water increases the strength and reduces the amount of air-entraining agent required compared with "hard" water.

Aggregates

Apart from lightweight, aggregates are generally derived from natural sources consisting either of gravel or rocks, which are usually crushed, washed and graded to comply with BS 882. Tests made on aggregates need to be performed very carefully. *One singularly inept treatment of aggregates is to oven-dry them before they are used in trial mixes.* It is best to sample the aggregate first for test purposes and then to prepare the remainder to a saturated surface dry (SSD) state. The sample for test purposes can be dried to a standard condition before determining the grading analysis, particle shape, and so on, but for absorbed water and density, the aggregate should be brought carefully to the SSD state before testing.

When considering the source of the aggregate, it is as well to define from the onset the amount of water that will be supplied as surface water or moisture content of the aggregate. The moisture content can vary from as little as 0·5% for coarse aggregate to more than 20% for some fine aggregates. This invariably creates problems with "stock reconciliation", i.e., the difference between that purchased, that used and that remaining, particularly if aggregate is stored for several days before use. Coarse aggregates are generally less of a problem, but as a precaution it is as well to define the moisture content at the quotation stage and before a purchasing order is placed with the supplier. It can happen that the cheaper aggregates make the more expensive concrete. This, in turn, raises the issue of whether it is necessary to investigate the possible variability and status of the aggregate resources and methods of processing. While much depends on the conditions of the contract, a visit or visits should be made to the various aggregate sources, particularly if the concrete is required for a very large contract or if concrete production will be required over several years, as in the case of an established readymixed concrete works.

Admixtures

Admixtures usually take the form of concentrated solutions of active chemicals which induce some change to the fresh properties, such as water-reducing agents, set retarders and superplasticisers. The first two types should comply with BS 5075. Other admixtures, such as airentrainers and surface cleaners (certain stearates) not only affect fresh concrete, but also enhance the performance of concrete in the hardened state. The use of set accelerators should not usually be necessary as the effects can be induced by other means. In no circumstances should any limitations on the use and application of calcium chloride be abused or ignored.

Mix composition

As has already been explained, concrete materials, cement with or without cementitious components, fine and coarse aggregates and admixtures, are mixed with water in such proportions as to fulfil the constructional requirements.

Cement

Usually the amount of cement—and here it should be accepted that ground granulated blastfurnace slag (ggbs) and pulverised-fuel ash (pfa) are accepted components of cement—used in a cubic metre of compacted concrete usually varies between 150 and 450 kg, depending on the requirements of the specification. This approximates in volume terms to between 5–15%.

Water

While the objective is to use as little water as possible, the amount, depending upon workability, maximum aggregate size and so on, varies between 150 litres and 250 litres per cubic metre, which represents 15–25% by volume. Generally, the greater the water content of a mix, the greater the cement content will be for a given compressive strength. Thus the balance of the volume, about 70%, is aggregate and entrapped and/or entrained air.

Aggregates

Aggregates, as such, have traditionally been sub-divided at 5 mm into coarse and fine. They are used in proportions approximating to two parts coarse to one part fine, but this varies depending on the grading, particle size, etc., of the aggregates themselves. Thus the proportion of coarse to fine can be from as much as 6:1 to as little as 1:6.

Air

The amount of entrapped air normally retained, even after the concrete has been well compacted, varies between 1–3%. If an air-entraining agent is used, the amount rises to between 4–8% and then it is impossible, with normal testing methods, to distinguish between the air that is entrapped and that which is entrained. However, the purpose of compaction is to remove as much as possible of entrapped air, because for every 1% of such air, above that which would normally be retained, there is about a 5% loss of compressive strength.

Objectives of mix proportioning

The usual aim with sanded concrete is to compact it as easily and as fully as possible with the least amount of water. It is essential that the workability of the concrete should be appropriate for the job, but as water content is affected by both slump and aggregate, the combination that results in the lowest water will ensure that the cement content will be as low as possible for any given water/ cement ratio and strength. A common misconception is that low water/cement ratio implies low water content. In fact, the water content for low and high cement contents, i.e. below 200 and above 400 kg/m^3, actually increases if precautions are not taken to adjust the aggregate grading properly, by varying the proportions of the fine and coarse aggregate. Thus, for concrete low in cement, the fine aggregate needs to be increased to improve cohesion, and conversely with greater cement contents, the proportion of fine aggregate needs to be reduced to relieve cohesiveness.

The water content

The free water content of a mix is an excellent guide to the aggregate's grading and compatibility. The factors which most effect free water content are:

1. Aggregates—maximum size and shape
2. Workability, as affected by:

    i. cement and/or the cementitious components
    ii. type of admixtures
    iii. temperature at which the concrete is mixed
    iv. mixing and agitation

To understand more fully the reasons for this, it is appropriate to discuss the influence of each factor in turn.

The interaction of coarse and fine aggregate

Coarse aggregate

In normal circumstances, coarse aggregates are graded to 20 mm maximum size. Although aggregates of maximum size approximately to 40, 30, 15 and 10 mm may be available, it is generally easier to use 20 mm as it has become more widespread and accepted than other sizes.

Fine aggregate

Fine aggregates (sand) can be manufactured by crushing rock, but they are more usually derived from gravel beds corresponding very well in grading to the gravel beds from which they were extracted and in consequence can usually be classified into one of the four grading zones (Table 7.1). However with limitations on new or existing resources beginning to restrict supplies of aggregate, the practice of blending crushed fines with finer sands to produce, in effect, a coarser grading, is growing. These "constituted fine aggregates" behave differently in concrete from naturally occurring sands.

TABLE 7.1
Fine aggregate grading zone classification

Sieve size	Percentage by mass passing BS sieve Grading Zone			
1	2	3	4	
10 mm	100	100	100	100
5 mm	90–100	90–100	90–100	90–100
2·36 mm	60–95	75–100	85–100	95–100
1·18 mm	30–70	55–90	75–100	90–100
600 μm	15–34	35–59	60–79	80–100
300 μm	5–20	8–30	12–40	15–50
150 μm	0–10	0–10	0–10	0–15

Combining coarse and fine aggregate

For the purpose of illustration, concrete can be compared to brickwork which, after all, is a system of large pieces of aggregate (i.e. bricks placed by hand in a jointing layer of mortar). The thickness of the mortar joint depends, among other things, on the fineness or zoning of the sand. If the sand is too coarse, i.e. it contains more particles approaching 5 mm in size, the joint thickness could be greater than 5 mm. Inevitably this leads to the use of more mortar. In concrete, the "mortar" fraction, i.e. the cement, fine aggregate and water, is used not only to provide plasticity and cohesion to the freshly mixed concrete, but also to provide the binder in the hardened state. Generally, the less mortar used, and thus the less water, the smaller the spacing between the coarse aggregate particles and the less the drying shrinkage when concrete hardens.

Effects of aggregate size and grading

The proportion of voids in a loosely packed volume of coarse aggregate increases as the maximum aggregate size reduces. For instance, it may be expected that the voids in the dry loose bulk volume of 20 mm coarse aggregate, will be 45%, whilst with 10 mm it will rise to 50% or more. However, the actu al dimensions of the void between the aggregate particles reduces with aggregate size, while the average dimension of the voids in 20 mm coarse aggregate might be 5 mm, with 10 mm it might be about 2 mm. It is this aspect of void size that helps explain why the "degree of fineness' of the fine aggregate can become critical if the size of the coarse aggregate varies. It is often impossible purposely to select both coarse and fine aggregates, but it is for this reason that the fines content of a mix increases as the coarse aggregate size decreases.

In many respects, and again for the purpose of illustration, the cement content of freshly mixed concrete behaves as an "ultra-fine" aggregate and, once the PRIME MIX is determined, mixes leaner in cement content are subject to an increase in fine aggregate content while mixes richer in cement have their fine aggregate content proportionately reduced.

With a knowledge of these concepts of aggregate particle interaction, it is easier to understand the relationship between the maximum aggregate size and fine aggregate grading. Previously, BS 882 conveniently classified fine aggregates into four grading zones as shown in Table 7.1, where Zone 1 is "coarse or sharp" while Zone 4 is "fine or soft" and the most compatible combinations of coarse and fine aggregate are shown in Table 7.2:

TABLE 7.2
Compatibility of coarse and fine aggregates

Maximum size of coarse aggregate (mm)	Fine aggregate grading Zone
40	1 and 2
30	2
20	3
15	3 and 4
10	4

Although this does not mean that a Zone 1 fine aggregate should not be used with a 10 mm coarse aggregate, it does mean that the proportion of fine aggregate could be as high as *85% of the combined aggregate*. This appears to be in conflict with what is customarily accepted—*remember what was said about pre-conceived ideas*!

Inevitably, the opposite will be true in the extreme case of a highly rounded and well graded single size 40 mm coarse aggregate, which may require less than 20% of a particularly suitable Zone 4 fine aggregate. At this point it is appropriate to examine the difference between continuous and gap-graded aggregates.

Continuous and gap-graded aggregates

Most methods of mix proportioning have adopted "continuous" gradings because it is more convenient to do so, for by the very nature of gravels or crushed rocks, the gradings are continuous. That is, the gradings produced are compiled from a number of sequentially sized materials, ranging from very coarse to very fine. It is thus not unreasonable to assume that it will ultimately be more economic to use "continuously" graded aggregates in preference to gradings that deliberately omit some of the intermediate sizes. However, this does not mean that "gap" gradings do not have a place in concrete mix design, particularly where some technical benefit is especially required.

The most appropriate use for "continuous" graded aggregates is for pumpable concrete or concrete which is required to flow. The most effective application for gapgraded aggregate is for concrete which, after compaction is for immediate demoulding. Gap gradings can also be useful for reducing the temperature effects in mass concrete from the heat of hydration of the cement.

It is for these reasons that the PRIME MIX method presents information for concrete using both continuous (Table 7.3) and gap-graded (Table 7.4) aggregates.

Continuous grading: As such continuous gradings have wider universal acceptance if only because the concrete can be made to have a greater range of workability. When proportioned correctly, the concrete should neither bleed nor segregate and it should flow evenly during mixing. This type of concrete, therefore, is appropriate for *free fall* mixers, such as truck mixer/agitators. The technique for obtaining the most suitable continuous grading is that the next three sizes down from the largest size should account for not more than 30% of the combined grading. For instance, for a 20 mm maximum nominal size coarse aggregate, the amount of 10, 5 and 2·5 mm ideally should total approximately 25%, i.e. 15, 7 and 3% respectively.

Gap-grading: Although gap-grading is a technique for obtaining some technical benefit, it ought to be used only in construction where above average quality control is exercised, as changes in water content tend to be more critical. When proportioned correctly, the concrete has an immobile and stodgy appearance, yet the mortar fraction has a richness of appearance which is deceptive once compaction commences. The best mixers are the pan type with forced action rotating blades.

If the maximum aggregate size exceeds 10 mm, free fall mixers—particularly truck mixers/agitators—are singularly unsuitable as the concrete tends to compact in the mixer drum, making it very difficult to mix and discharge. Compaction should be by vibration. The best gap-graded concretes are instantly demouldable and so are the most suitable concretes for extrusion, slip forming and so on, as well as for obtaining very high strength concrete with crushed coarse aggregates.

To obtain best results from the technique of gapgrading, at least the next three sizes down from the top size must be omitted. For instance, for a 20 mm maximum nominal size aggregate, there should be no 10, 5 or 2·5 mm. In theory, this means no materials between 10 and 1·2 mm. Two important factors apply to the supply of aggregates for gap-graded concrete:

1. The fine aggregate supply dictates the top size to be used. Table 7.2 provides a good guide to compatibility of coarse and fine aggregates for gap-gradings. For example, if only a Zone 2 fine aggregate is available, the nominal maximum size is either 30, or better 40 mm.
2. The coarse aggregate *must be nominally single size and should comply with the requirements of BS 882: Table 1 for single-sized materials*. Graded coarse aggregate will not give the required effect.

Failure to observe these two basic rules will mean that it will be virtually impossible to derive maximum benefit from gap-graded concrete—the mix will be unstable because the intermediate sizes, which should not be there, will cause particle interference and prevent the maximum packing of coarse aggregate. The best test of a gap-graded concrete is to cast a test specimen, such as a cube or cylinder, and demould it immediately after compaction. If it either deforms or collapses it is not what is properly termed a gap-graded concrete. The success of the technique was once demonstrated where eight columns were cast 4 m high in one day with one set of column formwork.

TABLE 7.3

Components for Prime Mix using 10, 20 and 40 mm nominal size coarse aggregates for concrete of medium workability (Continuous gradings)

* Aggregate particle shape R = rounded I = irregular A = angular		Nominal maximum aggregate size 10 mm					Nominal maximum aggregate size 20 mm					Nominal maximum aggregate size 40 mm				
		Target slump: 40 to 70 mm					Target slump: 40 to 70 mm					Target slump: 40 to 70 mm				
		First trial mix (kg/m³)			Trial mix cohesion correction (kg)		First trial mix (kg/m³)			Trial mix cohesion correction (kg)		First trial mix (kg/m³)			Trial mix cohesion correction (kg)	
		Aggregate particle shape*					Aggregate particle shape*					Aggregate particle shape*				
FINE AGGREGATE GRADINGS		R	I	A	High	Low	R	I	A	High	Low	R	I	A	High	Low
1	Water	200	215	230			170	180	190			140	150	160		
	Cement	360	390	420			300	320	340			250	265	285		
	Fine	1005	1045	1075	−120	+120	760	830	890	−100	+100	650	675	720	−80	+80
	10 mm coarse	720	620	520	+120	−120	425	345	265			275	245	215		
	20 mm coarse						680	650	625	+100	−100	420	405	390		
	20 mm graded						1105	995	890	+100	−100	695	650	605	+30	−30
	40 mm coarse											655	635	595	+50	−50
	40 mm graded											1350	1285	1200	+80	−80
2	Water	200	215	230			170	180	190			140	150	160		
	Cement	360	390	420			300	320	340			250	265	285		
	Fine	845	885	915	−100	+100	665	710	760	−80	+80	605	630	670	−60	+60
	10 mm coarse	880	780	680	+100	−100	445	380	305			285	260	225		
	20 mm coarse						755	735	715	+80	−80	430	420	410		
	20 mm graded						1200	1115	1020	+80	−80	715	680	635	+20	−20
	40 mm coarse											680	650	615	+40	−40
	40 mm graded											1395	1330	1250	+60	−60
3	Water	200	215	230			170	180	190			140	150	160		
	Cement	360	390	420			300	320	340			250	265	285		
	Fine	685	725	755	−80	+80	580	605	655	−60	+60	565	585	620	−40	+40
	10 mm coarse	1040	940	840	+80	−80	465	410	335			295	270	235		
	20 mm coarse						820	810	790	+60	−60	440	430	420		
	20 mm graded						1285	1220	1125	+60	−60	735	700	655	+15	−15
	40 mm coarse											700	675	645	+25	−25
	40 mm graded											1435	1375	1300	+40	−40
4	Water	200	215	230			170	180	190			140	150	160		
	Cement	360	390	420			300	320	340			250	265	285		
	Fine	525	565	595	−60	+60	520	535	575	−40	+40	525	540	570	−20	+20
	10 mm coarse	1200	1100	1000	+60	−60	485	430	355			305	280	250		
	20 mm coarse						860	860	850	+40	−40	450	440	430		
	20 mm graded						1345	1290	1205	+40	−40	755	720	680	+5	−5
	40 mm coarse											720	700	670	+15	−15
	40 mm graded											1475	1420	1350	+20	−20
Mix Chart Range on the Prime Mix																
	Cement − +	90	195	100			80	85	90			65	70	75		
	Fine + −	75	80	85			65	70	75			55	60	65		
	Water − +	20	25	30			20	20	25			10	15	15		
	Coarse + −	50	65	80			50	50	65			25	40	40		

Effects of aggregate shape

Apart from size and grading, the other major influence on the void content of a loosely compacted coarse aggregate system is the particle shape of the aggregate itself. Highly angular, rough surface texture coarse

TABLE 7.4

Components for Prime Mix using 10, 20 and 40 mm nominal size coarse aggregates (gap-grading)

* Aggregate particle shape: R = rounded, I = irregular, A = angular		Nominal maximum aggregate size 10 mm					Nominal maximum aggregate size 20 mm					Nominal maximum aggregate size 40 mm				
		First trial mix (kg/m³)			Trial mix cohesion correction (kg)		First trial mix (kg/m³)			Trial mix cohesion correction (kg)		First trial mix (kg/m³)			Trial mix cohesion correction (kg)	
		Aggregate particle shape*					Aggregate particle shape*					Aggregate particle shape*				
** SS denotes: single size		R	I	A	High	Low	R	I	A	High	Low	R	I	A	High	Low
FINE AGGREGATE GRADINGS 2	Water											170	120	130		
	Cement											200	220	240		
	Fine											520	560	600	−40	+40
	40 mm SS** Coarse											1565	1480	1395	+40	−40
3	Water						125	135	145			110	120	130		
	Cement						225	245	265			200	220	240		
	Fine						595	630	665	−40	+40	490	520	550	−30	+30
	20 mm SS** Coarse						1450	1375	1300	+40	−40					
	40 mm SS** Coarse											1595	1520	1445	+30	−30
4	Water	135	150	165			125	135	145			110	120	130		
	Cement	250	275	300			225	245	265			200	220	240		
	Fine	675	695	720	−40	+40	550	590	630	−30	+30	460	480	500	−20	+20
	10 mm SS** Coarse	1310	1230	1150	+40	−40										
	20 mm SS** Coarse						1500	1415	1330	+30	−30					
	40 mm SS** Coarse											1625	1560	1495	+20	−20
Mix Chart Range on the Prime Mix																
Across	Cement − +	70	70	75			55	60	65			50	55	60		
	Fine + −	55	60	65			45	50	55			40	45	50		
Down	Water −	15	15	20			10	15	15			10	10	15		
	Coarse +	40	40	50			25	40	40			25	25	40		

aggregate can have void systems easily in excess of 50%, while for highly rounded, smooth texture aggregate of the same nominal size and grading this figure can be well below 40%. This phenomenon greatly influences the amount of fine aggregate to be used, more being required as the angularity increases. In turn, the amount of fines increases with its own coarseness and whether it is constituted from more than one material. Thus, while the conditions influencing the fines content of a mix are infinitely variable, they are generally consistent for any given set of materials for a given mix with one important exception. Invariably during the summer months, the demand for aggregates will increase with increased construction activity. The effects of this on some sources, particularly gravels, is to cause more size reduction by crushing, which in turn increases the overall angularity of the aggregates and so reduces the cohesion of the mix if the fines content is not increased. As a result the water content of the mix, and thus the cement content, are increased.

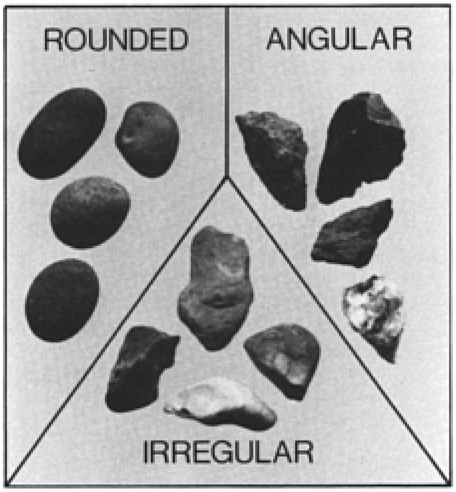


Figure 7.2.

Often, while these aspects are regarded as marginal in effect, they can nevertheless have a significant bearing on the relationship of trial mixes to practice—as occurs in the inevitable period between sampling through to obtaining the results of trial mixes and actually starting the concreting operation—because changes may have taken place in the properties of the aggregate being used.

Particle shape is normally described as angular, irregular, rounded, with combinations in between such as angular/irregular (where the majority of the shape is angular) or irregular/angular (where the majority is irregular). As discussed earlier, with the exception of crushed rock, any gravel aggregate will be neither completely angular nor rounded. Nevertheless, there will be exceptions and they have to be accommodated. An illustration of the range of different particles shapes is shown in Figure 7.2.

The effects of aggregate surface texture

Surface texture can be as important as shape because it can have a considerable effect on the strength of the concrete. The surface texture is generally characterised by its origin, i.e. uncrushed flint is generally *smooth* while crushed flint is usually *glassy*. Granite is either rough or crystalline, depending upon size of crystals that make up its structure (see Figure 7.3).

Surface texture has two effects. First, the smoother and glassier it is, the greater the tendency of lean concrete to bleed or segregate, so creating a false impression of the true water/cement ratio which is lowered by evaporation of the bleed water. Second, a rough surface textured aggregate, such as granite or basalt, is preferred for stronger concrete because it offers a *mechanical* bond between cement paste and aggregate. In this instance, it is important that the surface is free from encrustations of dirt and dust, achieved if necessary by thoroughly scrubbing before use.

Reference samples

It is important not only to retain a representative sample of the aggregates used in the trial mixes, but also to perform and repeat the tests on the aggregates with care and precision for correlation purposes later.

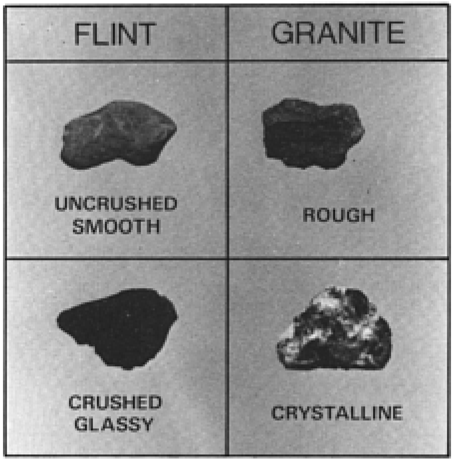


Figure 7.3.

Guideline checklist for aggregates

The guidelines given in the preceeding section must be regarded as just what they are. Nevertheless, they can be compiled into a personal checklist which will assist in explaining different aspects of mix composition. For example, an examination of the grading analysis gives a significant clue as to the probable proportions of coarse and fine aggregate.

Workability

Workability and its relationship to water content

Workability is significantly affected by water content and before any examination of the procedures of mix proportioning, it is as well to study some factors which alter the water content of the concrete. As stated earlier, the amount of voids in the combined aggregate system to a large extent determines the water content. Thus, if the usual maximum aggregate size is 20 mm, the workability, as judged by the slump of the concrete, independent of the cement content within the limits of normal concrete of a particular range of mixes, approximates closely to that shown in Table 7.5.

However, these typical water requirements are affected by other factors, necessitating adjustments when conditions change. It can mean that the workability, i.e. slump, of a mix may alter when, for instance, the cement source is changed, for it is well known that different sources and

TABLE 7.5
Typical water requirements for various slumps of 20 mm maximum sized irregular aggregate concrete at 20°C

Slump (mm)	Typical free water requirement for 20 mm aggregate of irregular shape (litres/m^3)
10 to 50	160
50 to 100	180
100 to 150	200

types of cement have different water requirements in the concrete.

Factors affecting water requirement of concrete for constant workability

The workability of concrete, as measured by slump, is affected not only by changes in water requirement of a mix, but also by other factors which inevitably occur during the period of a contract. While each factor alone may be insignificant, collectively they may have an important effect on the amount of water used in any mix.

Factors which cause most changes are:

1. The materials which may be nominally manufactured to either the same standard or specification but can, by different manufacturing processes, cause changes to the characteristic performances of that material, i.e. including crushed material in a natural gravel.
2. The ambient conditions. The temperatures in laboratories are notoriously variable, usually no two laboratories have similar conditions, air conditioning being the exception rather than the rule.
3. The practices involved in the manufacture of the concrete. For instance, the longer the time between mixing and discharge, particularly during hot weather, the more the concrete will require *tempering,* i.e. extra water to increase the slump to counteract the loss of workability due to affects of increasing temperature and time on the hydration of cement.

The principal factors affecting water requirement

In particular, the factors causing most changes to the water requirement are:

1. Type of cement.
2. Aggregate size, shape and grading.
3. Use of chemical admixtures for water-reduction, set retardation and air-entrainment.
4. Concrete density as affected by the density of the aggregate.
5. Initial temperature of the concrete.
6. Duration of agitation after mixing.

This does not, however, imply that any one source of ordinary Portland cement does not show changes in performance. Like any other manufactured material, its characteristic performance in freshly mixed concrete could alter over a period and different sources of cement, made to the same nominal specification, do behave differently in concrete, but for the purposes of mix proportioning it should be assumed that the water requirement will remain constant for a single sample of cement and that changes to the PRIME MIX will be effected only by a limited number of considerations, because the temperature and mixing time should be reasonably constant.

Changes to the amount of water required

If any aspect of a mix is changed, then for the same workability the water requirement usually has to be adjusted. The factors and their effects are indicated in Table 7.6. The water requirement for a particular set of circumstances cannot be absolute but, by considering the factors causing change, it can be demonstrated that the water requirement of a *works* mix, i.e. that used on site as compared with that in the laboratory, often requires significant adjustment. For example, using 180 litres/m^3 of free water in a trial mix made at 20°C in the laboratory from aggregates sampled in the winter, changes on site in the summer could alter the demand as follows:

1. Aggregate shape: from irregular to angular—10 litres more.
2. Concrete temperature: from 20°C to 25°C—5 litres more.
3. Agitation time: increased to between 1/2 and 1 1/2 hours— 5 litres more.

In this example some 20 litres extra water—increasing the amount of free water in the mix to 200 litres/m^3—is needed just to maintain constant workability. On the other hand the same mix in the winter may undergo only one change:

4. Concrete temperature: reduced from 20°C to 10°C— 10 litres less, which reduces the amount of water to 170 litres/m^3.

The effect of this on the 28-day compressive strength will not be as pronounced as might at first appear, because the combination of higher temperature and longer agitation time in the summer will increase the compressive strength, while in winter it will be reduced by the lower temperature. Nevertheless, the water/ cement ratios for the same cement content will be significantly different because if the cement content were 275 kg/m^3, the water/ cement ratio would rise to 0·73 in the summer and fall to 0·62 in the winter. This aspect of concrete technology has not been the subject of much consideration, but it helps to put into perspective the relationship of laboratory design to actual site conditions.

Compressive strength

The compressive strength of specimens made with concrete has become by tradition and practice the usual criterion not only of the acceptance of mixes but of their compliance also. The fallacy, and it must be accepted as such by all concerned, is that each cement differs in its performance, not only within source but between sources. No doubt in the future these effects will be reduced by more efficient control measures during manufacturing and standardisation of strength gradings for cement but, until these measures become common practice, the method suggested here should produce concrete with strength very close to that required.

The problem of mix selection is compounded by ambiguous specifications which detail not only strength but also many alternative requirements such as water/ cement ratio, minimum cement content, which depend for compliance purposes solely on the basis of acceptable compressive strength. Thus, in the absence of a credible method of knowing before the concrete is accepted and placed that it will be acceptable, the only meaningful way at present is to seek from the cement manufacturer details of tests made on standard concrete according to BS 4550 *Methods of testing cement*. Unfortunately, the test does not adjust for the differences in workability which characterise each cement source. However, once trial mixes of the required workability have been made, the strength can be forecast more predictably than was previously possible.

TABLE 7.6

Factors affecting changes to the water requirement of concrete for constant slump

Consideration	Standard condition	Condition change from standard		Change of water requirement (litres/m³) More	Change of water requirement (litres/m³) Less
Cement	Ordinary Portland cement to BS 12	Rapid-hardening Portland cement to BS 12		5	
		Sulphate-resisting Portland cement to BS 4027			5
		30% substitution with pfa to BS 3892: Part 1: 1982			15
Aggregate: (a) size	20 mm nominal size to BS 882	10 mm		35	
		15 mm		15	
		30 mm			15
		40 mm			25
(b) shape	Irregular	Angular		10	
		Rounded			10
(c) grading	Continuous	Gap			10
		Oversanded		10	
Admixture	Plain concrete—no admixture	Water-reducing	single dose		10
			double dose		20
		Set retardation	24 h		15
		air-entrainment	3–5%		10
			5–8%		20
Concrete density	2250–2500 kg/m³	1750–2000 kg/m³		20	
		2000–2250 kg/m³		10	
		2500–2750 kg/m³			10
Concrete temperature	20°C	Reduced to:	2°C		15
			10°C		10
		Increased to:	25°C	5	
			30°C	15	
			40°C	30	
Period of agitation after mixing	Up to ½ h after adding water	Increased to between:	½–1½ h	5	
			1½–2½ h	10	
			2½–3 h	15	
			3–3½	20	

Forecasting strength

The grade of concrete is usually determined by the strength required at 28 days. Figure 7.1 has been produced for predicting the 28-day cube compressive strength of concrete from the strength grade of cement to be used. The grade of cement is determined here by the compressive strength of concrete made at 0·60 water/ cement ratio as described in BS 4550: Part 3.4. Thus, if the 28-day strength grading of cement is known to be 40 N/ mm^2, the forecast 28-day strength of concrete made at 0·80 and 0·50 water/cement ratios are 25 N/mm^2 and 50 N/mm^2 respectively. Naturally, the illustration is convenient for as long as such a test for cement exists, but recalibration of the "cement grade" axis can establish similar relationships for many of the compressive strength tests used by the different cement standards of the world.

Whatever the strength grading of the cement, the objective must still be to keep the water requirement as low as possible, so that the most economic mix will be obtained. Other approaches for the estimation of strength do require calibration, some using data obtained from the mixes in everyday use, and this will be discussed later.

The Prime Mix Method

With an appreciation of the factors affecting the mix proportions, the water requirements and strength of the concrete, the approach made by the Basic Mix Method to apportion the various materials can be adapted to the Prime Mix Method, which will now be described.

The term Prime Mix refers to a mix at the centre of a group of mixes made with the same materials and including mixes which are not only weaker and stronger, but are also more and less workable. It will be demonstrated that not only can a network of mixes be developed from the Prime Mix, but that within the scope of that network any mix may be selected to suit a different requirement without the need for another and separate mix design exercise. Alternatively, the versatility of the method enables mixes of different workability and strength to be correlated with one mix made with the same materials, irrespective of its workability and strength within the network.

The Procedure

Preliminaries:

Decide cement type and source.
Obtain a representative sample.
Obtain details of cement grade, i.e., 3-day and 28-day standard compressive strength of the concrete.
Obtain representative samples of coarse and fine aggregates.

Determine: coarse aggregate—maximum size and shape and fine aggregate-grading zone and coarse aggregate — grading type.

Select: Prime Mix (no adjustments for temperature, etc.) from Table 7.3 or Table 7.4 and apply adjustments for:

1. Density of cement and aggregates.
2. Moisture content of aggregate.

Make: first trial mix to the slump required by:

1. scaling batch quantities to capacity of mixer,
2. batching the aggregate mix for 0·5 minute with equivalent of 100 litres/m^3 water,
3. adding cement and mixing for further 0·5 minute,
4. adding remainder of water to target slump and mixing for 1 minute,
5. leaving for 4 minutes and while waiting reading *Appendix 1,*
6. mix for a further 0·5 minute.

Test: for slump and density. Correct if necessary to obtain Prime Mix. If slump and density are not correct, check with *Appendix 1* and begin again by applying corrections. For actual density check with theoretical values. If within ±10 kg/m^3, adjust by correcting the mass of the coarse aggregate and if within ±25 kg/m^3, adjust by correcting proportionally the fine and coarse aggregate. If density is not within ±25 kg/m^3, recalculate on a proportional basis.

This is the Prime Mix for these materials.

Prepare: Mix chart (see Figure 7.4) and:

1. Apply the mix chart range of cement and fine aggregate to Prime Mix (see Table 7.3 and Table 7.4).
2. Apply the mix chart lower and upper water requirements for slumps more and less than the Prime Mix.
3. Adjust the mass of coarse aggregate to accommodate for increase or reduction in the water requirement.
4. With the known value of cement strength grading, plot for the various water/cement ratios the forecast 28-day strengths of mixes not only of lesser and greater slump than the Prime Mix, but also at the limits of cement content.

Summary

The approach used to obtain the components and porportions for the Prime Mix combines both mathematical and practical solutions to the question of mix proportioning, in so far that it acknowledges the principle of over-filling the voids in the coarse aggregate which is the basis of many mathematical solutions.

The basis of Prime Mix has been to calculate the proportions of the different components not only using the differences in particle size, but also taking account of their different densities—Portland cement 3100 kg/m^3, aggregates 2600 kg/m^3, and water 1000 kg/m^3—with due allowance for entrapped air. This expedient permits the interchange of materials of different density but of nominally the same grading and size. For example, if the actual density of 20 mm graded irregular shaped coarse aggregate to be used is 2700 kg/m^3, the mass of aggregate to be batched when using a Zone 1 fine aggregate would be increased from 995 kg/m^3 to $995 \times \frac{2700}{2600}$ or 1035 kg/m^3. Similar factors must be applied to correct for the usual differences found in practice for the density of both cement and fine aggregate.

The other, and just as essential, corrections which must be applied are the effects of causing changes in water content. Remember that any increase in workability should be accompanied by an increase in cohesion. The most effective means of achieving this is to reduce the amount of coarse aggregate by the same volume of additional water. Thus, to effect an increase in slump of, say, 50 mm, the extra amount of water required would be 20 litres (from Table 7.5). Th[illegible]nt of coarse aggregate of, say 2700 kg/m^3 density would be reduced from 1035 kg/m^3 by $\frac{20\ l}{1000\ l/m^3} \times 2700\ kg/m^3$ or 55 kg to 980 kg/m^3.

Inevitably, after the concrete has been batched and mixed to the correct workability and cohesion, the slump may need to be increased by the addition of water. The effect on the concrete will be to reduce the strength as well as the cohesion. Many systems for mix design overload the voids with fine material to compensate for this type of adjustment with the inevitable increase in costs. Thus, if the concrete mix is designed on purely economic lines, it is invariably less accommodating to this type of adjustment and the result will be a harsh and, paradoxically, less workable concrete.

Approximate rules for concrete property and component adjustment can be summarised as follows:

1. For increases in any one component it is easier to reduce only one other component: Interchange—cement and fine aggregate and Interchange—water and coarse aggregate.
2. For every 2 litres of water changed, a change of about 5 mm slump and 0·8 N/mm^2 28-day compressive strength will occur.
3. It requires on average an interchange of about 75 kg of fine and coarse aggregate to affect a noticeable change of cohesion, being less with smaller sizes than larger.
4. After batching and mixing, it is as well to remember that to add 10 litres of water dilutes, on a volume basis, all the other components by 1%, hence the cement content would be reduced by about 2·5 kg/m^3 and at least 15 kg/m^3 more cement would be required just to maintain the 28-day compressive strength.
5. Above all it must be remembered that freshly mixed concrete is a perishable commodity with a shelf life not normally longer than 2 1/2 hours and that to be effective it has to appropriate for the job.
6. *It must also be remembered that adding water alone on site is the quickest way of destroying all the quality control and quality assurance measures taken.*

Examples

Selection of the proportions, preparation of a mix chart and calculation of mix costs can initially be quite difficult. However, given an appreciation of the features of concrete previously described, continual practice will lead to skill and it will be found that the technique is quick and efficient, avoiding many of the tedious and often unnecessary adjustments which cause and increase error.

Example 1

Ordinary exercise with the aid of Table 7.3

Determine:

cement	type	Ordinary Portland
	density	3100 kg/m^3
	strength grade at 28 days	40 N/mm^2
aggregates:		
fine	grading	Zone 3
	shape	irregular
	density	2600 kg/m^3
	state	saturated surface dry
coarse	nominal maximum size	10 mm
	shape	irregular
	density	2600 kg/m^3
	state	saturated surface dry

Select: Prime Mix from Table 7.3:

water	215 litres
cement	390 kg
fine aggregate	725 kg
10 mm coarse aggregate	940 kg
density	2270 kg/m^3

[No corrections as all the materials are in the standard state]

Trial mix:

observed cohesion	good
slump (mm)	50
density (kg/m^3)	2270
corrections	none

Mix chart range: from Table 7.3

cement	– + 95 kg=295, 390, 485
fine	+ – 80 kg=805, 725, 645
water	– + 25 litres=190, 215, 240
coarse	+ – 65 kg=1005, 940, 875

Calculations: water/cement ratio and strength estimation using Figure 7.1

Cement content (kg)	Water requirement (litres)		Calculated water/ cement ratio			From Figure 7.1 at 40 N/mm^2 cement grade strength estimate (N/mm^2)			
Low	Normal	High	Low	Normal	High	Low	Normal	High	
295	190	215	240	0·64	0·73	0·81	37	30	25
390	190	215	240	0·49	0·55	0·62	51	44	38
485	190	215	240	0·39	0·44	0·50	65	58	50

Complete the Mix Chart as shown in Figure 7.5.

From Figure 7.5, choose a concrete of specified strength—Grade 30

Grade 30=characteristic cube compressive strength of 30 N/mm^2 at 28 days+10 N/mm^2 margin for target strength=40 N/mm^2.

1. The required slump=120 mm

Mix quantities to the nearest 5 kg for 1·0 m^3 on a dry basis, would be:

water	240 litres
cement	410 kg
fine aggregate	715 kg
10 mm coarse aggregate	875 kg
density	2240 kg/m^3

2. Alternatively, a different slump can be selected, i.e. for 5 mm. Then the mix quantities to nearest 5 kg for 1·0 m^3 on a dry basis, would be:

water	190 litres
cement	315 kg
fine aggregate	790 kg
10 mm coarse aggregate	1005 kg
density	2300 kg/m^3

This has traditionally been where most other mix design methods have been concluded, but completing this exercise the method of calculating the mix costs will be demonstrated (and here it must be noted that the costs quoted were approximate at the time of writing and obviously adjustments in line with prices at the time of reading are necessary). For example, if the price details typical for Great Britain in 1984 were as follows:

Cement in bulk deliveries	£45·00/tonne
Fine aggregate at 7% moisture content [factor 1·07]	£5·20/tonne
10 mm coarse aggregate at 2% moisture content [factor 1·02]	£5·70/tonne

The cost of 120 mm slump concrete is:

cement	0·410×45	=£18·45
fine aggregate	0·715×1·07×5·20	=£3·98
10 mm coarse aggregate	0·875×1·02×5·70	=£5·09
Cost of materials/m^3		=£27·52

and the cost of the 5 mm slump concrete is:

cement	0·315×45	=£14·175
fine aggregate	0·790×1·07×5·20	=£4·395
10 mm coarse aggregate	1·005×1·02×5·70	=£5·845
Cost of materials/m^3		=£24·415

Example 2

Advanced exercise with the aid of Table 7.3

Determine:

cement type	Portland pulverised fuel ash cement containing 30% pfa*
density	2870 kg/m^3
strength grade at 3 days	15 N/mm^2
strength grade at 28 days	35 N/mm^2

water reduction (Table 7.6)=15 litres and, in this instance, a proportional increase in the amount of both coarse and fine aggregates

aggregates	
fine	
grading	Zone 3
shape	irregular
density	2650 kg/m^3
state	saturated surface dry
coarse	
(i) *nominal maximum size 10 mm*	
grading	single size
shape	irregular/angular
density	2500 kg/m^3
state	saturated surface dry
(ii) *nominal maximum size 20 mm*	
grading	single size
shape	irregular/angular
density	2550 kg/m^3
state	saturated surface dry

Select: Prime Mix from Table 7.3

Interpolate between irregular and angular

water	185 litres
cement	330 kg
fine aggregate	550 kg
10 mm coarse aggregate	390 kg
20 mm coarse aggregate	855 kg
density	2310 kg/m^3

Corrections: (all calculations to nearest 5 kg. Type of adjustment shown in brackets [ ])

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* Portland pulverised-fuel ash cement to BS 6588 may have been chosen for durability purposes, i.e. to make concrete which is more resistant to either sulphate attack or alkali-silica reaction. The same effect may be obtained by a combination of not more than 70% of any Portland cement to BS 12 with not less than 30% pulverised-fuel ash to BS 3892: Part 1: 1982 *Pulverised-fuel ash for use as a cementitious component in structural concrete*. Thus, when considering the cement content in this case, it could equally well be made from 70% Portland cement to BS 12 and 30% pfa to BS 3892: Part 1: 1982 which would have to be treated separately at the mix cost stage.

Material	Correction	Mass with corrections	
water	[reduction]	$185-15$	$=170$ litres
cement	[density]	$330\times\frac{2870}{3100}$	$=305$ kg
fines	[density]	$555\times\frac{2650}{2600}=565$	
	[addition because of water reduction]	+ $5\times\frac{2650}{1000}=15$	$=580$ kg
10 mm	[density]	$390\times\frac{2500}{2600}$	$=375$ kg
20 mm	[density]	$855\times\frac{2550}{2600}=840$	
	[addition because of water reduction]	+ $10\times\frac{2550}{2600}=25$	$=865$ kg
	theoretical density		2295 kg/m^3

Trial mixes

First mix: batch the materials to the size and mix to the procedure described previously

observed cohesion	low
slump (mm)	70
density (kg/m^3)	2300

Apply corrections for cohesion

fines 580+60	640 kg
20 mm coarse 865–60	805 kg

and prepare for a second mix

Second mix:

water	170 litres
cement	305 kg
fine aggregate	640 kg
10 mm coarse aggregate	375 kg
20 mm coarse aggregate	805 kg
theoretical density	2295 kg/m^3

Batch and mix as before strength prediction

observed cohesion	good
slump (mm)	55
density (kg/m^3)	2305

Apply correction for density, in this instance to 20 mm coarse aggregate by increasing batch mass by 10 kg to 815 kg.

Prime mix: final stage

water	170 litres

cement	305 kg
fine aggregate	640 kg
10 mm coarse aggregate	375 kg
20 mm coarse aggregate	815 kg
theoretical density	2305 kg/m^3

Mix chart range: from Table 7.3

cement–	+85 kg=220, 305, 390
fine +	–70 kg=710, 640, 570
water–	+20 litres=150, 170, 190
coarse:	
10 mm	nil=375, 375, 375
20 mm +	–50=865, 815, 765

Calculations: water/cement ratio and strength prediction

Cement content (kg)	Water requirement (litres)			Calculated water cement ratio			From Figure 7.1 at 35 N/mm^2 cement grade strength estimate (N/mm^2)		
	Low	Normal	High	Low	Normal	High	Low	Normal	High
220	150	170	190	0·68	0·77	0·86	37	30	25
305	150	170	190	0·49	0·56	0·62	51	44	38
390	150	170	190	0·39	0·44	0·49	65	58	50

Complete the Mix Chart as shown in Figure 7.6.

Once completed, the Mix Chart provides a comprehensive component guide for concretes of different workability and strength. For instance, the components for three mixes of the same strength, say 35 N/mm^2 at 28 days, but of different slump, calculated on a dry basis, would be:

	Mix		
	A	*B*	*C*
water (litres)	150	170	190
cement (kg)	255	290	325
fine (kg)	700	650	610
10 mm coarse (kg)	375	375	375
20 mm coarse (kg)	865	815	765
Trial mixes:	*A*	*B*	*C*
cohesion	good	good	good
slump (mm)	10	55	110
density (kg/m^3)	2345	2300	2285

Example 2: Mix costs

To appreciate fully the effects of workability on the cost of similar strength concrete, made with the same materials, the exercise has to be completed. Naturally prices of various components vary with location, inflation, and so on, but the relative costs of the three mixes can be demonstrated irrespective of the price of materials ruling at any one time. For the purpose of this exercise the following prices were assumed:

Cement: 20 tonne minimum bulk delivery	£40·00/tonne
Fine aggregate at 8·5% moisture content [factor 1·085]	£6·10/tonne
10 mm coarse aggregate at 2·5% moisture content [factor 1·025]	£5·50/tonne
20 mm coarse aggregate at 1·25% moisture content [factor 1·0125]	£5·20/tonne

Thus, the following calculations (to the nearest 0·5p) can be made:

Mix A

cement	0·255×40·0	=£10·200
fine aggregate	0·7×1·085×6·10	=£4·635
10 mm coarse	0·375×1·025×5·50	=£2·115
20 mm coarse	0·865×1·0125×5·20	=£4·555
	Cost of materials/m^3	=£21·505

Mix B

cement	0·29×40·0	=£11·600
fine aggregate	0·65×1·085×6·10	=£4·300
10 mm coarse	0·375×1·025×5·50	=£2·115
20 mm coarse	0·815×1·0125×5·20	=£4·290
	Cost of materials/m^3	=£22·305

Mix C

cement	0·325×40·0	=£13·000
fine aggregate	0·61×1·085×6·10	=£4·040
10 mm coarse	0·375×1·025×5·50	=£2·115
20 mm coarse	0·815×1·0125×5·20	=£4·290
	Cost of materials/m^3	=£23·445

As discussed earlier, the cement could just as well be from the components 70% Portland cement to BS 12 and 30% pfa to BS 3892: Part 1: 1982. To complete the example, say for Mix B, where the prices for:

Cement: 20 tonne minimum bulk delivery	£45.00/ tonne
Pfa: 18 tonne minimum bulk delivery	£22.50/tonne

the following calculations can be made:

cement	(0·29×0·70×0·205)×45·00	=£9·225
pfa	(0·29×0·30×0·085)×22·50	=£1·915
fine aggregate	0·65×1·085×6·10	=£4·300

10 mm coarse	0·375×1·025×5·50	=£2·115
20 mm coarse	0·815×1·0125×5·20	=£4·290
	Cost of materials/m^3	=£21·845

Compared to £22.305, which shows a saving of £0.46/m^3.

This demonstrates the varying costs involved with just one set of materials in mixes of the same strength, but of different slump, in that for every 5 mm increase in slump, the cost/m^3 of the concrete increases by almost 10p. Normally the exercise would not finish there, as it has to be completed with a different set of competitive materials to evaluate any change to concrete costs before selecting the most economic materials. An important aspect has been to demonstrate the effect on costs which changes in the workability of concrete have caused, as it is in the interest of both supplier and user of concrete that the workability be considered just as much a factor of the price of concrete as is the strength. It is this particular aspect of the mix design which leads to the question of quality control and the effects which variations in materials, production, testing, and so on, have on the performance of the concrete.

Quality control and mix design

It is now accepted by most producers of concrete that the value of effective systems of quality control and quality assurance are of as much benefit to themselves as they are to the specifier and user.

Of necessity, concrete usually has to be batched, mixed and placed within 2 1/2 hours. In winter this may be extended but in summer it may have to be shortened, and here set retarders are of use to extend the period beyond 2 hours. It must be remembered that the problem remains that once cement comes into contact with water—even if it is the moisture contained in the aggregates—an irreversible chemical reaction begins, which is usually impractical to halt.

A principle which has to be adopted with all fresh in situ concrete is that its acceptability relies on trust. Unlike any other product, its compliance with a strength specification cannot be decided until 28 days after it has been used. Precasting has an obvious advantage, but the criterion is usually very different in that the elements are required to have sufficient strength for early removal from the mould to maintain production in the factory; if necessary, the strength of concrete used can be determined prior to the element being supplied.

Once concrete has set, it produces most of its hardened strength by 28 days. However, the rate of strength development is mainly dependent upon water/cement ratio and the temperature experienced during hardening. The effect of cement heat of hydration on the temperature of in situ concrete depends chiefly on the size of the element. Large elements, such as foundation bases, retaining walls, and such like, usually undergo large temperature changes, even under very cold conditions, of up to 70°C. While this is an aspect of concrete technology which is outside the scope of mix design, its existence must be borne in mind, though not as regards the conditions relating to the supply of concrete and its compliance with the specification. Temperature-matched curing is a recent development, not to be confused in any circumstances with the standard conditions of curing required for test specimens.

Conditions of testing

For the purpose of quality control, it is imperative that all concrete specimens should be cast, cured and tested under standard conditions. This is important, for without control of the temperature—and thus the

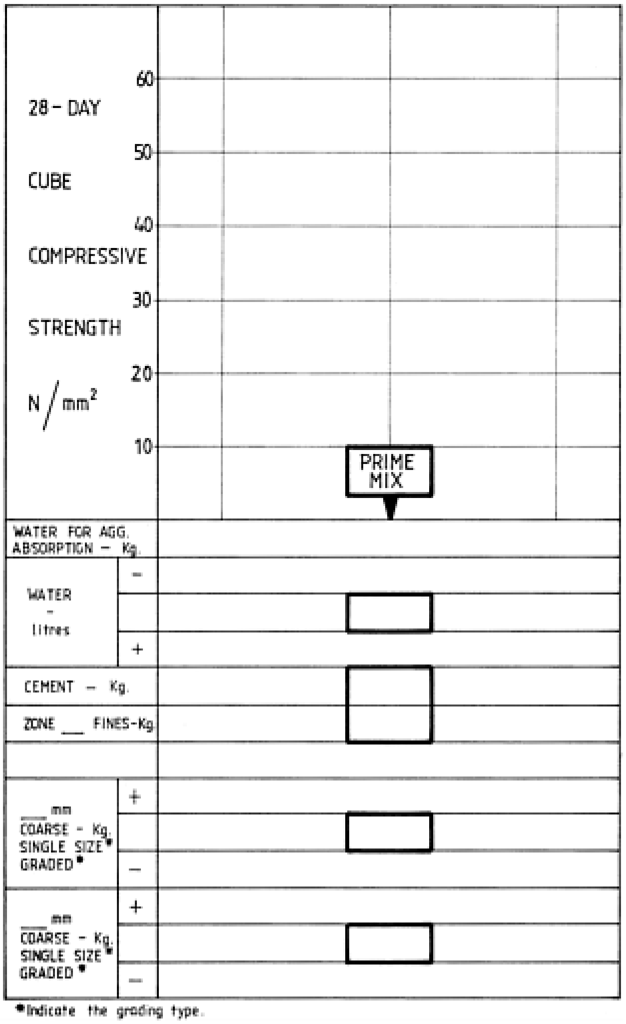
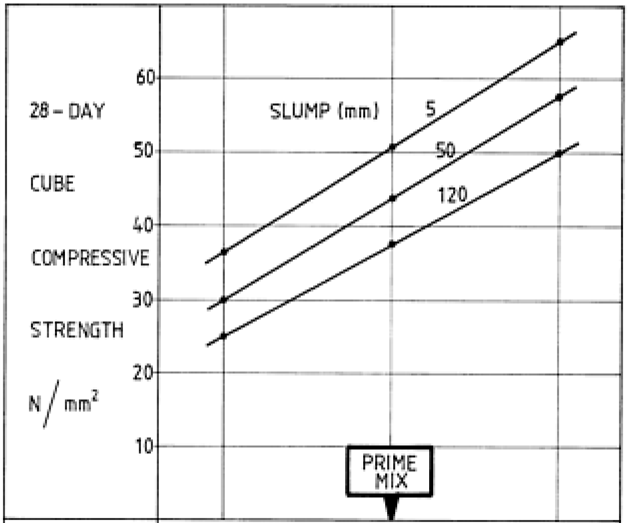


Figure 7.4. Prime mix chart

curing conditions as detailed in BS 1881: Part 111: 1983 *Methods of normal curing of test specimens (20°C method)*—it is impossible to apply meaningful quality control by means of the strength of concrete. Variations of curing temperature outside those permitted by BS 1881 create inaccuracies which, in turn, produce misleading results. In these circumstances, it may be better to consider the alternative of ordinary prescribed mixes as described in BS 5328. Such mixes are so adequately overdesigned that they accommodate for the worst conditions and for the worst combination of all the influences which affect concrete from both materials and practice.



WATER FOR AGG. ABSORPTION – Kg.				
WATER - litres	–	190	190	190
		215	215	215
	+	240	240	240
CEMENT – Kg.		295	390	485
ZONE 3 FINES - Kg.		805	725	645
10 mm COARSE – Kg. SINGLE SIZE*	+	1005	1005	1005
		940	940	940
	–	875	875	875
___mm COARSE – Kg.	+			
	–			

*Indicate the grading type.

Figure 7.5. Prime mix chart— Example 1

The application of strength as a means of quality control

Most structural concrete is still produced and controlled by strength and is likely to be so for the foreseeable future. However, only those producers and users who are unable to apply any effective quality control would resort to the use of ordinary prescribed mixes. The determination of strength at 7 days or 3 days, or even 1 day, is used to forecast the 28-day value but careful calibration is necessary. The common practice of targeting the 7-day strength at the 28-day characteristic strength level gives sufficient margin of strength to ensure that it satisfies the strength grade; for example, for a Grade 30 concrete, the strength at 7 days could be 30±5 N/mm^2. However, this approach tends to be less economical if a more precise calibration cannot be established between the earlier age and the required 28-day strength.

The target strength at 28 days is usually the Grade of the concrete plus a margin for error which depends on the variability of the concrete, being greater where there is a lack of, or there is poor, control. The margin

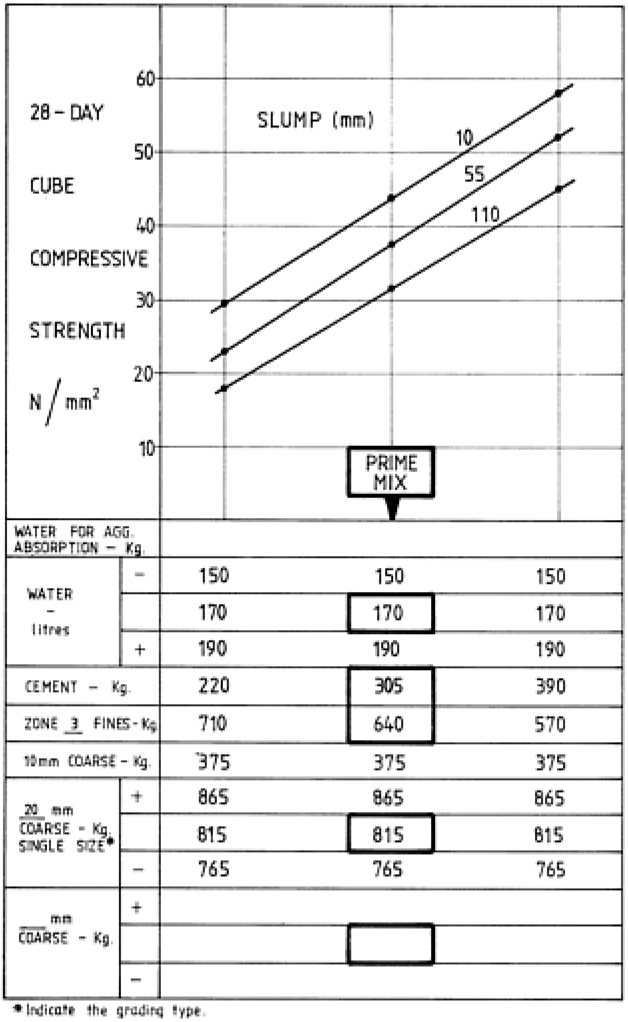


Figure 7.6. Prime mix chart— Example 2

is determined from the variability of the test result (the standard deviation), multiplied by a risk factor, k, which is selected beforehand. The risk factor, k, varies from 1·64 for 5% expectancy of failures to 2·33 for 1% failure. The lower is k, the greater the risk of any individual result failing the specification. Therefore, at the start of any concreting operation, it is usual to assume a larger margin of error because it is expected that the variability will be greater, but that a lower risk of failure is acceptable. Thus for a standard deviation of 8–5 N/mm^2, and a k factor of 2.33, the margin is about 20 N/mm^2, which for Grade 30 concrete results in a target strength of 50 N/mm^2. From Figure 7.6, this would given the following mix proportions for the 55 mm slump concrete:

water	170 litres
cement	380 kg

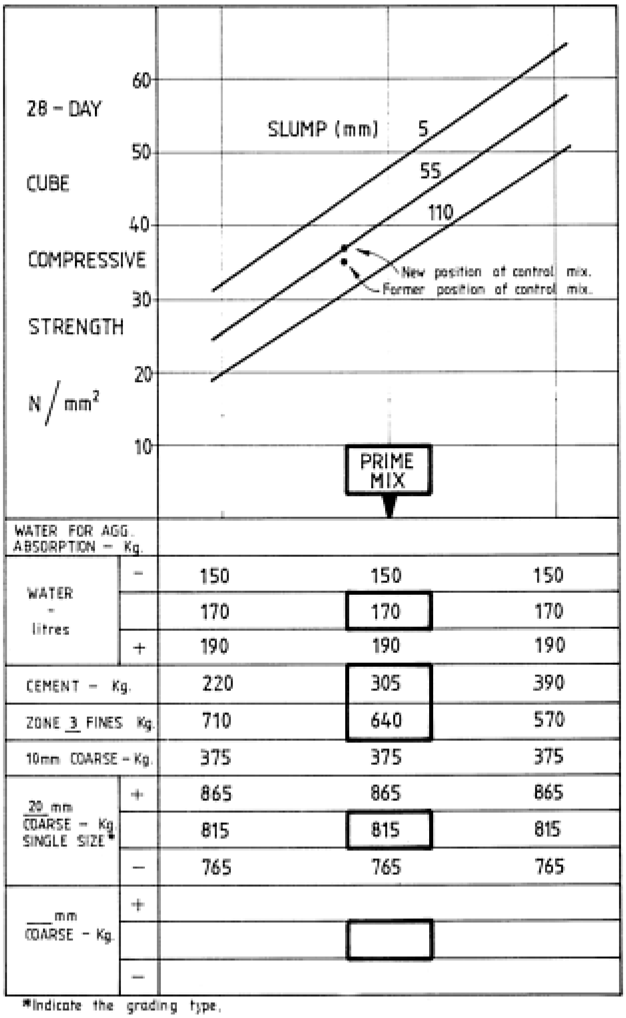


Figure 7.7. Prime mix chart— Quality control adjustment

fine aggregate	570 kg
10 mm coarse aggregate	375 kg
20 mm coarse aggregate	815 kg

As the result of compression tests at 28 days become available and the standard deviation is found to be lower than estimated, say $5{\cdot}1$ N/mm^2 which, for a k factor of $2{\cdot}33$ produces about 12 N/mm^3 margin, the target value for the Grade 30 concrete is reduced to 42 N/mm^2. On the same basis as before, Figure 7.6 shows that the mix proportions could be adjusted to:

water	170 litres

cement	330 kg
fine aggregate	665 kg
10 mm coarse aggregate	375 kg
20 mm coarse aggregate	815 kg

The difference in cost can be demonstrated by using the prices for materials as previously discussed. The cement cost is reduced by (0·380–0·330)×40·0 or £2.00 and the fine aggregate is increased by (0·665–0·570) ×1·085 ×6·10 or £0·63. The total reduction is about £1·37/m^3 which, for large outputs, can be a considerable proportion of the cost of the concrete.

Relationship between quality control and the variability in supervision of materials and equipment

Level of supervision

In terms of total benefit, the costs of operating quality control via the 28-day strength of concrete may be marginal if the output of concrete is low. The cost of skilled staff and equipment for effective quality control may be difficult to justify if only a few tests are required. However, the basis of judgement must be the importance of the structure to be built. For instance, concrete bridges designed for a 120 year service life need to resist the hostile environment to which they will be exposed throughout their lifetime and, therefore, need considerably more attention during construction, but the amount of concrete required would be low, relative to the volume required for the construction of a motorway pavement carried by the bridge. Any failure of the bridge usually has more serious consequences than failure of a section of pavement.

Another problem is the provision of adequate facilities and whether staff are capable of interpreting and following the test procedures specified by the various specifications and standards. This is important with the everincreasing demand for third-party inspection and quality assurance, as detailed, for instance, by BS 5750 *Quality systems*.

Quality control of the materials

One of the problems with quality control is that it can be very confusing if the objectives are not clearly understood. Once the proportions of the various ingredients have been determined, trial mixes and the mix chart network having been developed, the next step is to monitor the materials for property changes in the basic properties such as might occur with coarse aggregate shape, fine aggregate moisture content, cement strength grading, and water hardness.

Water hardness may seem an over-refinement, but does have an effect, for example, on air-entrained concrete. Air-entraining agents are based either on soaps or detergents, both of which are affected by the hardness of water. Hard waters require more soap to produce the required suds, and so less air-entraining agent is needed the softer the water. Control of air-entrainment becomes very difficult if the mains water originates from a variety of sources such as mixtures of artesian well and reservoired river water, as can occur in parts of the south-east of England. This increases the difficulties of controlling the amount of air entrained to the point where, if it is not properly understood, air-entrainment may have to be abandoned.

Specific attention is drawn to the requirements of BS 1881 *Methods of testing concrete* and how they relate both to BS 812 *Methods of testing aggregates* and BS 4550 *Methods of testing cements*.

The batching equipment and its reliability

It may not be obvious, but the trouble taken to develop the network of mixes on the mix chart is wasted if the equipment to be used for storing, batching and mixing the ingredients is incapable of producing either the quality or quantity required. It is necessary, therefore, to have a working knowledge of the equipment before the batch book, sheet or cards are prepared.

The prime rule is to know the capacities (which are usually linked) of both the weigh gear and the weigh hoppers before deciding the maximum size of batch. Always ensure that the readout or scale divisions on the chart will register to the accuracy required. It is pointless to prepare the batch cards to the nearest 1 kg if the scale divisions are at 5, 10 or even 25 kg. Justifiably, batchmen are notoriously cynical about the *theoretical* nature of batch cards, which should be well designed for easy reading. Developments in automatic batching will naturally reduce the dependence of such obvious requirements, but even with all such refinements the efficiency and accuracy of batching is an integral part of quality control, because if it is not possible to batch accurately, then the variability of the concrete will increase.

An important feature of the process of concrete production is mixer efficiency. With large, dry batchers, capable of dispensing 5 or 6 m^3 at one weighing, careful attention must be paid not only to the metering of coarse and fine aggregates, but also to the even charging of cement. This is very important as truck mixer/ agitators can mix very efficiently provided they are not overloaded and they conform to the minimum requirements of BS 4251 *Truck type concrete mixers*. The mixing efficiency reduces quite dramatically, particularly if the blade size and drum speed are not maintained to the minimum specification for truck mixers.

Principles of quality control

Complications caused by the misuse of quality control seem to be reflected in the proliferation of standards which appear to hinder the production of uniform quality products. However, if the requirement is quite simply to know the variability of the concrete itself, then the practices and testing procedures used must have had the least possible influence on the actual test result, for that is the objective. To put it quite bluntly, sloppy testing leads to inaccurate results which are often wrongly justified on the basis of principle.

At times it is difficult to recognise our deficiencies and all too easy to forget that nobody deliberately sets out to do bad work, but that it may result from a combination of factors which just add up to the same thing.

The tests and data used for quality control of concrete

To be truly effective, action should be possible as soon as a test result is known. The best tests are both simple and quick: the slump test, for instance, can be performed and repeated, if necessary, within minutes. The tests used in quality control of concrete can be divided into two main groups. First, information and tests relating to materials and the plant used for batching and mixing. Second, tests on the concrete itself. The results should be methodically and chronologically recorded and then used for computing the variability. A variety of statistical test methods are available for analysing test data, the most common method being via standard deviation. Today, with most pocket scientific calculators able to calculate standard deviation, it has become a quick, simple and cheap matter to examine considerable amounts of data.

Routine testing of materials

Aggregates

As tests were originally made on samples of materials to decide the Prime Mix, the objective now is to find whether the materials in use have changed or are in the process of changing. The frequency of testing depends largely on the facilities for doing the tests on representative samples taken from fresh supplies. The tests considered most critical are for moisture content, particle shape and grading.

1. *Moisture content* is determined to ascertain whether the supplies contain, on average, more or less water than agreed. Remember that the processes of aggregate manufacture are invariably wet and that the moisture content is an integral feature of supply, but that surplus water, above that agreed, tends to drain away if the aggregates are stockpiled for several days before use.
2. *Particle shape* is critical to concrete cohesion. Once aggregates have been dried to determine the moisture content, they should be examined for any change of shape. An increase in angularity of gravel coarse aggregate, for example, will mean that a higher proportion of fine aggregate will be needed to maintain the cohesion of the concrete.
3. *Grading,* like particle shape, is fundamental to the decisions of mix proportioning. While it is not necessary for a full grading analysis to be performed on each aggregate, there are specific and important sizes which need to be constantly monitored. For coarse aggregate, 20 mm nominal size particularly, the 10 mm sieve is critical, as the proportion of material passing through 10 mm increases, the cohesion is reduced. The only other size requiring occasional attention is the amount of material passing through 5 mm. However, in this case only about one test is needed for every ten made at 10 mm.

   Naturally for fine aggregate it is the 600 μm size which differentiates the grading zones and is thus important. The only other critical size is the amount of material passing 150 μm. For fine aggregates obtained from dry gravel beds or derived from crushed rocks, the 150 μm size is critical to several factors, including moisture content of the material supplied and the water requirement of the concrete. For additional cohesion in low cement content mixes, it is invariably beneficial for the concrete to contain a proportion of material passing 150 μm size, but excessive amounts can increase the water requirement. For different sources, therefore, rates of testing to determine the amounts of material passing both the 600 and the 150 μm sieve sizes will vary. Wet processed material, such as sands obtained from marine sources, may require only one test for 150 μm for every ten tests at 600 μm, whereas a crushed rock fine will require both tests as they are equally important.

The frequency of testing aggregates depends a great deal upon what decisions will be taken when the results become available, and here two aspects are worthy of consideration:

1. How characteristically different the supplies are from those originally sampled, tested and used in the trial mixes to obtain the Prime Mix, and whether those changes are significantly different to warrant reselection of the mix proportions.
2. What the quantities and rates of concrete production are. Supplies can be either continuous or intermittent, and may require random monitoring either every so many tonnes or on a time basis. For

example, on a large contract it would be excessive to test after every 1000 tonnes delivered since this could mean sampling twice daily, whereas on a small batching plant making less than 100 m^2/day it might take a week or 10 days to use that quantity of material and significant changes may have taken place in that period which go unchecked if the supplies are not sampled at least every other, or every third, day.

The tests for moisture content, particle shape and grading as previously described should take a technician no more than 90 minutes to complete.

Cement

Testing the cement is the most difficult of all quality control aspects. British cement manufacturers have recently become involved in a *National Quality Assurance Scheme* providing information to the user basic to the control of concrete quality in which the cement is used. However, the provision of and action on such data, as has been discussed at the beginning of this section on quality control, takes time and many concrete producers have developed and use accelerated testing as an effective means of controlling the mix proportions of the concrete.

Nevertheless, considerable effort and resources are needed to calibrate and reconcile the concrete test results to enable sufficient confidence for positive action to be taken on data from accelerated testing. The technique of the progressive cumulative summation of the variation of test results (CUSUM), has been used for a considerable time with success because it relies on the progressive trend of results to show rising, uniform or falling bias. In all cases the action taken depends on the degree of confidence which the technique is able to generate by forecasting the actual 28-day result of one concrete mix used in practice, provided all other things remain equal. That is why it is equally important to test both the aggregates and the slump of concrete. The implications of Figure 7.6 should now become clear, because the relative positions of the mean lines of the graph in the mix chart *rely uniquely on the strength grading of the cement used.* Thus, if this one item of information has been used to determine the position of the graph, then to confirm this all that remains is to choose one mix (from the mix chart) which has most of the other extraneous influences removed. The results will then act to help fix the position of the graph in relation to all the mix proportions.

This method of presenting the information has the further advantage that progressive corrections can be made for workability, because, as shown in Figure 7.6, and the summary (page 73) every 5 mm change in slump produces an equivalent change of 0·8 N/mm^2 at 28 days. Thus, if the mix chosen to control the mix chart has a slump lower or greater than that chosen, then it can be corrected before the result is used.

Routine testing of concrete

Generally, the routine tests made on concrete have involved a form of consistence of workability test, usually slump, and a strength test, normally the 28-day crushing strength of cubes. Another test, almost as important but seldom used, is the plastic density test. BS 1881: Part 107: 1983 *Method for the determination of the density of compacted fresh concrete* gives a positive guide to the actual volume of concrete produced, as well as a rapid indication of charges in both proportions and materials.

The purchaser of readymixed concrete usually relies on an order which details the strength, the workability and the volume of concrete to be supplied, and so it is important to measure and control those aspects which are quickly determined, such as workability and density. The temperature of the concrete is, at times, critical to the water content of the mix (see Table 7.6) and should be noted wherever possible.

Sampling

It is just as important to take a representative sample of the fresh concrete as it is of the constituent materials, and not to take the sample from either the start or finish of the discharge of a batch. The equipment for sampling and testing fresh concrete should be clean and damp dry, as the purpose is not to affect the test result by adding or extracting water to or from the sample. See BS 1881: Part 101:1983 *Method of sampling fresh concrete on site*.

The tests

1. The real objective of the slump test is to control the amount of water added at the mixer. It is implicit that this indirectly controls the water/cement ratio (which it does to a large extent) but other aspects of fresh concrete can also affect slump, such as changes in aggregate shape and grading, temperature, length of time from commencement of mixing and variation in sources and type of cement. The advantage of the test is that in sampling the concrete and rodding it in layers in the cone, subjective judgements are made, i.e. the resistance offered by the concrete to the scoop in transferring samples from the original container and the reaction when rodding it into place. Whether the concrete has a reasonable consistence or not is easily registered.

   The upward pressure from the concrete in the slump cone itself at the moment of transfer of holding down from the feet to the hands is also a measure of its consistency and pumpability.

   Just by lifting the cone, the cohesion of the concrete can be judged. This, coupled with observations of the concrete in the slumped state, are all subjective assessments which, when developed by the operator, become an invaluable secondary skill enabling more precise adjustments to be made to the cohesion of a particular mix.
2. Testing for density is essential for assessing yield, giving further information on the probable effects of water content and compactibility as well as giving warning of changes in the materials.
3. The objective of submitting a preformed and hardened specimen of concrete to a crushing test is to find out whether the cement has performed as intended and whether the water/cement ratio was low enough to produce sufficient strength. There are two main problems involved with sampling concrete at the point of discharge (particularly with readymixed concrete) and making the test specimens:

   (i) in the British climate it is unusual for the fresh concrete to have a temperature above 20°C, in fact it is normal for the concrete to be produced in the range 10–15°C. The sooner that concrete can be brought to 20°C the better for testing purposes, particularly if crushing tests are to be performed at 1 or 3 days. Those first few hours after casting, especially if the temperature of the concrete when sampled was below 10°C, will significantly depress the early strength, particularly before 28 days but, as it is the 28-day strength which is important for compliance purposes, the early temperature becomes a serious consideration for the laboratory which should have standard and controlled conditions, see BS 1881: Part 111: 1983.

   (ii) as time is the essence with all concrete, it is important when making tests and preparing specimens, to consider the elapsed time from the start of the mixing to when the specimens were lodged safely in a vibration-free curing cabinet, and to keep this period as short as possible. There are understandable deviations in the procedures as described in BS 1881, particularly concerning the transportation of freshly moulded cubes from a construction site supplied with readymixed concrete to the controlled conditions of the laboratory.

The mix/mixes to be used for control testing

Although several mixes may be commonly used on any construction site or precasting factory, it is not really imperative that every mix in use should be tested, as a proliferation of mixes makes insufficient data on any one mix. It is, therefore, important to decide whether minority mixes should be tested, apart from slump and density. In view of this it is better to produce sufficient test data about one mix and let these guide the position of the graph on the mix chart. Another consideration is the length of time taken to produce the standard 28-day test results on the cement in use. It is, therefore, important for the comparison of data to consider selecting a mix which will produce results close enough to those which might be produced from a standard cement test as in BS 4550. The selection of the *control mix/mixes* is, therefore, important and if a mix can be chosen which satisfies the requirement of a majority mix and that is close to a standard mix (usually equivalent to a cement content of 320 kg/m^3), then more than one aspect of concrete quality control will be achieved. To illustrate one aspect of quality control, the use of a *control mix* will now be considered.

Control of the mix proportions by concrete tests

As previously discussed, the 24-hour accelerated strength test data might be used where it is necessary to control the strength of the concrete closely. This involves heating the concrete specimens in their moulds and correlating the 24-hour test results to a previously calibrated chart to forecast the 28-day strength (Figure 7.6). Where 24-hour accelerated test facilities are not available, one alternative is to use the 3-day results. Unfortunately, however, this means that concrete produced on a Thursday—traditionally a day for high productivity—has to be tested on Sunday, which is obviously more expensive. However, if it is decided that tests at 3 days are needed, the technique is as discussed below:

The control mix

The control mix selected for use in this exercise for a 28day target strength of 35 N/mm^2 is:

water	170 litres
cement	290 kg
fine aggregate	650 kg
10 mm coarse	375 kg
20 mm coarse	815 kg
cohesion	good
target slump	55 mm
density	2300 kg/m^3

TABLE 7.7

Data obtained from concrete test results which have been corrected for slump variation to evaluate cement strength grading

Sample No.	Slump (mm)	Plastic density (kg/m³)	Actual cube crushing strength (N/mm²) at 3 days	28 days	28-day cube crushing strength and slump variation: Slump, Correction (mm) +	−	Strength, Corrected value (N/mm²)		Estimated 28-day cube crushing strength (N/mm²) based on 3-day value and slump corrected	
1	35	2320	18	39		20	−3·2	35·8	38	34·8
2	75	2290	13	30	20		+3·2	33·2	33	36·2
3	85	2295	10	28	30		+4·8	32·8	30	34·8
4	40	2305	19	40		15	−2·4	37·6	39	36·6
5	30	2315	22	45		25	−4·0	41·0	42	38·0
6	80	2290	12	34	25		+2·4	34·4	32	34·4
7	60	2285	13	32	5		+0·8	32·8	33	33·8
8	45	2300	20	42		10	−1·6	40·4	40	38·4
9	30	2310	20	40		25	−4·0	36·0	40	36·0
10	75	2285	14	32	20		+3·2	35·2	34	37·2
11	45	2315	16	34		10	−1·6	35·6	36	34·4
12	55	2310	17	38				38·0	37	37·0
13	25	2320	24	45		25	−4·0	41·0	44	40·0
14	70	2290	14	32	15		+2·4	34·4	34	36·4
15	55	2285	17	37				37·0	37	37·0
16	60	2295	15	34	5		+0·8	34·8	35	35·8
17	30	2315	19	42		25	−4·0	38·0	39	35·0
18	65	2300	20	39	10		+1·6	40·6	40	41·6
19	80	2285	9	29	25		+4·0	32·2	29	33·0
20	60	2310	18	38	5		+0·8	38·8	38	38·8
Mean	55	2300	16·5	36·5				36·5	36·5	36·5
Standard deviation	19	12·5	4·0	5·1				2·85	4·0	2·2

Test information

At least 20 samples consecutively taken from the control mix and tested for slump and compressive strength at 3 and 28 days are required to calibrate and reposition the graph given in Figure 7.6. Table 7.7, which shows typical results, presents the following information for calibration purposes:

1. Though the mean slump is 55 mm, which is the target value, it has a higher variability than many specifications suggest as permissible, i.e. ±25 mm. In fact, 95% of the results are spread ±31 mm (19×1·64) of the mean, say 25 to 85 mm, which suggests that more control should be exercised at the batching plant.
2. The mean plastic density is the target value of 2300 kg/ m^3, the variability being probably indicative of changes in water content.
3. The difference between the mean of the 3-and 28-day strengths is 20 N/mm^2, which confirms the relationship noted from the information supplied by the cement producer.
4. In this instance, corrections to the 28-day strength can be made by adjusting the strength by 0·8 N/mm^2 for every 5 mm difference from the mean value of 55 mm required. This demonstrates how, by

controlling the slump, a less variable concrete is made, as it reduces the standard deviation from 5·1 N/mm^2 to 2·85 N/mm^2.

5. The information can be further extended to forecast the 28-day strength by adding 20 N/mm^2 to the value obtained at 3 days and then this, corrected for slump, to forecast a truer 28-day value.

For example, for sample number 1 (Table 7.7) the slump value of the concrete was 35 mm, 20 mm lower than the mean of 55 mm required. This indicates less water and thus a lower water/cement ratio than intended and so the 28-day strength ought to be reduced by $\frac{20}{5} \times 0{\cdot}8 = 3{\cdot}2$ N/mm^2. When the 3-day compressive strength of 18 N/mm^2 is obtained, then the estimated 28-day strength would be 18+20=38 N/mm^2, which would in turn be adjusted by reducing it by 3·2 to 34·8 N/mm^2, as an estimate of the 28day value. When the value at 28 days of 39 N/mm^2 is obtained, it too can be reduced by 3·2 N/mm^2 to 35·8 N/ mm^2 to obtain more precise information on cement strength grading.

Adjustment of the mix

The purpose of the previous exercise was to provide sufficient actual data for the mix chart to be completed more precisely. Figure 7.7 shows how the new position of the 28-day strength relative to both slump and mix proportions can be made with the data obtained. By appropriate use of the control mix, effective control can be exercised over the full range of concrete mixes within the scope of the mix chart by application of progressive review and adjustment. For instance, the cement and fine aggregate contents for the three mixes determined to satisfy the strength requirements of 35 N/mm^2 at 28 days, can be adjusted as follows:

		Mix		
		A	*B*	*C*
Former	cement (kg)	255	290	325
	sand (kg)	700	650	610
New	cement (kg)	245	280	215
	sand (kg)	710	660	620

All that remains is to maintain progressive records of the relationship so far developed, which have been expressed in such a way that whatever technique used will provide meaningful and actionable response to changes.

Conclusion

The real problem with concrete mix design and quality control is that as concrete is man-made, as much as any other product it tends to reflect the variability of materials, machinery and conditions. However, early recognition of a change, either in conditions of manufacture or properties of concrete, enables necessary corrective action to be taken, so increasing the uniformity of the concrete. More effective use of the materials will thus have been achieved which, after all, is the purpose of mix design.

Appendix: workability and cohesion

"Workability is that property of a plastic concrete mixture which determines the ease with which it can be placed and the degree to which it resists segregation. It embodies the combined effect of mobility and cohesiveness."

(T.C.Powers. *Studies of workability of concrete*. ACI Journal, March 1932).

As with all subjective judgements, the workability and cohesion of a particular mix is a function of the materials, the proposed method of transport and placing and the element under construction. Concretes of low slump (5– 25 mm) should tend towards low cohesion, where concretes of high slump (100–150 mm) should tend towards high cohesion.

Cohesion of fresh concrete is a very difficult property to measure qualitatively or describe, and is best assessed on appearance to suit the equipment and application. However, faults in both the measured workability and perceived cohesion of fresh concrete need correction and the following guidelines are given to aid the process of correction.

FAULT: *Workability marginally unacceptable,* but cohesion correct. If the measured workability is outside the minimum limit, add more water until workability meets target and then re-test.

Note: 10 litres/m^3 extra water approximates to:

Maximum aggregate size (mm)	Slump (mm)
10	10
15	20
20	30
30	40
40	50

If the measured workability was beyond the higher limit, reject the batch and start again with reduced water content. Add last 50 litres/m^3 carefully.

FAULT: *Cohesion and workability are not acceptable*. Reject the batch. Refer to cohesion trial mix correction in either Table 7.3 or 7.4 and apply adjustments to the aggregate batch masses. As a demonstration of how corrections work, the following adjustments can be made to Example 1 (Table 7.3):

Mix quantities (kg/m^3)		Cohesion fault			
Material	Original trial mix	High		Low	
Adjustment	New	Adjustment	New		
water	215		215		215
cement	390		390		390
fines	725	−80	645	+80	805
10 mm	940	+80	1020	−80	860

Then proceed to batch and mix as if starting afresh until a satisfactory trial mix is obtained.

REMEMBER, there are three principle things which may go wrong:

1. the aggregate tests have not been performed properly,

2. the first trial mix has been incorrectly batched,
3. the procedure has not been followed properly.

8.
Accuracy in construction

Provided that normal methods of setting out, forming and placing, compacting and curing the concrete have been employed, a certain standard of accuracy can be achieved. BS 5606:1978 *Code of Practice for accuracy in building* sets down the accuracy which may be achieved in using specifie materials. This degree of accuracy is known as the *characteristic accuracy* for the material. Characteristic accuracy does, of course, differ where various types of concrete and concrete products are concerned, for instance, precast concrete and in situ concrete or massproduced components and elements produced by jobbing techniques. The location of the work and the conditions in which it is carried out will also affect variations in the characteristic accuracy achieved. Measurement carried out on a number of buildings has established certain values for this characteristic accuracy in terms of displacement of the mean size from the work or space size and the spread of the sizes about that mean. The designer uses this information in determining the tolerance, in terms of permissible deviation, to ensure that the structural element meets certain requirements of the brief. The permissible deviations thus specified take into account such important factors as:

the visual quality of the finished work, including such matters as joints, line level and location;
structural quality of joints as regards bearing widths and accuracy of location of loads;
legal requirements of building location with reference to building lines and boundaries;
practical aspects of construction, avoidance of cutting to fit;
suitability of the construction to meet the functional requirements of the designer's brief;
the avoidance of unnecessary production costs, excessive cost of rework in achieving standards beyond those essential to the requirements of the structure.

In the case of special structures where the accuracy of the concrete is essential to performance (wind tunnels, testing tanks and such like), the local specification will include special reference to critical dimensions. Achievement of accuracy in critical dimensions and control of accuracy to limits exceeding that which is described as characteristic accuracy requires special attention, possibly including changes of method and closer control of production activities. These demands are reflected in increased construction costs due to additional costs of setting out, checking and supervision.

Whatever the standards established by local specification or reference to Code recommendations, it is the task of the supervisor to ensure that the standards specified are achieved in practice. In this area his specific problems will include the following:

translation and verification of detail;
the establishment of standards;

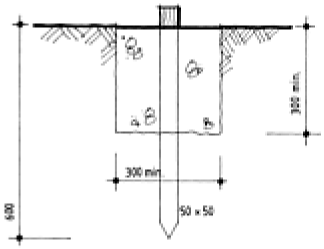
informing tradesmen and operatives of the appropriate standards;
setting out or arranging the setting out of lines and levels;
controlling equipment and materials, ensuring their conformity with specification;
checking and maintaining standards of workmanship with particular reference to specific critical details and dimensions.

The quality of appearance and consistency has been discussed elsewhere in this publication. The degree of accuracy achieved depends upon the amount of care exercised in the initial stages of site setting out, the provision of accurate bench marks and the subsequent transfer of local lines and levels to the work place. At this stage it is worth examining the sources of inaccuracy or deviation from specified size or position. These can be divided into those *inherent* in the materials and those *induced* in setting out, manufacturing and assembling the structure.

Inherent inaccuracies arise from such factors as thermal movements, creep and movements resulting from settlement and deflection under load. Induced deviations arise from the way the work is carried out, workmanship in setting out and manufacture or construction. Inherent deviation can be aggravated by workmanship as, for example, when the movements within the structure are accentuated by excessive early loading, thermal shock or bad curing. Precast elements, for example, can be spoiled by the use of substandard stacking techniques or their performance may be upset by poor jointing and connecting techniques.

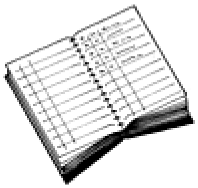
Achieving the required accuracy

Using various aids, such as the results of surveys and statistical analysis of the accuracy achieved in a variety of structures, the designer establishes the specification for a particular construction. Having secured the contract, the contractor is then legally bound to achieve the specified standards of accuracy. The supervisor will be well advised to familiarise himself with the main bench marks and the key setting out points of the structure for which he is responsible. Local bench marks will have been established and reference can be found as to the way these marks are related to some established level or a nearby structure or structures. The local bench mark must be inscribed on



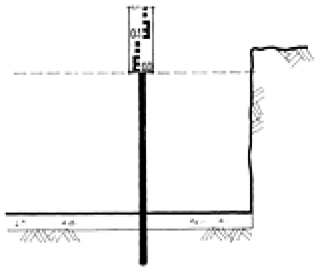
temporary bench marks (TBM's) should be established, preferably on an existing stable structure, otherwise a substantial pin, as sketched, should be concreted in—details can be inscribed in the fresh concrete

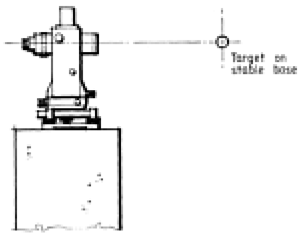
location and reduced level should be recorded and information displayed in the site office



dimension books and other records will be required for valuation purposes—they are equally as important as the drawings and site diary

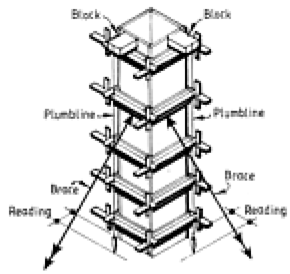
pins establishing levels of foundations, and so on, should be carefully levelled—considerable waste of concrete can otherwise be incurred

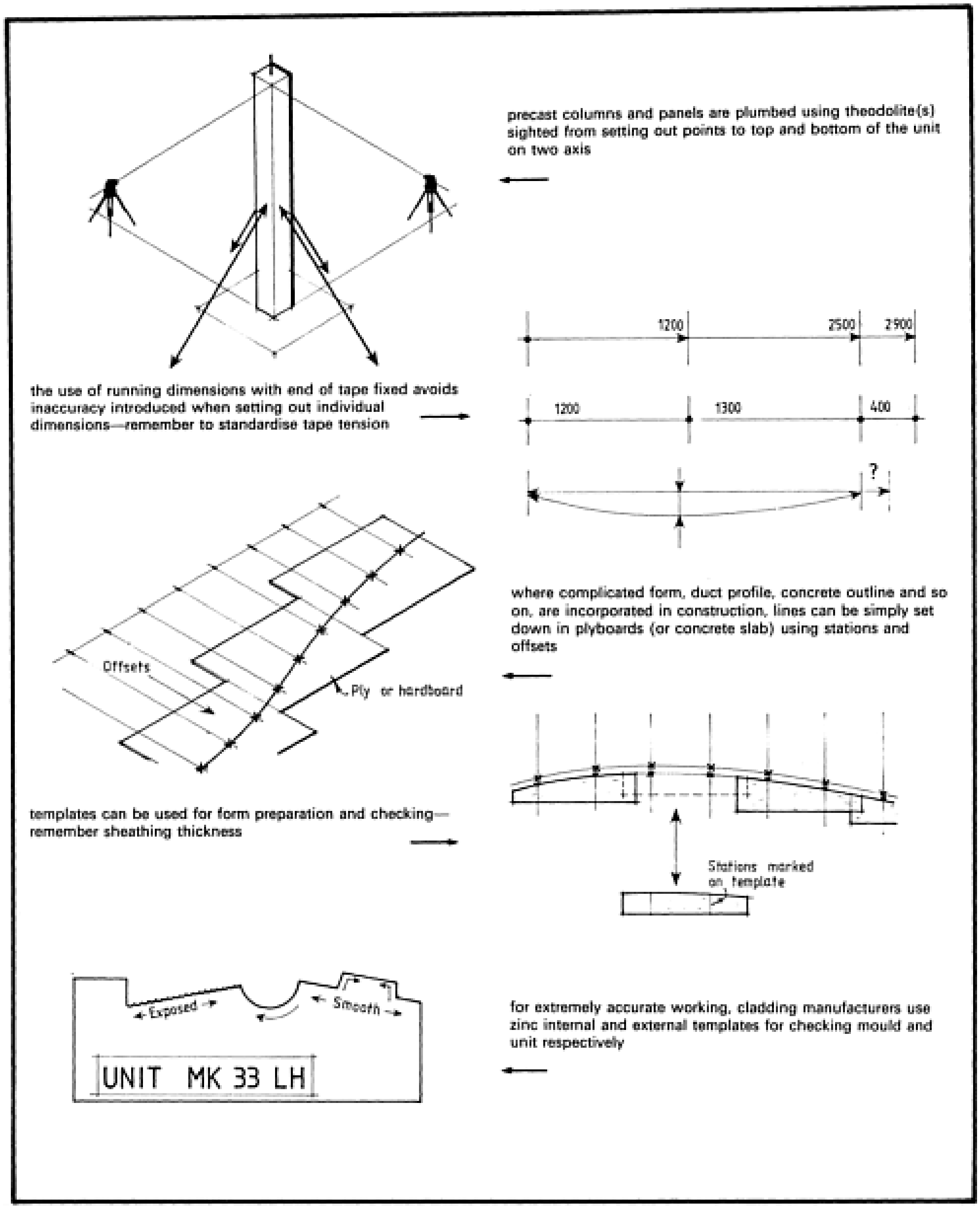




where critical geometry is concerned, an "optical" base is set up to provide a datum from which measurement can be made

column forms are plumbed using plumblines and blocks of known thickness set on adjacent faces





some substantial block of concrete or indicated on some previously constructed building or structure. Reference stations, about which the main building grid is set out, are generally inscribed on concrete blocks or on steel plates let into previously cast elements of the structure. When some particularly critical part of the structure requires constant reference to bench marks and station points, it will be helpful to construct concrete piers taken down to such levels as not to be affected by frost or movement. In critical work, piers can be used to support targets—others to form theodolite mounts, so that an instrument can be readily set into position and used to provide optical reference lines. Targets for work in shafts and chimneys must be protected and illuminated. All targets should be identified by reference number and date and a suitable record maintained regarding the information they provide. Profile boards used to indicate grid lines—the width of walls, foundation beams and so on—should be of sound construction and set in concrete located in such a place as to avoid disruption during excavation work or by local traffic. Shot-fired studs in structural concrete and lines inscribed in mortar are current means employed in establishing permanent reference points. Whilst it is possible to combine the function of profile boards with level pegs, better results will be obtained if both pegs and boards are provided individually.

It should go without saying that setting out is part of the process of construction which cannot be hurried. There are a number of clearly established pitfalls in the process which will be aggravated by undue haste or where the setter out is put under pressure of time. These include:

errors in the site survey;
difficulty in accurate measurement;
incorrect transfer of level from the master bench mark;
difficulty in translating drawing information;
inaccuracy in measuring and setting out equipment;
human error.

During construction deviations arise which result from material and method, and these include:

deflection of formwork, settlement of props and compression of carcassing members;
inaccuracy due to wear on form components and fixings;
adjustment of connections, ties and sub-assemblies;
displacement and rotation of formers;
measurement inaccuracy in setting up lifts, bays and sub-assemblies.

Where building components, frame buildings, beams in bridges, and panels in precast construction are concerned, deviations arise from, among other things, the following:

difficulty in accurately locating large or heavy elements;
difficulty in controlling the movement of loads on cranes and lifting equipment;
clearance in fixings and fastenings allowing deviation in position;
problems of location of setting out instruments and the achievement of adjustment in plane, line and level.

The supervisor can introduce measures to control the majority of these problems, *within limits*. Once having established what are critical dimensions, he can devise means of control using appropriate techniques, jigs, templates, check dimensions and surveys. It is essential that he should know and understand the designer's intentions regarding accuracy and what further construction work and installation work demand in terms of accuracy. The supervisor should check what allowance has been made at the interface between the concrete and other materials, such as steel, timber, plastics and so on, what tolerance has been allowed for deviation and the changes in size resulting from the characteristic accuracy of the particular combination of materials. Ways of accommodating these deviations have traditionally included:

the insertion of holding down bolts into tubes for later grouting;

the casting of foundation beams and blocks to a reduced level allowing the insertion of shims below columns or machine bases, subsequent grouting providing a bearing surface;

the use of oversize opening formers, openings for pipes, ducts and so on being subsequently masked by cover plates;

the use of continuous fixing angles and slot forms which allow for variations in bearing location;

the use of washers and oversize holes on bolted connections;

the use of slotted angles and brackets in cladding fixing; fixings and fastenings made to concrete as a secondary operation;

the casting of columns overlength to allow beam casting at correct position;

the use of closer elements in cladding and where curtain walling is used with concrete;

the use of shims and levelling bolts prior to dry pack or stitch construction;

the introduction of changes of plane between assemblies;

the use of linings and architraves at door and window openings which mask discrepancies between as cast openings and the inserted frame member;

the use of through-fixing systems.

Latterly, the adoption of modular concepts, the allocation of space for components and parts of the structure within which the work can be located without encroachment upon, or detracting from, the function of components in adjacent spaces, has formalised these traditional arrangements. There are a considerable number of points within the supervisors control which will assist in the achievement of the specified accuracy of profile location and position of embedded fixings and fastenings, such as:

co-operation with the section engineer which will ensure that the correct lines and levels are established for a particular lift or bay with due regard to critical dimensions;

the use of kickers to allow a location check to be made on steel and formwork prior to the actual casting operation;

a check on opening formers and essential cast-in components made prior to closing the form will establish their accuracy and the correct cover on steel at jambs, head and sill;

discussion with authorities may allow the use of oversize openings for services and thus reduce the demands of accuracy;

all cast-in fixings and opening formers should be related to a datum and level on the form which in turn should be related to a datum and level on the kicker or adjacent concrete;

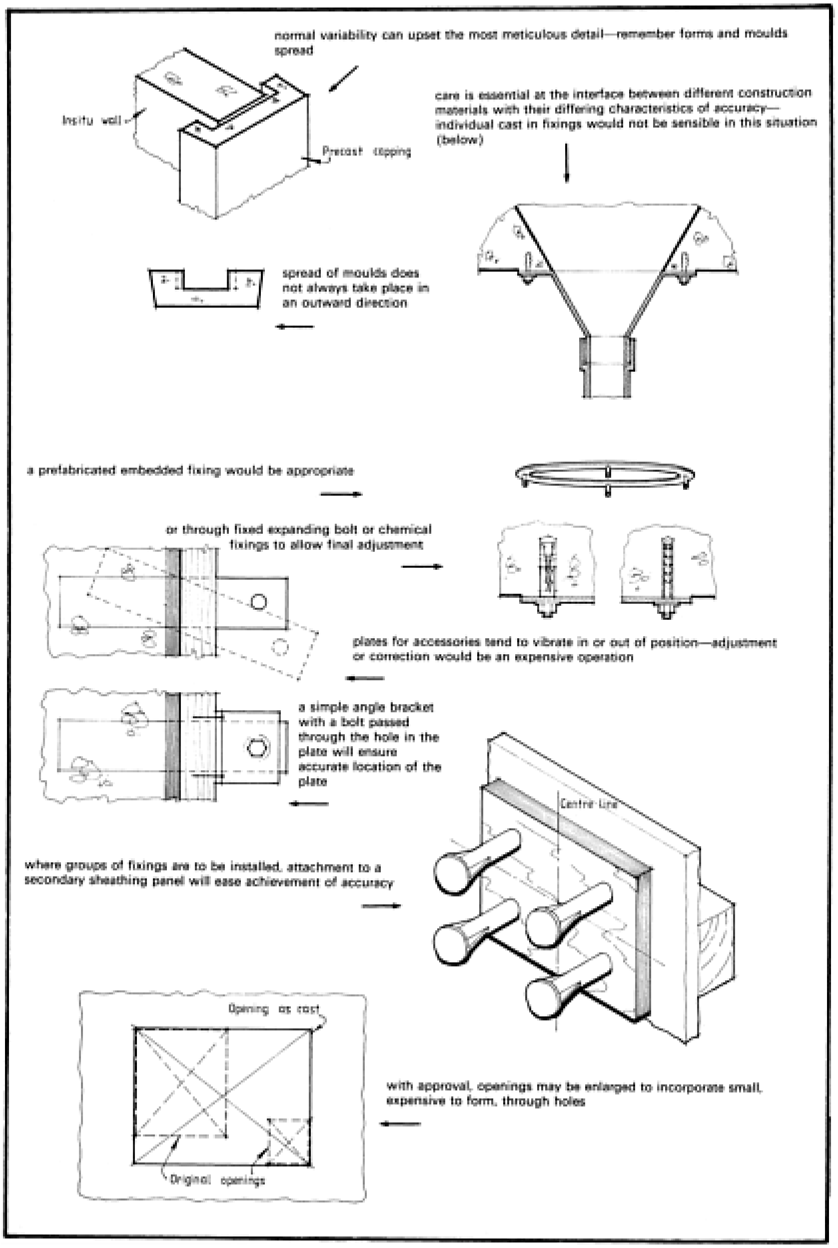
jigs and templates should be used where repetitive operations demand the accurate location of fixings, holding down bolts and so on, particularly where the fixing is a bar or plate projecting from the concrete surface;

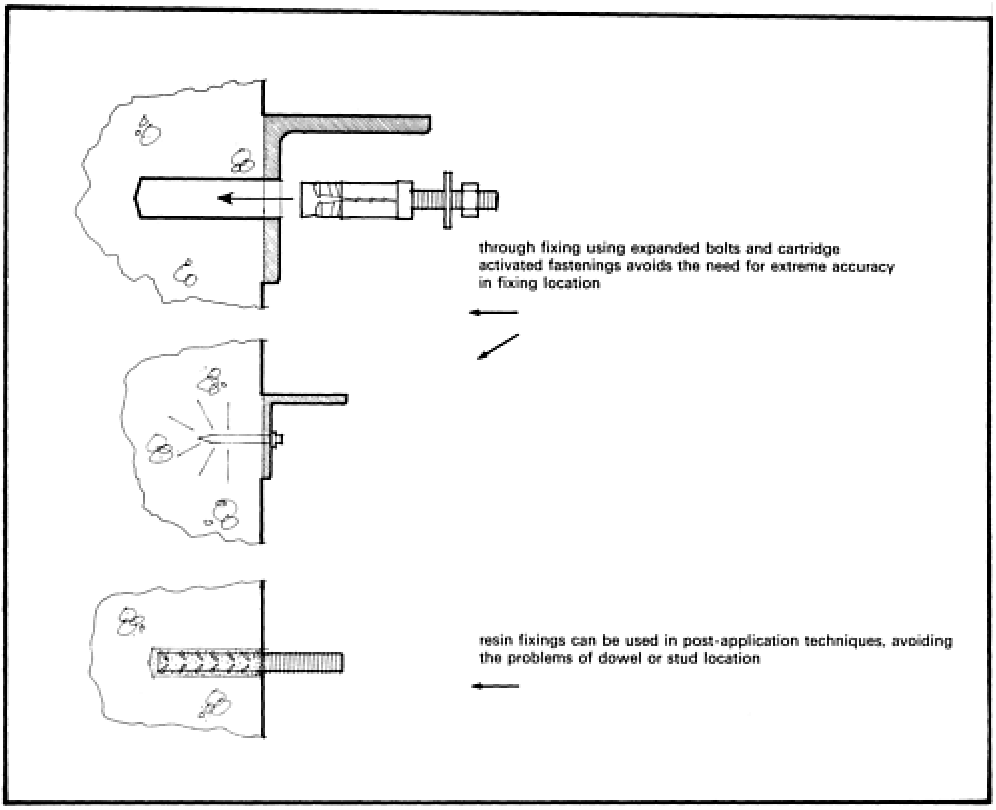
the jigs should provide restraint against displacement in, out or rotational under the influence of placement and vibration;

the formwork, should be checked for line, plumb, camber (built in), prior to, during and after casting;

all supports, bracing ties and struts should be made at strong points or node points and taken from secure foundations or attachments to previously cast, matured concrete;

systems should include built in telltales which indicate deflections or movements;


normal variability can upset the most meticulous detail—remember forms and moulds spread
Insitu wall
Precast copping
care is essential at the interface between different construction materials with their differing characteristics of accuracy—individual cast in fixings would not be sensible in this situation (below)
spread of moulds does not always take place in an outward direction
a prefabricated embedded fixing would be appropriate
or through fixed expanding bolt or chemical fixings to allow final adjustment
plates for accessories tend to vibrate in or out of position—adjustment or correction would be an expensive operation
a simple angle bracket with a bolt passed through the hole in the plate will ensure accurate location of the plate
Centre Line
where groups of fixings are to be installed, attachment to a secondary sheathing panel will ease achievement of accuracy
Opening as cast
Original openings
with approval, openings may be enlarged to incorporate small, expensive to form, through holes



the use of an instrument, or instruments, fixed on critical planes, will allow ease of control of precast (or critical in situ) operations;

formwork should always include more than one layer of backing material to ensure maintenance of lines, and struts should only be connected to such continuous members;

deflections should be monitored, apart from compressions taking place at junctions between members, under washer plates and so on, deflections in sheathing materials, if timber or timber derived, tend to increase due to heat and moisture effects of casting;

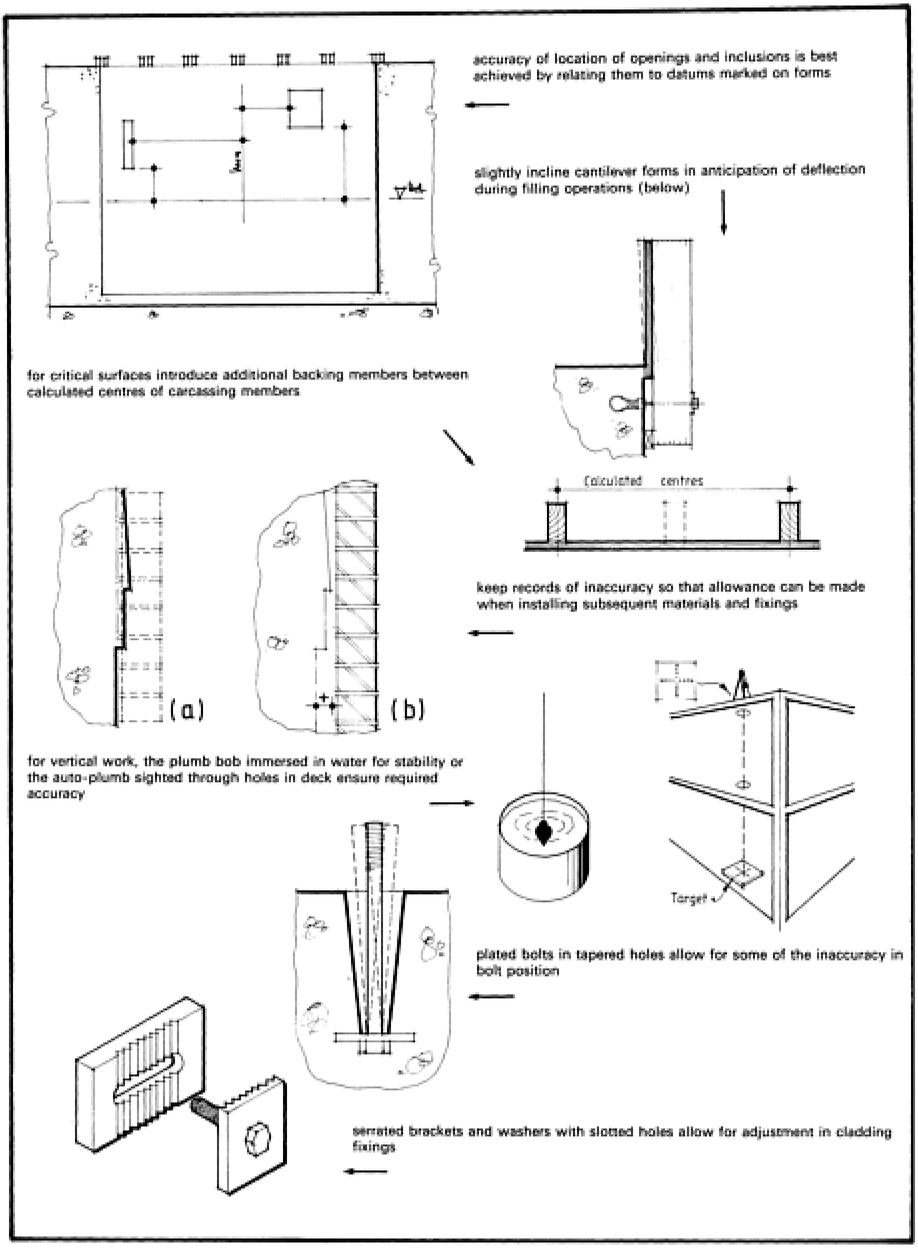
opening formers, door openings and the like tend to be displaced by impact loading, particularly sideways pressure within forms, and substantial fixings are necessary to control movements;

the method statement should include a sequence of placement, the rate of placement and similar detail to ensure the uniform placement of concrete into wall and onto slab forms, avoiding excessive local forces which otherwise cause deflections and movement;

in all cases a check must be maintained on the footing foundation or attachment of props, laces and braces; special provision of cast in bars, bolts and loops allow the fixing of substantial braces to matured concrete;

imported kentledge or the use of scrap concrete cast into local excavation provide sound anchorage for push-pull props or winches in positioning forms (cables should be avoided as a fixing method).

A record should be kept of inaccuracy arising during the construction. Inaccurate work is not necessarily reject work, but problems may arise during subsequent operations, cladding, erection, machine installation and similar. In precast erection the use of templates, storey rods and such simply prepared equipment, allows any member of the team to establish lines and levels from the basic datum set by the engineer. The use of running dimensions is a valuable aid to accuracy, eliminating as it does cumulative errors in individual measurements. Care in instructing those using tapes on the requirement of keeping even tension and a level tape, square to the grid line, will reduce the likelihood of inaccuracies in measurement. A considerable amount of inaccuracy results from impact between casting equipment and formwork and care should be exercised in training and instruction of operatives and banksmen. Inaccuracy may become apparent at various stages in construction—sometimes at a stage when immediate action can be taken to rectify the situation, or other occasions when, for example, casting is in progress or after the concrete has hardened, when it may prove difficult or even impossible to achieve an immediate solution. Instances of the first situation, where



remedial action can be taken, include:

situations where pre-prepared forms or previously fabricated steel cages cannot be made to fit onto or into the allocated spaces at the point of construction;

where, on inspection, deflections in previous work prohibit the close attachment of a form to a previously placed lift or bay of concrete;

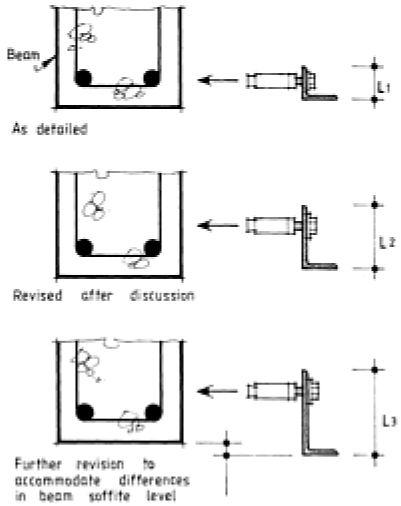
where a previously inserted through hole, anchor or tie point is malpositioned and a fixing capable of sustaining future construction loads is unlikely to be obtained;

where there is evidence that in-process revisions to design have resulted in wrong positioning of cast in reinforcement or openings (or where some superseded drawing has been used in error).

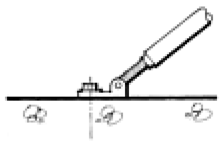
Instances of the second situation, and possibly more difficult to deal with arise where:

ommission of a tie bolt or support or where movement or settlement results in some major displacement of the form;

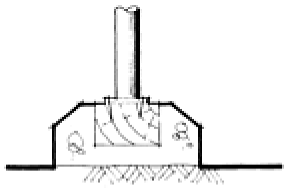
poor appreciation of concrete pressures has resulted in



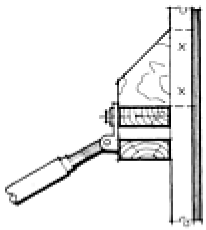
early discussions with designer and detailer can avoid cost and delay resulting from poor detail when fixing is drilled in

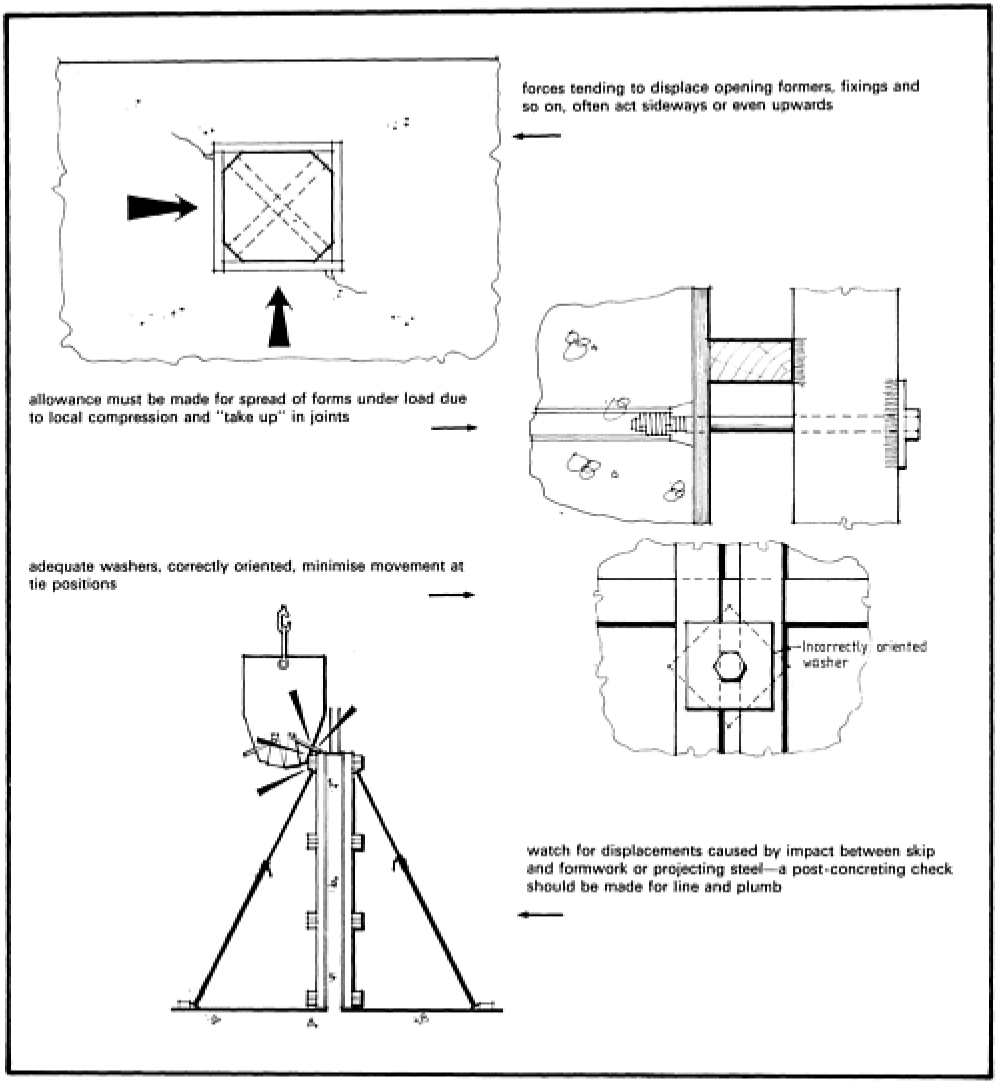


all equipment used to adjust for line and level must be taken to secure fixings in mature concrete or kentledge or to sound footings



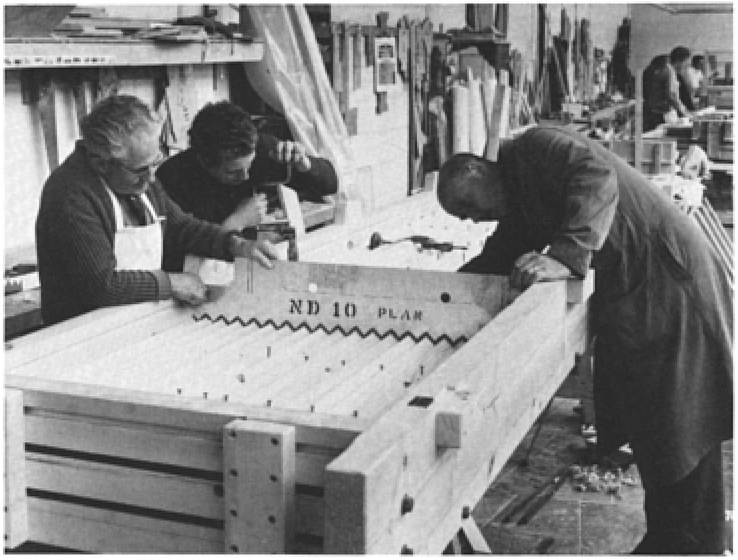
fastenings should be made at strong points in the form





excessive deflections of the form face.

Whenever possible, immediate action should be taken—in the context of the concreting operation, this will largely amount to slowing or even stopping the placing operation. After the event, once the concrete has hardened, the matter must be brought to the attention of the appropriate authorities. A survey should be made of the inaccuracy or defect and the implications in terms of the effect on structural performance and impact on succeeding trades or operations should be assessed. At this stage it is necessary to decide whether remedial work or local removal of concrete (in a section of the lift or bay) will provide the best solution. Considerations at this stage will hinge on the basic requirements which govern most aspects of concrete construction, being those of:



Zinc templates in use checking moulds during construction (Empire Stone Ltd)

aesthetics,
structural integrity
and
economy.

Checklist

What does specification say?
Have standard samples been established?
What are critical dimensions?
Where are inclusions detailed?
Have necessary datums/lines been established/checked?
Has allowance been made for the inherent inaccuracies of construction?
Can jigs or templates improve the accuracy achieved?
Will post-attachment ensure accuracy of attachments?
Can permanent optical lines be set up?
Do we have appropriate equipment for production and measurement?
Will the traditional means of masking inaccuracy suffice?
Are there previous inaccuracies to be overcome in reestablishing line, plumb and so on?

9.
Joints

Ideally a concrete structure should be cast monolithically (in one piece) and reinforced concrete is designed in such a way that, although concrete structures work as though made in one piece, they may, in fact, be cast in many sections. The sections in which the structure is cast are known as lifts and bays. A lift of concrete is the section of concrete between two horizontal joints in the height of the structure as in a wall, beam and hopper construction. A bay of concrete is that section between two vertical joints in the length of the structure as in wall and floor construction.

Joints are formed in concrete structures for a variety of reasons and the configuration of the joint is determined by the reason for its inclusion. Structures can be designed to work monolithically, although one or several joints are included in the structural members. The continuity is achieved by the inclusion of steel reinforcement in such a way as to transmit the forces through the jointed section. There is a wide variety of joints. For example, it may be necessary for joints to be formed as open joints containing some compressible material, such as in the case of the expansion joint. In other types of construction, however, every effort is made to achieve watertight jointing, for example in structures whose purpose is to retain liquid in storage.

Apart from the technical requirements for the provision of joints, there is the very direct requirement of the constructor. Whilst in slip-forming and extrusion it is possible to construct massive quantities of concrete in a monolithic fashion, and although it is becoming more usual to construct heavy slabs and foundation blocks in very large pours, in general construction, particularly in building construction, it is more economic to break the concrete structure down into a number of lifts and/or bays to provide a series of repetitive construction operations.

Construction joints

When the structure is designed as a monolith, considerable care must be taken in any jointing. Construction joints and “day joints” must be discussed with and approved by the designer or his representative and must be formed in a workmanlike manner. The location of certain joints are detailed in the drawings and specification, although many are brought about by the practical needs of the constructor. It is usual to locate these construction joints (day joints as they are sometimes known) at points of change of section and in such a position that they ease the construction of otherwise complex parts of the structure. Joint locations are determined in some instances by the amount of concrete which can be cast in a given period or by the amount of steel which can be fixed in a working shift and yet remain stable and undistorted. In special cases it may be necessary, when the contractor is locating joint positions, to request re-design of the reinforcement, although many construction joint locations can be arranged to coincide with the laps as normally detailed.

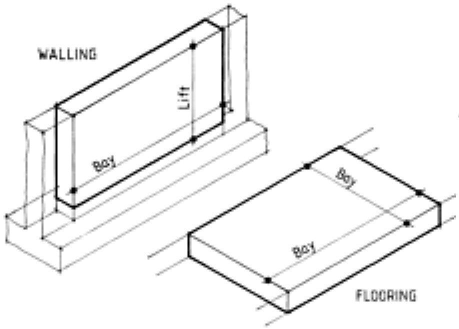
Construction joints are usually formed approximately 150 mm above the junction between a slab and wall or between a slab and column, and it is normal to form construction joints at or adjacent to the level of the deepest beam soffit intersection and the head of a column. In beams and slabs the joints are generally made at or adjacent to the 1/3 point of the span, thus avoiding concentration of reinforcing steel which occurs nearer the ends of the beam or bay of concrete slabs.

It is convenient to arrange construction joints at columns and piers in such a way that a nib or lead-on is formed onto which the formwork for subsequent operations may be clamped or fastened. Where the location of a construction joint interrupts the continuity of a structural member, it is necessary to provide a standing support at the joint until the member has been completed and the concrete element has achieved sufficient strength to be capable of supporting its own dead load and any loads which it will be called upon to support during the construction.

Present day concrete lifts and bays are larger than has previously been planned or permitted. Specifications used to be quite restrictive, allowing only lifts of about 1·2 m or so in a wall, whereas today, with increasing knowledge in the behaviour of concrete in large masses, specifications are less restrictive and storey height concrete casts are quite normal. Wall bays are generally specified as being about 5 m in length. With regard to the number of lifts or bays into which a structure is divided, the aim is to break the work down into a series of economic and repetitive operations—economic in so far as steel erection, form handling and concrete placement are concerned. In some instances it is convenient to make day joints and construction joints coincide with some feature of the construction, in which case the actual joint line at the face of the concrete can be masked in shadow or hidden in a recess.

It has been established by research that the preparation of the concrete surface at the joint, prior to placement of the next lift or bay of concrete, has a major effect on the performance of the joint. The traditional technique of pouring buckets of cement grout over a surface has proved totally unsatisfactory, in effect forming a plane of weakness in the structure. Joggled joints make it difficult to place and compact concrete and are generally best avoided. Scrabbling of concrete, whilst essential in situations where fresh concrete is being placed onto or against previously cast concrete, has a tendency to induce cracking at the face of the older concrete and this damage may result in failure of the joint.

Where construction joints are to be considered as providing a monolithic structure, there is now little doubt that the most effective joint is achieved by the early washing and brushing of laitance and paste from the fresh concrete at two or three hours after finally placing and compacting the concrete. The aim is to provide a surface which exhibits clean aggregate faces against which the



reinforced concrete is designed on the basis that it acts monolithically and is cast in lifts and bays determined by steel, concrete supply, and so on

location of construction joints can simplify construction

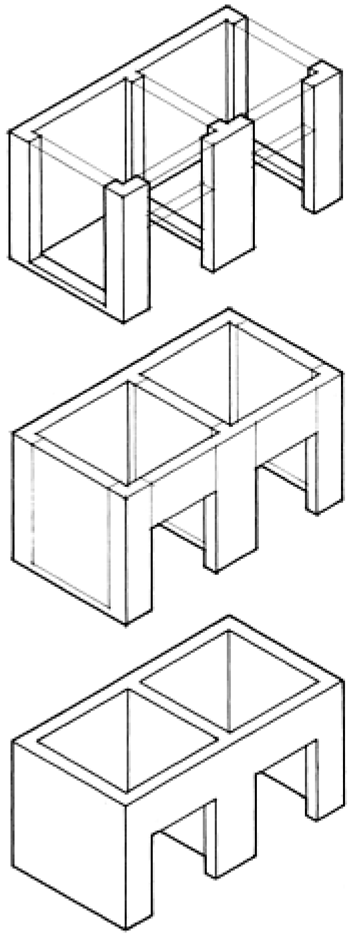
here core of building is broken down into a series of simple operations

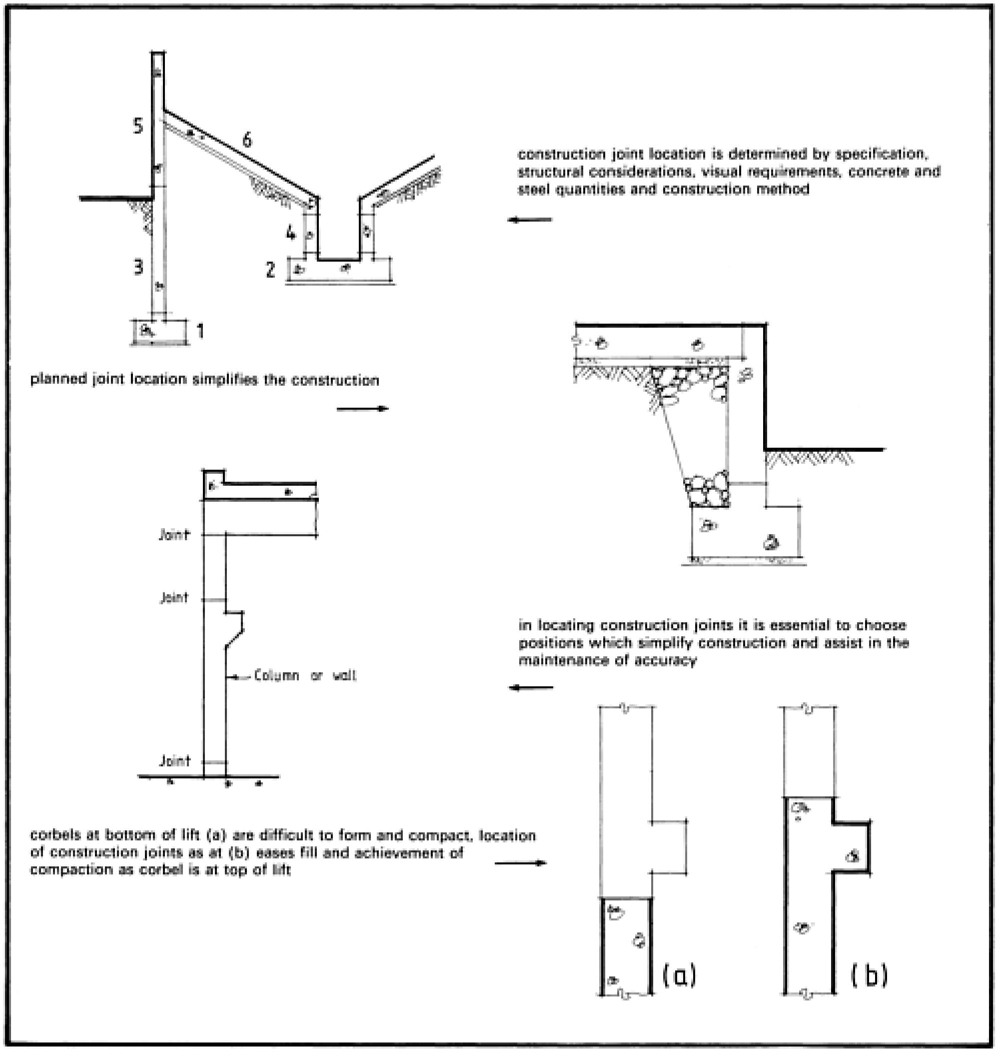
columns and walls are cast first

plain infill and simple lintel forms complete operation

avoiding congestions and problems of access for various trades

skilled analysis is required to establish the best method suiting the available skills and the supervisor, whilst achieving the required accuracy and the finish specified





paste in the fresh concrete will adhere. This surface should ideally be in a surface-dry condition when the fresh concrete is placed, although this presents difficulties when working within a form as getting rid of the washing water is somewhat awkward. Where a surface is being washed off, care must be taken to avoid scouring other previously cast faces; mainly these will be protected by the formwork, but there will be concrete faces lower down the structure which are only relatively young. Where it is impossible to wash the joint surface, preparation can be by wire brushing within 18–24 hours of placing and compaction. Grit blasting using flint fines or similar aggressive grits provides an excellent jointing surface, but unfortunately produces considerable quantities of dust which can be injurious if inhaled, so that the process must be carefully supervised and controlled. Another technique used is painting the surface with surface retarders which facilitates the brushing away of the paste upon removal of the form and a clean aggregate surface results. The surface retarder can be painted either on the concrete face or on the form face at the stopend.

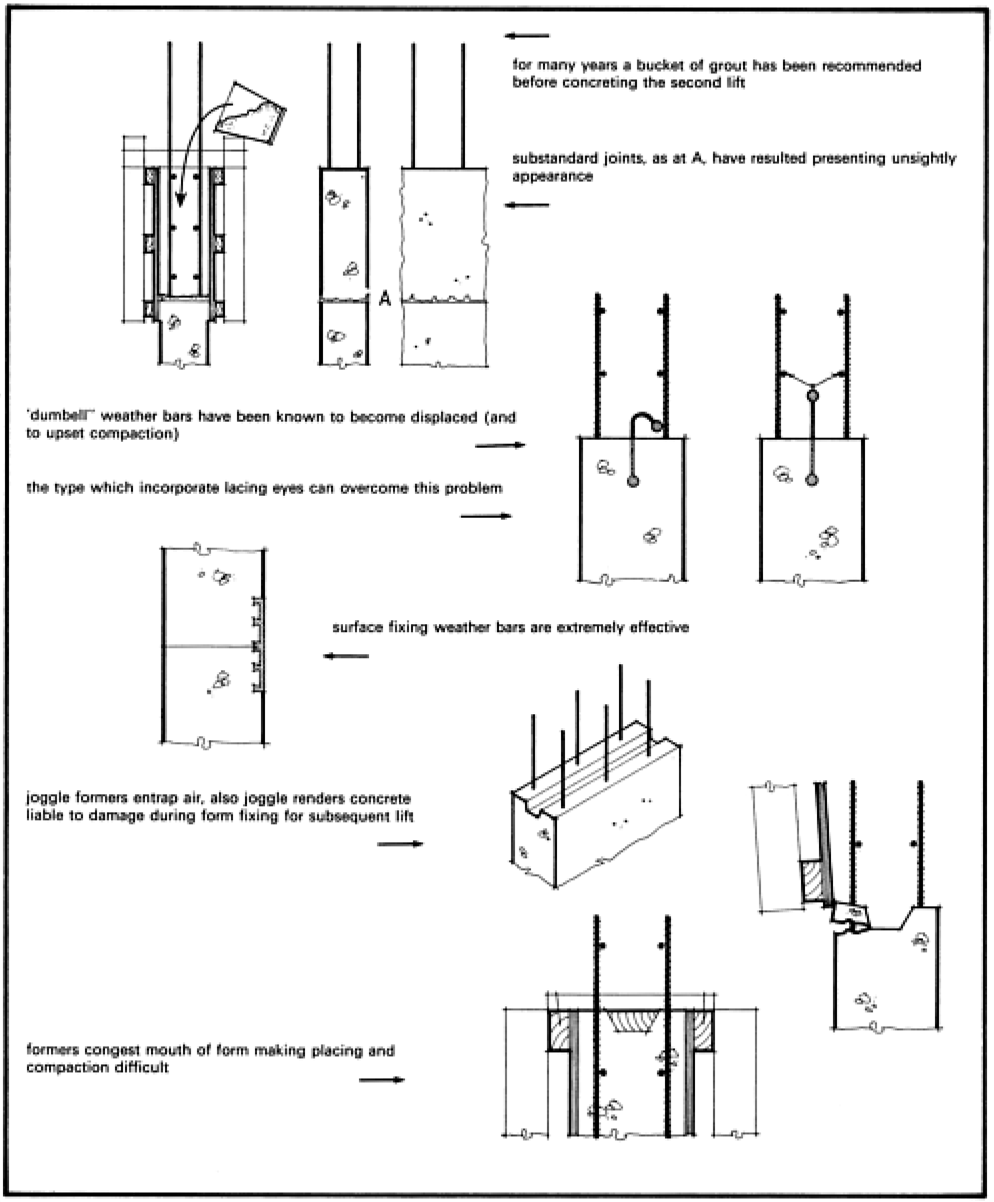
Expanded metal lathing fixed onto a timber frame provides a simple means of forming stopends and continuity reinforcing steel can be simply passed through holes formed in the material. When the metal sheet is torn from the face of the concrete, a very good key is formed which requires little extra work to bring it to the required texture for jointing purposes.

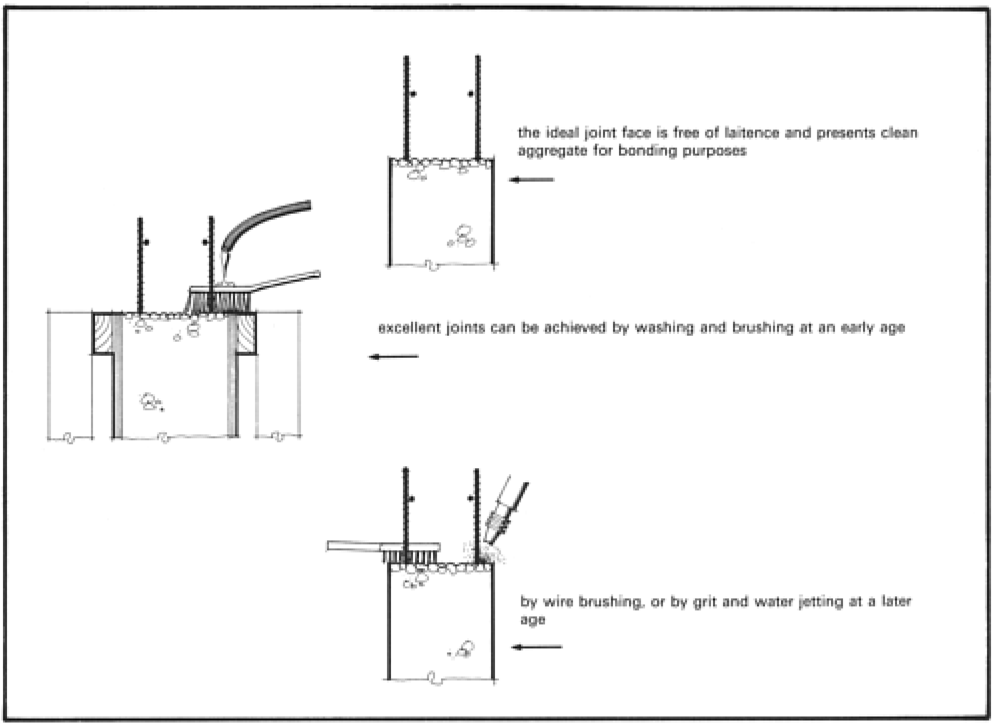
The constructor is required in many specifications to include water-bars at construction joint positions. These water-bars, which come in a variety of configurations, tend to upset the placement and compaction of the concrete. The most practical configuration appears to be that which can be fixed to the formwork and which remains embedded in the concrete at the time of striking. This type is not prone to the problems of folding and displacement which other embedded types are apt to suffer. Water-bars cannot be omitted if specified, although in many instances better joints would result if they were excluded.

Joints between precast concrete elements

Joints used in precast concrete construction can be classified as:

- open joints, drain joints and similar;
- wet cast concrete connections;
- dry packed concrete connections;
- grouted joints;
- contact joints.


for many years a bucket of grout has been recommended before concreting the second lift
substandard joints, as at A, have resulted presenting unsightly appearance
A
'dumbell' weather bars have been known to become displaced (and to upset compaction)
the type which incorporate lacing eyes can overcome this problem
surface fixing weather bars are extremely effective
joggle formers entrap air, also joggle renders concrete liable to damage during form fixing for subsequent lift
formers congest mouth of form making placing and compaction difficult

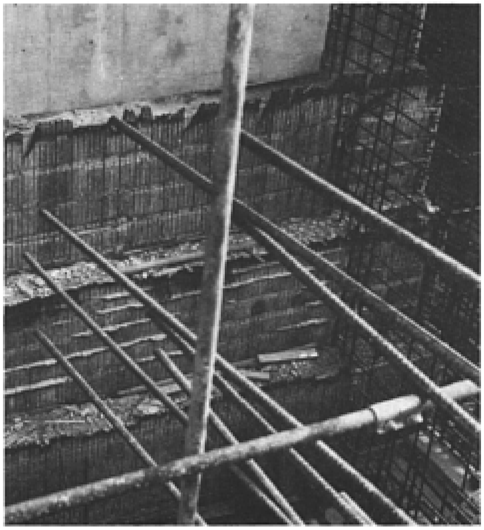


Each of these joints has specific applications and the illustrations give examples of situations where each is used.

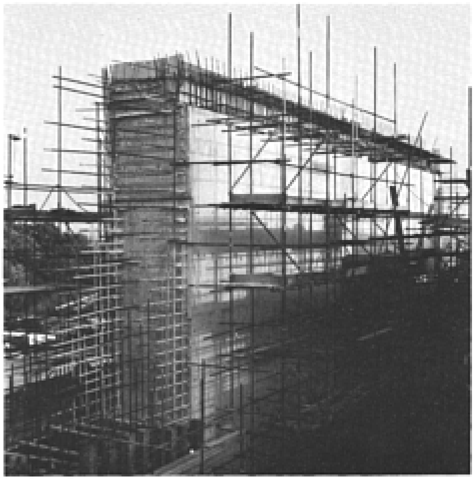
Open joints

Open joints, drain joints, and similar joint configurations, are used in the building envelope or cladding. Factors such as variations in panel size, location, movement and so on, should be taken into consideration in the careful selection of joint size. The joints frequently include a baffle and a weatherproof membrane and many are designed in such a way that rainwater penetrating the baffle or first line of defence is routed within the joint to the ground or to a horizontal joint where it is redirected back to the face of the building.

Elastomeric jointing is used to seal certain of the face joints in cladding and again care is required to ensure that the joint is of adequate size and proportion that the gunned mastic can bond to the sides of the joint, that there is sufficient width of mastic to deal with movements in the concrete and yet that the joint is not so wide that the elastomer sags away from its intended location. Elastomers can generally tolerate movements of 25% of their own width and will do so for many years. Where joint widths are small relative to thermal movements and movements resulting from settlement, then the jointing material may tear away from the concrete face resulting in



Pierced metal sheathing in use forming construction joint face in massive bridge anchor block (Hy-Rib Ltd)

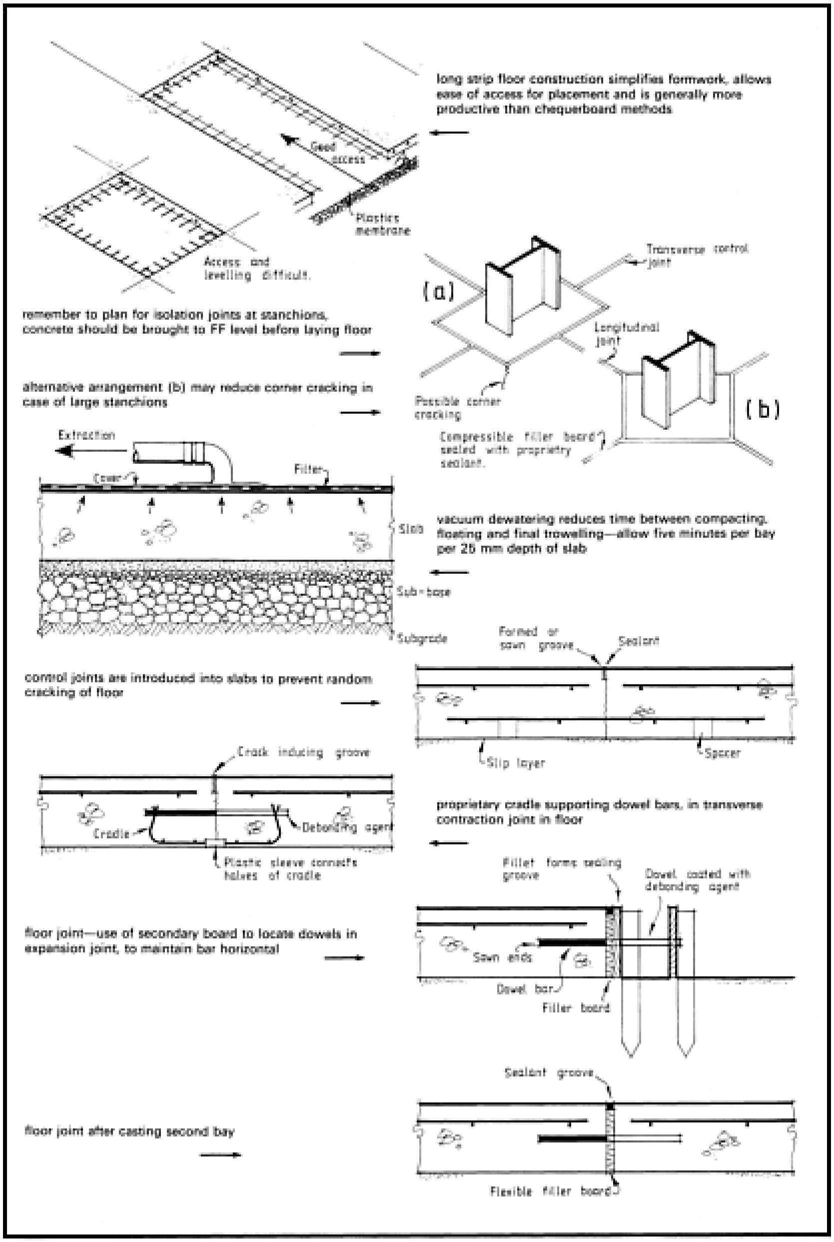


The stopend to this bridge pier was formed using "hi-rib" proprietary lathing. The surface is ready for the succeeding operation (J Howard & Company/The Expanded Metal Company Ltd)

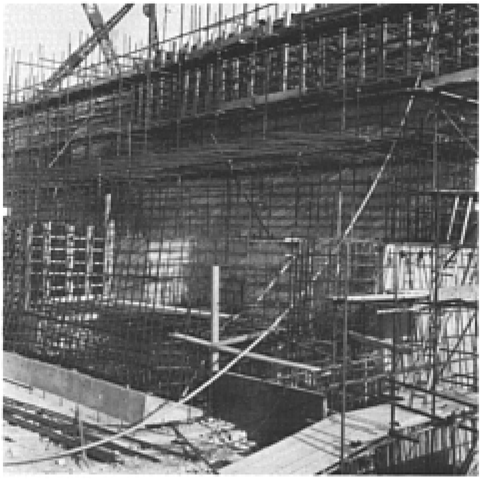
joint failure. This defect can also arise where powdery joint surfaces prevent sound adhesion being achieved.

Wet cast concrete connections

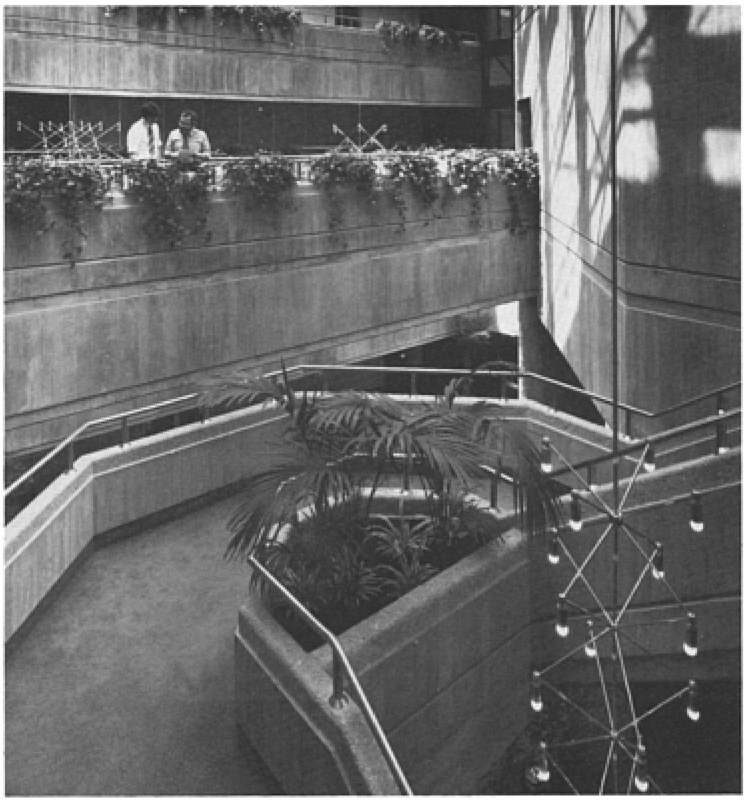
Joints between structural precast elements are often made by casting good quality concrete into the gap between the elements as placed on site. These joints should be of such section that the concrete joints, or "stitches" as they are sometimes known, can be properly placed and compacted. In some instances, such as



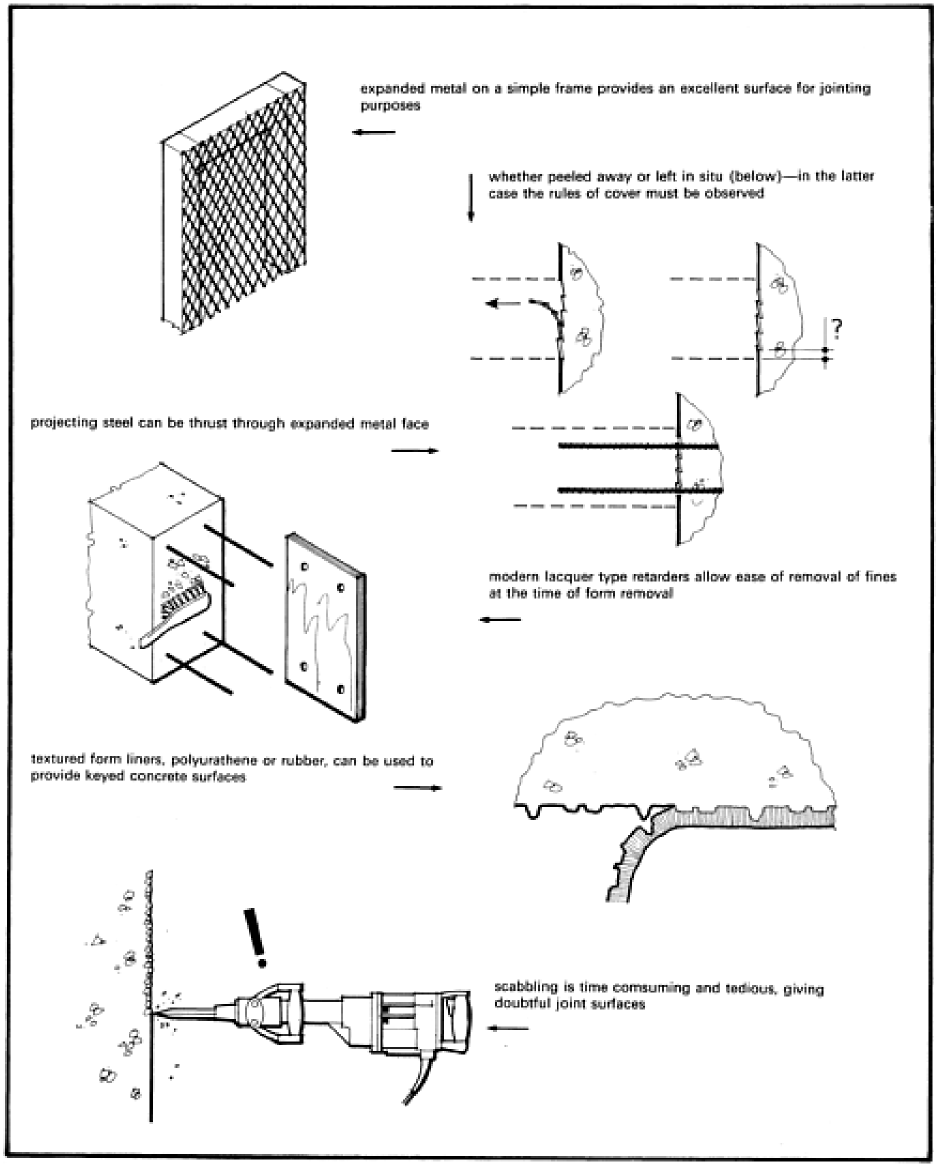
in industrialised building, many stitches depend on the insertion of extra steel to that incorporated in the precast elements. The supervisor must ensure that there is a very careful check on the inclusion of such steel. A well compacted reinforced



Expanet "hi-rib" forming a construction joint—continuity steel can easily be thrust through the sheathing and the surface provides a positive key (J Howard & Company! The Expanded Metal Company Ltd)



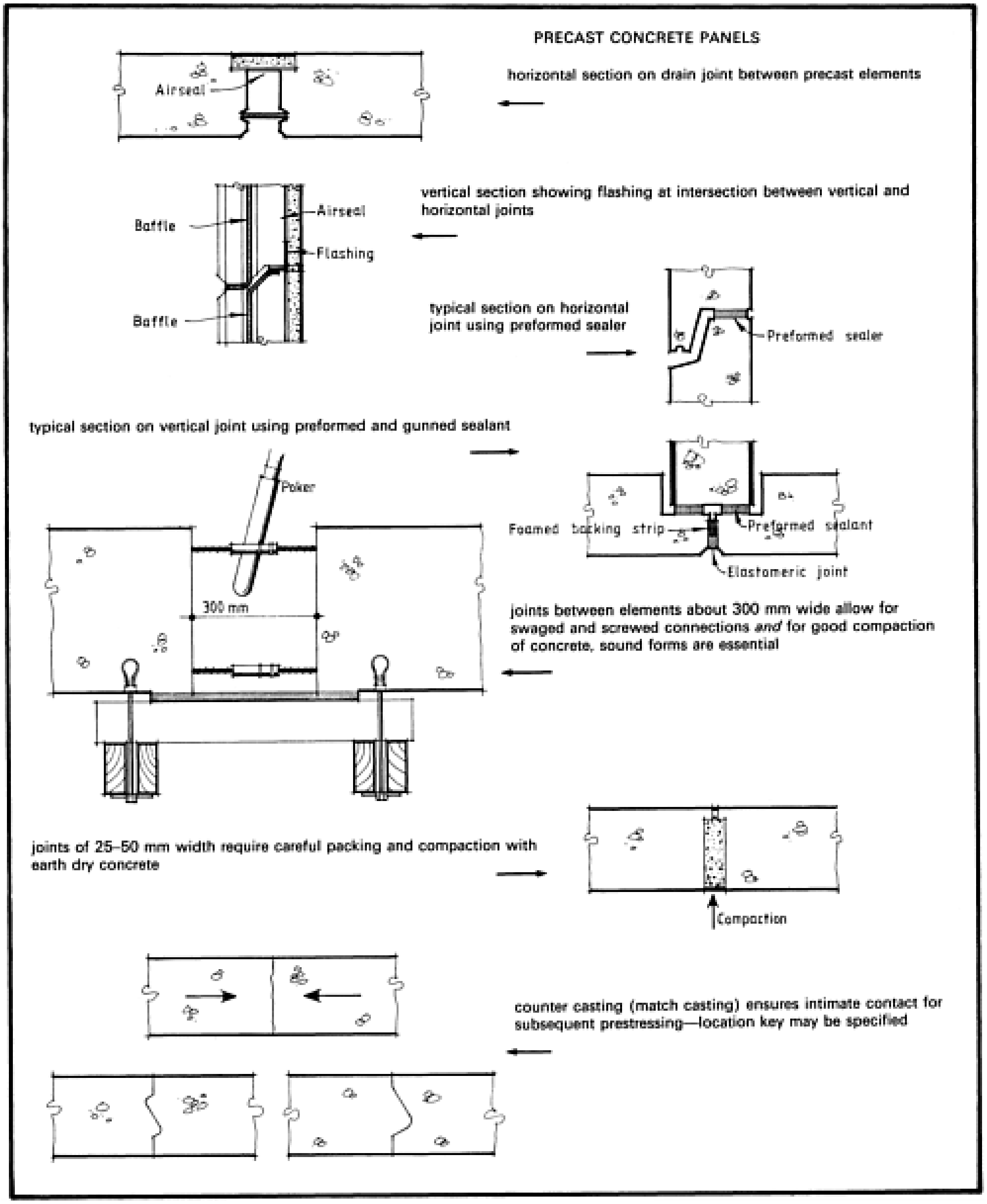
Excellence in concrete—absolute care has been taken over joint detail and features in this modern office complex



concrete joint can be made in 300 mm width, although it must be remembered that the mass of the previously cast concrete in the precast elements deadens the compactive effort applied to the jointing concrete and particular care must be taken over this point to achieve sound construction.

Dry packed concrete connections

Dry packed concrete connections are made with fine aggregate and cement in an earth dry condition. The joint design is usually such that one side of the joint is closed, or nearly closed, by a concrete nib on one of the units, providing a stop against which the dry pack material is systematically plugged, either by hand or by machine. The operator must be carefully supervised to ensure a



uniform amount of compaction being applied to the material.

Contact joints

A technique currently used in jointing precast elements is the contact joint. The contact joint is used in bridge construction where segments are precast off site or on a casting yard and then subsequently prestressed together to form continuous spans. The joint is formed by casting the segments progressively one against the other. Casting takes place directly without intervening formwork. In this way, each face is a model of the face against which it is cast and an exact fit results. On the job site, the elements are placed in contact one against the other, a thin coating of resin adhesive serving to bed the units closely together and prevent water or vapour ingress. This is one of the few joints where joggles or keys provide an advantage in assisting in the location of segments by the first stage prestressing tendons.

Checklist

Are joint positions specified?
Do specified locations suit construction method?
Can joint detail be improved?
Do steel laps facilitate joint formation?
Where expanded metal forms are used, are rules of cover observed?
Do joints require special setting out?
Will elastomer perform properly in joints exhibiting normal accuracy?
Where joints are expressed in visual concrete, is plumb and line built into system?

Points of supervision

Joints must be plumb or level at concrete face.
Joints should generally be normal to the axis of beam or slab.
They should be cleared of laitance.
Early washing and brushing provides an excellent joint face.
“Expanded metal” provides an excellent joint form— observe rules of cover when metal left in.
Rule battens ensure straight line joints.

10.
The concrete construction process

The supervisor with construction experience will have a good overall view of the process of in situ concrete construction, having probably spent some years in one or other of the trades concerned. The technician or specialist from a cement company or service industry commencing their study of construction at a supervisory level, however, will have to achieve an understanding of the sequence of events and the natural order of construction processes. What may initially appear on site to be a haphazard and somewhat disorderly arrangement of construction work does, of course, follow a carefully planned sequence, the programme for which has been prepared by planners, engineers, and method study men, based upon the general scheme envisaged at the pretender stage by planners and estimators as the basis for their bid for the contract.

The following description is somewhat simplified but the overall process is described for the benefit of those concerned with learning the principles of concrete construction. Whilst in this chapter construction is described in terms of an ongoing sequence of events, this may not be the case in the light of the overall programme as the work may stand for various periods of time between the operations described. It is preferable for one team of men to carry out a sequence of operations, particularly where repetitive work is concerned, as once experienced, the workers can become specialist in that task improving their output as they go. The number of skilled tradesmen required on site varies from stage to stage and the supervisor smooths these variations by transferring his men from job to job as the priorities of the overall contract change. The supervisor is concerned with organising the flow of work such that each trade involved can be gainfully employed without the delay or upset caused by shortage of working space, lack of access, shortage of materials, plant, equipment, and so on.

Working conditions

The conditions in which work is to be carried out determine to a large extent the speed of the operations and the standards of workmanship achieved. Bad conditions of access, poorly drained ground and the like, all make work and the supervision of the work, more difficult. Ground conditions can be improved by local sumps, by pumping and on the larger site, by dewatering.

One detail often overlooked is that of the provision of adequate lighting at the workplace. Lighting sets driven by petrol or diesel are available and mobile lighting towers avoid the need for special scaffold towers, where work is in the ground or detached from the main contract. On exposed sites, care must be taken to ensure that forms and falsework are not blown over. Large areas of quite substantial formwork can easily be displaced by high winds and, apart from damage to steel and formwork, consideration must be given to possible damage to personnel working on or near the equipment. Wind force is a detail to be considered in formwork design. Rain is not generally a critical problem in the UK as the form can be covered to exclude the ingress of excessive amounts of water. In bad weather it is necessary to cover concrete skips and to ensure that water is drained from large forms prior to commencement of concrete placement. Forms should, wherever possible, be protected from rain and frost, particularly where mould oils and retarders could be washed away or spoiled.

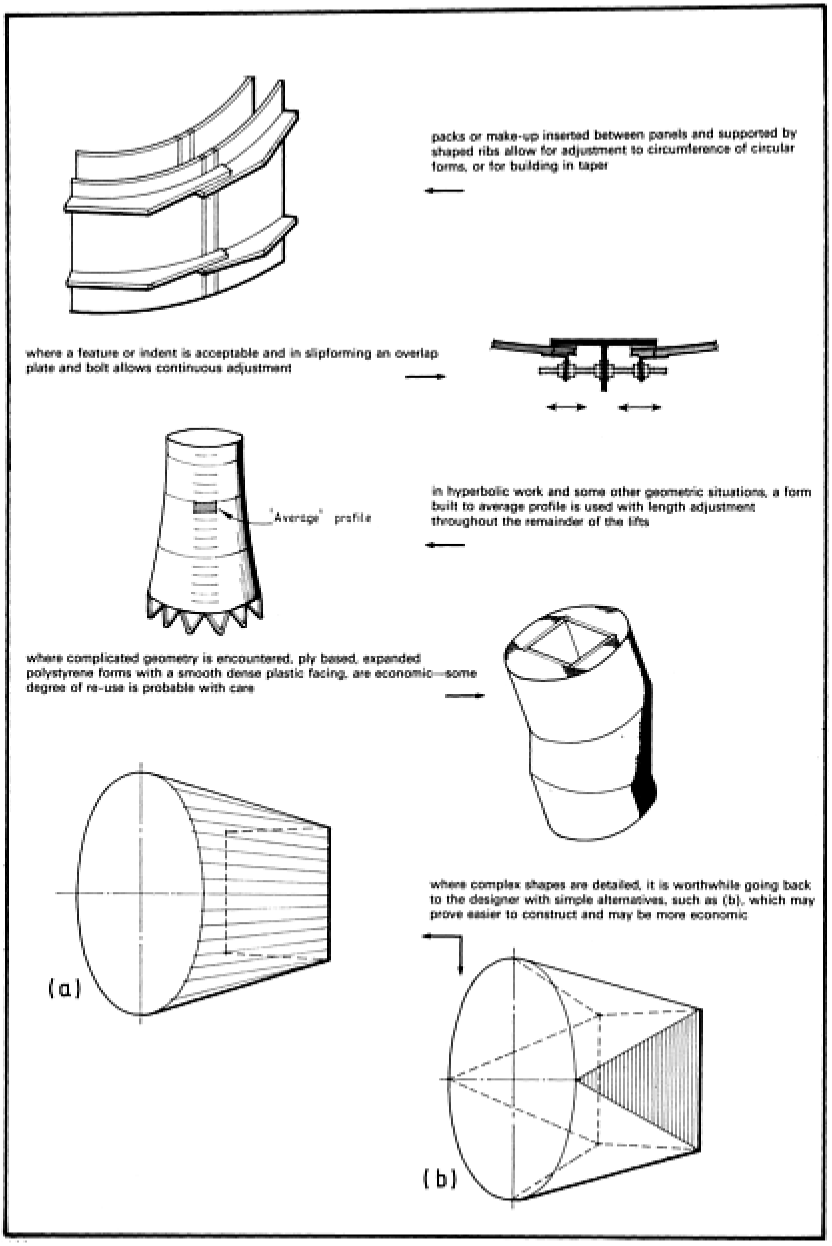
The operators, of course, must also be supplied with suitable clothing to ensure that they can continue work in all but the most inclement weather conditions. Trends in building construction and some civil engineering works are towards the total protection of the workplace using windbreaks and enclosures of reinforced plastic on scaffolding supports. The proprietary suppliers of formwork all have lightweight portable shelters which can be erected in the manner of travellers and then moved to provide shelter as the work proceeds.

On a point of safety, the supervisor should always bear in mind the need for emergency access in the case of accident and should have a clear picture in his mind as to how a stretcher case can be dealt with in the instance of personal injury. Good communications are also essential and the more so in bad conditions, conditions of detached working and so on. Telephone and radio form important links, especially during difficult operations or in times of emergency.

Preliminaries

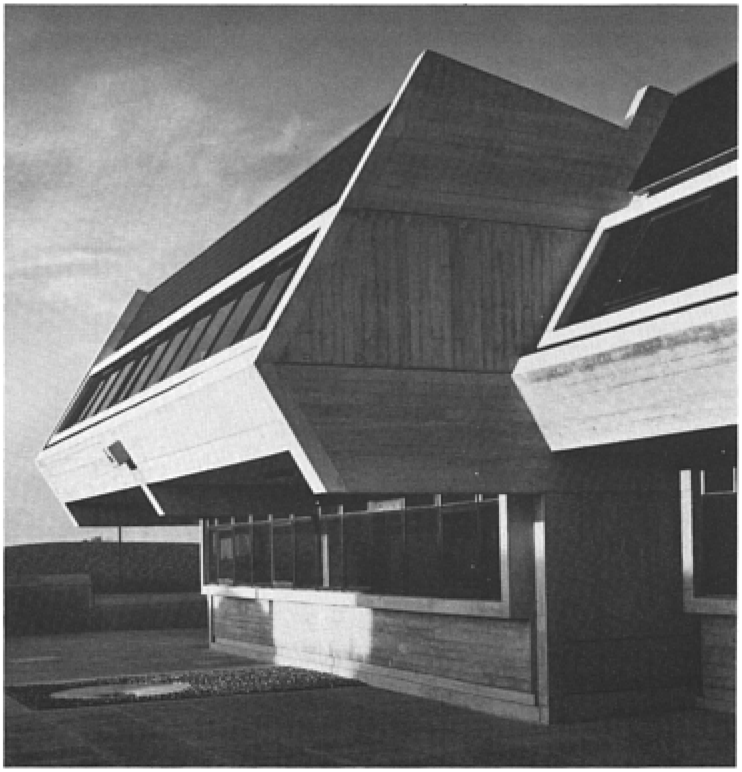
The building lines will be established within carefully indicated site boundaries and a datum established relating in the first instance to some known level or bench mark. Any necessary demolition work is carried out and the site cleared and fenced. Top soil is cleared away and any which may be required for reinstatement of the site upon completion of the work should be stored.

Site investigation carried out when the architect and engineer were designing the structure will be used to decide upon the design of foundations, depth of piling, location of ground beams and pile caps. Sections on the structural drawings indicate the final shape of the con



struction and give accurate levels for blinding, finished floors, height of walls and similar details. The contract drawings indicate the outline in plan and relate this plan to the building lines.

Skilful detail combined with careful workmanship was essential in the construction of this striking building

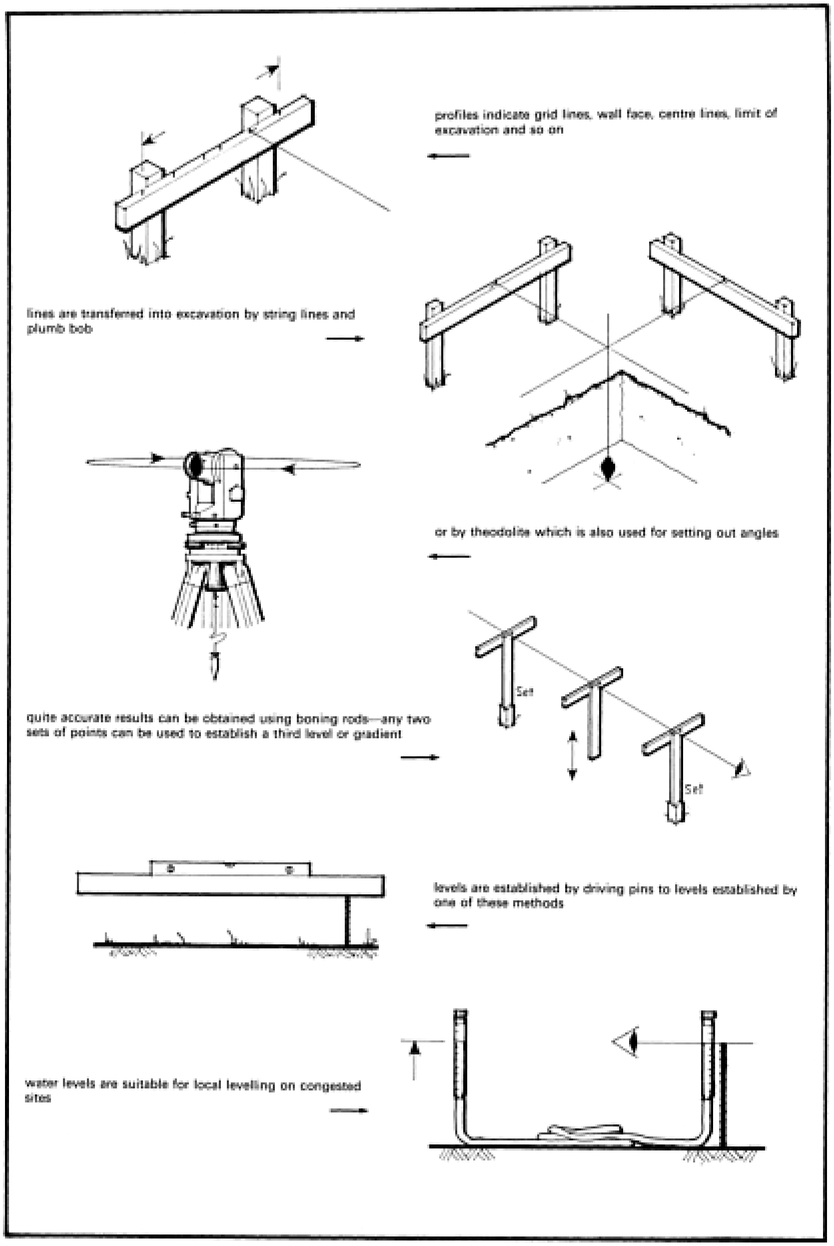


Setting out

To commence setting out, profiles are set down, based on the actual building line. These indicate the position and overall shape of the excavation, as well as grid lines and the line of wall faces and returns. Machines are used to excavate to the correct depth, often according to level pegs set up by the supervisor or an engineer responsible. The plan positions of walls, toes and such like, can be related to the profiles by string line, taut wire or by lines set out onto the blinding by the engineer using a theodolite. Levels are transferred into the excavation by dumpy level. Level pegs or spots of mortar will be placed in the ground to which the trades supervisors will refer their work. Simple water levels allow the work to be carried out by the ganger or charge hand. It should be mentioned that quite simple equipment, such as water levelling equipment, can yield satisfactory results at this stage of the work.

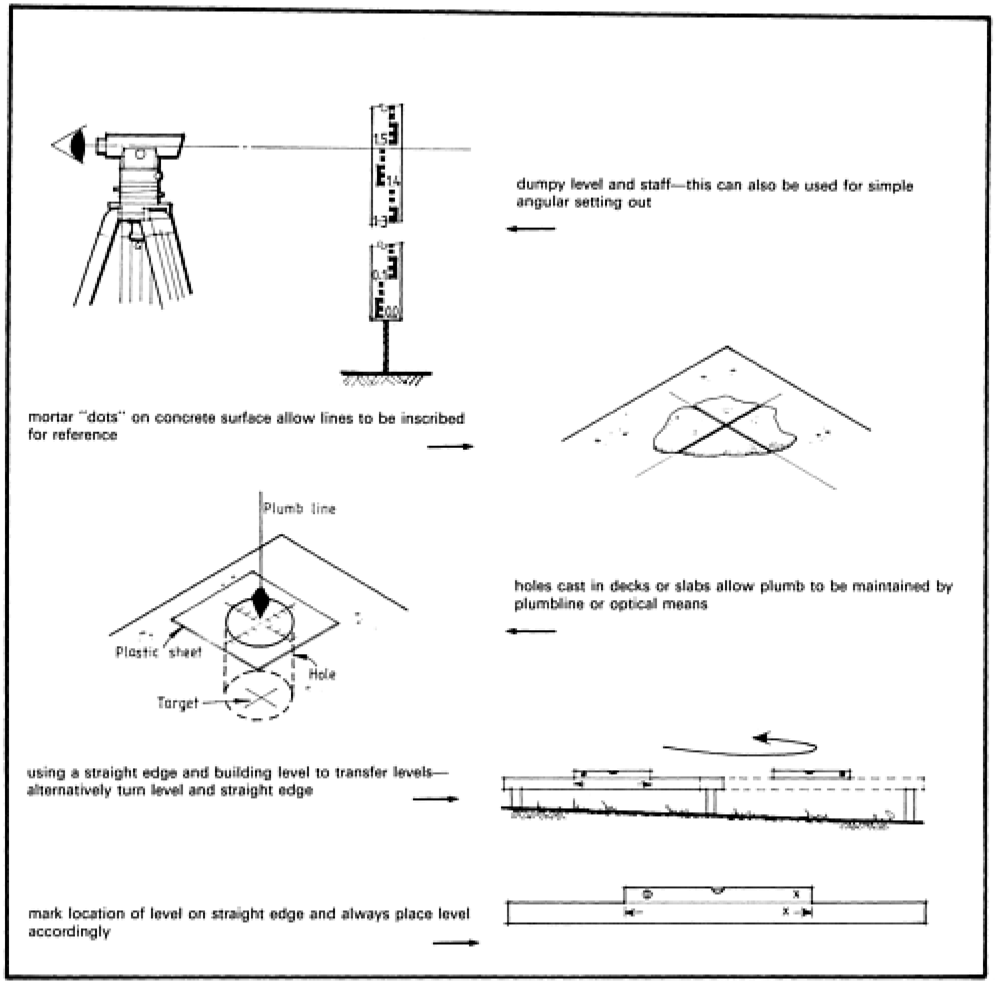
All datums given should be clearly marked and dated, a record kept of the information in the dimension book or site diary. It is advisable that site datum marks should be supplemented by marks established on nearby structures for reference, should site markers be obscured or inadvertently displaced.

Checks on the verticality of the structure may be facilitated at the stage of floor casting if small openings are cast at the corners of the main building slab, plastic pipes make excellent formers, so that a plumb bob can be dropped through the floor on a line or wire to a target at ground level or basement level. As an alternative to plumb bobs, which are affected by wind, an optical instrument, the autoplumb, can be used, sighting through translucent plastic marked with some relevant form of grillage. When positioned accurately, the lines thus established can be transferred to the adjacent slab and provide a permanent reference point.



Excavation

The excavation must be carefully carried out as every piece of ground excavated in excess of requirements will result in the need for expensive backfilling or reinstatement work. Such is the skill of the majority of machine operators and the power of the machines, coupled with soundly designed control systems, that little manual work is required to clean up the excavation in preparation for the next stage of the work. This final cleaning up is done with reference to pegs or indicators, again provided by the



setter out, who may be an engineer attached full-time to the site or section of the site. Alternatively, on a smaller site, the supervisor may deal with both setting out and control of the construction operations, calling in a visiting engineer for more complicated instrument work if required.

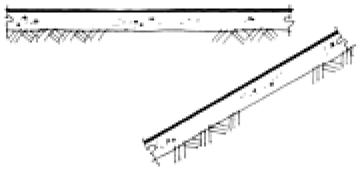
It is important at this stage of the work to avoid spoiling the ground by churning with tracked vehicles or allowing water to drain into excavations, thus spoiling the loadbearing capacity. Such problems can be avoided by delaying the final cleaning, and by provision of sumps and pumps or, in the case of low water tables and deep excavations, by major dewatering operations, until just prior to laying the blinding. The bottom should be checked for soundness and inspected, if necessary, by local authority engineers.

A great deal of groundwork requires supporting work, piles, poling, trench strutting and so on. This is an extremely hazardous area of construction and many accidents are reported where the supporting works have been badly executed. Formworkers, steelfixers and concreters often have to work in or around such strutting, and indeed much of the concrete work in the ground must be carried out sequentially with the removal and insertion of standing shoring to excavations. An example exists where retaining walls are being cast against sheet piling, which is shored across an excavation. In this instance the shoring is often dismantled as the walling proceeds, being reinstated against the walling once the concrete has hardened sufficiently. The supervisor should take time to study the shoring operations and to discuss the sequence of construction with those responsible for shoring operations. A watchful eye should be maintained to avoid the removal, either accidentally or in the course of construction, of struts, shores, props and such like, and the sheathing to excavations monitored for signs of movement.

Blinding

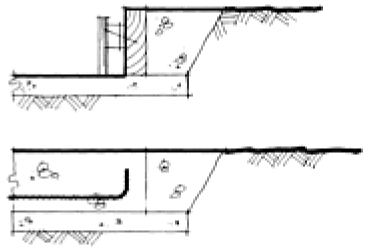
The layer of concrete which is indicated in structural drawings between the excavation and the structural reinforced or mass concrete is called "blinding". Blinding concrete is spread from the skip and left smooth and level by cross screeding, wooden floating or spading. Blinding serves several purposes:

1. It protects the ground, which has been cleared ready for foundations and footings, from the effects of rain, frost and other weather conditions which would upset the loadbearing capacity.
2. It provides a barrier between the ground and the structural concrete preventing contamination of that concrete.
3. It provides a clean working surface and allows for the correct location of the steel reinforcement in the foundation concrete, ground beams and so on.
4. It can be used in the location of the forms to the structural concrete by the embedment of concrete blocks. Alternatively the forms can simply be wedged against the edge of the blinding, in which case accurate location of the edges of the blinding concrete is necessary.

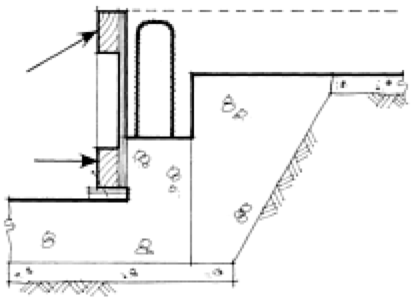


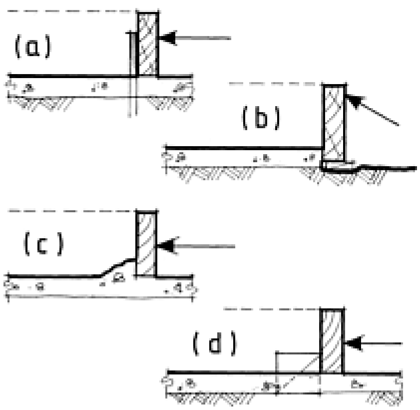
blinding concrete is important in ground protection and avoiding the contamination of steel

back casting, the introduction of lean concrete fill behind an outward-facing form, provides a clean working space for foundation construction



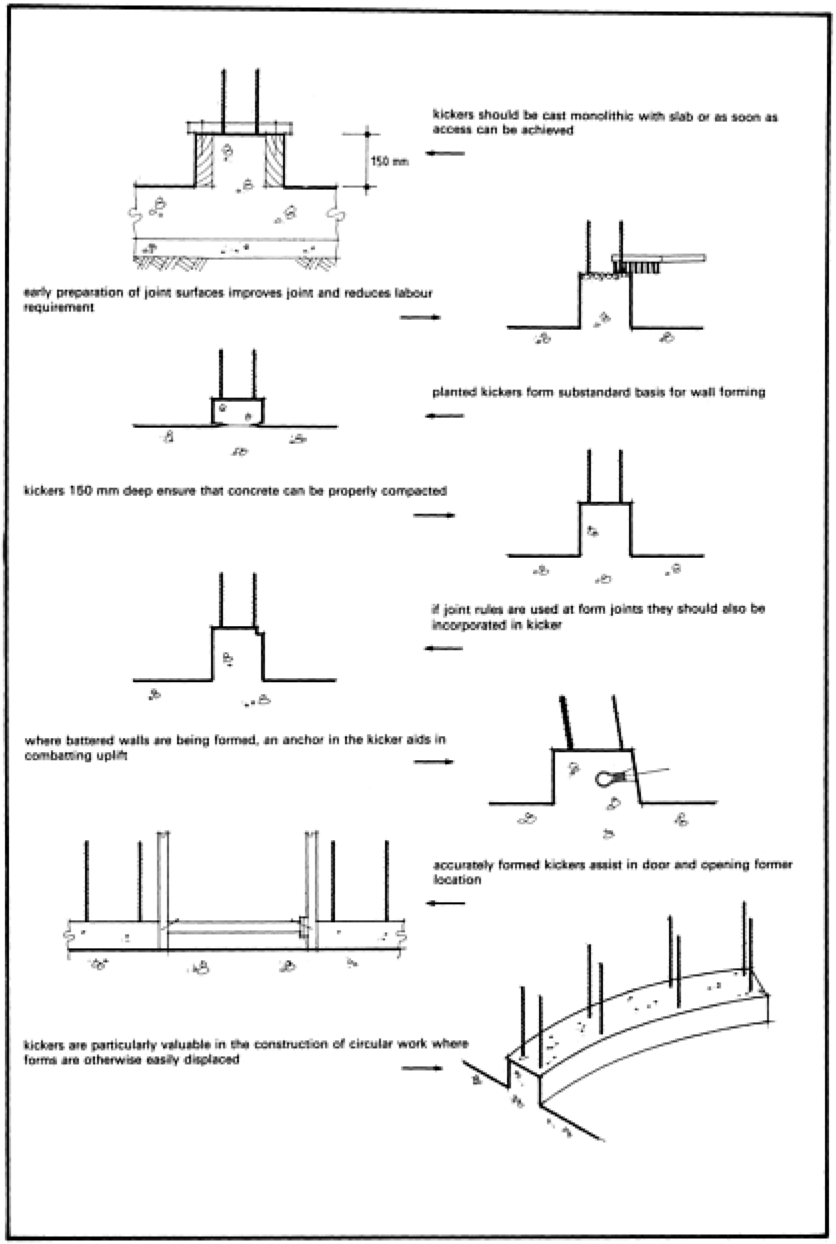
the construction of a slab and kicker within the back casting lean concrete eases duct construction in bearing slabs

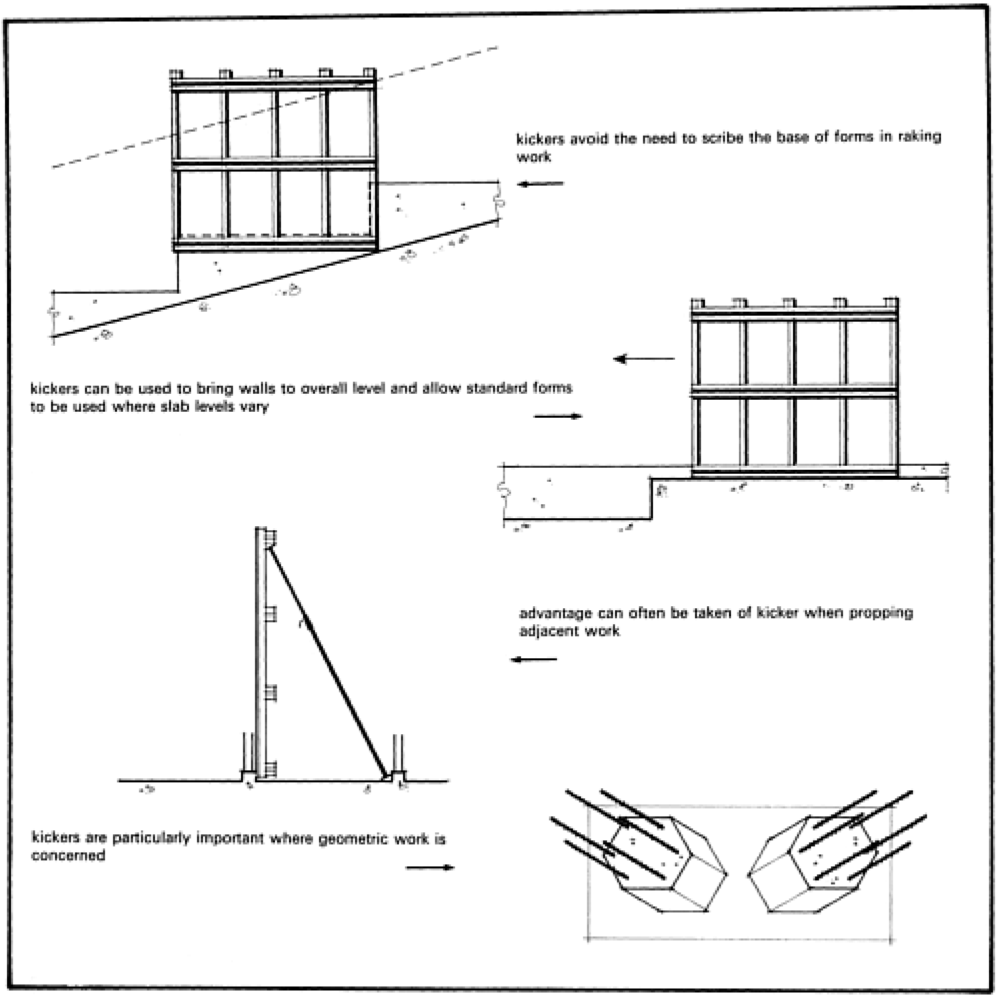




setting forms into blinding

(a) against pins determining line
(b) against edge of blinding
(c) against shelves cast in blinding
(d) against blocks inserted in blinding


150 mm
kickers should be cast monolithic with slab or as soon as access can be achieved
early preparation of joint surfaces improves joint and reduces labour requirement
planted kickers form substandard basis for wall forming
kickers 150 mm deep ensure that concrete can be properly compacted
if joint rules are used at form joints they should also be incorporated in kicker
where battered walls are being formed, an anchor in the kicker aids in combatting uplift
accurately formed kickers assist in door and opening former location
kickers are particularly valuable in the construction of circular work where forms are otherwise easily displaced



Ground beams and pile caps

This type of construction is rarely critical as far as appearance is concerned. Accuracy, however, is important to ensure that the required cover and protection to steel can be achieved. Ground beams and pile caps are often formed by back casting, where lean concrete is formed to the profile shape of the base or beam using rough forms simply supported by cross bracing. On removal of these forms, the steel reinforcement can be placed on the blinding, positioned relative to the pile or column position. Spacers can be inserted and the reinforcing cage accurately located into a clean prepared concrete form. Alternatively, sets of forms prefabricated into beam sides or pile cap struts can be landed into the blinding concrete and propped from the excavation via plates or sleepers, bags filled with lean concrete or, in extreme conditions, against poling driven around the excavation. Where deep pile caps are to be formed it is likely that the complete excavation will be shored using driven poling boards or the rather more modern poling systems activated by hydraulic rams.

In good ground conditions where the profile of beams and pile caps can be accurately cut to shape, it may be sufficient to line the openings with heavy gauge polythene to ensure cleanliness and avoid contamination of the steel with clay and such like. In some circumstances the forms to ground beams and pile caps are treated as “lost” items, simply being left in place after the concrete has been placed. Except where ground beams or pile caps of exceptional size are being formed, the formwork is generally strutted, avoiding the need for through ties. In larger scale operations the forms will be of conventional tied construction consisting of sheathing, a carcassing layer and then waling members collecting the forces from the sheathing and framing and transferring them into the tie system.

Setting up forms on blinding

The slab outline having been transferred from the profiles, edge forms can now be set up onto or against the blinding. These forms are often constructed prior to use in some facility set up for the formwork carpenters. The forms must be appropriate to the required finish and must incorporate any details for subsequent fixings or fastenings, projections to support sheathing and similar features. Where the surface appearance is not critical, the materials can be reclaimed forms from previous concrete, steel plates or proprietary forms. Normal road forms used as in the construction of road slabs or stacked on longer pins, suitably braced, can provide economic edge forms. Timber or ply on open spaced backing members provide the best basis on which features and formers can be mounted where complicated edges are to be formed.

Pegs can be driven through the blinding to support edge forms or blocks of concrete can be located in the blinding such that with the addition of plates and wedges their sides can be located and strutted into their correct position. The formers should be levelled in and lean concrete used where packing is required on irregular blinding. The location of the construction joints within the slabs must be clearly established, whether chequerboard casting or long strip techniques are to be used.

Slab casting operations

Joints

Whilst construction joints are discussed elsewhere in this book, it is appropriate at this stage to consider joint location, profile and inclusions.

In slabs the traditional techniques have included joggle joints, weather bar and similar means aimed at preventing water penetration and ensuring that adjacent bays of concrete combine to act monolithically. Recent trends have brought about simpler joints, the elimination of joggles—the adoption of surface fixed weather bars and wash and brush techniques applied to preparation of fresh concrete faces. Further advances have included the adoption of long strip casting, the use of retarders in joint preparation and the use of expanded metal in stopend construction. The local specification will govern the methods adopted but the supervisor should make himself aware of the improved outputs and probable improved results achieved from the adoption of one or several of these techniques.

Whatever the joint profile, it is essential that it should be formed parallel to the construction grid, that the concrete should be well compacted and, where steel is indicated for continuity or to promote composite action, that it is correctly placed, spaced parallel to the surface of the concrete and square to the joint. Should crack inducers be specified, these must be correctly formed— dowel bars, where included, must be suitably supported and, where specified, debonded.

Regarding bay sizes, where slabs are being cast according to a specification which stipulates discrete bays, the overall area of each bay must be considered as well as the proportion of length to breadth. The latter is important in the control of cracking.

Kicker details

Kickers may take a variety of forms but those which are about 150 mm deep, or the actual width of the wall, are simplest, most reliable and most successful. The 150 mm depth ensures that it is possible to properly compact the concrete using an internal vibrator. The top ariss of the kicker should receive the same treatment by way of joint rule fillet or indent former as the rest of the work—this is particularly important where visual aspects are concerned.

The accuracy of kicker location is critical both structurally and visually and a careful check on positioning should be made—preferably using a theodolite set over the setting out point on the profile board or by reference to other known points of the structure. Where battered or sloping walls are being cast, buried anchors or ties can be inserted into the kicker to assist in the location and tieing of the form and to restrain the form against uplift resulting from concrete pressure. If uplift is considerable then the kicker depth should be increased to ensure sufficient embedment of the tie. The same attention should be applied to the preparation of kicker surfaces as to any other day joint or construction joint. Kickers may seem to be a rather elaborate way of providing some connection between slab and wall formwork, but it must be borne in mind that the kicker provides:

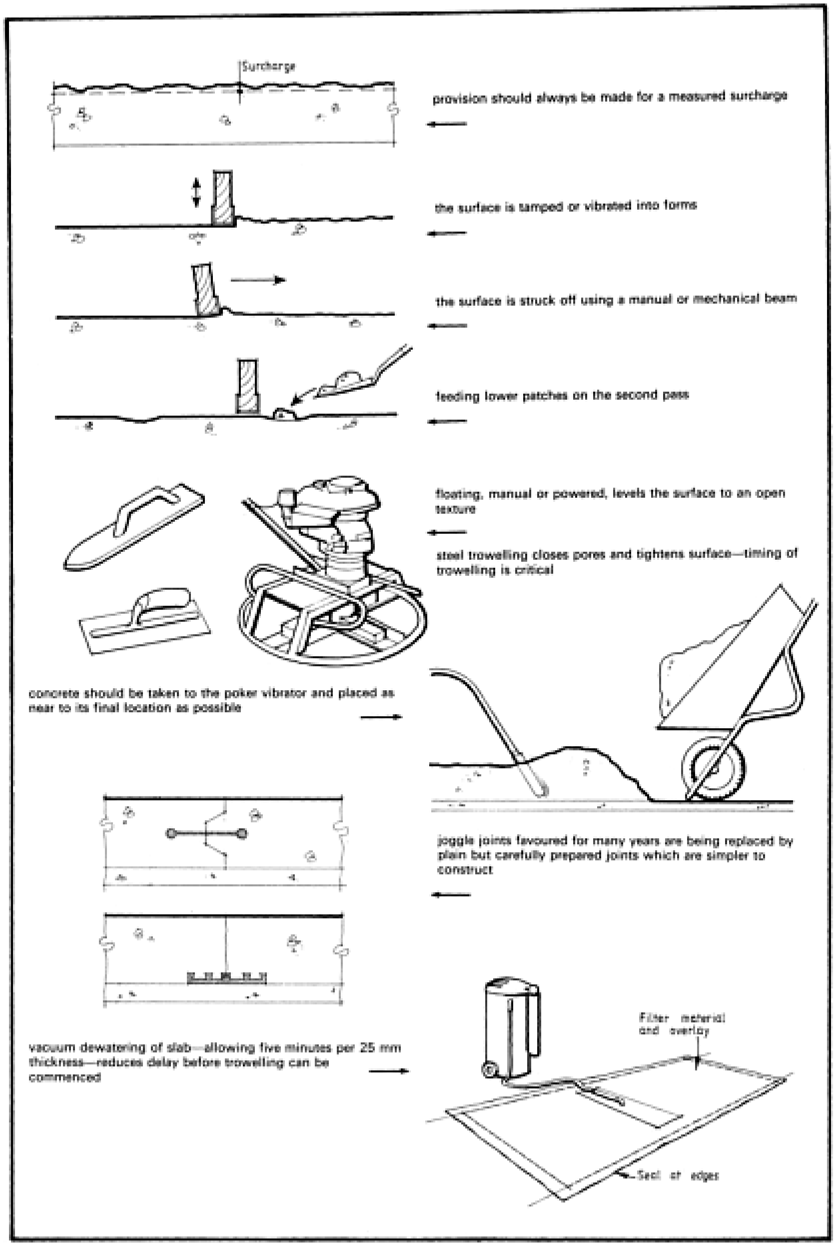
an opportunity of checking the accuracy of setting out; a positive land against which the formwork can be braced to locate the form and provide a grout-tight seal between the two;

a standard level to allow the use of standard wall forms overcoming the problems of form height resulting from differing levels or sloping slabs.

Access and placement into slab forms

Means of access are provided for workmen as required, particular care being taken to ensure that the steel located by stools is not displaced by the weight of men or equipment employed in placing and compacting the concrete.

Concrete placement is carried out after a final check with the drawings and a pre-concreting check to avoid contamination by rubbish, shavings and such like. The placing may be carried out by simply chuting the concrete from the edges of the excavation, by conveyor, by crane and skip or by pumping. The casting technique for a slab up to about 450 mm thick will be to place concrete into the forms at one corner or one end of a strip and to continue the placement of each batch or the flow from a chute into, as near as possible, the point where it will remain. Movement of concrete by vibrators is a wasteful and time consuming process and should be avoided. The poker vibrator is a tool for use to promote the flow of concrete locally between and around steel as well as driving away



excessive and unwanted entrapped air and water. A face of workable concrete must be maintained and placement carried out in a manner to bring this face along or across the bay or strip. Delays or upset in production cause stiffening of this face which would result in a dry joint or defect in the structural concrete. Retarders are sometimes incorporated into the mix to prevent this premature stiffening. The concrete is placed in such a way as to maintain a surcharge, which can be achieved using battens on the side forms. This surcharge is then tamped into place aiding the compaction and avoiding hollows in the surface. The screed, whether manually or mechanically operated, is fed with a concrete maintaining the surcharge and thus ensuring that a level surface is maintained for subsequent floating or trowelling.

Many concrete surfaces can be left as screeded or simply screeded and lightly brushed to give a non-slip texture. Where a finished surface is required, the process develops in the following fashion:

> After screeding, feeding the screed, striking off and rescreeding, the concrete surface is left until excess water has evaporated. At this stage the concrete must be level as the later operations are finishing rather than levelling operations. Small local adjustment can be made by skip float or by sleeve float. The floating operation may be repeated to improve the surface to some extent. It is essential that the surface is not overworked, as this will result in production of excessive laitance at the surface and a dusting surface can result.
>
> Once the surface can withstand the full weight of the body applied by the fingertips without indentation, the trowelling operation can proceed.

Surface preparation

Where the concrete surface is to be used as a walking or working surface, continued curing is essential to avoid later dusting and on no account must the use of cement driers be permitted. The practice of sprinkling cement onto the surface to allow earlier trowelling is wasteful and destructive. If the screeding process is carried out properly, the excess paste or workability fines will be worked off the top of the concrete progressively, leaving a good quality concrete surface which can be lightly textured or trowelled to a hard mirror-like finish.

It remains at this stage to complete the kicker ready for the wall casting operation, which is to follow, and *Chapter 9: Joints* deals with this topic in some detail. For the present it is assumed that the method of washing and brushing to expose aggregate has been selected. The upper surface of the kicker can be washed using a high pressure hose, an air and water hose or even water sprinkled from a watering can and brushed off with a stiff brush. It will be necessary to protect the finished concrete surface, although the washing and brushing operation is carried out at a stage when water flowing over the surface of the slab will cause little damage. If the slab finish is critical, the kicker must be prepared using a wire brush at a later stage or by use of a surface retarder applied on completion of kicker casting. The latter process may be found acceptable where there is not too great a quantity of projecting reinforcement, although of course if it is adopted, care must be taken to avoid contact between steel and retarder. Preparation of day joints and construction joints should then follow. Any treatment which is applied at an early age is desirable as the task in hand is made that much easier by the concrete being less hard or in its green condition. Newly treated surfaces should be protected using hessian or plastic sheeting to avoid early drying out or frost attack.

Finishing

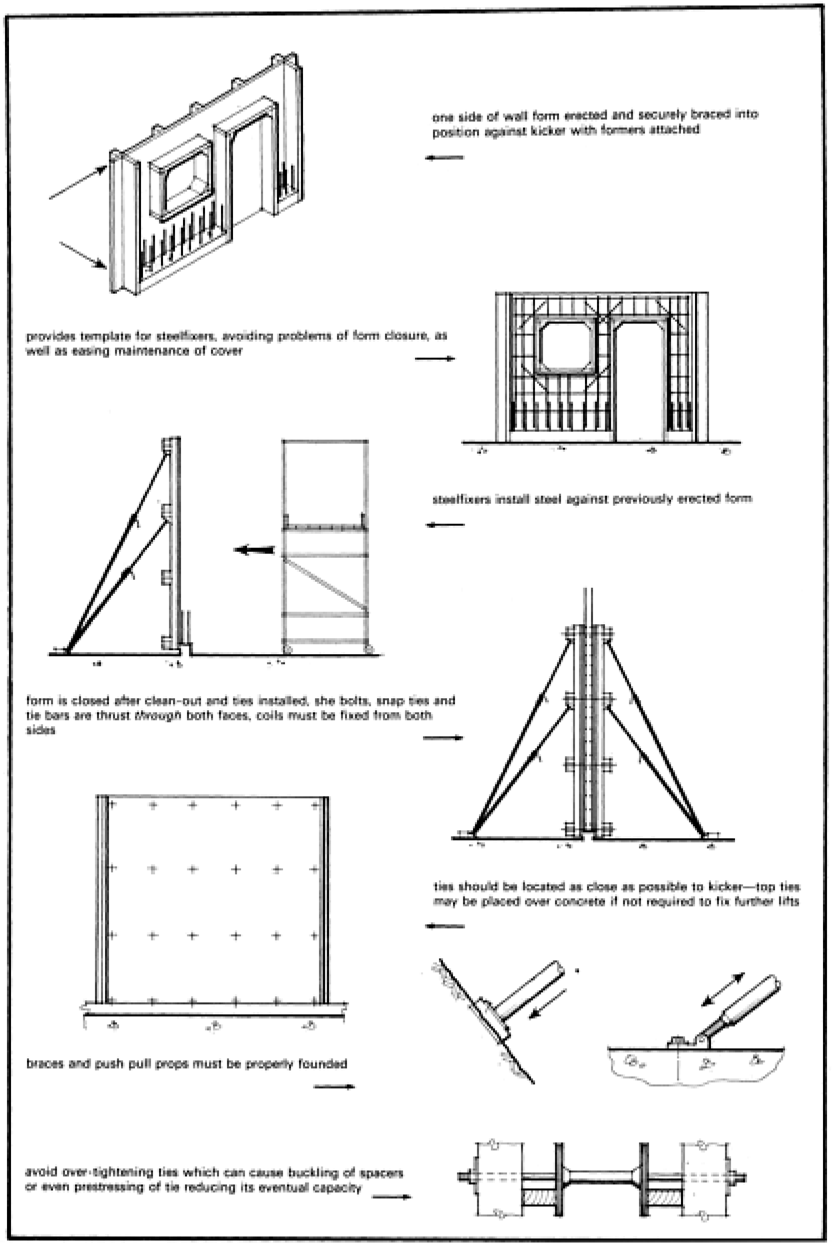
As the concrete is laid and compacted it is levelled by tamping or the use of a vibrating screed beam running on the form edge and stooled sections. This is fed with a surcharge of concrete to ensure that tamping and compaction combine to produce the dense concrete essential to sound construction. Where a smooth surface is required the concrete will be floated to remove local undulations and left to allow bleeding to take place and the glaze to disappear from the surface. At some period approaching an hour, but depending on the concrete mix, weather conditions and conditions of relative humidity, the trowelling operation can be commenced to close the surface pores and polish the surface. With the slab casting and compaction completed, and before workability is lost at the kicker location, the kicker concrete is placed and compacted. It is important that the operatives realise that kickers are just as important structurally as the wall or base and that they compact the concrete accordingly.

Vacuum dewatering allows earlier trowelling of floor surfaces and helps considerably in reducing the hours worked by flooring teams. After vacuum treatment the same attention must be given to the curing process. The process of vacuum dewatering using a proprietary system with a perforated filter and plastic sheet connected to a vacuum pump and water separator allows the removal of excess water at the rate of approximately five minutes pumping time for each 25 mm slab thickness. All concrete bleeds to some degree and whilst it is impossible to vacuum dewater deep lifts, it is quite feasible to remove water from the upper layers using this method. The maximum slab depth which can be satisfactorily dewatered is about 200 mm.

Immediately following slab casting operations, stopend forms and former boxes should be removed and the construction joints formed by the stopends prepared by washing and brushing or in the manner agreed with the engineers. Forms to other vertical surfaces can be removed and cleaned and oiled ready for re-use, the concrete being sprayed with a curing membrane or covered to prevent drying out.

Curing

Curing must be commenced and carried out in the manner and for the period specified as soon as finishing operations allow. This can be achieved by applying a sprayed membrane and covering down with plastic



sheeting and hessian. In some situations, ponding (settling little dams of clay around the edges of the slab and flooding the whole area with water) may be a sensible way to cure concrete.

WallingÐsequence of operations

The sequence of operations may vary according to a number of factors such as local custom, nature of the work, whether simple or complicated in profile and the degree of accuracy required. The degree of complication of the reinforcement will also have a bearing on whether steel fixers or formworkers carry out their part of the work first. The advantage of first erecting form work and then installing steel reinforcement is that the form and formers for through holes, door openings and such like, act as a template for steel location. This offsets the slightly more difficult task of steel fixing from one side only.

Access in wall construction

Scaffold arrangements are important. Scaffold platforms cannot easily be used in the form erection process but steel fixers require access and it is essential that adequate scaffold access is provided for concrete placing and compaction operations, otherwise these will be skimped as men find work difficult. Most proprietary systems incorporate some form of access scaffold bracket which can be bolted into place on the form and remain as an integral part of the formwork arrangements. Mobile scaffold towers are also useful and if they are properly braced can provide useful working space. Any scaffold arrangement must have proper guard rails and toe boards, access ladders must be securely fixed in place, projecting above the working level to provide hand holds during use. Given correct access, men can use both hands to control skips, delivery pipes and so on, and can concentrate on the proper use of vibratory equipment. Care must be taken to ensure that scaffold arrangements are complete—walkway ends must be enclosed complete with toe boards and guard rails, just as is the walkway proper. Care must be taken to ensure that all lacing and bracing is maintained. 85% of formwork and falsework accidents have resulted from the non-provision or removal and non-replacement of essential ties and bracings from platforms and supports. On no account should braces or struts be taken from or to access scaffolding. All braces should be properly founded on hardcore, sleepers, concrete slabs or similar footings. Ties should only be taken to adequate kentledge or to a suitable component cast into previously cast and *matured* concrete.

Wall construction

Once the kickers have matured, and preferably within a day or so of kicker casting, the walling operation can commence. Regardless of the considerable care which will have already been taken, it is advisable to re-check kicker location as in structural work some packing can be introduced in the event of any inaccuracy. When producing visual concrete, however, this would produce an undesirable nib or shelf and must be avoided.

Erecting the first form

Where the erection of formwork is to precede steel fixing, a suitably oiled or treated form can be put into place, either crane handled as one piece, or manually handled as individual panels, as in the instance of proprietary formwork. The panel or forms must be securely tied or propped against the kicker using either the embedded ties, wedges against dowel pins, or props against plates on the excavation. The form can then be adjusted to the vertical using push-pull props against kentledge or timber nailed to pegs driven into the ground. Where the walling is being carried out on internal situations within the structure, support can be achieved by propping or tieing from previously cast concrete, from kickers ready for subsequent work or from drilled or shot-fired fixings into the concrete slab.

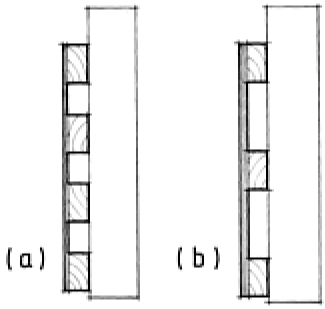
Door and window formers, boxings for ducts and any formers for rebates or chases, can be fixed to the face once the form has been adjusted to its correct height by wedging below the soldier members. Where forms are being erected around the perimeter of a slab on the outside of the structure or adjacent, say, to the lift opening, it will be advisable to provide some form of ledge or plate bolted to the surface of the concrete to form a bearing onto which the form can be placed at first erection and which can later be used for the wedging or levelling process. Once door frames and such like are secured and the form faces oiled, the steel fixers can be set to work installing the reinforcement. In this way the correct spacing and cover are easily maintained by reference to the features fixed to the form. The reinforcement will be spaced from the formwork using approved spacers, generally ring-type plastic spacers of correct size to suit the specified cover. Chair members made from reinforcing bars tied to both leaves of the reinforcement maintain the correct separation of the steel and further plastic spacers ensure maintenance of cover once the next operation, closing the form, has been carried out.

A check is made to ensure that the kicker is free of wire clippings, wood shavings and so on and all is ready for the next operation. If coil ties are being used, these must be attached to the bolts which will be threaded through the wallings, bearers, and sheathing of the first panel.

Locating the second form

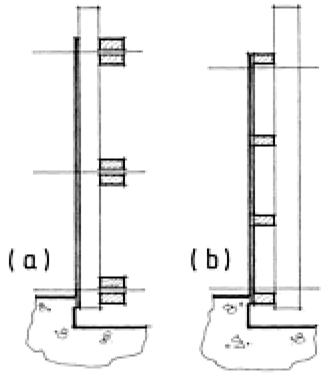
The second form, suitably oiled, can now be positioned against the kicker and rotated into the vertical position ensuring that cleats and locations for the through formers are engaged into their correct positions. The second bolt can be engaged into the coils. It may be necessary to use a hooked wire or bar to adjust the position of the coil, but this is a skill which carpenters soon acquire. Snap ties, through bolts or she bolts, are inserted directly through both forms on completion of the erection. All these activities are simplified if arrangements are made using projecting cleats or bolting brackets to secure the members to the back of the soldiers if this particular form configuration is being used.

Most systems incorporate some positive spacing device and the tie arrangement can be tightened to the stage waling where the form just nicely grips the spacers. Overtightening of ties must be avoided as it is possible to pretension bolts to such a stage that further application of force, either by form movement or concrete pressure, can

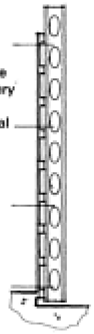


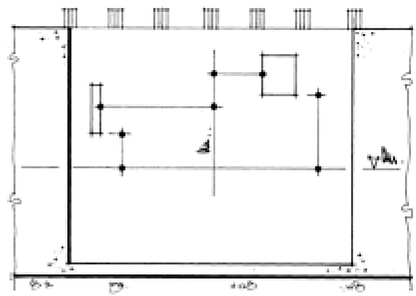
left vertical forms may comprise (a) thin ply on closely spaced backing members or (b) open backing members and more substantial ply

below form panels may be constructed using (a) ply face fixed to vertical studding members with twin horizontal walings or (b) horizontal studding with twin soldier members

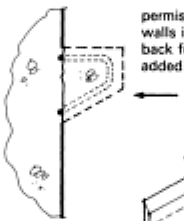


as lift heights increase or where larger tie centres are appropriate, then proprietary soldiers are often used in conjunction with horizontal studding members

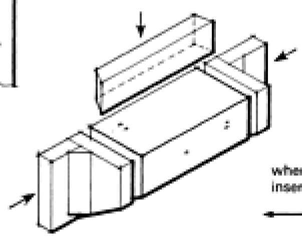




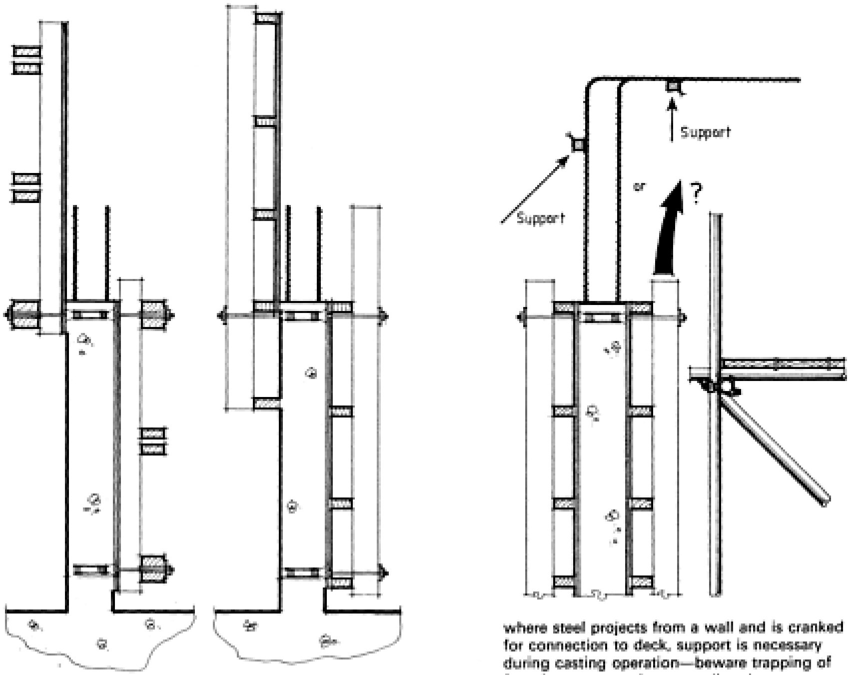
above always set out inclusions, fixings, fastenings, welding plates and so on, to datum lines which can be set out with reference to established levels and lines on previously cast concrete



permission may be given to cast walls incorporating bars bent back for inclusion in corbel added later



where corbels or beam starters project from the face, stripping fillets must be inserted in form to permit striking



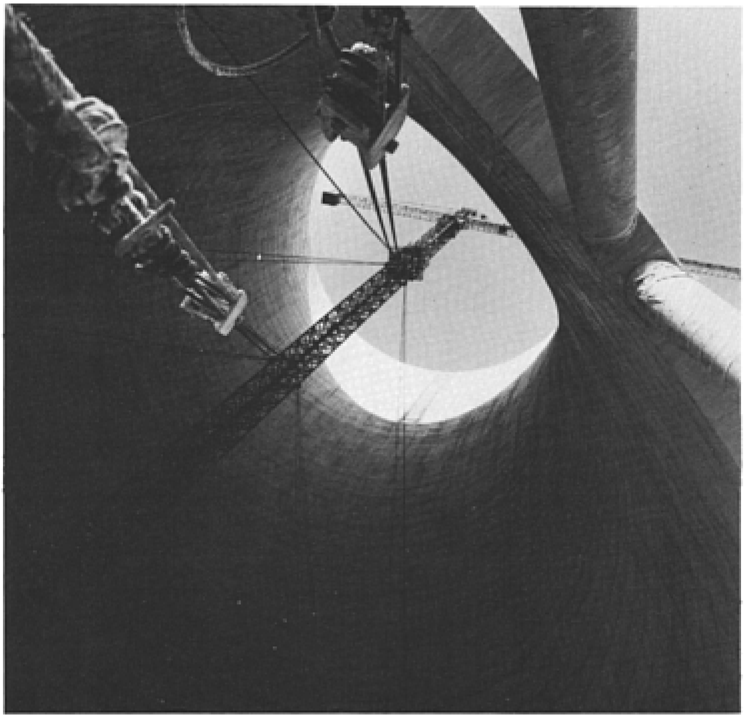
where walls are cast lift over lift, coil ties allow one form to be raised to act as a template for the steel fixing process

it may be necessary where twin soldiers are used as cantilevers to improve stability of form to either use loose twin soldier members or invert the form in the first operation

where steel projects from a wall and is cranked for connection to deck, support is necessary during casting operation—beware trapping of form between newly cast wall and access scaffold

cause failure. Once a tie fails the load is redistributed onto adjacent ties which may not be sufficiently substantial to contain this additional loading and will also consequently fail. Formwork pressures and loading can be calculated and more is being learned constantly about the behaviour of fresh concrete under the influence of vibration. Meanwhile all formwork is designed with a substantial safety factor to guard against exceptional loading, poor workmanship and practice.

Waling members or strongbacks will be incorporated in the forms or added to the forms once they are erected. In the case of proprietary forms they may only need a simple tubular member fitted at the head of the form to maintain the line. Levelling of the form and plumbing are carried out just prior to the final tightening and preconcreting check. These operations are achieved by the adjustment of wedges and props—some assistance being afforded from “Tirfor” or wire rope winches in the case of long pours, although these must on no account be used as permanent tie arrangements due to the relatively elastic nature of the wire bonds employed.



This illustration gives some indication of the scale of operations in the construction of a cooling tower. Supports for the crane are taken to ground level (Norwest Holst Ltd)

Fixings, fastenings and former location

Where there are inclusions in the concrete such as lift fixings, welding plates, cast in sockets, channels and such like, these should be set on the form face by reference to two previously established datum lines. The datum lines should be established at a sensible height above finished floor level and at some discrete distance from the grid lines governing the plan layout of the structure. When the form is finally levelled, these fittings must be within an acceptable distance of their specified location in the concrete element.

Care is required when installing inserts, checkouts, hole formers and such like, to ensure that whilst they are suitably located to avoid displacement during the concreting process, they do not tie the form faces or trap the forms on the concrete at the time of form removal. Particular care is required in the case of projecting steel reinforcement, starter bars and similar protrusions, to ensure that these do not trap the form or cause damage to the forms at the time of striking.

Features and projecting nibs

Where there are protrusions on the face of the concrete, as where bearing corbels are formed for the subsequent support of slabs or landings, particular care is required in formwork detailing, steel location, concrete and in the subsequent striking operations. The striking operations must be planned and stripping fillets and similar details adopted to allow the form to be struck from the concrete without damage to either the form or the concrete face or displacement or damage to corbels or projecting steel.

The position of day joints relative to corbel and projecting steel positions are also key points for consideration. In exceptional cases the permission of the engineering authorities may be sought to allow nibs or corbels to be left off (for subsequent addition) or precast for inclusion into the form. Both these methods lend themselves to speed of construction avoiding massive alteration to the form at the point of placement. Where it is decided that a nib or corbel must be cast monolithically with the wall or beam, local joints, construction or day joints, should be arranged such that the nib is formed at the top of the lift with consequent ease of fill. At the same time a small upstand member should be formed to provide a suitable kicker for the wall above.

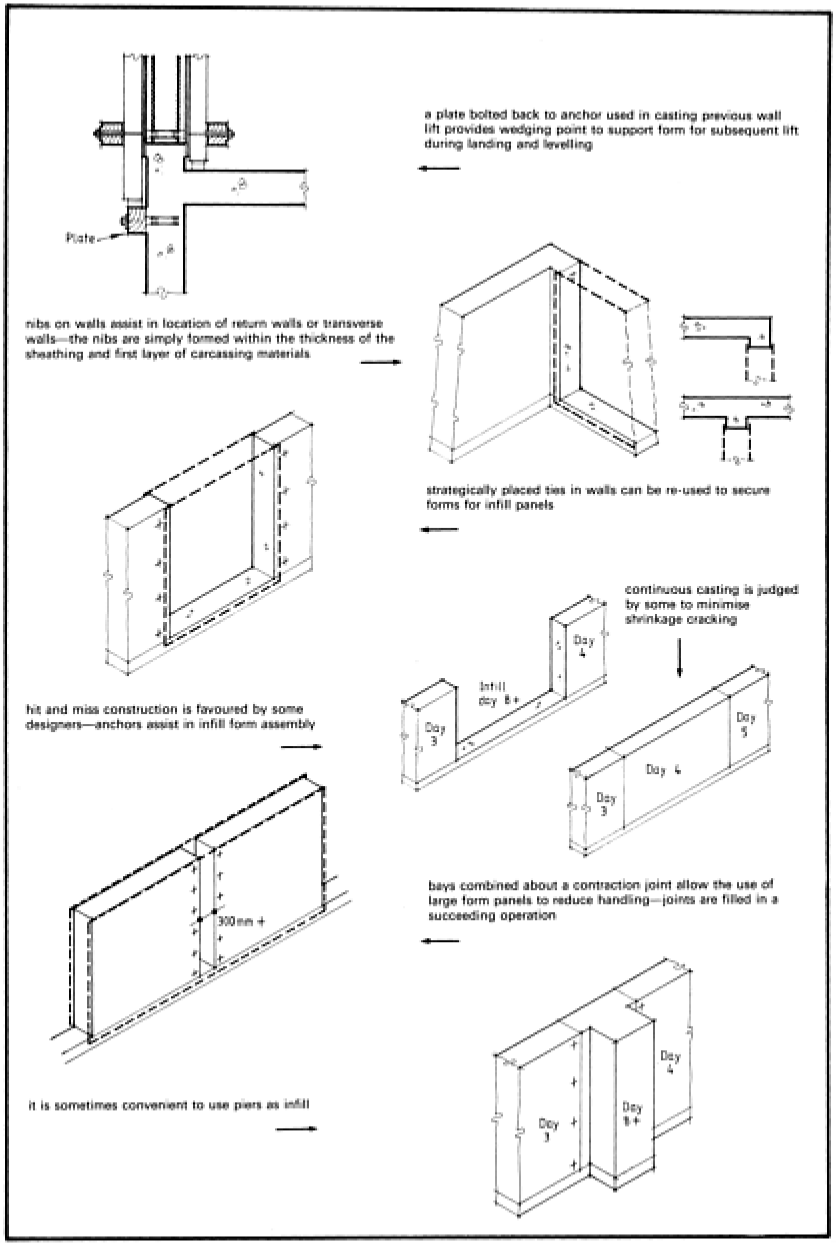
Casting lift-over-lift

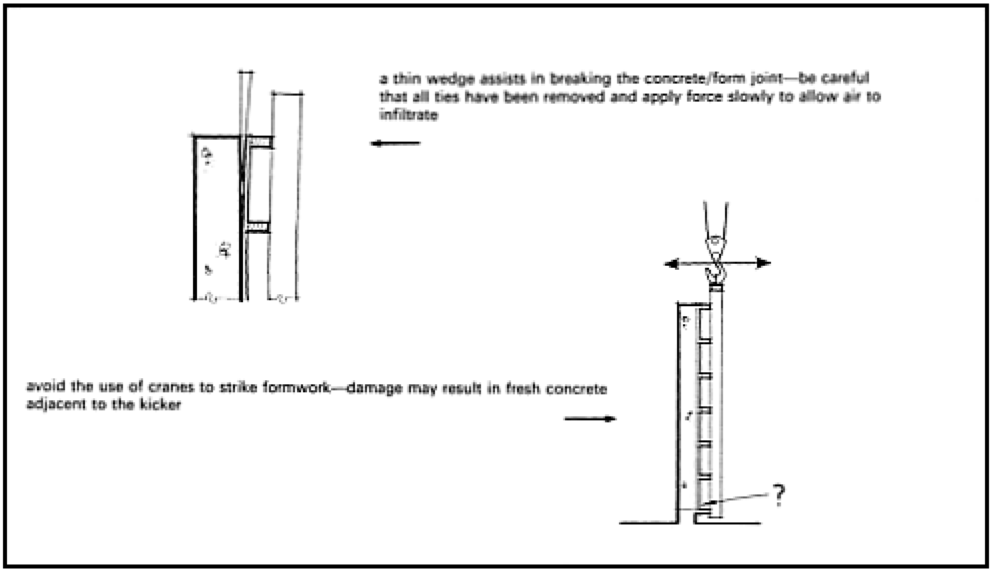
Where a wall is to be cast (for reasons of structural detail) lift-over-lift in heights of, say 1·2 or 2·4 m, it will prove helpful if, apart from the normal buried tie fixing, a further plate is secured to one side of the wall some distance below the level of the bottom of the form. This plate can provide temporary support when the crane lands the panel, as well as providing a ledge or landing from which wedging or jacking can be carried out in lining and, particularly, levelling of the form.

Where relatively shallow lifts of concrete are being cast, it may be helpful, in maintaining line and plumb, if strongbacks are inserted in the system at suitable centres to allow wedges or jacks to be used in these operations, the wedges being inserted between the strongback and the previously cast concrete.

Stopends

The stopends, or end filler panels, form the day joints or construction joints. The stopend line will be visible at the face of the concrete and must, therefore, be vertical and be given the same treatment as other visual details. It is essential that stopends are grout-tight and this can only be achieved if they are well fitted to the face. It is advisable to provide additional backing members in the form construction to avoid leakage occurring as a result of local deflection of the sheathing material. Stopends can be constructed in a number of ways depending upon the amount of continuity steel which will project from the ends of the bay of concrete. Generally individual pieces of


a plate bolted back to anchor used in casting previous wall lift provides wedging point to support form for subsequent lift during landing and levelling
Plate
nibs on walls assist in location of return walls or transverse walls—the nibs are simply formed within the thickness of the sheathing and first layer of carcassing materials
strategically placed ties in walls can be re-used to secure forms for infill panels
continuous casting is judged by some to minimise shrinkage cracking
hit and miss construction is favoured by some designers—anchors assist in infill form assembly
Infill day 8+
Day 3
Day 4
Day 3
Day 4
Day 5
bays combined about a contraction joint allow the use of large form panels to reduce handling—joints are filled in a succeeding operation
300mm +
it is sometimes convenient to use piers as infill
Day 3
Day 8+
Day 4



sheathing are used, notched between the steel as necessary, the whole being carried on a sub-frame of studding material. The studding in the form of soldiers is supported by ledgers which bear upon cleats attached to the form. For high quality work it is desirable that these cleats should be bolted through the carcass of the main forms. Stopends are required to contain the same forces as the form face and thus the strutting and location of the stopend is equally as important as that of the main form. It is usually possible to introduce props against the stopend frame to gain a purchase from adjacent kickers, projecting steel and so on.

The concreting operation in walling

As soon as the pre-concreting check has been carried out and plant and equipment prepared, concrete placement can commence. In the initial stages of filling a form it may be advisable to reduce the quantity of aggregate in the batch until the concreting equipment has become coated with a layer of paste, although this should only be done with the permission of the engineer. Care must be taken to avoid build up of paste on the form face, as in the event of this drying out prior to the concrete reaching it, defects in the face will become apparent on striking the forms. Chutes, "elephant trunking", and such like will be helpful in this respect.

As soon as there is sufficient concrete within the form to contain a poker vibrator, the compaction process should commence. Concrete should be fed to the poker and not placed and then moved by vibratory effort. The poker is a compacting tool and should only be used as such. As the pour proceeds, the next layer of concrete should be placed. The poker should be withdrawn slowly from each location (to avoid forming pockets of fines) and then quickly inserted back into the next position of the order of 400–600 mm along the wall. It is important that the vibrator should be used in such a way as to promote the compacting and knitting together of the layers of concrete. This is achieved by allowing the poker blade to penetrate through each layer into the preceding layer. In this manner, the workability fines and laitance will be drawn through the concrete mass to the top of the upper layer.

Care is required to establish a system of filling such that concrete fully fills the form and is properly compacted adjacent to stopends, openings and below the member for through hole formers. In the case of substantial forms, it may be necessary to place a man (with suitable safety harness) into the formwork.

A watchful eye must be maintained for movements, leakage and form displacement and any defects made good as the work progresses. There must always be a standby carpenter or suitably skilled person to maintain a running check on ties, bracing and supporting systems. In the event of excessive movement or deflection, the rate of placing must be slowed down or concreting stopped. In the latter instance, concrete should be levelled and a joint form filler introduced between the steel and form face to ensure a reasonable visual joint being obtained upon recommencement of the fill.

When the concrete reaches the top of the form any excessive quantity of fine materials should be cleared away and replaced with fresh concrete. The surface can then be levelled by cross screeding and floated as required. This top surface should remain covered and undisturbed until the correct stiffness for trowelling is achieved. A spray with curing compound or the replacement of covers will allow curing to be continued.

Particular attention is necessary to achieve good fill around and especially under opening formers and win dows. This requires strong discipline on the fill, the concrete being placed in one location until it can be seen to flow from under the lowest former. The fill location can then be changed to a position which will ensure a sound fill under the next lowest former. Only when a flow of concrete and a build up takes place at each successive location should the placing be transferred to another location.

Walls having textured to featured faces are difficult to fill and achieve constant distribution of the concrete. The features upset the flow and make it even more essential that the concrete should be placed in small quantities just where it is required. Failure to observe this recommendation will result in patchy surface appearance. The supervisor should bear in mind that, whatever the subsequent treatment, whether grit blasting, exposure using surface retarders or acid etching, inconsistencies in the concrete face cannot be eradicated and, in some instances, may even be amplified in the course of that treatment.

Wall formwork striking

Wall formwork can be removed between 5 and 15 hours after casting, depending upon the ambient temperature, the concrete temperature and the degree, if any, of acceleration applied to the concrete curing process. This operation commences with careful removal of the majority of ties, bolts or wedges. A crane is attached via a suitable spreader bar and lifting arrangements so that the full weight of the panel is taken by the crane. The remaining ties are removed and the form is peeled away from the concrete face. Should there be any difficulty in parting the form from the concrete, thin wedges of timber should be inserted between the form and the concrete at one end and time allowed for air to penetrate at the interface between sheathing and concrete. Once the vacuum is broken the form can be lifted clear. Between uses the forms should be lightly oiled and stacked out of wind and wracking, care being taken to ensure that the forms cannot be blown over risking damage to people, equipment or materials.

Regarding striking times, vertical formwork can generally be struck in 9 hours (16°C) to 12 hours (7°C), the main considerations being the ability of the concrete to withstand mechanical damage, impact and plucking which may occur at the interface between the form and concrete face.

In the event of a form proving difficult to strike, it is most likely that some bolt or tie has been overlooked and a check will be necessary to identify the element and clear it. Continued difficulty may exist where lead or draw is tight and, in this case, care must be taken to remove the form in a direction normal to the concrete face. The peeling process discussed above can be applied even to the largest forms by wedging, jacking or similar. This action should, however, be carried out slowly to permit the infiltration of air at the form/

concrete interface, without which parting cannot take place. The jacking or wedging operations must be controlled as damage may otherwise be caused adjacent to the joint with previously cast concrete. In the case of featured work it is again essential that the lead or draw on the feature is not negated by wracking or twist in the form.

Single sided wall construction

Where walling is being placed within a sheet piled excavation or where the pour is so substantial as to preclude the use of through bolts, single sided work is involved. Normally the pressures from the concrete are collected and contained by ties passing between the two form faces to a wall. In the case of single sided work, these forces must be transmitted into a previously cast concrete element, either using a propping system or utilising anchors cast into mature concrete in the lower lifts. Bracing becomes more difficult as the height above ground level increases and thus the inclination of the props increases. Here it becomes necessary to use buried anchors in conjunction with strongbacks to support the forms.

Supervisors should be warned that accidents have occurred due to a lack of appreciation on the part of those concerned of the capacity of the anchor to sustain load when embedded in relatively green concrete. Where anchors are concerned in single sided work the geometry of the strongback-tie-bearing arrangement is such that substantial forces are applied to anchors in concrete which may be only 15–20 hours old.

It is not economic to design a form support system in single sided work, which completely eliminates the movement of the form due to deflection of the main members, the soldiers. It is usual to incline the top of the form slightly inwards to allow for the anticipated outward movement of these members.

Should it be necessary, due to the configuration of the work, the incorporation of steel for a landing or mezzanine, to stop the filling operation in single sided work and to continue to pour the next day, then it is advisable to incorporate a cast in anchorage adjacent to the stopping place. This anchor will limit subsequent movement of the form avoiding further deflection under load with the formation of curtains of grout infiltrating between the form and previously cast concrete.

Curing

The construction process must continue with the curing of the concrete, either using a sprayed membrane or a hessian or plastic sheet covering immediately after removal of the formwork.

Column casting

The procedure for column casting is similar to that for wall construction. In this case, the column kicker is carefully located by reference to the profile boards. Kickers are cast around the projecting steel starter bars which, in many cases, are substantial enough to provide a fixing for the kicker forms. The surface of the kicker is treated as normal for construction joints prior to the installation of the reinforcing cage. The cage can be supported by ties to the starter bars, although where bars are cranked or the cage is substantial, some temporary props may be required for safety.

Having been treated with oil or release agent, the column forms are erected either individually or in Lshape assemblies, spacers being used to ensure cover. Again ring spacers will be used, this time on the links. Once the side members are in place they can be tied by yokes, or more typically today by column clamps. The wedges in the column clamp allow the forms to be clamped tight to ensure a grout-tight junction between the side members. The form is plumbed using push-pull props from suitable fixings in the previously cast slab. Columns are generally cast to approximately 10–25 mm above the level of the lowest beam or the soffit of the floor slab. Column concrete can be placed using all the normal methods, such as skip or pump, but best results will be obtained by placing small quantities, carefully compacting the concrete as the work proceeds. Struts should be watched constantly and movement checked. The plumb of the column should be checked by plumb bob or theodolite immediately after casting and any necessary adjustments made early. Attempts to plumb columns once the concrete has stiffened can result in damage at the junction between the kicker and column proper. Regarding access, it is usual to provide trestle or trolley access on two adjacent sides of the form. Extreme care must be taken in skip handling to ensure skips are not allowed to strike the steel projecting from the column being filled (or previously cast concrete for that matter), as a number of accidents have resulted from this. In all these operations the crane must be under the control of a capable banksman. The skip should have a chute of such proportions that concrete can be efficiently discharged into the space available during concrete placement.

Columns of special configuration, inclined, heavily featured or geometric in section, will require special formwork to be prepared. Where inclined columns are to be cast the formwork must incorporate some means of support or strutting which will allow the removal of forms without the imposition of stress on the junction with the kicker or previously cast concrete. Where geometric sections are involved, it is advisable that formwork be contained within an overall framework of yokes or clamps so that the pressures are simply contained. Special profiles can then be incorporated as built up panels and the whole geometry of setting out and setting up is simplified.

Columns which are located in pairs or mullions in sets can generally be incorporated into one overall form carcass. This speeds erection and eases the operations of plumbing the columns and maintaining the correct spacing. In the case of L-shape and circular columns, as well as hexagonal and similar geometric sections, the smaller the number of panels in the complete assembly, the easier the operations of erecting, plumbing, tieing and bracing the form. Circular columns can, if constructed of steel or grp, be produced in one piece so arranged that on release of the bolts at the seam/joint, the form springs sufficiently to allow it to be lifted clear over the cast column. Obviously this is only possible where projecting splicer bars are straight.

All braces and standing supports must be sound, ideally taken from previously placed and matured concrete.

Where columns are of considerable height, such as under roadways or in the podium area of a multi-storey development, the line of the lifts of the column casting must be carefully maintained. This can be achieved by allowing two adjacent sides of the form to be continuous over the two or more lifts. Alternatively, thought should be given to the landing ring principle, where a ring of formwork at the head of the form is so arranged that it can stay in position when the form is struck and provides a footing for the subsequent form erection.

Column form striking

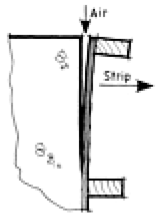
As with walling, column formwork can be struck 9–12 hours after casting, depending upon the degree of acceleration applied. Stripping can be carried out easily, if necessary using thin wedges to break the bond between concrete and form. Curing must take place immediately either with a wet hessian/plastic sandwich or by sprayed membrane. In extremely hot climates the curing is often assisted by wrapping with straw rope, one end of which is immersed in a water supply, thus maintaining a moist environment at the concrete face by evaporation. The arrisses of columns must be protected from damage during ensuing work and this can be achieved by wiring timber or plastic strips around the vulnerable corners.

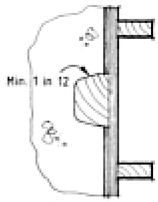
Beam construction

The casting of reinforced concrete beams between columns begins with the preparation of the supporting grillage, which may be of tubular scaffold and fittings or of adjustable props suitably laced and braced. Systems using propping arrangements simplify the erection as the plumb and spacing of the members is determined by the prefabricated tie members. For simple supports and where timber is readily available, timber suitably cleated and braced forms an excellent sub-structure. Runners or substantial lengths of timber are placed into forkhead fittings at the top of the standards and form the main carriage pieces for the formwork. Short cross members are installed onto the levelled bearers, projecting either side of the eventual beam location, to provide support to the beam side members. A sheathing, either of timber and ply, is set down to the precise dimensions of the soffit of the beam and the level checked against datum marks set out on the columns. The soffit thus formed is oiled or coated and the fabricated steel cage set into position. Plastic spacers can be used to ensure correct cover to the steel. Formwork side members are then installed with such cleats or cut-outs as are necessary for supporting boxes for ducting or allowing hole formers to penetrate the formwork. Side members can be through bolted or tied in the case of 600 mm or more deep beams. The ties will be taken through a ledger which spans behind the vertical cleats used to stiffen the side form construction.

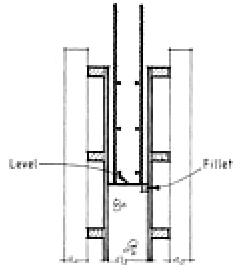
to allow the form to be stripped from a concrete face air must infiltrate between concrete and sheathing

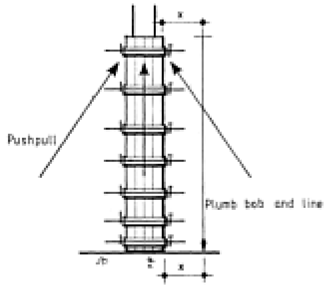
sufficient lead or draw must be allowed at features





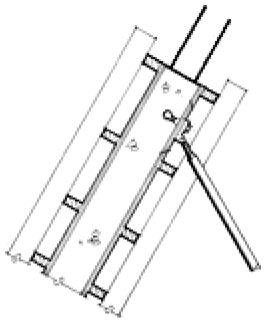
in the event of an unscheduled stoppage in wall casting a fillet should be introduced if possible at top of concrete to provide a straight line joint, this may avoid need for form removal and cutting prior to further concrete work

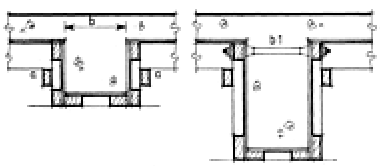




check and re-plumb columns immediately after casting to avoid damage to stiffening concrete at base

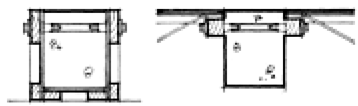
in the case of inclined works, anchorages must be incorporated to provide standing support after forms are struck—alternatively soffit form will be left in place

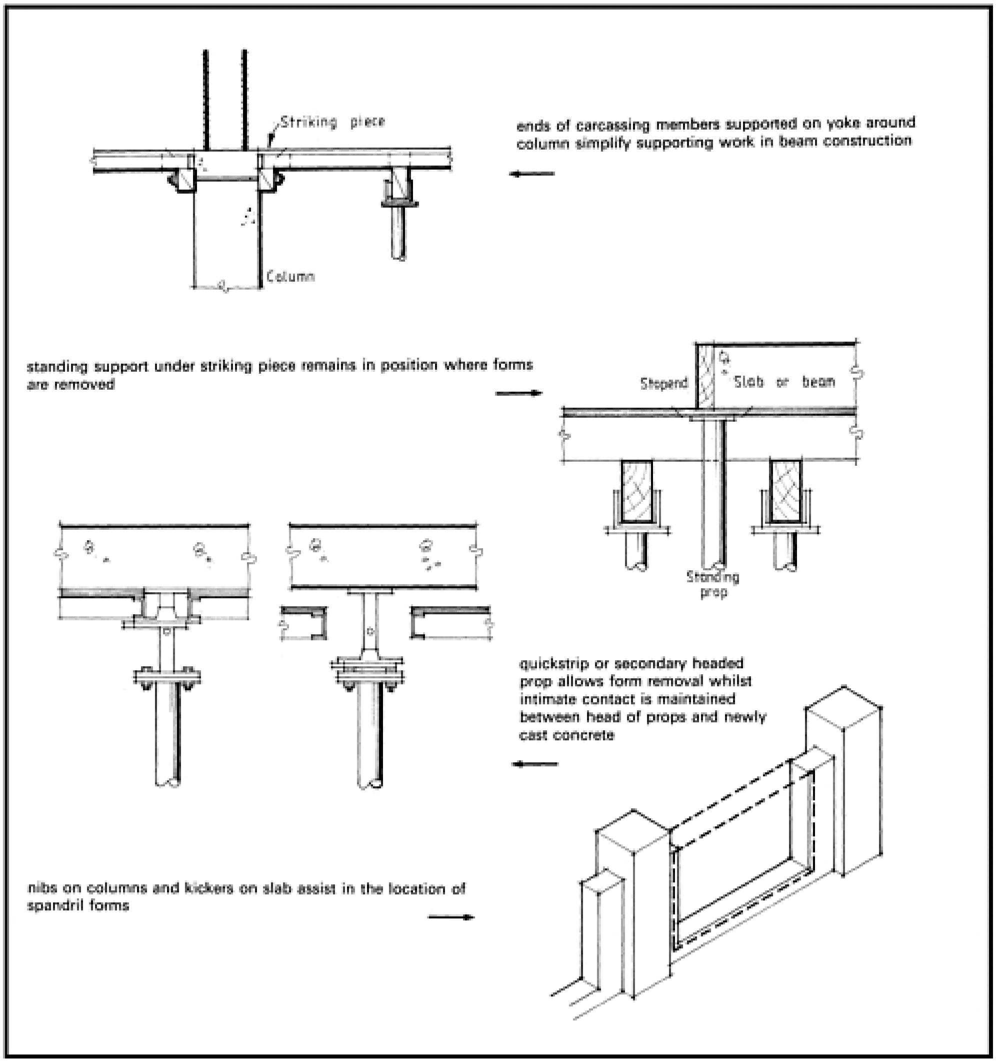




beams and slabs may be cast integral in which case spacing at b and b1 and support at a is essential in the case of deep beams, then bolts or ties may be used at b1

where beams are cast separately from slab, plates bolted to beam can be used to support soffit sheathing





Where the floor form supports are to be taken from the beam side forms, the cleats or bearers must be placed so that they support the ledger from which the floor bearers or joists take their support.

In all cases, temporary timber spacers can be inserted at the top of the beam side to ensure that the correct width of beam is maintained. The bottoms of the beam sides are clamped back to the sides of the soffit member using runners and folding wedges which must be spiked to avoid their shaking loose during the vibration processes. Stopending to beams will normally be carried out within the middle third of the members, the stopends usually comprising split plywood notched over the steel and suitably stiffened. Stopend cleats should be firmly secured to the sheathing and, in the case of deep beams, bolted into the backing members to prevent displacement during the casting operations. The arrangement of formwork should be such that the side or vertical form members can be removed, whilst allowing continuity of support to beam soffit. Where there are many re-uses or where large beams are being constructed, it may be useful to incorporate pads within the soffit sheathing which can be used to provide standing support positions whilst allowing the removal of the remainder of the formwork. Supports should always be provided at the stopend locations to avoid local deflections of the sheathing causing grout nibs or curtains on the finished work.

In the planning stages, certain decisions regarding the location of horizontal construction joints must be made—considerations with regard to the beam/slab connection are particularly critical. The designer will indicate whether the operation of beam casting can be separated from slab construction or whether the two must be concreted in the same operation. Where the two can be separated, and this is particularly important in the case of substantial sections, a completely revised method of beam casting becomes viable. In this method, the soffit can be erected, steel cage set up on the soffit and the side members installed. It is often advisable to use through bolting arrangements to tie the forms as in walling, in the case of the deeper beam a more stable form results. It is, however, still necessary to incorporate a strutting system to ensure the plumb and stability of the formwork assembly. The through tie equipment or through holes can be re-used to facilitate attachment of a plate for further supporting floor bearers or adjustable centres used in floor forming.

Upstand beams are often cast as secondary operations, set into kickers cast on the floor, which must remain propped until the beam is capable of sustaining the floor loading. Where upstands are cast integral with a floor at changes of level, then the beam is generally cast integrally with the second floor casting operation. In the course of concreting, care must be taken to achieve a sound joint between the concrete of the two operations at the junction with the lower slab. Where the pour is continued from lower slab, through beam casting to upper slab, careful timing is required to avoid a surge of concrete occurring adjacent to what is the riser form. This riser form can be supported on concrete blocks of floor thickness and it is advisable to incorporate some means of tieing down the form as well as tieing it to the opposing form face.

Striking beam formwork

The vertical forms to beams can be struck at an early age between 9 hours (16°C) to 12 hours (7°C). Provision must be made in the formwork design, and in the design of the supporting works, to ensure that these forms can be removed with minimum disruption to the complete system. The soffit sheathing can be removed between 8 days (16°C) and 14 days (7°C) with the following provisos regarding periods of cold and freezing weather:

> An additional period of 1/2 day should be allowed for each day when the temperature is generally below 7°C.
>
> An additional period of 1 day should be allowed for each day when the temperature is below 2°C.

The props to beam soffits, critical to the integrity of the falsework system, should remain in position for a minimum of 15 days (16°C) or 21 days (7°C), these times being extended with regard to cold and freezing conditions. The props must remain in position until the concrete achieves the specified 28-day compressive strength or whilst subjected to loads from subsequent construction operations. These guidelines have proved satisfactory in practice during many years of construction. Recently there has been a trend towards the establishment of "maturity values" which can be related to cube strength. These maturity values can then be used as a guide to more realistic and possibly reduced striking times. Research has also established guidelines regarding strength of concrete required to resist frost and mechanical damage.

Where the construction cycle for succeeding floors is short it is quite likely that the load of fresh concrete in the uppermost floor is transmitted by its supports and the supports to the preceding floor into the floor below. Unless the beams in the intermediate floor are able to deflect and work they cannot contribute to the support of the floor, the combined load thus being transferred into the props lower down the building with the possibility of straining or failure of the props. To avoid damage to the props or structure, engineering judgement must be brought into play and the props lower in the building eased to allow the structure to work and relieve the props of some of the load. The supervisor is referred to *The Formwork Report* for a more detailed account of this problem.

Floor castingÐsuspended floors

The supporting structure for a reinforced concrete suspended floor slab is generally formed by adjustable props, suitably laced and braced, positioned at carefully calculated centres or by the use of system props with an inbuilt lacing system. Although these are the two main methods used in casting floors, telescopic centres are sometimes used spanning between precast beams or between previously cast in situ beams, they can also be used advantageously in spanning between beam side arrangements whether timber or of proprietary nature.

The locations of uprights are set out on the previous floor slab and the grillage of props is set up. In multistorey construction it is advisable to set the grillage out from a common baseline—a given distance from one edge of the slab; this will ensure that props are reasonably continuous throughout the construction. The standards are capped with forkhead fittings into which bearers can be laid, positioned in such a way that the section is directly above the centre line of each prop. Joists are run transversely across the bearers and the whole area is sheathed with plywood or steel panels. The ply decking or panels can be coated or oiled and boxings for through holes assembled into place. Steel fixing using spacers and chair continues, the stopends being fixed at the day joint and construction joint positions. These are located by cleats fixed to the decking and are strutted from further cleats, spaced sufficiently far from the stopend cleat to avoid the tendency of the struts to lift under load. A check on steel location and position together with the accurate positioning of through hole formers and cast in services precedes the concreting operation.

Slab soffits are frequently based upon trough or waffle former arrangement. Large spans can be achieved using deep slabs, the weight of the slab being reduced by their ribbed and voided configuration. The trough and waffle formers of grp, grc, polypropylene or expanded polystyrene, are supported either on a fully sheathed soffit form or what is called a “skeletal” arrangement of system formwork. Stopend installation is quite a laborious operation and extreme care is needed to avoid displacement of the waffle and trough formers. In view of the long spans, particular care is required in standing prop arrangements for continuing support. The location of supports on succeeding floors must be studied in view of the slender section of parts of the decks. Additional supporting members must be inserted where sections of the decks are cast solid to act as spine beams in the construction.

Whenever concreting is interrupted, particularly at day joint positions, supports must be incorporated to avoid deflections which would otherwise upset the accuracy of line of the soffit. Where large spans are being constructed the engineer may require a precamber to be built into the form work. This camber will be incorporated at the time of levelling in the forms. Normal levelling is carried out in two stages:

> The forms are roughly located for height using a batten or rod from a datum set on one or more of the columns. Final levelling is carried out using dumpy level in conjunction with accurate levels transferred from the main site datum level.

It must be borne in mind that floor and roof slab forms provide a working platform for all trades involved in the construction, including steel fixers, carpenters, electricians and plumbers, a well as the concreter. Floor soffits are designed to resist and contain the load of the concrete and allowance must be made for concrete placing forces and loads imposed by workers, plant and equipment.

Striking formwork to suspended floors

The striking operation, which will be carried out when the concrete achieves some agreed strength or maturity or, in the absence of such agreement, when the concrete is 4 days old (16°C) or 7 days old (7°C), must be carried out systematically in such a way as to avoid damage to concrete or forms. This striking time is based on the maintenance of a standing support system of props which will remain in place until the concrete element is capable of sustaining the loads imposed upon it in the construction process. The prop system must remain in place for a minimum of 11 days (16°C) or 14 days (7°C). Earlier removal without special curing, in the form of electrical or steam heating, will result in undesirable deflections and excessive creep movement.

The quickstrip systems of proprietary formwork allow the sheathing to be removed whilst the standing supports remain in direct contact with the concrete, eliminating removal and reinstatement of props. In winter, striking times are increased for cold and freezing conditions, 1/2 day being added when temperatures are generally below 7°C and a whole day being added for every day when temperatures are below 2°C.

Considerable research has been carried out regarding striking times but, whilst concrete may be resistant to damage once it has achieved 5 N/mm^2 compressive strength and in general terms striking will be allowed once concrete has achieved a compressive strength in cubes stored under the same condition as the site concrete of at least twice the stress to which the concrete will be subjected at the time of striking, local specification governs and the supervisor must ensure that the site authorities are in agreement with the proposed timing of striking operations.

Table forms in slab construction

Fabricated platforms, which incorporate leg supports, truss members and a sheathing arrangement, are used for speed and economy where a great deal of repetition occurs during construction. Tables, the larger types being constructed in aluminium alloy, enable crane handling of very large areas of formwork in a single operation. They can be constructed in such a way that they fold or are retracted to pass through limited access space at the side of a building during the course of movement from one casting location to another.

Where there are considerable numbers of re-uses in construction, it has proved possible to incorporate beam side forms along the table edge. Beam soffit members are supported from integral bearers and the whole floor and beam form can thus simply and speedily be erected. Where large span construction calls for the provision of standing props, these can be incorporated by dividing a bay into two table areas—the longitudinal joint thus providing a space into which props can be inserted under a strip of sheathing which remains in place when the main tables are struck. Where non-standard bays occur adjacent to the main table forming operations, these are generally formed using traditional form methods. The stripping of forms is a hazardous operation and care must be taken:

to avoid excessive upward loading on the freshly cast concrete slab;
to ensure that edge beams and floor edges are not overstressed;

to ensure that operatives who must work on the cantilevered table are protected from falling by harness or guard rails.

Regarding the exceptional loadings which may be imposed on slab edges, these are generally catered for by the addition of reinforcement within the beam in redesign after the decision to use table forms has been made. Otherwise the floor edge adjacent to the columns may have additional support from special props as part of the formwork detail.

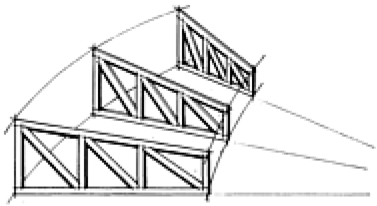
Domes, barrels and geometrical work

Where spherical construction is required forms are generally constructed from timber or steel ribs and ply or board sheathing. The ribs are set radially and the sheathing, often in two thin layers, is bent over the spherical carcass thus formed. The steel fixing and concreting operations involved in the construction of spherical work are similar in most respects to the more straightforward operations in casting plain walls and slabs. The steel reinforcement usually provides the greatest problem area and speed of construction will depend on the skill with which steel has been detailed and scheduled. Trial assemblies of steel are essential and, if carried out early enough, will assist in the verification of schedules before the main supplies are cut and bent.

Concreting is always commenced at the lowest part of the lift and the workability must be adjusted such that the concrete already placed does not flow down a slope as the layer above is placed and compacted. Top formwork will be needed above 30° from horizontal, depending on the workability. A slow fill is desirable, working all along a barrel or all around a dome, so that a face of workable concrete is maintained and dry joints avoided. On sloping walls to reservoirs, and in the case of substantial barrel roofs, it is sometimes possible to use a heavy section of top form and to slide this up screed boards as the fill proceeds, so that the effect of a continuous form is achieved using a small amount of formwork.

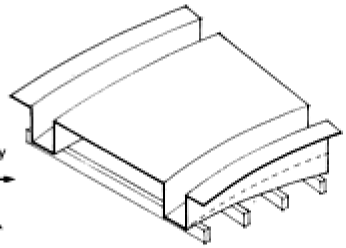
Spandril walls

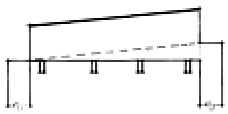
Spandril walls are often detailed spanning between columns and forming upstand beams at the perimeter of a slab. Where possible the construction of these walls should be carried out independently of column casting operations. The technique most usually employed is to incorporate in the column form some boxes which allow for the casting of projecting nibs at each column edge for the height of the Spandril. The outer face of the nib former will be pierced for projecting continuity steel and the box provided with a capping piece to allow the completion of column casting without surge. After column striking and Spandril steel fixing, the forms to the spandril can be clipped into place (using previously installed sockets in the case of large walls), and steel fixing and concreting follow. Particular care will be necessary to ensure that the concrete in the spandril is thoroughly compacted at the junction with the column nib, where the previously cast concrete and continuity steel tend to immobilise the fresh concrete. Here again a feature will assist in masking the construction joint.



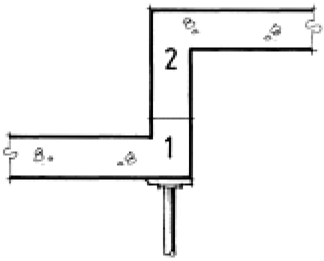
spiral ramp construction is simplified by the use of simple truss members which if laid radially generate the required soffit geometry

prefabricated forms or form carcass taken into datum level can be simply set up onto supports established at site—all critical geometry is governed by form

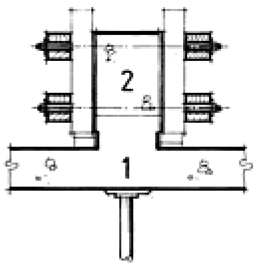


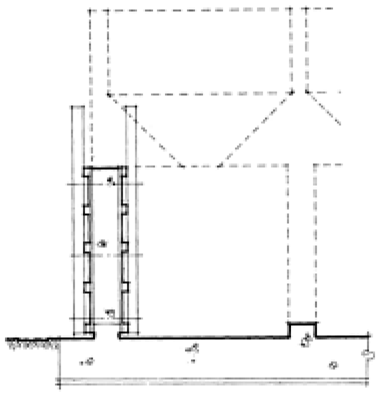


stepped slabs are best cast in two operations—again strong discipline is required over standing supports



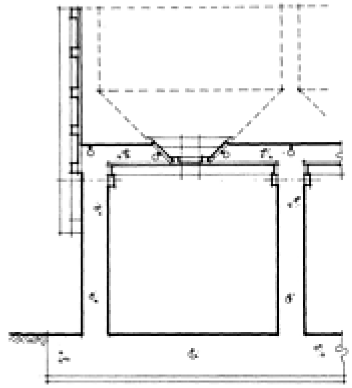
upstand beams are generally cast separately to slab—strong discipline is essential regarding location of standing support members

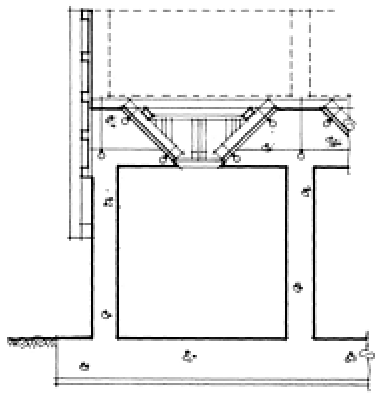




in bin and silo construction, the sequence of construction must be clearly established to ensure design of forms suitable for re-use as well as the insertion of anchorages

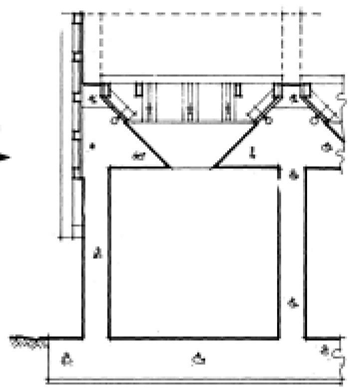
for subsequent form fixing and support, the hole formers must be securely and accurately located and tied down with care taken to combat uplift





in the case of upper forms to sloping surfaces, as well as providing a suitable opening for concrete placement

it would probably be sensible to bring the bins to kicker level with a shallow lift so that geometry can be re-established



Access ramps

Ramp construction is encountered in both car parking and in road construction and, with the attention now paid to the needs of the disabled, there are a greater number of ramps in building construction. Straight ramps, part from the work of setting out, are little different to normal suspended slab work, except for the concreting operation which must be commenced at the lower end of the construction so that the “front” of the concrete can be maintained during the placing process. The support system, of course, requires careful attention to ensure that the thrusts which develop from impact loading, plant movement and so on, are countered by lacing and bracing members.

Ramps which are geometrical in plan, circular or elliptical, need special care in setting out and form erection stages. Ideally reference points and datums should be established on previously cast concrete. Alternatively, mortar spots or pins set in concrete can be used to establish the key setting out points. Where economics allow, it is advisable to use a scaffold or system prop supporting arrangement which will remain in position while the ramp concrete cures. It has provided helpful to construct a series of prefabricated frames which generate the section of the soffit, particularly where downstand beams are incorporated in the design. These frames, used in conjunction with a supporting system brought to a datum level in each bay of the construction, simplify the process and, provided they are set down on known lines which will generate true sections, will make the operation of sheathing straightforward.

Upstand beams or parapet walls should, where possible, be cast as a secondary operation. Most designers will agree to this provided some feature or detail is used to mask the construction joint. This two part operation allows discrepancies in setting up of the ramp form to be mastered thus easing the problem of achieving a fair line at the head of the parapet wall.

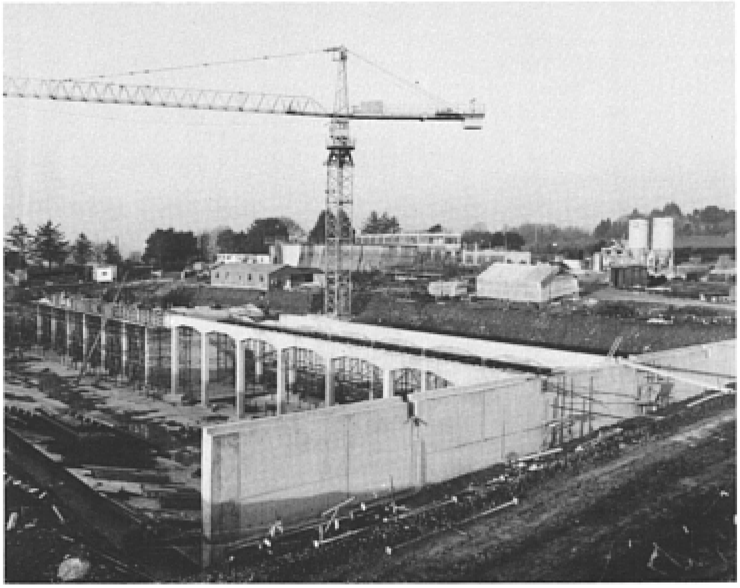
The steel fixing operation is complicated in curved work and special attention is required to the achievement of the correct cover between bars of an approximate radius and beam forms of accurate radius, the tendency being for a bar to take up a location of excessive cover in one position and too little cover further along the beam. In this instance the use of additional spacers securely fastened to steel is essential, supplemented where necessary by a batten of thickness equal to the cover which is withdrawn as the concreting work proceeds. In awkward locations it may be advisable to secure the cage from the back form taking care to ensure the disengagement of the ties prior to form striking.

The concreting operation demands concrete of such workabilty that a working face of fresh concrete can be maintained, that compaction can be achieved and the unformed surface maintained level by the normal screeding process. The screeding operation can, in the case of narrow ramps, be carried out by working from the top of the edge forms and, to maintain the required surface, it will be helpful to mark those forms radially providing guide marks for the screed operator. In the case of wide ramps it will be necessary to provide screeds on chairs to allow maintenance of level.

Stair construction

Stair construction is commenced with the establishment of the correct levels for treads, landings and half-landings. Drawings are studied to confirm thickness of floor finish, finish to treads and visor and to landings. These levels are then used to calculate the actual concrete profile. A soffit is set up at the half-landing level or, in the case of straight flights, at the level of the succeeding floor. It is then possible to erect the sloping stair soffit making allowance for the waist thickness. Depending upon the detail of the stair string

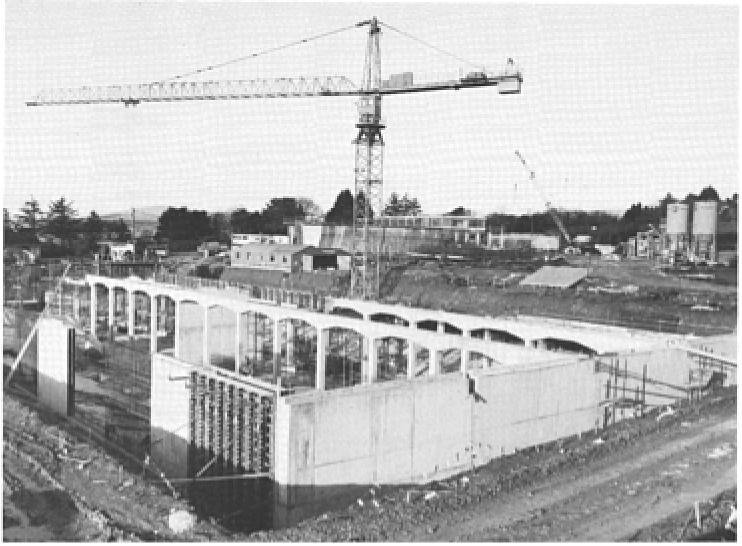
General view of the reservoir construction site (South West Water Authority)



members, solid panels or panels shaped to the stair profile can be erected and strutted into place. Due to the sequence of construction it is usually possible to find plenty of support for struts and braces, although in the absence of adjacent kickers or walls, struts can be taken to cleats shot-fired into mature concrete. At this stage the reinforcing steel can be fixed, particular attention being paid to cover to the steel. The longitudinal steel must be cranked to the correct angle to ensure the maintenance of cover along its length and where it passes into the landing or half-landing. Cut strings and bearers attached to the flank wall facilitate the location and fixing of riser boards and, in the case of wide stairs, it will be necessary to introduce stretcher members or bearers to restrain riser boards from lifting and deflecting upwards due to concrete pressure. After pre-concreting checks the fill may commence, using concrete of low workability to avoid surge under the riser board as vibration is carried out.

Where the risers are inclined and where nosings are to be included, these can be worked into the riser board detail. Trowelling takes place as in slab construction. After curing it is essential that the nosings and treads are protected using hardboard strips to prevent wear.

It is advisable to keep stair casting in time with, or as close as possible to, the floor casting operation from the aspect of access and to avoid problems incurred by the need to leave unconcreted areas where continuity steel must be incorporated into the slab. All other considerations allowed for, it becomes difficult to set up forms and concrete stairs when they are in a well some floors down from the floor currently under construction.



Reservoir construction—ground slab, column and beam construction well advanced, walling and decking operations proceeding (South West Water Authority)

Bin and hopper construction

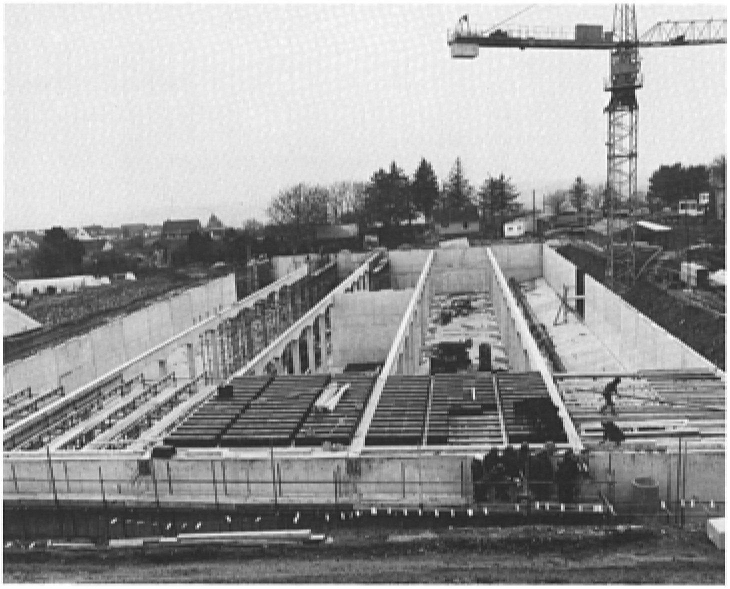
Once the basic principles of form construction, reinforcement placing and location, and casting techniques, have been assimilated, it becomes relatively easy to visualise the construction work involved in more complicated structural forms.

The construction of a silo or storage tank can be divided into a number of lifts vertically and bays horizontally—the location of joints being discussed with the structural engineer. The greatest number of operations for a particular section will govern the profile of the form provided, the height of the lift being determined by the specification and the rate at which formwork, steel and concrete can be handled, positioned and placed. Form construction will depend on the geometry and number of uses, either in traditional construction or utilising proprietary equipment hired or bought in for the contact. Provided that the designer has considered standardisation during the design process, it is quite likely that standard formwork, part of a proprietary system, can be used to generate the structural sections.

Special care must be taken in the ground to avoid the substantial pressure resulting from groundwater lifting the structure bodily from its position. Pumping and dewatering processes will assist in this instance. Extreme care is also necessary when casting sloping faces in pits and hoppers and when placing shaped inverts, that formwork is not displaced by the uplift generated by the fresh concrete. Where necessary ties must be taken into the early lifts or kentledge supplied to resist these forces. Where ties are used, they must be embedded deep enough into the adequately matured concrete to sustain the considerable forces generated by flotation of cores and forms. A way of visualising the force tending to displace a form to an inclined surface is to imagine the section completely inverted. The forces tending to cause the former to “drop out of place” are those which must be contained by the ties and hold downs. In the case of hopper formers it is advisable that the restraint should be taken through the former to the top of the assembly. In this way the formwork and its joints and connections are put into compression and bearing rather than in tension.

The construction of tapered work, particularly conical and square hoppers, requires considerable care. The problems of uplift, fit against previously cast faces and the compaction of the concrete up to the

Reservoir construction—decking operations (using trough moulds) well under way, beam and wall casting virtually complete (South West Water Authority)



underside of an inclined face, need a careful methodical approach at all stages. One problem is that the area into which concrete can be introduced is reduced with each succeeding lift. It is extremely difficult to get a good fit at all points between form and previously placed concrete and there will be considerable quantities of projecting steel to be located and maintained in place.

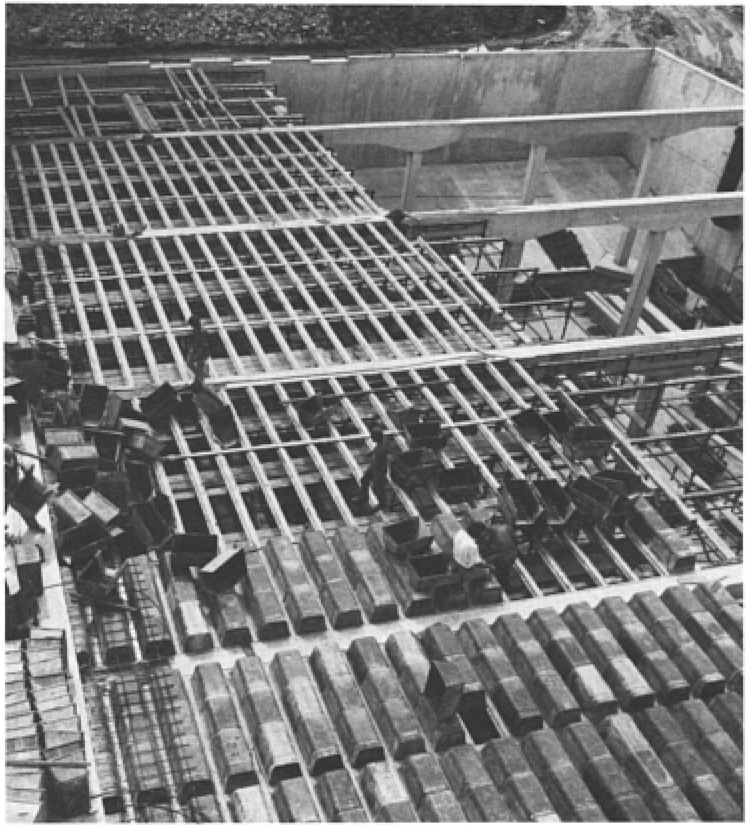
Good access, probably a continuous walkway over or attached to the formwork, is essential to ease concrete placement and once again it may be desirable to put a man into the formwork to place and compact the concrete. Generally it is better to use "man-access" doors in forms than "concrete placement" doors, although often by the late fixing of steel it is possible to eliminate doors and the resultant imprint on the concrete face.

Where structures of constantly changing section, such as conical hoppers, tapered chimneys, shafts and such like, are concerned, a basic form will be constructed such that it can be expanded by the addition of sheathing inserts or, so that the geometry can be altered, by insertion of packing members at each level. Whilst this cannot result in a perfect continuity of line, the structural engineer will usually accept the resulting compromise profile provided it has been discussed and agreed early enough in the course of the contract.

Culvert, tunnel and shaft construction

The construction of major tunnel and shaft works generally comprise major civil engineering works carried out by specialist contractors. There are, however, many instances where small constructions of this type are included in work encountered by the general contractor responsible for concrete works. Such small works are quite within the capability of most contractors and can be carried out using normal concrete construction techniques and simple formwork. The formwork used will again be dependent upon re-use, but heavy

Reservoir construction—trough moulds being set out onto skeletal support system (South West Water Authority)



timber or steel forms are likely to prove most successful. Heavy rubber inflatable forms have been used successfully in large culvert construction and grp has often been used in casting small shafts and access chambers. Where there is any amount of complex geometry, the use of special polystyrene forms will prove economic.

Shafts and access chambers

Shafts will be cut in rocks and support rings inserted as required or, in the case of more friable soils and clays, sheet piles will be used to retain the sides of the excavation. Precast concrete rings or cast steel liners may be inserted in the lower levels. The final lining will then be provided in the form of reinforced concrete. Frequently a complete ring of formwork is provided, comprising sheathing on timber or steel ribs and arranged to ensure the specified wall thickness. Tie bars or wire bonds taken to ground level are then used to raise the lining formwork intermittently or continuously as steel fixing and concreting proceed.

Tunnels

Tunnels are generally of a special nature and will be cast using very sophisticated tunnel forms. The forms are devised such that they can be "collapsed" and fed through themselves to be established into position for the next casting operation. Most tunnel forms are completely mechanised and incorporate self-contained monorails which bear upon the newly cast invert and the excavation in advance of the invert and form the track upon which the remainder of the formwork is advanced. Control is generally by hydraulic means and the forms incorporate targets which, in conjunction with lazers, ensure the correct line being maintained. Concrete in tunnels is placed by pumping or pneumatic placer, the latter process assisting with the achievement of compaction in the concrete.

Supervising the construction process

Given the basic knowledge of the construction methods so far discussed, the supervisor can devise means of constructing a wide range of structures. The essence of any method is:

it should be simple;
it should be operable using available plant and skills;
it should produce an appropriate degree of accuracy and finish in accordance with the specification;
it should meet the economic requirements of the contractor.

There are a range of special techniques used in concrete construction, any of which may present an economic alternative to the basic methods described in *Chapter 25: Special techniques* (Volume 2). It will be necessary for the supervisor to carry out certain tasks in preparation for the concreting operation. To ensure that no major point of equipment, technique or safety has been overlooked, the following checklist has been compiled.

As discussed in the section on man-management and training, each group in the construction team will be controlled by a leading man or chargehand and the supervisor is advised to go through the appropriate section of the checklist with this person to ensure the success of the operation. The checklist is broken down into sections relating to particular activities within the overall operation. Certain of the points listed must be covered days, or even weeks, in advance of the actual operation, others often after the event. Much of the material included in the list, such as points of safety and attention to welfare, will become an automatic consideration as the supervisor gains experience. One warning, however—*NEVER* assume that because a point has been covered by one of the team in previous operations, that it will automatically be dealt with in successive operations. The supervisor must take every step to check and maintain continuity of arrangements. Pressures of work and time, interruption, sickness and absence from work have all been known to upset continuity of control, and the supervisor must guard against all of these.

Checklist

Concrete supply

Is the concrete to be mixed on site?
What mix is to be used?

Reservoir construction—a view of the completed structure (South West Water Authority)

Does the batcher man have appropriate batch weights?
Are materials stocks adequate?
Is there any special requirement for aggregates/cement/ admixtures?
Is the concrete to be bought in from a readymixed supplier?
Have suppliers been advised of mix requirements?
Have suppliers been advised of total quantity required/ time and rate of delivery/point of delivery on site?

Access

Is there access for readymixed concrete trucks or dumpers?
Is there adequate parking space for suppliers' vehicles?
Are tremies or chutes required?
Are washdown facilities available?

Labour

Is a concreting gang available?

Are special conditions to be catered for (height/exposure/ and so on)?
Will the gang be required to work exceptional hours?

Equipment

Are skips available?
Is a special type required (side discharge/bottom opening/ rollover)?
Are vibrators available?
What size is required?
What type is required (air/electric)?
Have vibrators been tested?
Are supply cables, pipes, and so on, available?
Is “stand-by” equipment available?
Is lighting available?

Curing

Are covers available?
Is curing membrane in stock?

11.
Groundwork

By R.A.WILSON CEng MICE FIStructE FSCET

Footings and foundations

The Building Regulations, *D3—Foundations,* requires that all foundations of buildings shall:

1. Transmit to the ground the combined dead, imposed and wind loads so as not to cause any settlement or other movement in any part of the building or adjoining works;
2. Be of adequate depth so as to avoid damage by swelling, shrinkage or freezing of the subsoil;
3. Be capable of resisting attack by sulphates or other matter in the subsoil.

These apparently straightforward requirements should be considered in detail by the supervisor, beyond the design to the construction and supervision of the construction.

By investigating the soil type occurring on site, the designer will have chosen a footing width which will ensure that the relevant loading is spread safely into the soil. This investigation will involve the digging of one or two trial pits and then combining the results with existing local knowledge. This information is meagre, to say the least, and the first priority of the supervisor will be to confirm or report on the type(s) of soil actually found when digging the trenches for the footings. It should become practice for the supervisor to contact the designer each morning and again each evening with information as follows:

1. Position on site and ground level o.d.;
2. Each layer or strata dug through, the depth from the ground surface to each change of layer and the condition of consistency of the bearing layer;
3. Any ground water met or found running into the excavation;
4. Any unusual features which might, for example, show disturbed ground filled with ashes.

From the information in 1 and 2, the designer can tell whether the soil is as expected and, if not, can consider whether a change in the foundation size will become necessary. From information in 3, the size of foundation may again need to be changed because the strength of soil alters with water content. Item 4 will probably not be expected and may require major alteration in the foundation works. For example, on one site known to the author, a swallow hole was found. Initially the contractor dug down, as instructed, but did not find chalk as had occurred on the rest of the site. He was instructed to dig deeper, but still no chalk was found. Eventually, a boring rig was tried and chalk was found some considerable way down. The designer called for a capping plug over the hole and the structure now stands on this. It is important that complete records are maintained in this instance for the purpose of design checks and for payment of the contractor.

The requirement…*so as not to cause any settlement or other movement*…, if taken literally, would virtually mean that no building foundations would be acceptable, because all materials are elastic and all strain under load. Allowable settlement will be taken into account by the designer, but the supervisor must ensure that no instability occurs. For example, when excavating for footings next to an existing structure, the trenches should not be deeper than the adjoining footings as the load from the adjoining building could cause the soil to slip into the freshly dug trenches. An example of such instability was found where a pond was allowed to form where the gable end of a house was to be constructed. The gable end subsequently settled nearly 150 mm and extensive underpinning was necessary. It is not unusual for trenches to become flooded, but the real damage is caused when the water is not rapidly removed. Most specifications, therefore, require that storm, surface and subsoil water be drained away to prevent damage and nuisance.

The depth of footings, i.e. the depth from the finished ground surface to the underside of the footing, often about 1 m, will be shown on the drawings although the supervisor would be wise to make the following checks:

1. On a sloping site the footing will be stepped. On the uphill end of a stepped run the trench can become quite deep and proper timbering must be used if the trench is to be entered at all.
2. Where the ground is of a clayey nature and trees have been, or will be planted, the foundations will need to be substantially deeper. Instead of traditional footing or trench fill foundations, piles or piers with ground beams may be required. Where trees have been cut down and the stump grubbed out, it is usual to backfill the hole with hoggin and build over the top. It must also be remembered that because the tree is no longer there to keep the soil dry, it will obviously swell.
3. Frost susceptible soils include silts (a very fine grained soil between clay and fine sand), chalk and chalkey soil, fine silty sands and some so-called lean clays. When found near the ground surface, where the groundwater level is high, these soils can expand on freezing. The effects of freezing on the soil in this country can be seen on tarmacadam roads where the surface has crazed and mud has pumped through, eventually causing a pothole.

The requirement…*be capable of resisting attack by sulphates or other matter in the subsoil*…should be carefully considered. Before sulphate attack can occur, several factors need to combine:

1. A *soluble* sulphate must be present in the ground. Small glassy crystals in clay soils, or sometimes layers of gypsum (a hard white layer, not unlike a layer of plaster), can be seen in such soils. A laboratory test is usually necessary to identify the mineral and the soil investigation report should comment on the soluble sulphate risk.
2. A regular flow of water must be present to dissolve the sulphate. Stagnant water may start an attack but this will peter out when the sulphate has been used up.

Concrete which is likely to be the subject of attack will be more resistant if it has a high cement content and is well compacted, dense and impermeable. BS 8110 and BRE Digest 259 both contain tables of the requirements for concrete exposed to sulphate attack. The water/cement ratio must be controlled and a general maximum value is 0·5. This means that the free water content of the concrete may not be greater than half the weight of the cement (per cubic metre). For example, if cement content=300 kg/m^3 with w/c ratio=0·5, the weight of free water=150 kg/m3, which is equivalent to 150 litres/m^3. The free water content is the quantity of water poured into the mix *plus any water already wetting the aggregates*. Sand may have 6% of its weight consisting of water between grains and gravel 2% of its weight. Therefore, a mix of 300 kg cement, 150 kg water (litres) and 640 kg sand and 1260 kg aggregate, may have $640\times\frac{6}{100}=38{\cdot}4$ kg=litres of water plus $1260\times\frac{2}{100}=25{\cdot}2$ kg=litres of water, totalling 63·6 litres of water. If this water was ignored the total free water in the mix would become 150+63·6=213·6 litres, and the water/cement ratio would equal $\frac{213{\cdot}6}{300}=0{\cdot}712$, which is well above the permitted maximum, and the concrete would most certainly suffer.

With regard to the expression…*or other matter in the subsoil*…, the thinking behind this is that acids and certain industrial wastes attack concrete. Peaty soil will be acidic (with low pH value) and aggressive chemicals found in waste dumps will usually require specialist advice. The question of whether it is safe to build at all will have to be settled at the planning stage.

The soil aspects of foundation work have been discussed in detail because they are fundamental. No matter how good the concrete above, the sufficiency of the foundation depends on the soil. However, it is often true to say that a good soil support can be spoilt if the structure above lacks durability or strength.

It is necessary to check several matters before concreting commences:

1. The bottom of the excavation needs to be free from loose lumps and the sides must be stable. Where the soil is crumbly, it may be worthwhile lining the excavation with polythene sheet, then when a lump falls off the side it is trapped behind the polythene sheet and does not roll out and spread over the foundation surface.
2. Where reinforcement is incorporated into the foundation, or where the foundation will be uncovered for some time, the bearing surface of the soil must be covered with a thin layer of blinding or oversite concrete for the following reasons:

   i. protects the foundation;
   ii. provides a level and support for reinforcement;
   iii. keeps the reinforcing steel clean;
   iv. prevents mixing of soil and concrete;
   v. may provide support and a base level for the form work.

   The concrete is usually specified as a weaker mix than the structural mixes, and in fact, need only be as strong as the soil below it. Ordinary Portland cement is used, but where sulphate-resisting Portland cement is specified it must be borne in mind that a lean mix cannot resist sulphate attack. Any mix using sulphate-resisting Portland cement for blinding must be a *structural* mix. It is generally agreed that 50 mm is the minimum thickness for the blinding layer considering both aggregate size and the practical regularity of the excavated soil surface. However, it must be remembered that where water-retaining concrete or external tanking is called for, 75 mm is the minimum thickness.
3. In foundation work the quality of formwork is usually of little importance. The selection is most often based upon considerations of cost, and the choice will be made between:

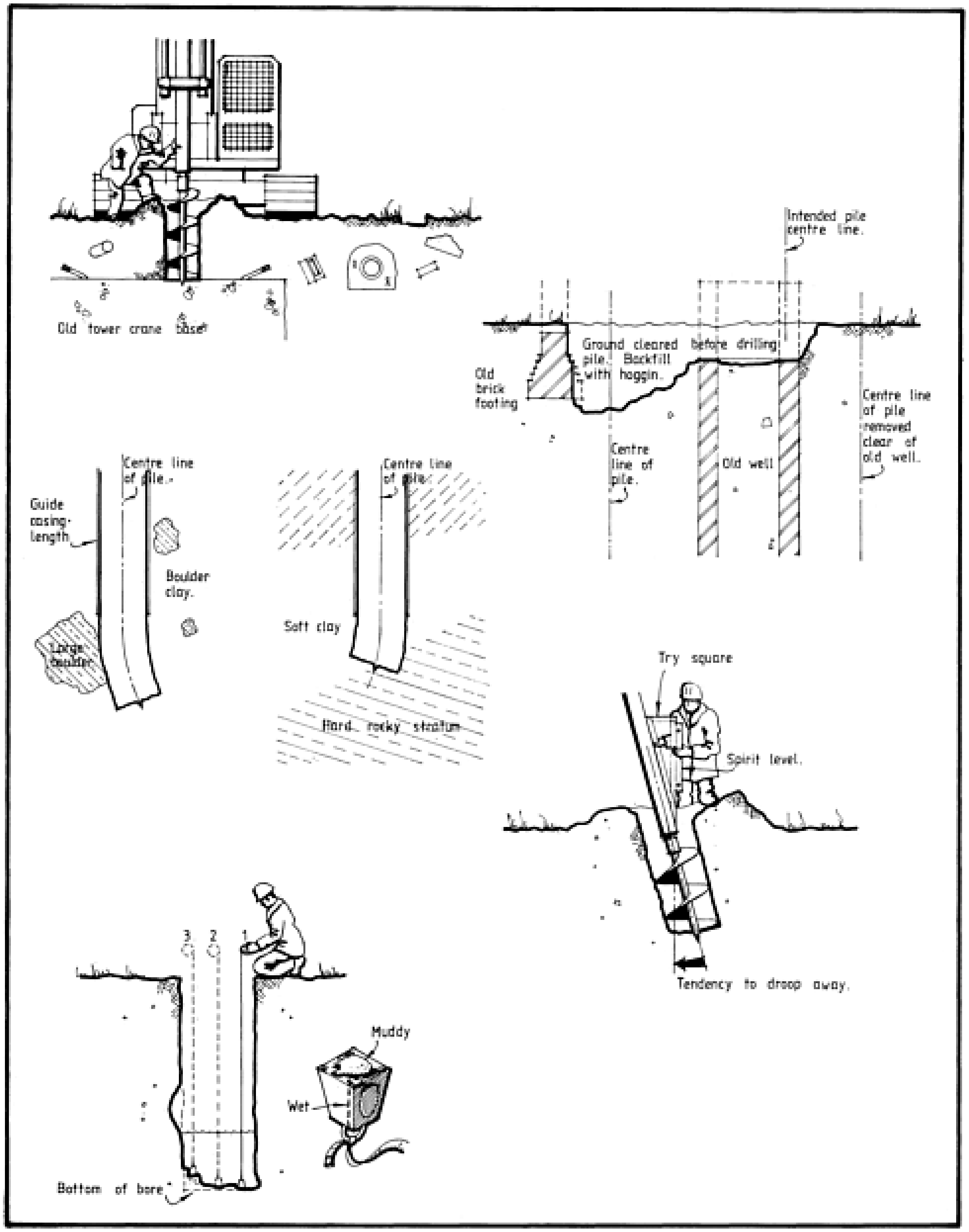
   i. traditional timber or plywood;
   ii. proprietary metal and ply or metal alone;
   iii. blocks, bricks, blinding concrete and similar “lost” material;
   iv. expanded metal sheet.

An important decision affecting the choice of formwork will be the method of forming construction and end-of-the-day's work joints. These are most efficiently made flat or plane and a rough surface formed for key. This rough surface can be formed in four ways:

i. by removing the formwork quite early and washing the surface with a brush and clean water;
ii. by retarding the concrete surface and brushing off the skin quite soon after removing the formwork;
iii. by using a rough surface, such as expanded metal sheet;
iv. by bush-hammering the whole surface when the concrete has hardened.

4. There will almost certainly be a fuzz of projecting reinforcement and this should not be bent out of the way. Where there is severe shearing effect on the structure at the joint it is reasonable to use a "joggled joint", but this shape of joint can cause difficulties, particularly in obtaining well compacted concrete under the planted insert former and later, in filling the insert shape with well compacted concrete. Projecting reinforcement piercing formwork is always a nuisance to the man on site but it is necessary in terms of design. The eagerness of management to reduce costs has recently brought attention to this problem. By using expanded metal, pierced while steelfixing and built in with the reinforcement, a considerable reduction in the traditional effort has been won. Another innovation is the pre-bent U-bar-and-plastic biscuit of which Connobar is typical. These are nailed to the inside of traditional formwork and the reinforcement is carefully straightened after the formwork has been removed. Two particular advantages in this system are:

   i. no projections until required—a worthwhile safety



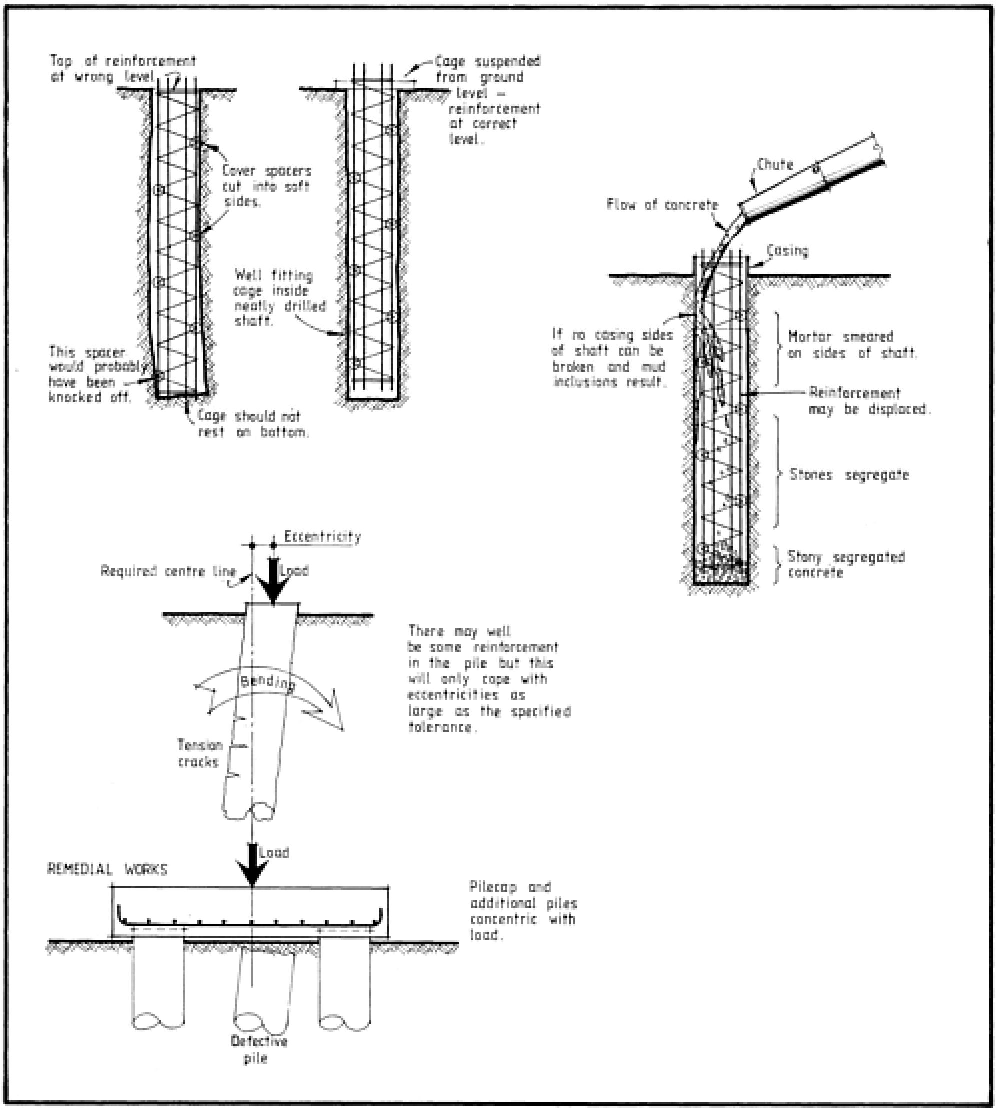
feature;

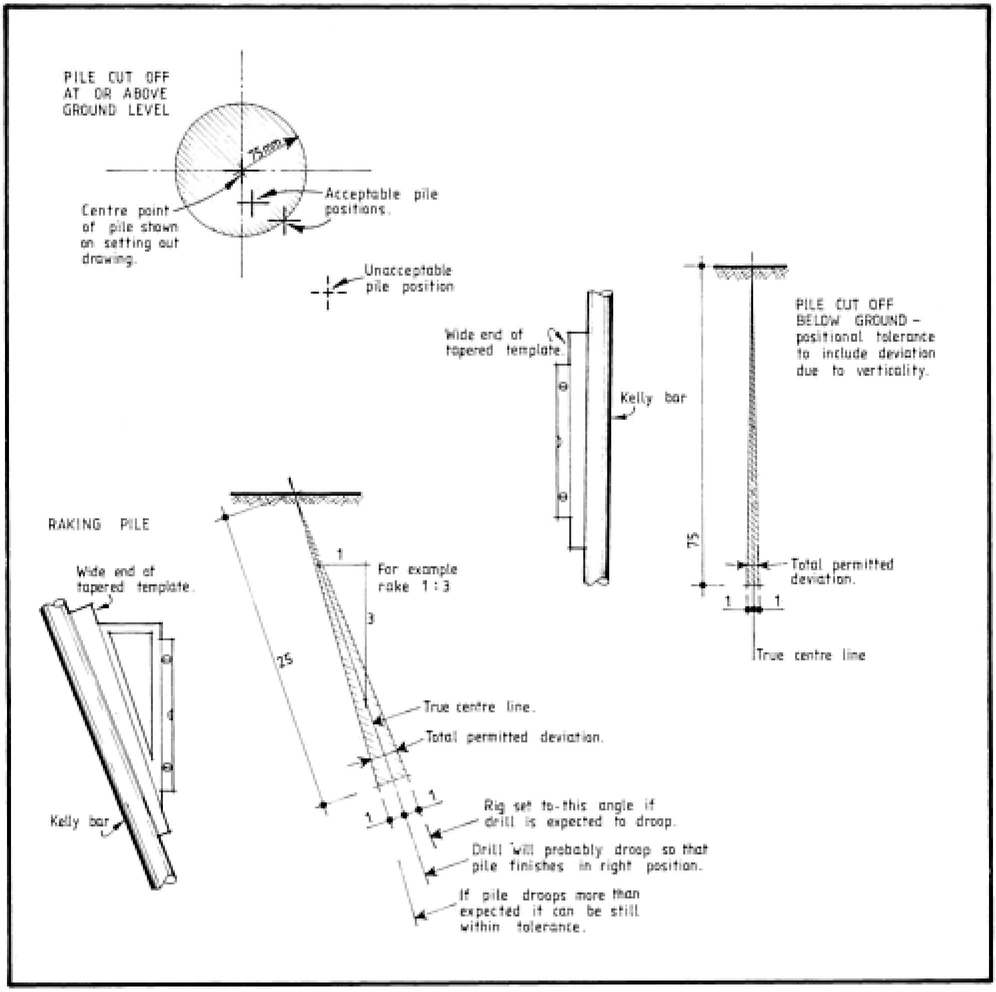
ii. starter bars on the beams, as occur in retaining walls where a car ramp, for example, runs alongside, are fitted with comparative ease.

> However, there are two precautions to be observed. The first concerns the plastic biscuit encapsulating the reinforcement—this should be removed by picking or scraping away with a nail or bar or similar tool—*on no account should it be burnt out,* as heavily toxic fume is emitted when this material is burned. A second concerns the reinforcing bars themselves—these must be straightened slowly and steadily without any sharp kinks or notches. If not done properly, the projecting end of the bar may well snap off. While on the subject of bars which are cast in and are to be bent out later, the bar should have a bobtail. This anchors the bar and prevents it twisting round when being straightened. Without it the bar can turn and break bond with the concrete, particularly if it is a smooth, mild steel bar.

Also to be checked before concreting are all aspects of the reinforcement. In foundation work in particular, reinforcement is very heavy. The bars are large diameter and often quite long and may also be in rather odd shapes. It is necessary to check that the bar can be manhandled or, if not, that a crane or other suitable lifting gear is to be available. Prefabricated cages should not be constructed to such a size that they create a handling problem. The strength of cover blocks should be considered and more added if the weight of the assembled reinforcement is likely to crush them. Heavy top reinforcement is not uncommon in foundation work and has to be supported in place. Scaffold tube frames have been known to be built in to support such reinforcement but, of course, it cannot be taken out and, therefore, is left embedded in the concrete.

Large diameter bars cannot be bent for adjustment in situ—rather than having a fixed overall length determined by a hook or bobtail at each end, there should be two bars, each with a hook at one end, lapped for adjustment. To avoid congestion the laps must be staggered or spread about. The cage should be erected working from the bottom upwards and each layer should be carefully


Top of reinforcement at wrong level
Cage suspended from ground level – reinforcement at correct level.
Cover spacers cut into soft sides.
Well fitting cage inside neatly drilled shaft.
This spacer would probably have been knocked off.
Cage should not rest on bottom.
Chute
Flow of concrete
Casing
If no casing sides of shaft can be broken and mud inclusions result.
Mortar smeared on sides of shaft.
Reinforcement may be displaced.
Stones segregate
Stony segregated concrete
Eccentricity
Required centre line
Load
Bending
Tension cracks
There may well be some reinforcement in the pile but this will only cope with eccentricities as large as the specified tolerance.
Load
REMEDIAL WORKS
Pilecap and additional piles concentric with load.
Defective pile



checked as it is erected—access to the lower layers is not possible if a bar has been omitted once the successive layers have been constructed.

Congestion is commonplace in foundation reinforcement. A check should be made that the details being built will allow concrete to pass between the bars, followed by a vibrator. If this is overlooked problems may result. Vibrators may become trapped or poor compaction may leave weak, honeycombed concrete. Some congestion problems can be relieved by the use of couplers of which several types are available. One type depends on a tapering thread, cut on the bar, fitted into a tubular nut. The extension rod is screwed into the other end of the tubular nut. Another uses deformed bars (T-type bars with ribs rolled along their length) and swagged or squeeze-locked sockets on the ends of bars. A short threaded coupler is screwed into the sockets joining the bars together.

Clearly threads and sockets must be kept in good order. Of more importance, perhaps, is the fixing of bars so that the socket can be relocated. The nut or swagged socket is provided with a plastic cap or plug. This needs to be securely fitted into place to prevent grout entering the orifice. Next the plugged end of the bar is snuggly fitted up against the stopend formwork. One big advantage of this system is that these forms do not need to be drilled or cut to let the reinforcement pass through. Because the plastic plug is slightly domed, a square of expanded polystyrene should be sandwiched between the formwork and the bar. If forgotten, the end of the bar will be covered over with grout and lost from sight as the stopend formwork deflects under the load from the fresh concrete. The polystyrene often saves hours of tedious work hacking away with a cold chisel trying to find the hidden plastic caps! Where continuation bars cannot be turned to screw them on, the coupler is threaded opposite ways at each end so that when turned it screws itself into both sockets.

Concreting

In many foundation construction situations a high workability concrete mix needs to be designed and used. The design can be carried out using trial mixes and cubes for crushing by the concrete supplier. At early stages when foundations are being built, it is often more convenient to use readymixed concrete than to batch and mix on site. A regularly used mix is proportioned as follows:

Cement	not less than 400 kg/m^3
Water/cement ratio	not more than 0·6 [this will give high slump test values in the order of 175 mm]
Sand (well in the middle of Zone 2) Stone (10 and 20 mm sizes)	between 35–45% of total aggregate content rounded aggregate for preference

Therefore,

Cement	400 kg	per m^3
Water	200 litres	per m^3
Sand	700 kg	per m^3
Aggregate:		
(10 mm)	350 kg	per m^3
(20 mm)	710 kg	per m^3

Note: These figures are given for guidance only—all normal factors in concrete mix design should be considered.

The mix is not designed for characteristic strength (although the designer may have specified one), but is designed taking into account site requirements:

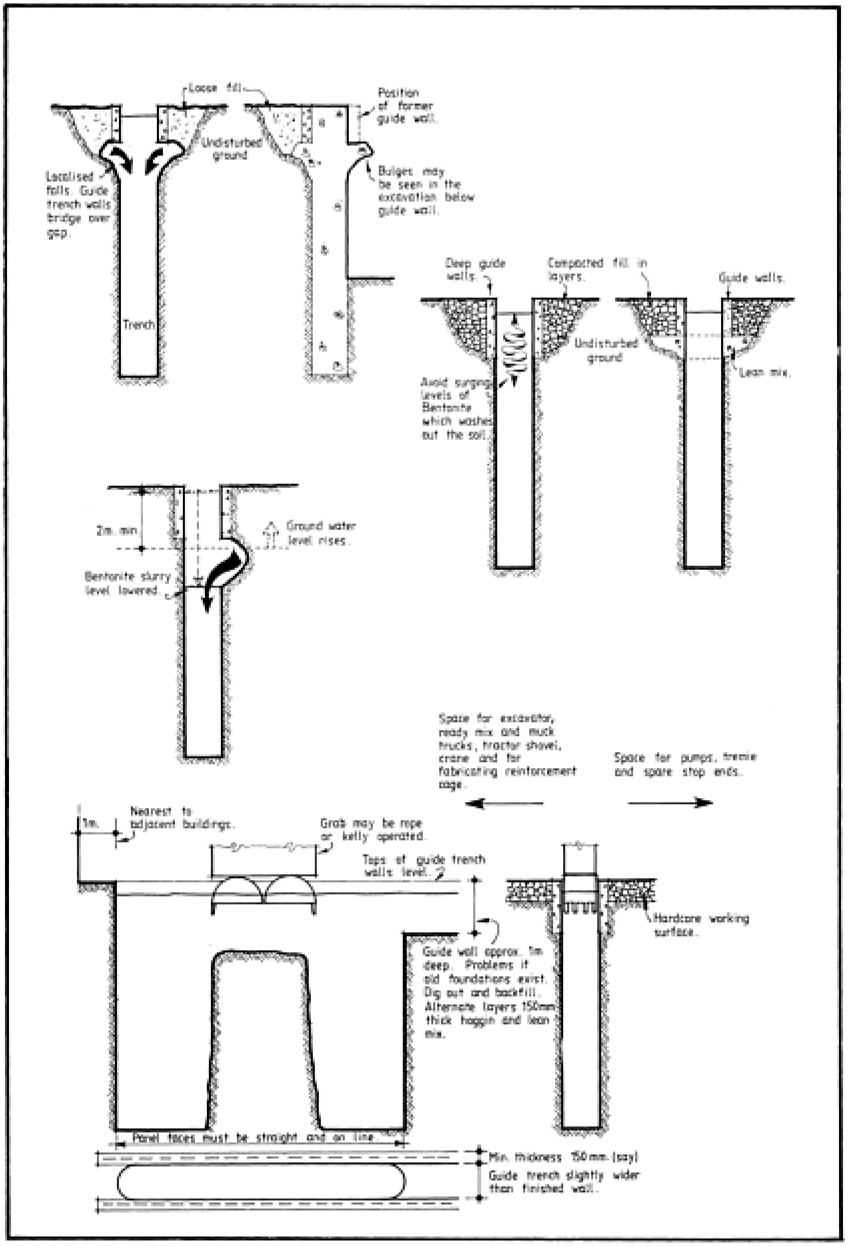
Workability	the ability to flow into the forms and engulf the reinforcement
Cohesion	remain cohesive even though it may have to travel up to 2 m from the point of placing
Bleed resistance	a well graded mix (including the cement particles) which resists water oozing through it and reduces the problems of plastic settlement and voids under reinforcement

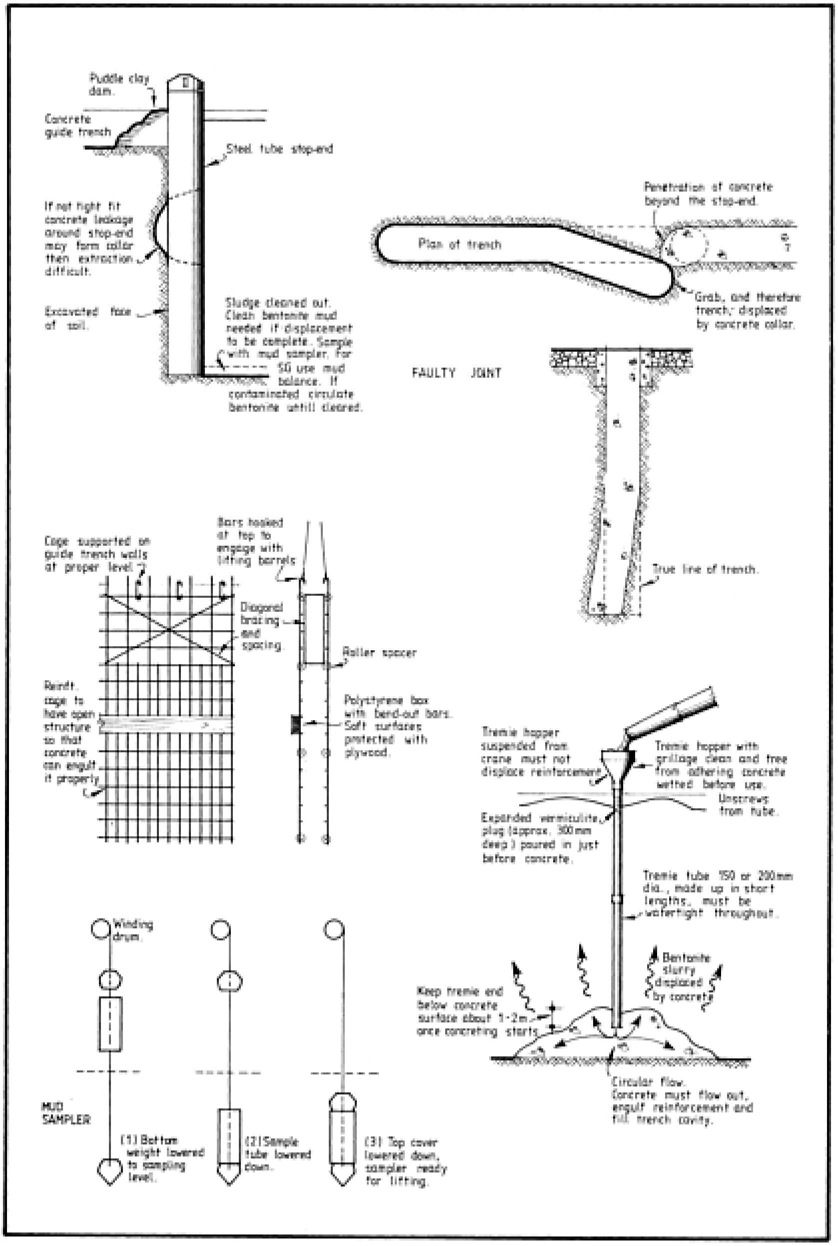
In actual fact the relatively high cement content necessary to produce the cement paste which gives the workability, also generates enough strength. A rather simple rule that each 10 kg of cement generates 1 N/mm^2 of cube strength will confirm that these mixes generally have ample strength. Such a mix as this will tolerate being dropped from great heights, provided that it is not allowed to bounce off the reinforcement and ricochet off the sides. Good practice will use a hopper and trunking and pour the fresh concrete into fresh concrete (except, of course, the very first batch). Concrete should not be allowed to slide down unprimed chutes and long chutes should not be used as the concrete sometimes segregates when it pours off the end. When trunking is used, care should be taken that the assembly does not fill up. When choked with concrete the trunking can become too heavy for the connecting chains, supports and so on, which may well become a safety hazard and break.

Good practice ensures that the concrete is placed just where it is needed. This is not always easy in foundation work, but can be controlled by restricting the flow of concrete with poker vibrators into difficult corners. The high workability concrete previously mentioned should be tolerant of being moved up to 2 m radially from its point of placing but this should be achieved under the concrete's own slumping effort rather than by driving it as a shallow layer over dry surfaces.

In all but the most difficult situations, concrete in foundations needs to be well compacted. Internal poker vibrations at about 500 mm centres, working in uncompacted concrete no deeper than the length of the metal casing of the vibrator, is probably the best and most common method of compacting foundation concrete. There is no real problem of over-vibration—the greater risk is of under-compaction if the rate of placing swamps the vibrator operator. Mass fill with concrete can be compacted if the job warrants it. Where substantial quantities of concrete are placed about rigid, large diameter reinforcement, some bleeding may occur and controlled revibration is beneficial. Any voids collapse and cracks caused by plastic settlement are closed. Providing the poker enters the still plastic concrete smoothly and can be withdrawn without leaving a hole, revibration is beneficial.

Extension of the mixing time, for instance where there has been a delay on site and the mixer truck has been churning away, is not in itself harmful. The principal problem will be that the concrete has considerably stiffened and may not be sufficiently workable for the job in hand. The problem now arises that if the batch is sent away, will there be a long delay before the next truck load arrives? If so, will this make matters worse by introducing cold joints, blocked hoppers or tremie pipes and so on? On the other hand, adding water to the stiffened mix and remixing is contrary to the specification. The hold up should never be caused by lack of preparation and, where possible, the batch should be redirected to and used somewhere else on site. Where delay is unavoidable, it is probably best to try the workability in a comparatively unimportant place, adding a little water (and it must be remembered that very little water is required to increase the workability), remixing for a couple of minutes and then continuing the pour. Contractually, the materials will still have to paid for with an additional charge for standing time. Where extra water is added, the receiver's signature will relieve the supplier of any responsibility for the quality of that batch. If the situation causing the original delay is not relieved, further deliveries should be cancelled and the concrete already delivered used wherever else possible on the site, as the batch is going to have to be paid for in any case. It is also very expensive to delay the truck unduly and incur extra costs for standing time.


Loose fill
Position of former guide wall.
Undisturbed ground
Localised falls. Guide trench walls bridge over gap.
Bulges may be seen in the excavation below guide wall.
Trench
Deep guide walls.
Compacted fill in layers.
Guide walls.
Undisturbed ground
Lean mix.
Avoid surging levels of Bentonite which washes out the soil.
2m. min
Ground water level rises.
Bentonite slurry level lowered.
Space for excavator, ready mix and muck trucks, tractor shovel, crane and for fabricating reinforcement cage.
Space for pumps, tremie and spare stop ends.
1m.
Nearest to adjacent buildings.
Grab may be rope or kelly operated.
Tops of guide trench walls level.
Hardcore working surface.
Guide wall approx. 1m deep. Problems if old foundations exist. Dig out and backfill. Alternate layers 150mm thick hoggin and lean mix.
Panel faces must be straight and on line.
Min. thickness 150mm. (say)
Guide trench slightly wider than finished wall.



Puddle clay dam.
Concrete guide trench
Steel tube stop-end
If not tight fit concrete leakage around stop-end may form collar then extraction difficult.
Excavated face of soil.
Sludge cleaned out. Clean bentonite mud needed if displacement to be complete. Sample with mud sampler. For SG use mud balance. If contaminated circulate bentonite until cleared.
Penetration of concrete beyond the stop-end.
Plan of trench
Grab, and therefore trench, displaced by concrete collar.
FAULTY JOINT
True line of trench.
Cage supported on guide trench walls at proper level
Bars hooked at top to engage with lifting barrels
Diagonal bracing and spacing.
Roller spacer
Reinft. cage to have open structure so that concrete can engulf it properly
Polystyrene box with bend-out bars. Soft surfaces protected with plywood.
Tremie hopper suspended from crane must not displace reinforcement
Tremie hopper with grillage clean and free from adhering concrete wetted before use.
Unscrews from tube.
Expanded vermiculite plug (approx. 300 mm deep) poured in just before concrete.
Tremie tube 150 or 200mm dia., made up in short lengths, must be watertight throughout.
Bentonite slurry displaced by concrete
Keep tremie end below concrete surface about 1-2m once concreting starts
Circular flow. Concrete must flow out, engulf reinforcement and fill trench cavity.
Winding drum.
MUD SAMPLER
(1) Bottom weight lowered to sampling level.
(2) Sample tube lowered down.
(3) Top cover lowered down, sampler ready for lifting.

Piling

Before the piling contractor arrives on site, the supervisor should ensure that the following general requirements are available:

1. suitable access to site;
2. a firm and level working platform;
3. basic setting out datum points and bench marks;
4. a place on site for their huts, with water, sanitation and, if possible, a telephone.

Before the piling contractor and equipment arrive, it is advisable to discuss and agree details. Much piling plant is heavy and will damage kerbs, paving slabs and so on, as well as buried services under the pavement, so that pavement crossings, where relevant, should be checked. It may be that a lean concrete mix or crossing sleeper access has already been constructed with dropped kerbs and an access gate for general site traffic, which may be wide enough for the piling plant. All access ramps must be in good condition, smooth surfaced and not too steep.

Piling is often carried out before the main excavation but a sound, clean working platform will be necessary for best results, upon which the piling rigs can stand without sinking or tilting. Piles are best driven or bored by one machine set up without constant adjustments being made when the machine sinks into mud or tilts, which will hinder satisfactory work. Moreover, when concrete is to be used for in situ piles, the readymix trucks will have to drive up to the shaft holes so that the speed of the whole operation will be markedly improved if a good, level and clean working platform has been provided.

Most piling needs to be set out piecemeal. Each pile position can be set out in moments from two base lines if the co-ordinates have been previously calculated. Two base lines, generally at right angles to each other and positioned down the sides of the site out of the way of construction operations, are used. The centre line of each row of piles is marked with a peg and nail. To set out a pile position, all that is necessary is to hook the ends of two tapes over the nail in the appropriate pegs, measure off the two centre line dimensions and where these meet is the pile centre. The two base lines are the responsibility of the main contractor. Temporary bench marks for levels will be needed so that ground level, pile base level and cut-off level can be determined. It is convenient to have several temporary bench marks so that there is never a need to go very far for a level. The best arrangement is an offcut of reinforcement driven into the ground and haunched round with a substantial concrete block. A dumper should be able to drive over it without disturbing the level. Pegs and such like often get disturbed and much time can be wasted checking datum before using the level.

With regard to statutory hutting, these may already have been set up by the main contractor, in which case the simplest arrangement is for the piling contractor to share. It is obviously going to waste time if workers have to leave the site for toilets or to find meals. A pay-phone is also an essential item on any site and a considerable saving on the telephone bill!

Precast piling should be inspected in the casting yard before delivery to site, upon arrival at site and before unloading, and again immediately prior to and during driving. The basic requirements of the drawings and specification need to be checked—size, length, type of concrete, curing time and maturity. Check also the stacking and handling stages. The supplier can advise on stacking but if in doubt, support the pile below the lifting points, care being taken to line the timber packing pieces directly above each other. From a safety point of view the stack should not overload the ground, nor be allowed to lean over. Again the supplier can usually advise on handling, but the shaft is normally picked up at points one-fifth of the pile length from each end. When handling piles, the movements need to be smooth and easy. A jerky movement can cause the pile to crack or even break. Examination of the pile should show an even section, well compacted concrete, no spalls or other obvious damage. Although it is almost inevitable that the concrete will have cracked, a close examination would be required to find these cracks, which will be barely visible hairline cracks. Such cracks will not make the pile imperfect, but any more substantial cracks will need to be brought to the attention of the supplier and the pile will probably need to be rejected.

Considerable care is required when loading piles onto delivery trucks as the pile will be damaged if it is allowed to bounce during travel. The shaft must be supported on bearers below the lifting points and the whole load securely lashed down. The load should be re-examined prior to off-loading and on site and any damaged piles should be rejected. Restacking on site needs to be carried out with the same care and attention as in the yard. It may be necessary to have and use a lifting beam, particularly if the pile is long and it has been necessary to handle it in this way in the supplier's yard. Pitching is often done using only the top lifting point, but where the crane has two independent winch drums the pile can be picked up by both lifting points and turned point down in mid air. This procedure will probably be necessary with very long piles, particularly in tidal water working.

There are many publications which discuss the theory of pile driving and an effort should be made to read and understand this basic theory—without this background information, pile driving can be compared to driving a car without having read the Highway Code—it can be done, but…!

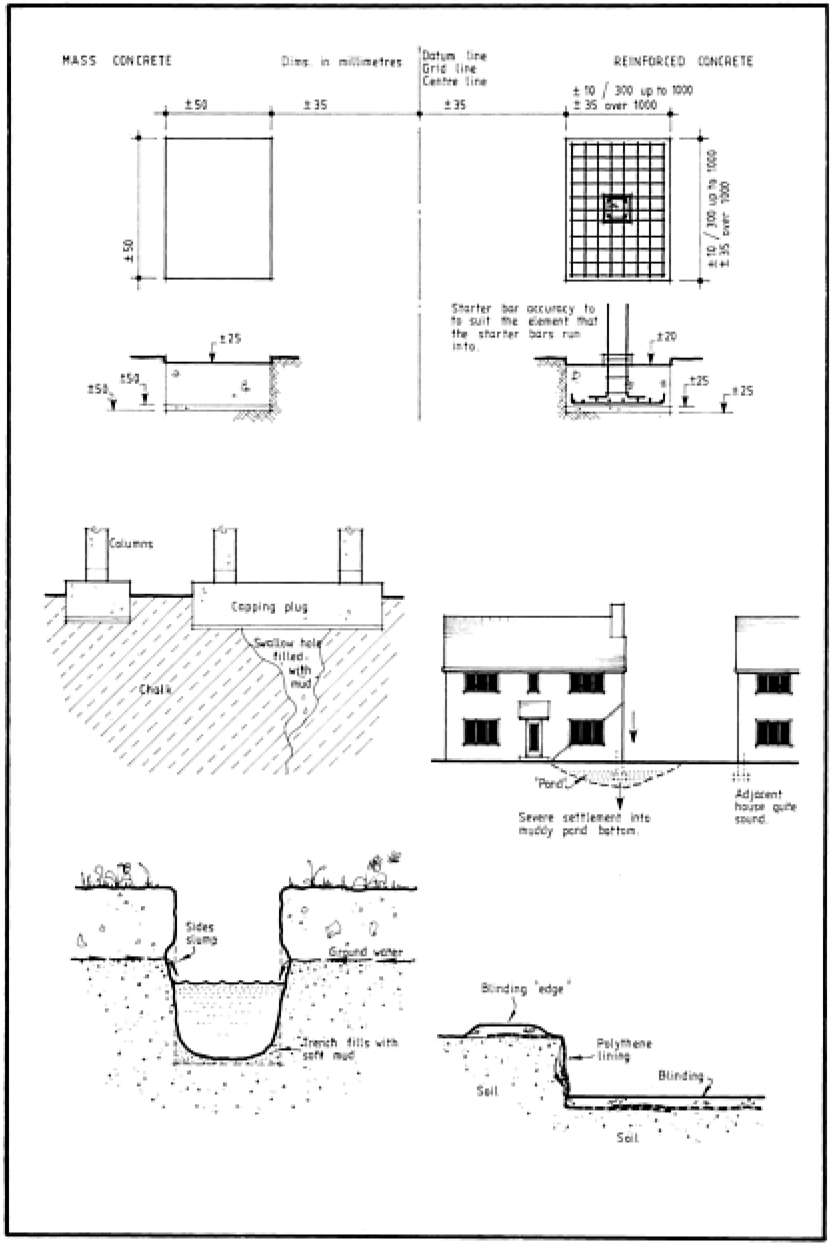
Two essential features cannot be ignored:

1. *The heavier the hammer the greater its efficiency*

   This relationship holds good however the hammer is operated, whether lifted by steam, compressed air, diesel expansion or rope. The hammer should not normally weigh less than the pile it is driving. A light hammer, weighing perhaps half the pile weight, uses up all its energy bouncing off the top of the pile, the penetration per blow becoming smaller and smaller until no progress is made. The energy thus being applied to the pile is actually destroying the pile instead of driving it.

2. *Never consider that a lack of energy can be overcome by an increase in hammer drop*

   The driving impact creates shock waves which travel down the pile and are reflected at the end of the pile. The reflected wave will be *compressive* if the pile stands on firm soil, and *tensile* if the pile stands on soft soil.



The magnitude of tensile or compressive stress (load divided by area), is in direct proportion to the length of hammer drop. The greater the drop, the bigger the stress. When a large hammer drop is accidentally used, the pile will shatter (in compression) on hard ground, or will be torn apart (in tension) when the pile breaks through the stiff driving into the softer stratum. Normal hammer drop is about 500–600 mm but can be reduced for soft driving to 300–400 mm, although the maximum hammer drop is generally about 1500 mm.

Ensure that the driving helmet is the correct fit, that the packing is in good condition and the hammer blows are delivered axially (i.e. not off to one side nor at an angle) to the head of the pile. Driving will commence with 150–200 mm of softwood packing in 25 mm layers and this packing must be renewed for each pile to be driven. If the pile head is cracking up while being driven with a correctly fitted end dolly (timber or plastic packing), there is a strong possibility that the pile may be breaking up below ground also. Either too light a hammer is being used or continuous driving with sets of 1–2 mm are the cause of the problem.

A useful safety motto for piling is the five W's:

WEAR HELMETS
WEAR EAR MUFFS
WEAR GOGGLES OR SAFETY GLASSES
WEAR SAFETY SHOES OR BOOTS
WEAR GLOVES (a dolly can catch fire during driving because it becomes so hot)

Bored piling is another matter altogether. The majority of cast-in-situ bored piles cannot be inspected after they have been installed. They can be tested but not inspected, so that supervision at all stages is vital to ensure the integrity of the pile. These piles are installed by length or to a recognisable stratum. When length is specified, it is probable that the pile is a "friction" pile. It must be obvious that the sides of the shaft should be sound and uncontaminated so that "friction" can develop. Where a recognisable stratum is specified, the pile is probably an end-bearing pile, when the emphasis is on obtaining the best contact between the end of the pile shaft and the bearing stratum. No loose or soft material can be allowed to intervene. Because many sites have been used before, there may be buried obstructions such as old foundations, rubble filled cellars, old wells and such like. Nearly all bored piling operations will be hindered and stopped by such obstructions so that it is wise to carefully review the situation prior to commencement of piling and, if necessary, employ a contractor to dig down, remove the obstruction at the pile position and backfill with suitable material such as hoggin. Although not all obstructions may be cleared, the situation will have been considerably eased and substantial delays avoided. Disused pipe runs, for instance, have caused a number of embarassing situations. When cut by the piling operator, no very obvious signs can be seen (unless someone very diligent spots the broken pieces of pipe), but later, when the shaft is filled with liquid concrete, this can be forced down the pipe by the concrete head, emerging in the sewer. If the seep of concrete is not very quickly washed away by the flow in the sewer, the concrete sets, causing a blockage which can be very difficult to shift. The Authority responsible for the sewer will almost certainly require recompense for the work involved in clearing the blocked sewer.

Where the ground is dug out and backfilled, the backfilling chosen must suit the piling system involved. Casing will probably be needed through the lightly compacted hoggin fill. This will be quite acceptable for piling systems which can use casing, but would be quite unsuitable for short bored piles, for instance, which are only used in clay soils and never use casing during boring. In this instance the backfill would need to contain sufficient binder, such as clay or cement, to make the fill self-supporting. An alternative would be to install expendable casing at each pile position before backfilling and drill the piles through these sleeves. Waxed cardboard tube, polythene or concrete pipe sections may all be suitable.

Since many bored piles involve a rotating auger, it is necessary to check at the start of each pile that the rotation does not displace the auger point off the pile centre. Once the auger or drill is well started it will generally be sufficient to observe that the kelly bar is perpendicular. Only if an obstruction is met, or a considerable change in soil density occurs to one side of the shaft, will the auger be deflected. Piles deliberately drilled at a “rake” need to be checked with a try-square frequently. If the raked pile is seriously deviating it may become necessary to case the shaft to keep to line, or possibly pour sufficient lean mix concrete into the shaft to stop the deviation worsening.

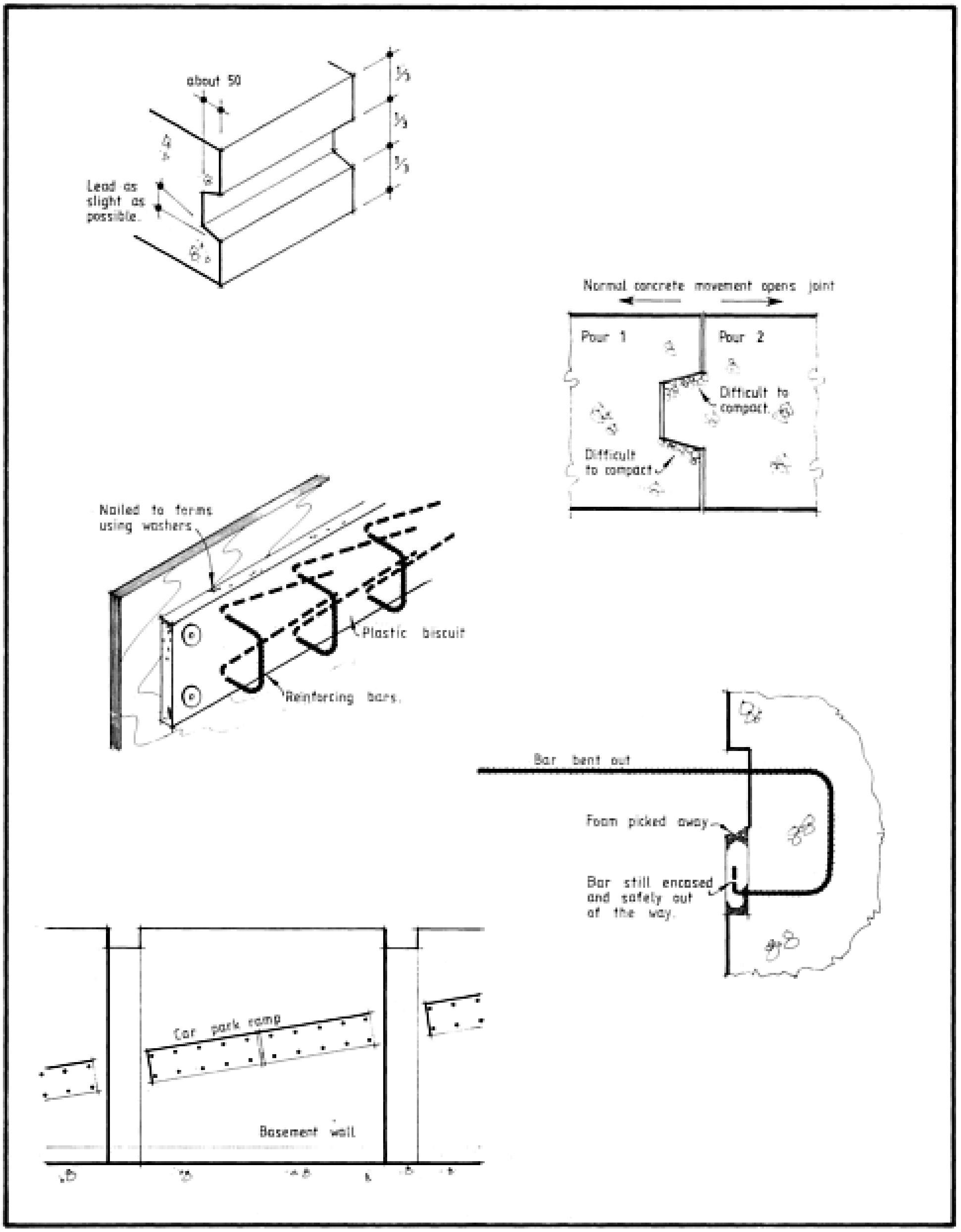
In some piling systems it is practice to add water while drilling. A short technical discussion with the piling engineer will rapidly establish whether this is necessary on a particular job. A short note concerning the discussion, circulated to appropriate personnel, helps to establish the circumstances when water may be added. Any departure can then be queried legitimately and the practice stopped.

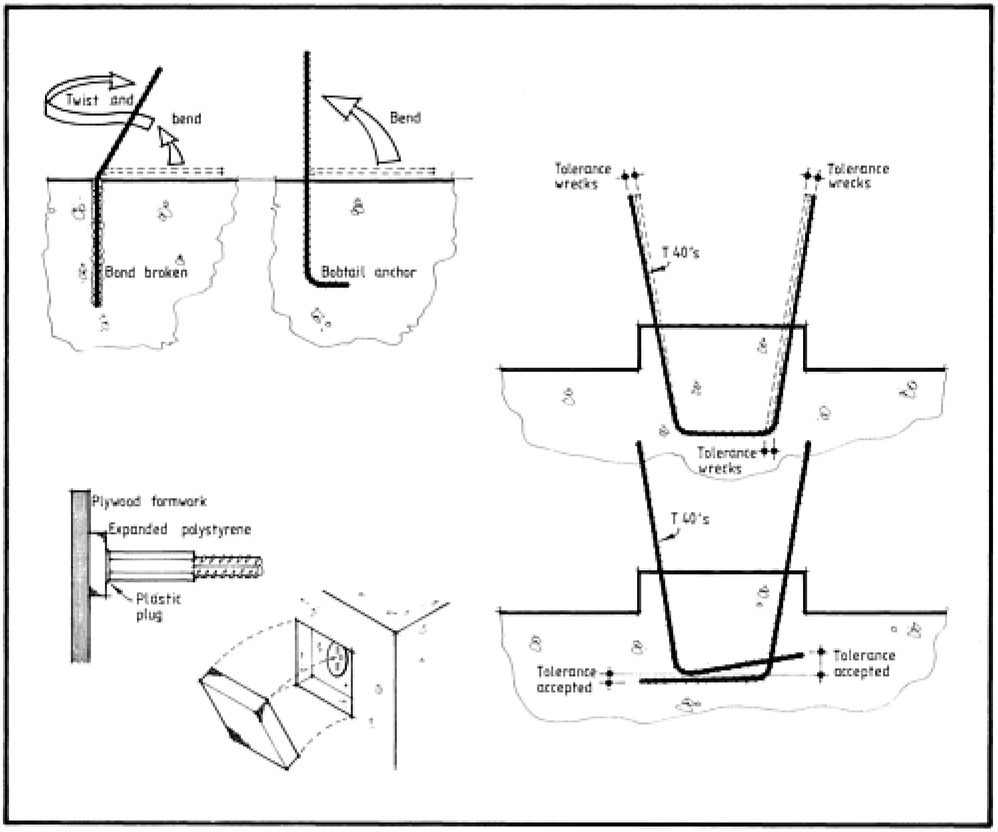
When the bore is complete the adjacent ground level should be checked. Measurement should be taken of the shaft depth in several places to ensure that the bottom is squared off and clear of any loose muck. The tape should be examined when pulled back up—unless the shaft is flooded and concrete is to be placed underwater, the tape weight should be clean and dry. It may be necessary to ask the driller to have another twirl at the bottom. If the pile is end-bearing it will be necessary to penetrate through any weathered surface on the bearing stratum. Moreover, it will be necessary to ensure that the correct level has been reached and samples from the end of the bore will assist here.

The reinforcement cage will have been assembled while drilling was going on. The number, type and size of longitudinal bars must be checked. The binding helical bars, pitch size and type must also be checked. If the reinforcement is lapped, ensure that the lap is well held together by ties of tack welding. Cover spacers will be clipped onto the binding bars, which can only locate a well fitting cage inside a neatly drilled shaft. If the cage or shaft are poorly shaped, cover spacers are either knocked off when inserting the cage or cut into the soft soil sides and insufficient cover results.

As the driller approaches the base of the shaft the concrete must be ordered so that there is a minimum of delay between drilling, approval, hanging the reinforcement cage in the shaft and concreting. If a delay should occur, be sure to remeasure the shaft depth prior to concreting as water and/or sludge have been known to seep into unfilled shafts. When the concrete arrives the site should be ready for it. There should be no panic and no yawns after a long wait. The same highly workable mix already mentioned for foundation work is frequently used in bored piling because it is nearly impossible to compact it otherwise. Poker vibrators are impractical for several reasons, but mainly because such a quantity of concrete is poured down the shaft at any one time that the vibrator would become swamped.

Regarding workability, a fair idea of the workability of the mix being delivered on site can be obtained by


about 50
Lead as slight as possible.
Normal concrete movement opens joint
Pour 1
Pour 2
Difficult to compact.
Difficult to compact.
Nailed to forms using washers.
Plastic biscuit
Reinforcing bars.
Bar bent out
Foam picked away.
Bar still encased and safely out of the way.
Car park ramp
Basement wall



listening to the "slush" of the concrete as the drum revolves. In the early days on site, it is sensible to have some of the mix poured into a wheelbarrow so that flow can be assessed—if it is lumpy or runny (it may be necessary to take a slump test and/or make cubes), and so that cohesion and bleeding can be noted. The mix will need to hang together or have good cohesion as it flops down the shaft. If the mix bleeds, several problems can occur and if the surface of the wheelbarrow full of concrete is swimming with water soon after discharge, you have a bleeding concrete. If the concrete is discharged with lumps of cement and sand about the size of a coconut, it is probably due to the blades of the mixer truck being worn and working inefficiently. Record the number of the truck and check it again when it returns with another load. If the lumps are still evident contact the supplier and ask for the truck to be replaced, refusing to accept further loads from that particular truck. Lumpy concrete causes several problems and the risks should not be tolerated.

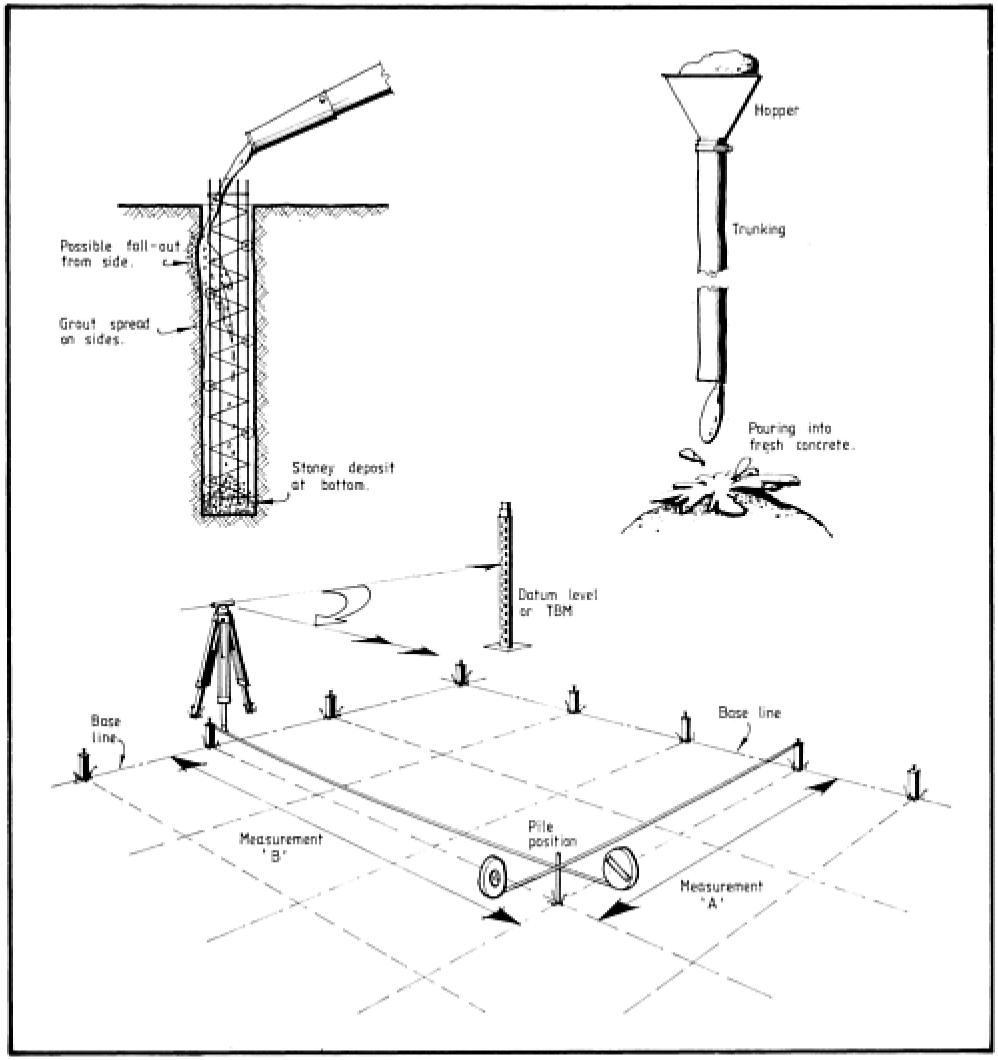
It should be possible during installation to ensure that the piling does not become out of tolerance. This is certainly the best time to discover that a pile is out of place or verticality because additional piles can be installed with the minimum of fuss. However, only too often tolerance checking is left until the main contractor is starting to build the pile caps, which is far too late because if additional piles are required, the piling contractor will have to return to site, and it may not be possible to install the original type of pile because of new construction preventing access.

Generally speaking, the designer would not expect a pile to take bending. An out of place pile will have eccentric loading which can cause bending. Tolerances are recommended as follows:

Position: Permitted deviation of pile centre from centre point shown on setting out drawing— 75 mm in any direction
Verticality: Permitted deviation 1 in 75
Rake: Permitted deviation of finished pile from specified rake is 1 in 25
Forcible corrections *should not* be made to concrete piles.

Diaphragm wall construction

The diaphragm process is a method of constructing loadbearing walls in the ground before making the main excavation. It is based on the use of bentonite mud slurry to hold open the excavation until concrete has been



placed. The technique is of special value in built up areas where other methods of piling and trenching are ruled out by access and noise restrictions; and a wall with high structural efficiency and few joints is required. The site needs to be levelled and a sound firm working surface prepared. Guide trenches are excavated and their sides lined with concrete. It is important that these guide trenches are built true to line, level and width, because the following work relies on their setting out.

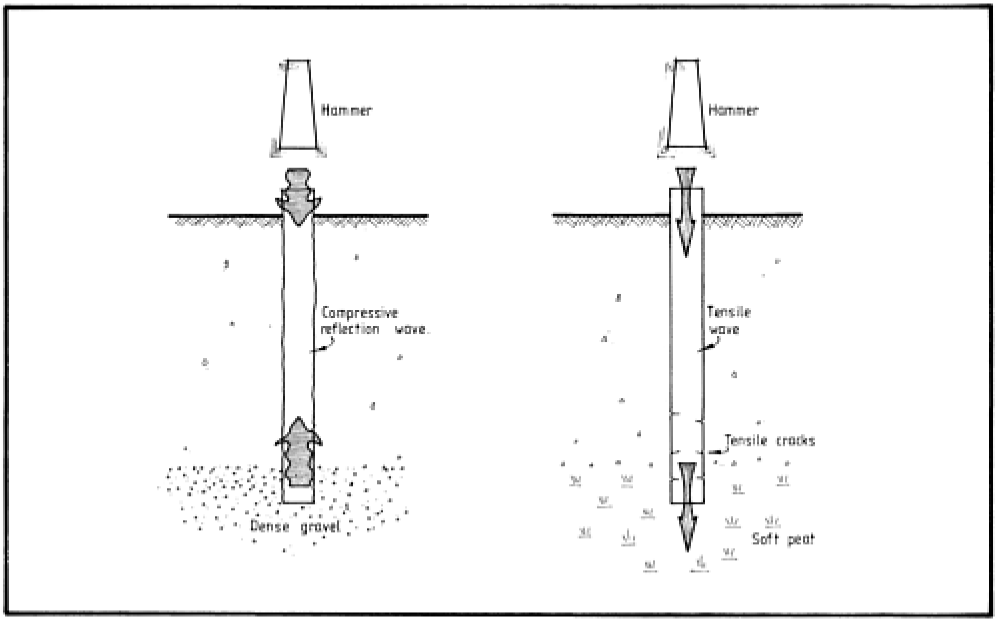
Bentonite is a clay rock largely comprising the mineral sodium montmorillonite. When in contact with water it has a characteristic ability to swell to many times its dry volume, resulting in suspensions of jelly-like consistency which, when stirred, become fluid. But when allowed to stand, revert to jelly form. This property is known as *thixotropy*. The four properties of bentonite/water suspension which are used in civil engineering are: lubricity, plastering or sealing ability, thickening and gelling. Bentonite is a free flowing, non-irritant, non-corrosive powder. It is generally available in 25 or 50 kg bags or may be delivered in bulk where suitable storage facilities, such as a silo, are available on site.

The mud-plant area may be 30 m^2 or smaller, depending on the size of the job and will contain a bentonite silo, water tanks, weighing and metering facilities, mud mixer, several storage tanks, de-sanding machinery and pumps. Hutting will also be required. Access will be necessary for bulk deliveries of bentonite and for removal of the "spent" mud at the end of operations. A water supply will be required and either electricity or compressed air, although much of the machinery will have its own independent power pack.

The bentonite mud is fed into a chosen length of guide trench, which often acts as a small reservoir for the mud. Excavation is done using either Kelly grabs or ropeoperated grabs. There are other techniques, but these are the two most common. The excavated soil is loaded into lorries for disposal. During the excavation the bentonite mud becomes contaminated with sand, silt and possibly soil minerals. As the panel excavation deepens, so more bentonite mud must be pumped in to maintain the mud level. If the mud level drops below the bottom of the guide trench walls, the surge and suck of the mud as the grab moves in and out for excavation can cause undermining of the soil which will later result in bulbs of concrete on the face of the finished wall.

Either before or during the excavation, the cage of reinforcement must be assembled. Structural design and detail of reinforcement will already have been done. If the cage weighs less than about 55 kg/m^3 of concrete in the wall, additional steel may have to be used to give necessary stiffness for handling and lifting the finished cage. In any event, check that there is firm bracing both within the thickness of the panel and along its length. It is customary to use tack welding in the cage assembly. If the cage weighs more than 110 kg/m^3 of concrete in the wall, difficulty may be experienced because of the closeness of the reinforcement. Congested reinforcement may be opened out by "bundling" bars together, although pairs are only generally acceptable (bundles of 3 or 4 bars should only be used after full agreement between all parties concerned). At any place where there is congested reinforcement there will be the unseen danger that the concrete will not engulf the reinforcement properly. Roller spacers are needed on both faces of the cage, and need to be of generous width. Rollers with too narrow a face cut into the trench sides. There may be a need for boxing out, for example, to provide a chase into which the basement slab can be cast. The box out must be stoutly constructed using expanded polystyrene core covered with thin plywood, securely fixed in place to the reinforcement cage. A generous margin oversize is needed since the box out will be located remotely by hanging the completed cage inside the excavated panel trench. Give thought to how the fluid concrete will flow around the box and chamfer to improve flow.

The finished cage may be 30 m deep, 8 m wide and weigh many tonnes. It should be lifted and tilted so that it remains as straight and plane as possible and should not be "rolled" by lifting at one end only. Safety measures should be applied at all times, particularly during cage lifting and handling. The cage is lowered into the panel trench and hung inside it at the correct level. The cage should hang and *should not* rest on the bottom because the shape will otherwise become buckled and distorted. Depending on the length of the panel, one or more tremie pipes, with their hoppers, should be used. Concrete should not be expected to flow evenly more than about 2 m horizontally, especially against a stopend or construction joint between panels. The tremie pipes should be clean inside (i.e. free from hardened grout and such like), and should have watertight joints. In the same way, the hopper must be clean, large enough that it does not overflow if there is a surge of wet concrete, and preferably have a grillage inside for safety. Before pouring, the hopper should be rinsed with clean water, and a plug



about 300 mm deep of expanded vermiculite poured down the tremie to rest on top of the bentonite mud filling the pipe. This will be near the top of the tremie and can be clearly seen and checked.

Desirable proportions of the concrete mix are tabulated in Table 11.1. The principal property is *fluidity and pourability*. The mix should be highly workable, cohesive, possess adequate strength, not stiffen too quickly and not bleed, and is usually readymixed concrete. Large quantities are often required so that the supply must be steady, reliable and quick. Two common problems are too stiff a mixture (low slump) or lumps in the mixture (usually caused by incorrect materials—charging sequence and worn truck mixer blades). In the first case, with too stiff a mix, extra water is often added on site and a limited period of remixing allowed. Because of the haphazard

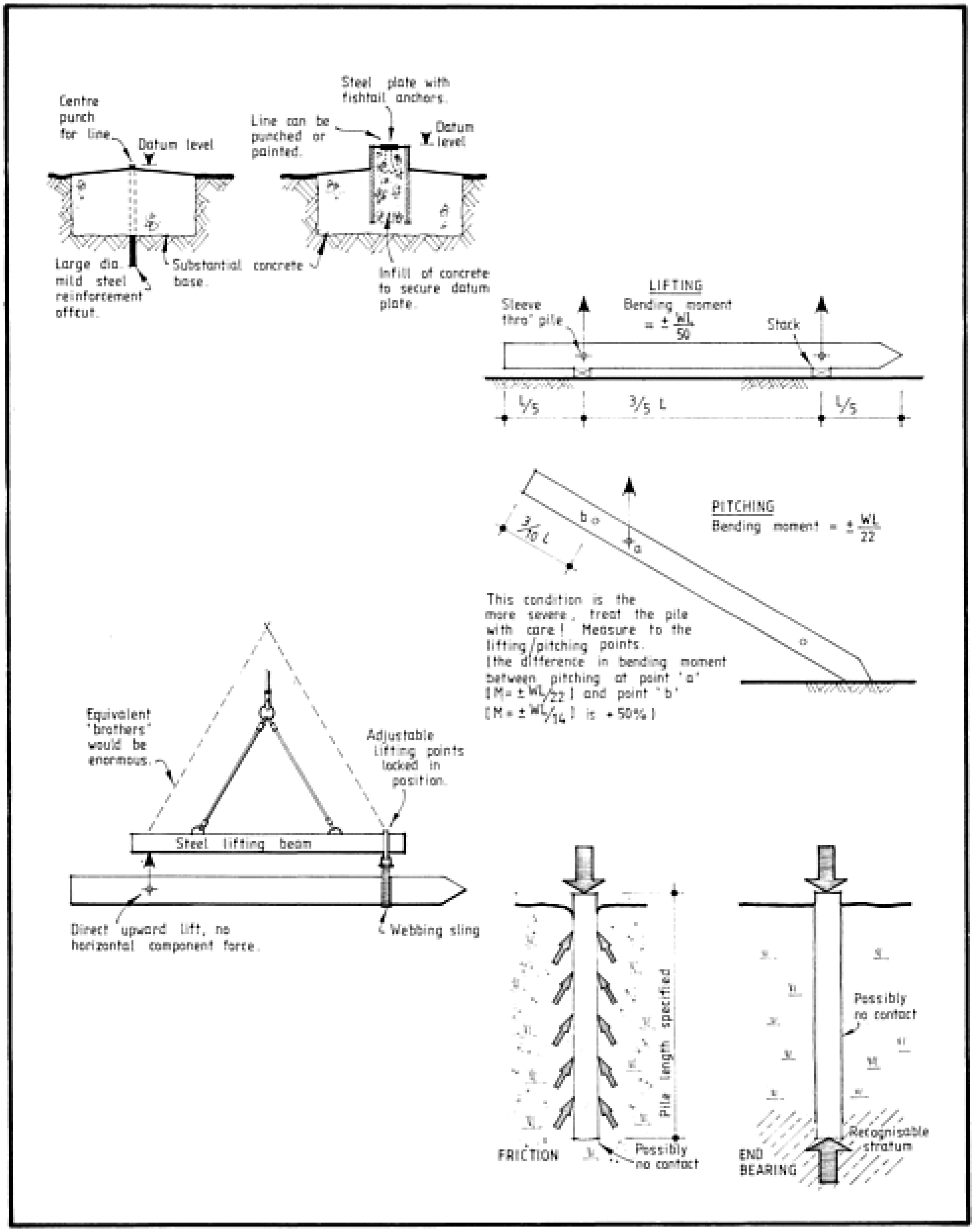


TABLE 11.1
Suggested concrete mix for use in diaphragm walls

Slump	150–200 mm
Water/cement ratio	Below 0·6

Aggregate	Natural rounded stone if possible—20 mm diameter maximum size
Sand type	Natural sand, Zone 2 or 3 grade
Sand content	35–45% of total aggregate weight
Cement content	Not less than 400 kg/m^3 of OPC or SRPC
Hence, trial mix proportions might be:	
Cement	about 400 kg/m^3
Water	about 250 litres/m^3
Sand	about 690 kg/m^3
Aggregate 10 mm	about 360 kg/m^3
20 mm	about 670 kg/m^3
If sand at 6% moisture content, then water about 200 litres/m^3	
The use of plasticisers is recommended, which can include air-entraining agents. Retarders may be used if necessary.	

nature of this operation, it should not be encouraged. With lumpy concrete, remixing rarely breaks up the lumps and it may be necessary to reject the load. In severe cases, the distribution within the finished concrete of fine aggregate and cement is erratic with corresponding effects on the quality of the concrete. There is also a possibility of a blockage in the tremie pipe, although this is prevented if the tremie hopper has a grillage fitted.

Before the concrete is poured, it is wise to have a last check that all is ready:

Is the reinforcement cage the right way round?
Are the necessary box outs in place?
Are line and levels satisfactory?
Has the trench been cleared of soft, sludgy soil which collects at the bottom of the panel?
Has the bentonite the right density?
[If the bentonite has too high a density or is contaminated, it will be difficult to displace it properly with concrete]
Are there suitable pumps, and so on, for removing displaced bentonite?
Has the right concrete mix been ordered and in adequate quantity?

Once concreting commences, a point of no return is reached. Concreting must proceed steadily uninterrupted until the panel is full, the reinforcement fully engulfed, and all the bentonite displaced. There will be a surface layer of cement-bentonite sludge which is chipped away later.

Joints between panels are generally formed in the female panel with a steel-tubular-stopend former. These should be withdrawn as soon as conveniently possible as they occassionally become stuck and cause delay.

If the checkpoints are followed, the contract has a share of good luck with weather and ground encountered when excavating, then the wall to be exposed by the bulk basement dug will be strong, sound, plane and will give satisfaction.

One final world: Concrete test cubes will be made and tested. If the test results fail to measure up to the standards set, what can be done? Certainly nothing very inexpensively! So, check and be as sure as possible that things do not have a chance to go wrong.

Points of supervision

Footings and foundations

1. Confirm soil.
2. Ensure adjacent buildings, roads, drains and works are safe—this may require underpinning or shoring.
3. Storm, surface and subsoil water must be drained away to prevent damage and nuisance.
4. Timber supports are needed to sides of trenches and holes deeper than waist-height if hole will be entered by persons.
5. Consider, report and seek instruction if the foundation is unusually shallow or if tree roots are found at bearing level.
6. When working in frosty weather be aware of the effects of frozen ground.
7. When sulphate attack is possible, check mix water and cement content throughout the pour.
8. When sulphate attack is possible, pay particular attention to compacting the concrete, especially in the "cover zone".
9. When building in peaty soil or waste material, do not neglect the specified protection. This may include special cements and bituminous or plasting sheeting wrapped around the buried concrete and laid below floors.
10. Check if the excavation needs lining and that the edges are protected from being broken down.
11. Check blinding.
12. Formwork, particularly stopends, must be correctly positioned and removable without damage to projecting reinforcement.
13. If reinforcement bars cannot be manhandled ensure necessary lifting equipment available.
14. Ensure sufficient support for whole steel assembly.
15. Lap bars for adjustment—stagger these to avoid congestion.
16. Ensure sufficient space between bars.
17. Where couplers are used, prevent grout clogging the sockets. Sockets should be visible when the formwork is struck and threads protected.
18. Determine and check allowable tolerances.

Concreting

1. Ensure mix is cohesive, workable and non-bleeding.
2. Ensure necessities of placing, compacting, finishing and curing are in place and that they will be satisfactory.

Piling

1. Ensure satisfactory access to site, working platform, setting out datums, hutting and telephone.
2. Confirm basic requirements of drawings and specification, size, length, type of concrete, reinforcement, maturity, and so on.
3. Examine piles for damage before loading, on arrival at site and before driving.
4. Calculate hammer weight necessary and control hammer drop height—especially when driving in mixed stiff and soft soils.

5. If the pile shatters, check: (i) packing; (ii) fit of helmet; (iii) accuracy with which hammer strikes the head of the pile.
6. Confirm whether pile is "friction" or "end-bearing".
7. Remove all obstructions, plug disused pipes at sewer if possible.
8. Bore hole should start in exactly correct position and boring proceed in a tidy and accurate manner.
9. Measure ground level near shaft and bore depth, ensure shaft is neat and clean/dry at the base.
10. Check reinforcement cage.
11. Check concrete ordered.
12. Check concrete placing.

Diaphragm wall construction

1. Guide trench.
2. Adequate plant area.
3. Efficiency of mud reduced if over-contaminated.
4. Adequate level of mud.
5. Reinforcement cage.
6. Box outs.
7. Handling and placing cage, and safety control.
8. Tremie and hopper sound and ready.
9. Suitable mix of concrete properly made.
10. Trench cleaned out.
11. Bentonite density correct.
12. All other matters in order and prepared.

12.
Falsework and temporary works

Definition

Falsework is by definition "any temporary structure used to support a permanent structure while it is not selfsupporting". The term *temporary works* covers a wide range of interesting processes, including dewatering, piling, excavation, shoring, access scaffolding, pipe jacking, bridging and so on.

Even the relatively simple working platform or platform for access and support of concrete construction may require a considerable amount of preparatory work in the ground such as the provision of foundations, shoring, coffer dams, trenching and similar. The supervisor's initial contact with temporary works often occurs at the commencement of construction in the ground where possibly ground beams and pile caps are constructed within a piled area or within a coffer dam in marine working. In these instances, and in the case of retaining walls, the concrete construction will be closely tied to the removal and replacement of horizontal shoring members. There is always some hazardous element in these situations and the supervisor must have a clear understanding of the work and must liaise closely with the appropriate specialists to ensure that gainful, safe working can be carried out by his team. The concrete supervisor will, therefore, require a working knowledge of the principles involved and their impact on his particular task. He will be working in conjunction with specialist suppliers and constructors and is dependent upon these people for access and support for his concrete construction operations. Close co-operation is also required with the supervising engineer, section engineer or the person responsible for the overall construction operation. Of course, where work is carried out in excavations and where water tables are high, there are exceptional problems in ensuring satisfactory working conditions for those concerned with formwork, steel fixing and concreting.

Statutory requirements

Site safety officers, representatives and management are governed by statutory safety requirements and the supervisor should acquaint himself with the requirements of the *Construction (General Provisions) Regulations,* 1961, and *Construction (Working Places) Regulations,* 1966, which deal with access, excavation, shafts, tunnels, coffer dams, caissons, use of explosives, work in, on or adjacent to water, scaffolding, working platforms and so on. As discussed in Chapter 4: *Safety and health in the construction process,* it is helpful if the supervisor can bear in mind the rights of the operative regarding safe methods and safe places of work and safety of fellow workers.

A number of problems have arisen in construction where shores, struts, guys and the like, have been removed temporarily to provide access or to ease work, and have not been properly replaced. The supervisor should ensure that such activities are carried out only on the advice of some responsible person with knowledge and expertise in the design of the temporary works and who is capable of predicting the outcome of such an alteration.

The falsework co-ordinator

Largely as a result of the *Bragg Report on Falsework,* a Code of Practice, BS 5975: 1982, has been produced. Amongst the recommendations contained in this Code is the appointment of a *falsework co-ordinator*. The supervisor is most likely to become concerned with temporary works which provide access, support or a working platform and in all cases will work closely with the appointed falsework co-ordinator. The duties of the falsework co-ordinator, as outlined in BS 5975, include the allocation of responsibility, ensuring that a design brief has been established and that the resulting design is independently checked. Further duties include maintaining communication between all concerned with formwork and checking work during construction, prior to loading and in use. Extremely important points relate to changes in materials used or construction processes employed, and the inspection and maintenance of the falsework. The falsework co-ordinator will also be responsible for issuing formal permission to load falsework and, when the permanent structure has attained adequate strength, issuing formal permission to dismantle and remove falsework.

Falsework is devised to accommodate specific methods of placement and sequence of operations and it must be remembered that variations in these arrangements lead to altered loading conditions and may perhaps result in dire consequences. The Code recommends particular attention to selection and use of proprietary adjustable props with reference to the way in which they are loaded, laced, braced and tied, with special attention being given to the footings and foundations upon which they are based.

Much of the material used in falsework, as in formwork, has already been used in previous contracts or is sent to site from the contractor's yard, and the Code strongly recommends careful inspection prior to use. Whilst exposure, wind and weather have always been a feature of formwork operations, the Code quantifies wind forces as well as the forces on falsework resulting from flowing water, snow, ice and other similar natural phenomena.

Loading

Considerable accent is placed upon the application of load to the falsework, especially forces arising from plant and equipment used in handling the concrete. Mention is made of surge and impact from concrete placement—two aspects which can dramatically increase the forces imposed on both falsework and formwork and which can, of course, result in changes in the direction of the forces within the temporary structure, causing sideways displacement or uplift.

Whereas formwork is used to support fresh concrete, falsework may support formwork, precast concrete, steel bridge sections or a variety of other materials. The supervisor must, therefore, ensure that he communicates with the person responsible, the person who has the experience or the required technical knowledge, to advise the safest method. Consultation with specialist suppliers or sub-contractors should be carried out in liaison with the falsework co-ordinator. The supervisor should not only be aware of changes in method and loading conditions during the course of the work, but should also be alert to changes in conditions. Ground conditions, for example, change radically during the transition between freezing and thawing, and changes in the flow of a stream overnight can result in scour and erosion, undermining the supporting system.

There are a number of positive steps which can be taken by the supervisor to ensure safety of those concerned with work in or about a temporary works structure. Distinctly different problems arise from those associated with the normal process of building construction where, for example, work is carried out in a repetitive programme, each set up being founded on previously cast concrete floors, columns or beams. Firstly, he should study BS 5975: 1982: *Falsework,* and should achieve an understanding of the key factors upon which the temporary works design was based. *Appendix J* of BS 5975 relating to forces from concrete on sloping soffits is perhaps one of the most important sections. This Appendix examines the way in which the forces resulting from the mass of concrete are influenced by the shape of that mass, and underlines the importance of identifying the direction of those forces and containing them by propping or ties. An interesting point concerns the change in load pattern between fresh concrete on a sloping face and hardened concrete on a sloping face. The fresh concrete generates pressures which, provided the sides are suitably braced or tied, cancel each other and simply result in a vertical load on the formwork and supports. Hardened concrete, on the other hand, depending on the degree of friction developing at the interface with the formwork, introduces sideways forces on the falsework and supporting system. The development of these forces, however, is subject to the movement of the concrete and, as the friction between the concrete and form is normally sufficient to prevent the movement, there is no problem. This situation is illustrated in Figure 10 of the Code (reproduced here by kind permission of BSI). It is particularly interesting, illustrating as it does the typical force combinations on hypothetical formwork and as such illustrates those aspects which must be considered. If the concrete were a precast element being loaded onto the supports, the designer would have to incorporate appropriate bracing and restraint against movement of the block and supporting work.

Supports

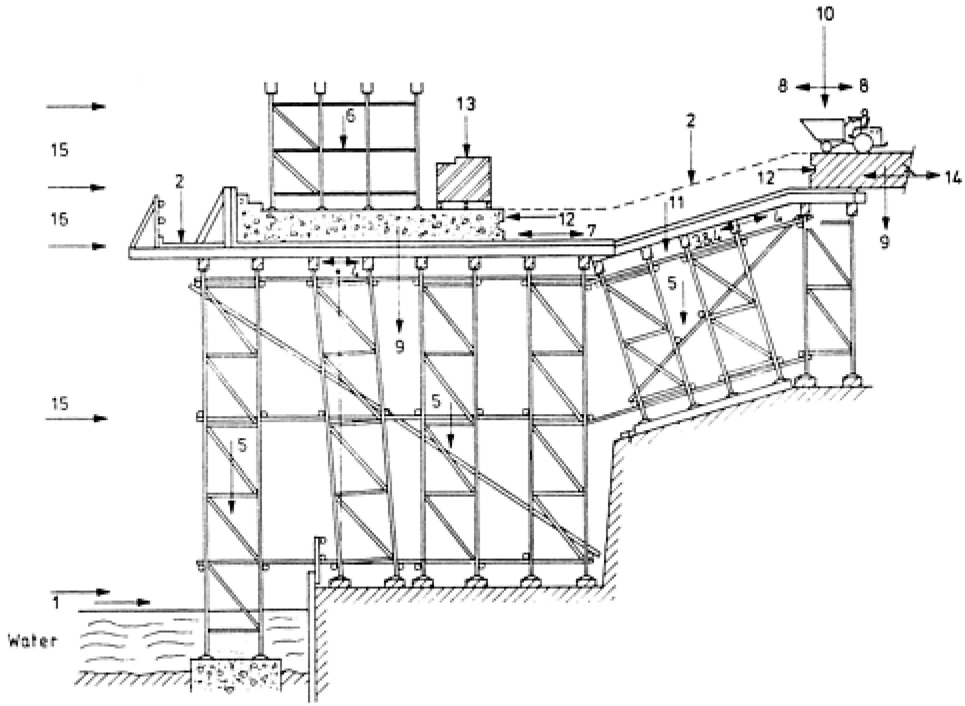
The supervisor must ensure that he is informed on the basic principles of scaffolding and supporting work using tube and fittings. There is considerable valuable information on this subject contained in BS 5975, which focusses attention on such matters as verticality, type and location of couplers and so on. The Code emphasises the essential points of the workmanship which govern the performance of tubes in supporting situations. Reference is made to BS 1139 which sets out requirements for tube and couplers and goes on to specific points which must be checked. Here the supervisor can maintain a watchful eye on detail and can co-operate with the trade supervisor and formwork and falsework co-ordinator in maintaining standards. Some points to be checked are as follows:

1. Tubes should be undamaged, not visibly bent and have smooth, square cut ends.
2. When vertical, tubes should be placed centrally under the member to be supported and over the member supporting them with no eccentricity exceeding 25 mm.
3. When vertical, tubes should be plumb within 15 mm over a height of 2 m and checked by means of a suitable gauge. In addition, the total horizontal displacement should not exceed 25 mm.
4. When vertical, tubes should be provided with plain or adjustable baseplates and forkheads or capping plates, laced and braced where their extension exceeds 300 mm.
5. The bracing tubes should be attached close to the fork or base plate and to an adjacent vertical member close to the lacing.

6. The tubes should be laced at head and foot and intermediate levels so that the vertical distances between levels of lacing do not exceed 2 m.
7. The tubes should be connected by right angle couplers, except for diagonal bracing where swivel couplers may be used.
8. The tubes should have end-to-end joints in adjacent tubes, staggered and made with sleeve couplers.
9. The tubes should be effectively located and stabilised using diagonal braces at a minimum frequency of one brace every sixth standard, in each line of standards.

   These braces should be attached as near to the top and bottom of the standards as possible and should be so inserted that they cross, and are attached to, every level of lacing. The angle of inclination to the horizontal should not be less than two vertical to one horizontal, but not more than one vertical to two horizontal.

Scaffold must be checked and inspected during erection, prior to use and in use to ensure that lacing and



Key
1. Wave forces
2. Working area loads
3. Out-of-vertical by design
4. Erection tolerance
5. Self-weight of falsework and formwork
6. Self-weight of later stage of falsework
7. Horizontal friction between concrete and soffit formwork
8. Impulse loads
9. Load from cast concrete
10. Mobile plant load
11. Applied permanent load, e.g. from concrete to be cast
12. Reaction from active concrete pressure against completed work
13. Load from stacked materials
14. Force from permanent work, e.g. thermal movement forces
15. Wind forces on falsework (either maximum or working)
16. Wind forces on formwork

bracing is installed and maintained as detailed by the designer. The supervisor will also be well advised to collect and maintain a library consisting of reports, details of falsework arrangements used in previous contracts, manufacturer's descriptive leaflets relating to support systems and so on, which will provide valuable information and will reduce the delay in obtaining details prior to placing orders with plant yards and suppliers.

It is essential whenever some new or revised application for equipment is envisaged, or where there is any likelihood of unusual load development within the supporting work, that the supervisor discusses this with a suitably qualified engineer. Drawings of temporary works and supports should be carefully scrutinised and, in the event of some unusual arrangement of supports or a detail being indicated which the supervisor has not previously experienced, he must ensure that this is intentional and that he understands the reason for its inclusion in the scheme. The physical positioning of temporary works and support systems, the accuracy with which the standards are located and plumbed, the manner in which the connection is made between the falsework and formwork, particularly where adjustable heads or forkheads are used, are all important details which the supervisor should check and inspect. The likelihood of wedges moving, couplers slipping and so on, must be borne in mind and tightness and soundness must be key factors in the inspection.

Checking

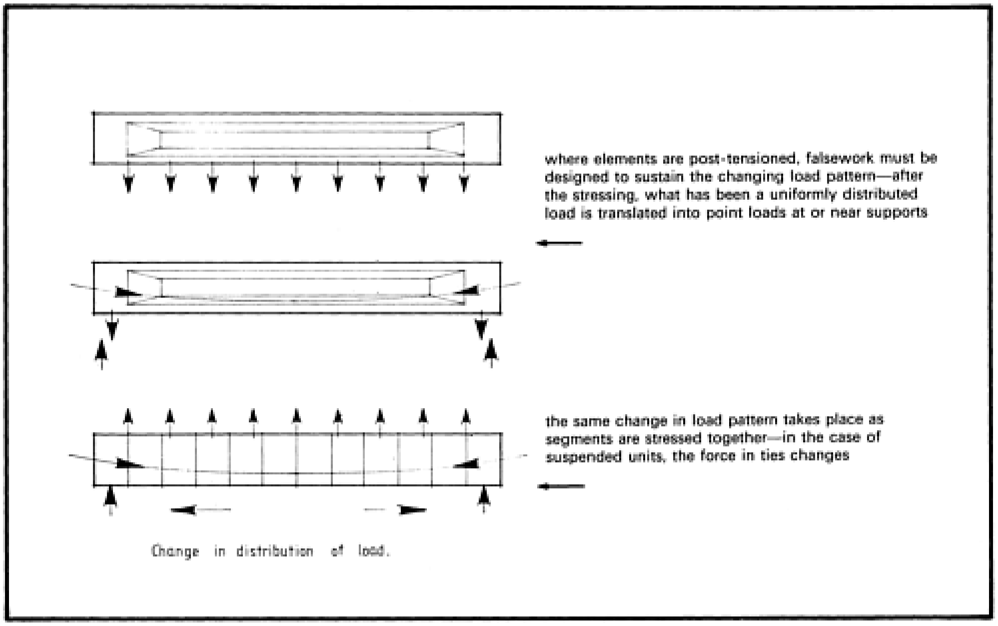
It is always beneficial to check things more than once and, in the course of his work, the falsework co-ordinator will also be checking the following in accordance with the Code:

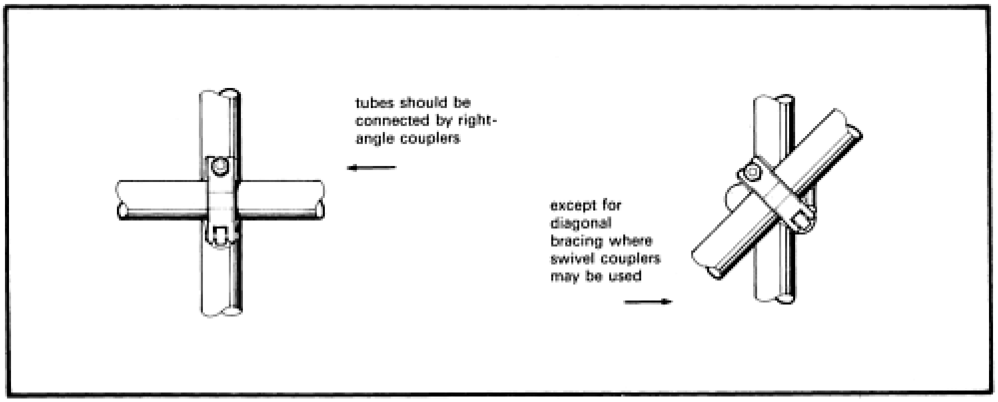
when the proposed founding level for the falsework is in preparation;

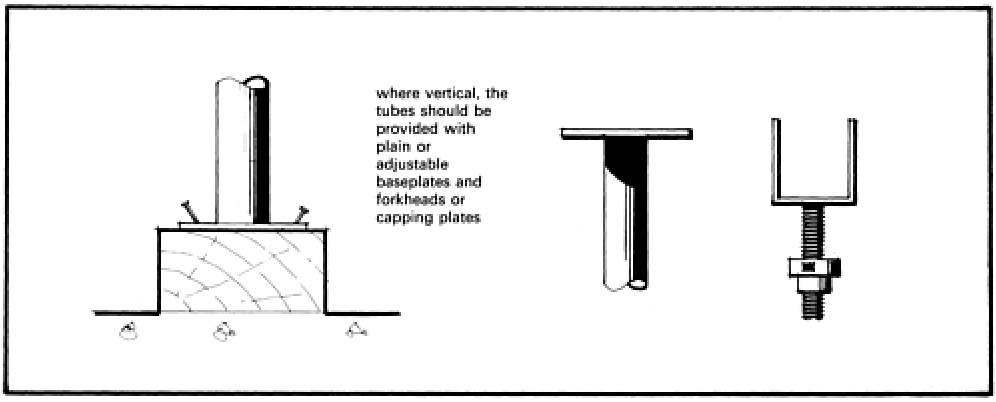
when the falsework has attained a height of 10 m or a height equal to 1·5 times the minimum of its plan dimensions;

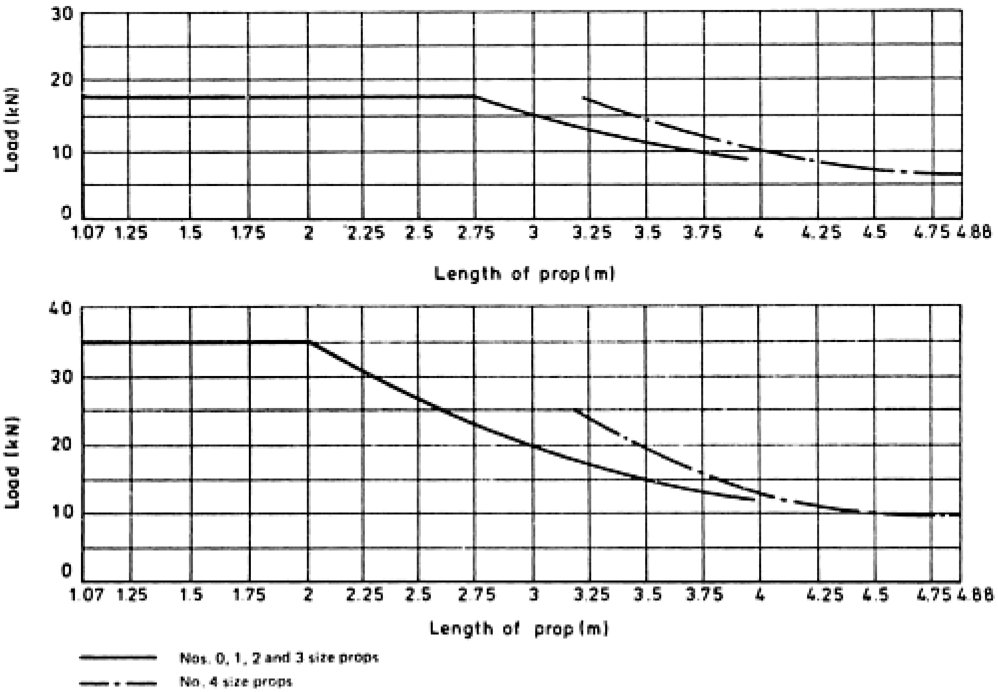
when the falsework reaches its support level;

at intermediate stages when the strength or stability of the falsework may have been adversely effected by


where elements are post-tensioned, falsework must be designed to sustain the changing load pattern—after the stressing, what has been a uniformly distributed load is translated into point loads at or near supports
the same change in load pattern takes place as segments are stressed together—in the case of suspended units, the force in ties changes
Change in distribution of load.


tubes should be connected by right-angle couplers
except for diagonal bracing where swivel couplers may be used





(a) Safe working loads for props erected 1.5° maximum out-of-plumb and with up to 25 mm maximum eccentricity of loading (i.e. concentric loading cannot be ensured)

(b) Safe working loads for props erected 1.5° maximum out-of-plumb and with concentric loading ensured

environment or other loading conditions, or unauthorised interference;
where equipment is being continually re-used and periodic checks are appropriate;
immediately prior to the application of loads.

The supervisor should keep a watchful eye for changes, movements, lack of maintenance or any damage to the structure, which is likely to detract from its ability to perform as designed. Without interfering with the authority of the falsework co-ordinator, the concrete supervisor can render useful services to all by running his experienced eye over the falsework and perhaps isolating practical points which may otherwise go unnoticed.

Propping and re-propping

Adjustable steel props are now widely used in formwork construction and falsework situations. The supervisor needs to understand the best ways of using the equipment remembering lacing and bracing, and the tables reproduced here (taken from BS 5975:1982) provide useful information on loads to which the props may be safely subjected. Steel props should comply with the requirements of BS 4074 in which the construction and sizes of props are specified. Prop height ranges are as follows:

	Range of prop height	
Prop size number	Minimum (mm)	Maximum (mm)
0	1070	1820
1	1750	3120
2	1980	3350
3	2590	3960
4	3200	4870

Included in the tables from BS 5975 are the safe working loads for adjustable steel props erected to the following limiting factors:

1. Props should not be damaged or visibly bent.
2. Props should be plumb within 1·5° or vertical (i.e. not exceeding 25 mm out of vertical over a height of 1 m).
3. Props should be placed centrally under the member to be supported and over any member supporting the prop with no eccentricity in excess of 25 mm.
4. Forkheads should be rotated to such a position that the bearer they support is centralised over the prop. Where beams terminate in a forkhead, they should extend past the centre joint of the forkhead by at least 50 mm. Alternatively, where timbers butt in a forkhead, the joint should be within 15 mm of the forkhead.

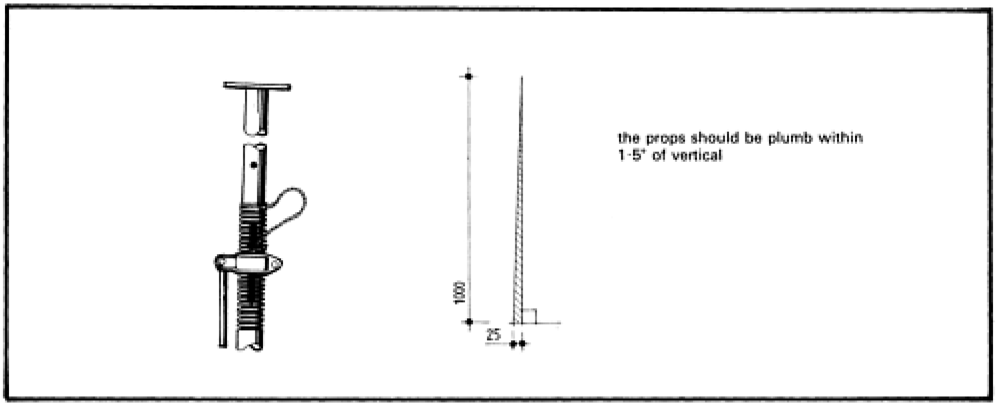


Figure 1a gives the safe working load for props erected to the maximum erection tolerances stated above. Figure 1b gives the higher loading permissible when concentric loading can be ensured. It is evident that the foot of the props should be soundly based on concrete or a timber plate. The installation and removal of props from below concrete beams and slabs must be carried out in a controlled and workmanlike manner. Considerable damage has been done to both concrete structures and formwork equipment by haphazard and crash striking. Setting aside, for the moment, problems arising from the fast rates of construction where the part loads of several floors are transmitted into the props supporting preceeding floors and beams, the methods of removal of props and supports should generally be as follows:

where slabs are spanning between beams the props to slabs both sides of the beam should be released before props under the beam are disturbed;

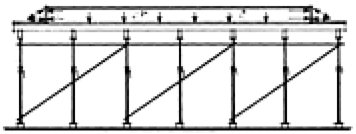
when removing props to beams or slabs these must be removed systematically by easing all props by the same amount and removal commenced at mid-span and then outwards towards the supports;

in the case of cantilever beams and slabs, prop removal should commence at the outermost point progressing towards the foot of the member.

It should be remembered that the props under a slab must sustain part of the load resulting from construction above. A reinforced concrete member must deflect to sustain load and, when this happens, props simply transmit the load to beams and slabs below. The effect is cumulative and in the case of fast construction cycles, in multi-storey work, the load in a prop can exceed twice that which it has to sustain in a similar situation in single storey work. In fact, if the props to lower levels are left too long without easing then they will be called upon to support the total weight of all the slabs constructed above. The easing of props is a scientific process and should be carried out on the instructions of a suitably qualified engineer.

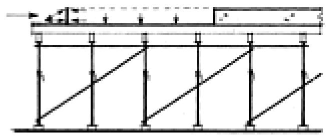
Quickstrip systems

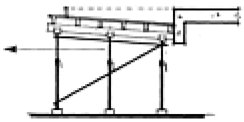
Quickstrip propping systems allow the removal of the sheathing and supporting beam part of the system whilst the primary prop head remains in contact with the concrete. The main advantage of quickstrip systems is that the concrete element is required to span over only a small part of its designed span, say $\frac{\text{span}}{5}$, at a time when concrete has reached, say, 2/3 of its characteristic 28-day strength, whilst the prop remains undisturbed.



in falsework to formwork with only horizontal and vertical forces, lateral forces are resisted by opposite sides and there is no resultant horizontal force external to formwork

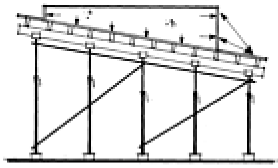
where one side is formed against previously cast concrete then there will be a need to resist the resultant force

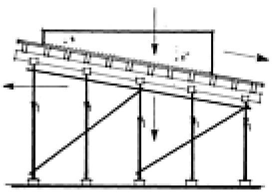




forces resulting from cantilever construction against an exisiting beam introduce lateral loads in the falsework

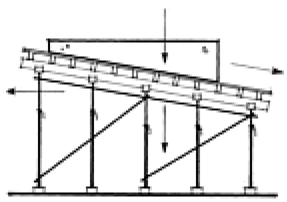
a slab with a sloping soffit *unconnected* with other work, imposes only vertical and lateral loads on the formwork—no resultant horizontal force is exerted on the falsework

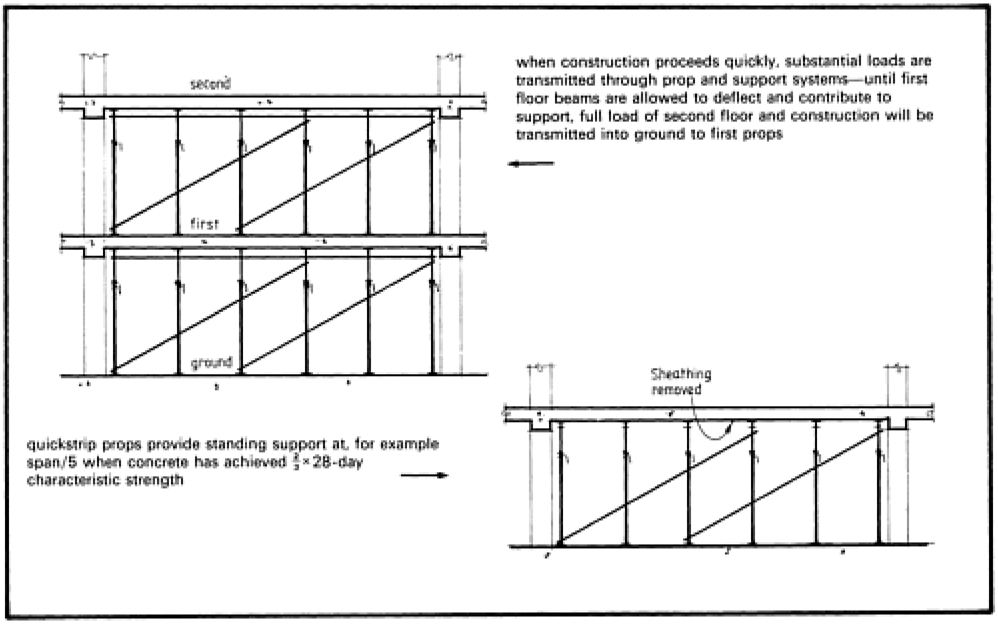




once concrete has hardened, only friction between the soffit of the concrete and the form face prevents lateral force being imposed on the falsework

placing precast concrete onto a sloping surface *does* introduce lateral, as well as vertical, loads





Checklist

1. Have drawings and written instructions been complied with?
2. Have correct materials in serviceable condition been used?
3. Are foundations adequate? (Watch for movement or settlement, particularly after rain or thaw.)
4. Line level and plumb drastically affect performance of the falsework, are they accurate?
5. Are kentledge, ties and anchors in mature concrete adequate?
6. Are lacing, bracing and ties inserted as detailed? Are chocks, wedges, jacks, and so on tight and immobilised?
7. Has any change in method of concrete handling and placing altered loading?
8. Are materials second hand—if so have they been inspected?
9. Is the intersection between falsework and formwork such that the forces are applied axially onto supports?
10. Has falsework co-ordinator given permission to load falsework?

13.
Formwork

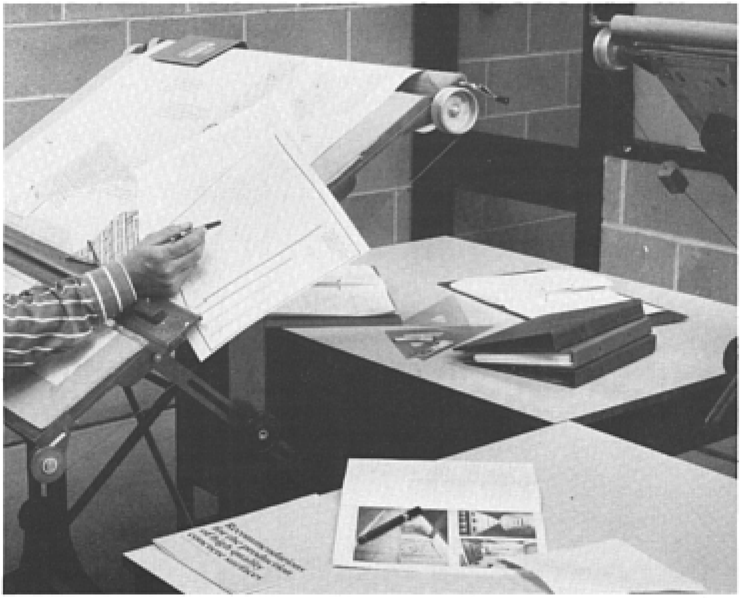
Formwork provides the container into which fresh concrete is placed, its shape and quality governing the accuracy and quality of the finished concrete. Apart from the moulding or forming process, the form also provides:

a workplace for a number of trades;
support for steel reinforcement; and
location for cast in components.

In building, about 60–75% of the total cost of concrete structures is that of providing formwork. In civil engineering, where larger masses of concrete are cast at any one time, up to 20% of the cost of the structure is spent on formwork. The remaining costs are in the provision of, cutting, bending and fixing reinforcement, and in the supply, handling, placing and curing of concrete. Formwork is largely the concern of the contractor. It is the contractor's responsibility to design the formwork, selecting method and equipment to meet the requirements of the Specification regarding surface finish and accuracy of the structure. In some circumstances, where problems arise by the need for extreme accuracy or where special surfaces are to be cast, the form design will be checked by engineers employed by the consultants or, where the works are to be executed over, or adjacent to, some public way, by local authorities. Although in these cases architects frequently inspect and approve materials and models cast from sections of formwork, in the majority of cases in ordinary concrete construction, the forms are designed and provided by the contractor, used by the contractor as many times as possible whilst meeting the requirements of the Specification and are removed from site. In these instances, the forms are seldom subject to scrutiny other than by those who use them. After use the forms are transferred to another site or to a depot or are scrapped. A Resident Engineer or Clerk of Works can, under the normal performance type of Specification, comment on the quality of formwork provided prior to its use and, although of course the contractor would be well advised to attend to such comment, the only criteria by which the form can be judged contractually is by the standard of the concrete component or structural element which is accepted or rejected in the light of the Specification for the contract.

During recent years formwork and formwork skills have been the focus of considerable attention from specialists in a variety of fields. To be successful, formwork depends on skilled design, careful selection of materials, care in construction, erection, handling and reuse. The designer, who is often the site supervisor, must understand and have a feel for the job and be well versed in the materials available to the construction industry, as well as being aware of the technologies of allied industries, such as mechanical engineering, and have a knowledge of available adhesives and chemicals. Experience should ensure that the designer

Early attention to form detail and the provision of a sound method are essential to successful concrete operations



provides formwork which is suited to the task, which can be used by the available labour force and skilled men and which, when handled by the available equipment, will cast concrete to the required standard of accuracy and quality. Many supervisors come to formwork from other trades and must depend, to a large extent, on textbooks and suppliers' catalogues to meet the requirements of the Specification.

The supervisor's interest in formwork lies in two main areas—the achievement of the required quality standards and achieving those specified standards economically. The supervisor is judged by the results he achieves in practice and by the maintenance of the margin between cost and price. It is simple enough to produce high quality concrete at high cost, all that is necessary is a fund of good labour and skills, a supply of first class materials for both formwork and concreting, ample time and assistance from capable people in setting out and trades supervision. In real life, of course, these factors are rarely freely available and every job becomes a compromise. The essence of good supervision is, however, the maintenance of a flow of work, broken down into sufficient steps or phases to allow the workforce to become proficient in the method of using available materials and equipment. Formwork is a means to an end, providing work for many trades and skills and, indeed, the formworkers, numbering perhaps a dozen men, make it possible for up to 100 or so other workers to be kept gainfully employed in steel fixing, concreting, electrical work, bricklaying, heating and ventilation works, and so on.

Formwork is not necessarily a complicated part of construction. As with all construction, however, the operative becomes more involved as the overall project becomes more complicated. Ideally, the supervisor should break the process into a number of discrete, clearly identified operations and then devise a formwork arrangement which can be employed systematically in the greater number of operations.

Preparing a formwork scheme

The supervisor working without the benefit of a central formwork planning and design facility would be well advised to follow a clearly defined series of steps which have been tried and proved in practice. Firstly, he must obtain the fullest possible information on the requirements of the various authorities—engineers, architects and so on—regarding accuracy and surface finish. He must study his drawings, Specification and Bills of Quantity to ensure that he is fully conversant with the reasons for various profiles indicated, as well as the aesthetic demands of the architect and functional requirements of the designer. He should attempt to clearly visualise the structure in its various stages of construction with particular reference to geometrical detail, ramps, canopies and various exceptions to the general items, which otherwise generate repetitive cycles of work. At this stage certain details emerge, perhaps unintended geometry, and items which are going to cause exceptional expenditure of labour and materials and may exceed the prices set down in the priced Bill of Quantities. The supervisor can help himself by making simple sketches from the drawings and constructing models of any sections of the work which appear to be in any way exceptional. He should study a range of sections through the building and look carefully at the layout drawings with a view to spotting any repetitive module which can form the basic shape around which a casting method can be built.

Discussions with authorities

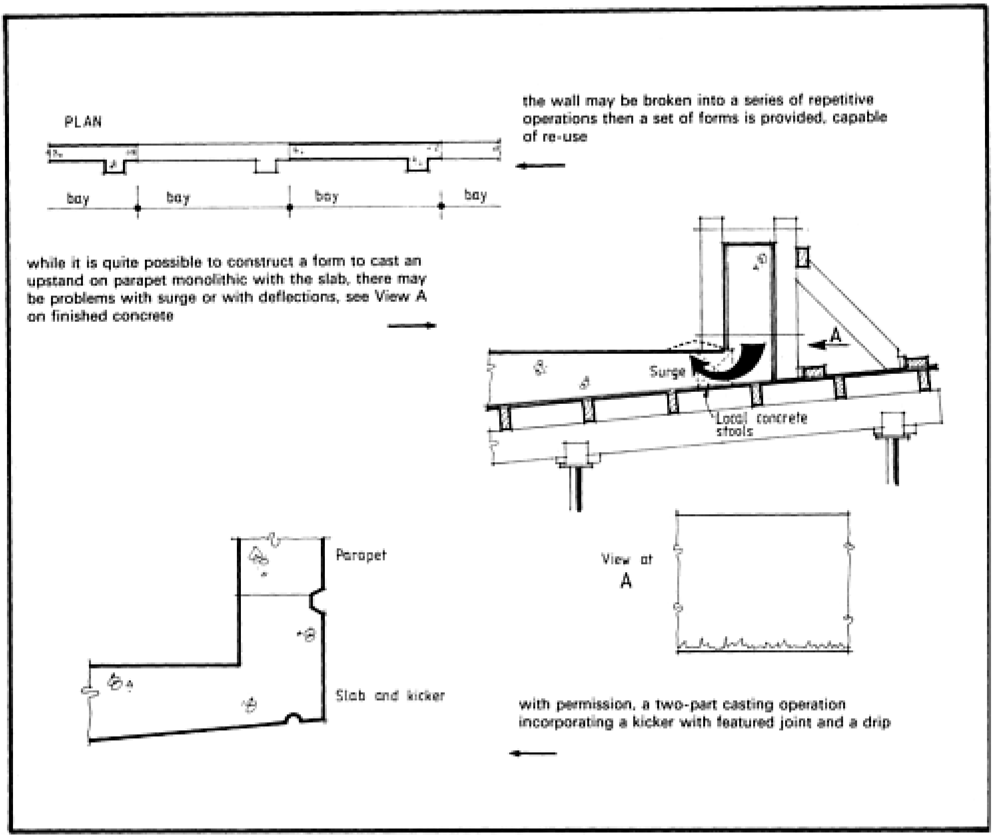
It is essential to discuss the various drawings and details with their authors to obtain an understanding of the function of various elements of the structure, to discuss finishes with the architects and designers and to discuss such matters as joint requirements with the engineer. At this stage the experienced supervisor can do much to simplify the construction task by going back to the designer with any minor changes to section, provision of joints and such details as were discussed in *Chapter 9: Joints* under the section *Construction and day joints*. It is often possible to recommend details which will reduce the dependency of work in one phase of the construction upon the completion of another, such as when provision is made for wall casting (incorporating starter bars) to proceed without delays being caused by the need to cast an intermediate or mezzanine floor. In certain types of construction, reprogramming may yield benefit where, for example, special foundations are to be cast to support specific equipment, in which case the structure and roof might be completed before construction of the base slab and machine foundation.

At this preliminary stage of consultation and discussion a helpful approach on the part of the supervisor will yield dividends later. Drawing errors spotted and sympathetically corrected and construction detail simplified will build up the designer's confidence in the contractors supervisor. It is often possible to offer some simplification of design which, as well as being easier to construct, will improve the performance or appearance of the structure and thus benefit all parties to the contract.

An outline scheme

With a sound understanding of the requirements of the various parties, as well as those of the contract manager regarding outputs, performance, standards and timing, the supervisor is in a good position to prepare an outline scheme for discussion with the trades supervisors and, where necessary, the formwork engineer. The success of the scheme will depend on the identification of some optimum shape and quantity of formwork, a choice of appropriate materials and methods, and then on arrangement of a programme incorporating these resources in such a manner as to capitalise on existing skills and experience.

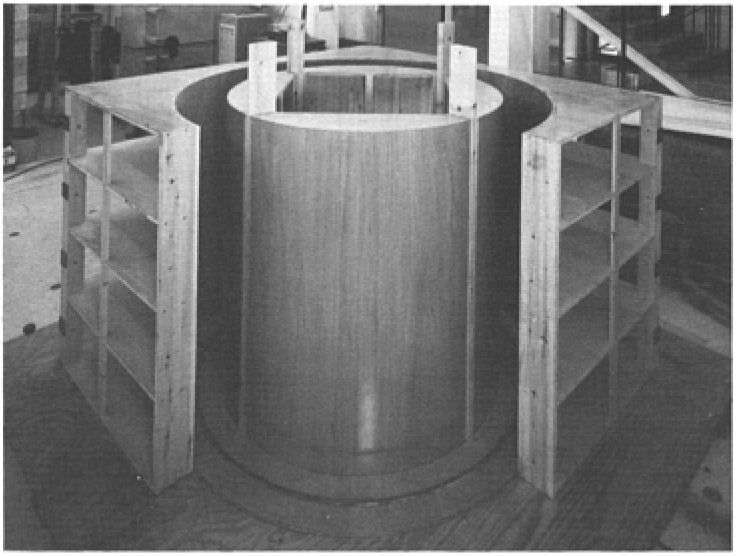
There are tried and traditional means of construction



which are generally applied to such processes as frame construction where the method may be broken down into a sequence such as: piles; pile caps; tie beams; slabs; columns and shear walls; service wells and stairs; beams and floors. This is quite a logical breakdown and one which is clearly recognisable in the case of most reinforced concrete frame construction. Whilst looking for such a logical sequence, the supervisor must not be lulled into thinking that such a sequence is the only one applicable, and must train himself to also consider the overlap and interdependence of the various construction activities.

In the sequence given, reference is made to stair construction. Consideration of this simple element of construction indicates the range of options open, such as stairs cast in situ, stairs precast or stairs cast in cycle or out of cycle. If cast out of cycle, then more and more of the floor slab needs to be left uncast to allow incorporation of continuity steel between stairs and slab. At the first level it will only be necessary to leave unconcreted that part of the slab in which the starters lap. On the succeeding floor it may not be possible to erect forms for edge beams as the previously omitted concrete prevents a sound footing being achieved for props. This problem is progressive, so that the simple omission of stairs at one level may preclude erection of forms, fixing of steel and placement of concrete over as many as two or three bays some two floors above. These are details to which the supervisor must remain alert if he is to achieve a flow of productive work for all trades.

The exceptional work in features of construction, such as special storey heights, walls curved in plan or otherwise shaped, ramps, balconies and such special forms of construction as upstand beams and mezzanine



Special mould for casting scale model storage tanks for research purposes. Construction incorporates shaped ribs, timber lathes and ply sheathing

floors, require particular attention. If there are sufficient of these details to provide a repetitive cycle, or if the larger elements can be broken down into a series of repetitive operations, it is still possible that their existence in the building will not upset the normal construction programme. If, however, there are only a small number of such exceptions, or demand for exceptional formwork treatment in the achievement of accuracy or surface finish, then they must be studied from all points of view as likely upsets to production. Where such exceptions are separable from the main construction, as in approach ramps, entrance features, service towers and chimneys, they can be set outside the main formwork programme— dependent, of course, on their importance to the structure. Indeed, if they are substantial enough, or complicated enough, they should be treated as quite separate sections of the work. Where the exceptions are integral within the overall structure, then the construction process must be designed around them as they may become the element which determines the general sequence of construction, lift height, bay size and so on.

The secret of successful formwork arrangement lies in devising a system based upon available materials which not only repeatedly form concrete to acceptable standards, but which can be readily handled using available equipment, by tradesmen and operatives on site. These men earn their living in this way and will only apply themselves to a system which they can understand and operate with relative ease in site conditions. Unless the labour force is convinced that the equipment and materials have been wisely chosen, difficulty will be experienced in using the equipment effectively. The wise supervisor will take heed of the views of his tradesmen and operatives—very sound ideas often emanate from people who are closely involved with the casting operations and an open mind on materials and method can yield considerable savings. Once the system has been selected and the equipment hired or bought in, the supervisor must concentrate on one of the major skills of supervision, that of maintaining the system in all its detail and ensuring that it is used as intended in a safe and workmanlike manner. It is easy for a system to fail by incorrect usage or omission of some part of the fixing, fastening or bracing. Some men will tend to “cut corners", especially where bonus or incentive is concerned, and this is where accidents and failure can occur.

Alternative methods of construction

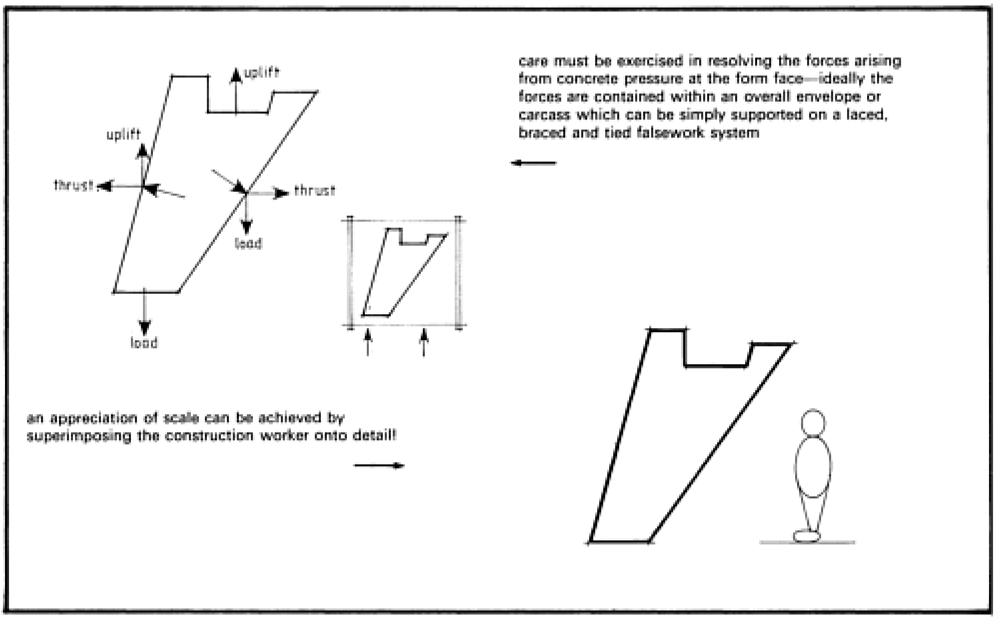
At this stage of the consideration of formwork method, a variety of possibilities arise. The supervisor will be involved in decisions as to methods of construction, the adoption of special formwork arrangements, system formwork or the use of traditional formwork methods and implications of that choice. As previously mentioned, the situation discussed here is that where the supervisor does not have the benefit of the services of centralised planning facilities or similar resources. The supervisor with the smaller construction company has a greater degree of autonomy in decision making than is generally experienced by those employed by national companies. The idealised situation whereby the supervisor can make all the major decisions governing the selection of materials is used in this discussion, although the wise supervisor will seek whatever technical support is available in selecting a scheme.

Traditional formwork methods

The term "traditional" in this description relates both to material and method. Timber and timber derived boards have, since the days of the centerer, been the materials most commonly used in forming and moulding concrete. Timber and ply are readily available in the UK, and are not difficult to obtain in most parts of the world. Also available in most countries is a fund of skilled personnel, albeit of various standards of ability. Throughout the years, basic methods of using timber and ply have been established; the design of forms and location of members to resist pressure and forces has been largely empirical. Many of the methods and materials have been propagated by the movement of labour and supervision from site to site and contract to contract. Each of the principal materials has been applied to a wide variety of uses and means devised to overcome problems such as those of scale and geometry. Illustrations accompany this chapter indicating the traditional uses of ply and timber in formwork construction.

Re-use is largely dependent upon the design of the structure—estimators base their costings on 12–15 uses from timber and ply and the site will do well to obtain something approaching 15–20 uses in forming in situ concrete. A very strong discipline is needed to control the use of materials avoiding cutting and wastage. The sheathing material could yield a higher re-use but, of course, where there is any amount of infill work, then it is difficult to avoid cutting and wastage. Carcassing materials can be used more often if kept intact without cutting, again causing wastage. A sound technique for the achievement of high re-use from traditional materials is that of forming the materials into prefabricated panels, the module being dependent upon the sheathing panel size. In this way 30–40 uses can be achieved in casting structural quality concrete, with some refurbishment of face plies, and indeed once the materials are too badly worn to cast facework, further uses can be achieved in casting foundation beams, pile caps, and so on, where the visual quality is not of paramount importance. Where high standards of visual quality are required the face materials must be replaced regularly, every 10 or so uses, but where retarders are used to provide exposed aggregate faces the concrete does very little damage to the mould face and apart from perhaps the occasional accidental damage such as vibrator burn or steel chafe at the face, the mould will be capable of yielding 40 or more uses without any additional refurbishment. Site conditions, weather and the standard of storage all vitally affect output in terms of re-use and it is wise to provide racks or storage facilities so that forms can be cleaned and stored out of wrack or wind. The coating or mould oil applied to the forms is another major factor to be considered—not only as regards traditional materials—coatings and oils critically affect the finish of the concrete, the ease of removal of the form and the resistance of the forms to aggressive attack, either by concrete in use or weather between uses. Mould oils and coatings are dealt with in *Chapter 14: Surface finish*.

The arrangement of members in traditional formwork must be studied to ensure that the resulting concrete is cast to acceptable limits of accuracy, apart from deflections generally limited to of the span of the member. The accuracy and overall continuity of face is very dependent upon the way in which the members are combined. The use of twin members permits overlap of individual timbers whilst allowing tie members to be passed between the twins. All formwork should include a minimum of two layers of carcassing to ensure not only that the forces are collected from the sheathing for transfer to the tie system, but also that the individual members are physically aligned by the secondary members in the carcass system. In practice, standard timber sizes as available ex-merchant are used and generally result in over-designed but satisfactory forms. For design purposes, timber is assumed to be in a green condition and the designer uses the appropriate design criteria. As timber is a natural material, adjustments are made to the grade stresses to allow for such items as the duration of load, the physical section and whether wear or defects exist, such as fissures or splits which might be encountered in the raw materials as delivered. Many suppliers have facilities for the grading and selection of timber and the use of graded materials provides assurance as well as allowing the imposition of additional loads.



Pressures on formwork

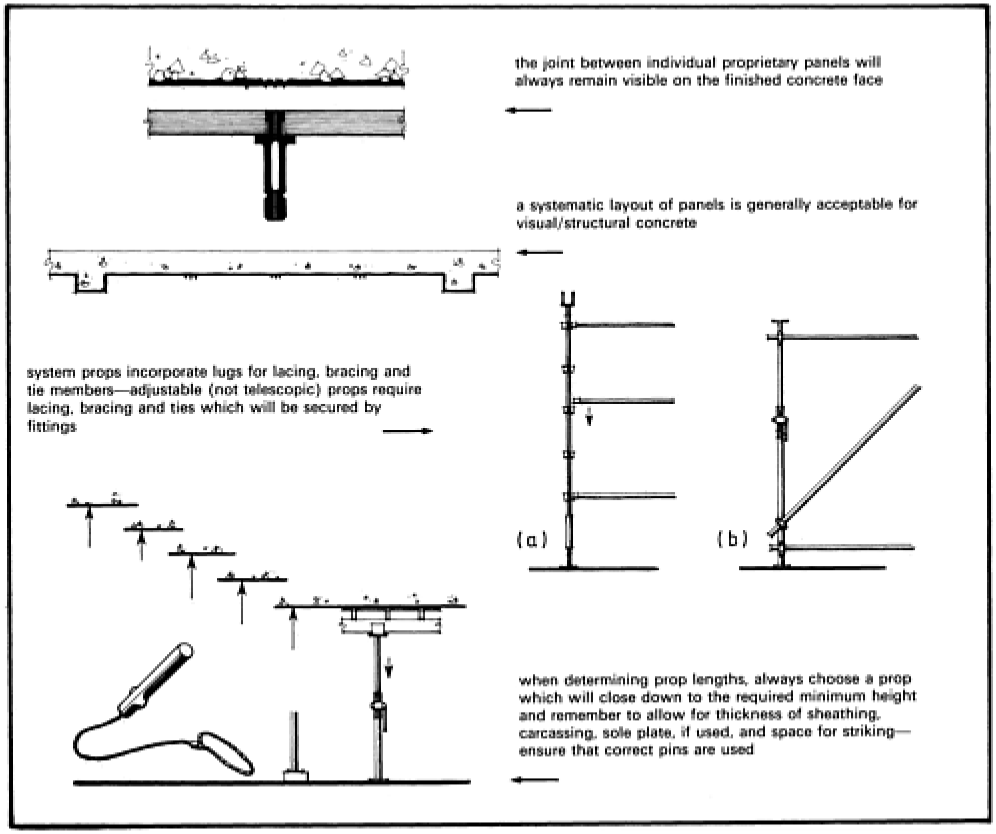
A considerable amount of research work has been carried out into the development of pressure at the form face. The supervisor will have experienced the problems presented, for example, by the pressure on a sloping or battered form, where the tendency is for uplift to develop. A study of the way in which concrete behaves under the influence of vibration, heat and rate of placement, and so on, is helpful and the effects of these factors have been quantified by research in laboratory tests and during on-site investigations. The various factors are as follows:

rate of placement;
temperature of concrete;
workability of concrete;
degree of vibration;
attitude of form;
width of form;
ambient temperature;
mix design;
absorbency of form face;
admixtures used.

These factors cannot be considered in isolation as, for example, mix design and temperature are interactive and the behaviour of concrete will be influenced by both. At the same time, rate of placement, degree of vibration and absorbency of the form face will also determine the pressure development. In general terms, the following will be the effects of the factors mentioned:

Condition	Increase (+) or decrease (−) in pressure
High rate of pour	+
Low temperature	+
Retarders and flow-promoting admixtures	+
High workability	+
Considerable compactive effort	+
Higher cement content	−
Low workability	May result in greater application of vibratory effort
Narrow forms	+
Less absorbent form faces	+

The factors considered by the formwork designer who works from graphs produced as a result of research, are form spacing, stiffening time and temperature, as well as the major consideration of rate of rise of concrete within the form (the latter governs hydrostatic pressure development). Figures are calculated from formulae which indicate the pressures modified by spacing of forms, stiffening times and temperature of the concrete, and the



least of these is used in the design of sheathing, backing, supports and tie spacings. The supervisor should be aware that superplasticisers and retarders dramatically affect the pressure development. They modify the stiffening time which otherwise generally reduces the form pressure.

The effects of pressure at the form face must be carefully considered, resulting as they do in displacement or distortion of the formwork. Where sloping faces are encountered, the forces resulting from pressure acting at the face can be resolved in thrust and uplift or force tending to displace the form. Thus uplift must be counteracted by suitably placed supports or ties taken into previously cast and mature concrete. The effect of changes in method must also be considered, the pressures resulting from concrete placed using a crane and skip may have formed the basis of design—placing the same concrete into the same form using a mobile concrete pump which happens to become available could result in disaster, displacement or bursting of the form. Full head loading of a form can be achieved very rapidly where, for example, readymixed concrete trucks can be discharged directly into a form by chuting. Formwork drawings generally indicate the design criteria adopted by the person responsible the mechanical design. In the event of any change of method, the supervisor should query the effect of that change, such as the need to incorporate additional ties or supports.

It should be remembered that stopends, opening formers and core formers are all subject to the same forces as can be calculated for the form face. Unfortunately this fact is often overlooked on site, where the form detail may be left to a tradesman who has perhaps not encountered the problem of core displacement or former rotation before. In the event of the in-concrete check revealing movement or where deflections tend to become greater than those encountered elsewhere, the concrete process should be stopped, or at least slowed, whilst enquiries are made of the designer. Allowance is normally made in design for impact of fresh concrete discharged from a skip. It should be realised that impact on a sloping surface will not only tend to displace forms in the direction of application of load, lateral displacement can also be caused and collapse has resulted where insufficient tie members, braces and lacers have been installed.

Striking formwork

BS 8110:1985 includes a table of striking times for formwork (concrete made with ordinary or sulphateresisting Portland cement). The Code refers to CIRIA Report 67 tables of minimum striking times for soffit and vertical formwork, commenting that striking time may be reduced in cases where, for example, the concrete strength in the unit is 10 N/mm^2 or twice the stress to which the element will be subjected, providing that such striking will not result in unacceptable deflections. This strength may be assessed by compression tests on cubes cured in as far as possible the same conditions as the concrete in the element. Where forms are stripped at an early age, the concrete should be protected from low or high temperature by insulation.

The table in BS 8110 is as follows:

Type of formwork	Minimum period before striking		
	Surface temperature of concrete*		
	16 and above	7	t (any temperature between 0°C–25°C
Vertical formwork to columns, walls and larger	12 h	18h	$\frac{300}{t+10}$h
Soffit formwork to slabs beams	4 days	6 days	$\frac{100}{t+10}$days
Soffit formwork to beams and props to slabs	10 days	15 days	$\frac{250}{t+10}$days
Props to beams	14 days	21 days	$\frac{360}{t+10}$ days

* If not obtainable, air temperatures may be used.

Reference material

Whilst there is considerable literature available, one publication which will be invaluable to the supervisor is *The Formwork Report* of the Joint Committee of the Concrete Society and the Institution of Structural Engineers revised for publication in 1985. This Report examines the current state of formwork in construction, suggest design criteria, discusses Specification and achievement of standards and sets down guidelines for both specifying authorities and contractors. As the Report was prepared by a body of people, all of whom were specialist in some aspect of formwork, it provides a valuable source of information and reference which will be of assistance to the supervisor. A number of members of the Committee who prepared the Report were drawn from the formwork service and supply industries.

The design of formwork using charts and tables is fairly straightforward and can be undertaken with the guidance of textbooks as included in the Bibliography appended hereto. The supervisor may wish to carry out some calculations to ensure that he is "in the right field". It is strongly advised however, before constructing forms using the spans and sectional sizes obtained, that the supervisor's calculations are checked by a suitable qualified engineer. There are certain circumstances, where bearing stresses are high or where considerable scour or wear is to be encountered, in which the use of hardwoods can be beneficial both as regards quality of finish and unit cost for forming concrete.

Traditional formwork

The following description of materials used in traditional formwork is brief, reference being made to excellent sources of information for the supervisor requiring a more detailed knowledge of the materials and their properties.

Timber and timber derived materials

Individual boards of timber are seldom used for formwork except where some particular surface finish is required, such as board marked concrete bearing the imprint of timber grain, in which case the timber has been specially prepared having been sawn and treated with, amongst other things, an ammonia solution to raise the grain. To provide the best possible imprints, the timber surface should be sealed using Shellac or a polyurethane based sealer and then sprayed with a selected oil or parting agent. Gaskets or seals must be used to offset the effects of movements of individual boards in the panel and to avoid grout leakage.

Timber is often used in the production of feature and fillet forms and, of course, in box outs, through holes and so on. In these instances a good quality whitewood or redwood of strength Class 3 or better, as defined in BS 5268: Part 2: 1984, is used. Where the material is to be used structurally rather than in sheathing of a form, the strength class should be such as to meet the particular application. The formwork designer is allowed to apply modification factors which allow for geometrical properties, moisture content, duration of loading and so on. The critical features of the stress grading of timber are the assessment of wane, splits and knots within the material. Machine graded material is graded continuously during the conversion process in accordance with BS 4978.

Timber is normally used in standard sections in traditional formwork construction. Common sizes are 100×75, 100×50 and 150×50 mm nominal sections. Timber is best used in lengths and as far as possible left uncut, ends being lapped, or allowed to project from the structure. Where any degree of repetition is possible, the supervisor will do well to arrange for the timber to be used in framed panels faced with ply or chipboard. As timber is progressively reduced in length, the shorter pieces would be set aside for use as soldiers, bearers and nogging pieces.

In some instances, hardwood is more expensive than timber, but the additional cost is offset in terms of increased bearing capacity and resistance to scour from placement and compactive effort. Hardwood is good for features and such items as bearing pads and wedges.

Plywood

Plywood is traditionally used for sheathing purposes, Douglas Fir and Finnish Birch normally being used. The designer can use BS 5268 and BS 5669 to establish safe working stresses and design accordingly. The materials do have some properties which are critical in the actual casting and forming process and these vary between the various species of materials comprising the plyboard. Douglas Fir ply, for instance, particularly when used with simple oils and parting agents, leaves a distinct grain imprint on the concrete, marked differences being evident between the heartwood and sapwood. Care in sealing and selection of parting agent can, however, reduce these differences and, of course, much ply today is used which incorporates a plastic facing material, as in the case of sheathing to proprietary formwork panels.

The supervisor will achieve best economies from plywood by framing it into timber backing members, planning the location of these panels within the structure and ensuring that they remain uncut. Small sections of plyboard can be successively cut and re-used for infill purposes. The panels themselves should be sealed at the face and particularly at the endgrain around the edges, using a good quality polyurethane varnish or high build plastic. With suitable protection, 20 uses or more per side can be achieved from plywood sheathing.

Chipboard or particle board

In the past, only quite limited amounts of re-use have been achieved from chipboard or particle board. Recent attention to resin content and the development of laminated plastics for facings have resulted in the material becoming capable of offering 12 or more uses when casting concrete. The supervisor is advised to use these materials fixed to a stout backing and to take every possible precaution against edge and corner damage.

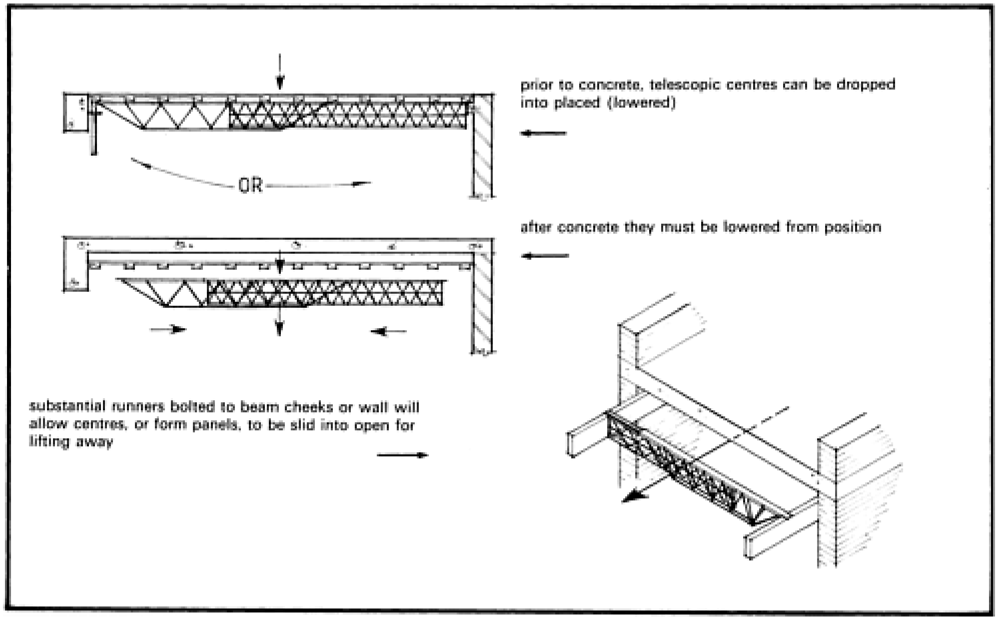
Hardboard

This material is valuable in formwork because it can be used as an economic liner, either to new or used form panels. Some degree of curvature can be achieved and, provided the edges and corners are protected, more than 5–7 uses have been achieved before replacement became necessary. Hardboard is also useful in the preparation of templates and for the purposes of setting out complicated work.

Proprietary formwork

Proprietary formwork suppliers market formwork plant and equipment of a more sophisticated nature than that used traditionally. They now provide a complete service which includes, in certain cases, design, provision, erection and striking of formwork, carried out on the contractor’s site. Many proprietary suppliers offer an extremely capable consultancy service for the cost of a telephone call asking a representative to call on site. The design service is extremely valuable as it is staffed by engineers who are fully conversant with the capabilities of their system and who are constantly in touch with developments in both construction techniques and formwork equipment and methods.

The suppliers of formwork equipment and systems survive in industry as a result of considerable effort in inventing and developing their own equipment and, in recent years, have also contributed considerably to research and the validation of that equipment. The supplier has a massive investment in materials which must be maintained and stored between contracts, and this in



an industry where there is no guarantee of continuity of work. Many systems and suppliers have been tried on the market and only the very best remain, mainly those companies which have grown steadily over the years and have invested capital in the acquisition of skilled designers and engineers. The supervisor, therefore, has the choice of a number of possible suppliers of proprietary equipment, although many contractors maintain contact with a few of these suppliers with whom they have worked over a number of years. The attributes of certain systems lend themselves to particular types of construction. Quite apart from heavy or light applications, there are special features, such as rapid demountability or the facility for production of special profiles, which may direct the choice to one or another suppliers. Ideally the choice should be based on both prior service and on the technical suitability of the particular system or component. The supplier himself will be pleased to advise and it is not unknown for a specialist to direct work to another supplier whose equipment may be better suited to the job in hand.

Purchase or hire

Most suppliers will quote for either hire or sale of equipment. Many quotations are indeed combinations of hire and sale, as such items as ties and anchors which are cast into the concrete are not recoverable. As a general rule, where there are large numbers of re-uses to be obtained from a piece of equipment, 40–60 or more, it would be worth considering outright purchase of the equipment. Equally, purchase might be economic if the equipment were needed for long periods of time due to particular requirements of the programme. The decision to hire or buy is, however, complicated by a series of factors, such as the need to store and maintain it, quite apart from the ramifications of finance, residual value, write-off and depreciation. One cardinal rule is clear, however, and that is that whether hired or purchased outright, the equipment is expensive and should be used and re-used as frequently as possible and then sent off the site or put off hire at the earliest opportunity. Whether hired or purchased, the equipment must be maintained, cleaned and handled carefully, and must be complete with any small fittings, wedges, pins and clips. The omission of the correct pin, the loss of a clip or the use of a damaged item, can result in a most devastating accident.

The way in which the equipment is used, props are plumbed, ties and braces are inserted, have a direct bearing on the safety of both the operatives involved in construction and the nature of the completed structure. The supervisor should, as part of his personal library, obtain full information and instruction manuals for the range of formwork equipment and fittings which he selects, or will expect to use, in his construction programme.

Main proprietary items of formwork

The following are the main proprietary items of formwork described in terms of their interest to the supervisor.

The plate or form panel

The sheathing element for the system is generally in the form of steel framed, steel or ply faced panel, modular in configuration, capable of incorporation into a large sheathing arrangement, suitably stiffened by waling members or capable of being handled panel by panel in small works.

Panels are able to support quite considerable distributed pressures. The manufacturer generally states that they will sustain loads resulting from a rise of concrete at the face of 2 m/hour. The joints between panels, especially ply faced, steel or alloy framed panels, will always be apparent on the concrete face, and in visual concrete should be laid in consistent patterns. Leakage can be avoided at these joints by the use of adhesive tape or form gaskets, but it will be advisable to discuss with the specifying authority the acceptability of lines so formed. Panels can generally be used for forming concrete in public spaces, such as car parks, and in situations where there is some applied finish or surface covering. On small contracts and in confined spaces, the universal or manhandled panels can be used to advantage for walling and decking. There is always the possibility of handling the panels from one use to another individually in the event of shortage or breakdown of cranage. Where cranage is available, panels can be framed onto waling members suitably designed to enable complete assemblies to be moved from bay to bay. It should be mentioned here that it is usual to use a waling member only at the top of panels, ties and wedges being used at intervals in the height as specified by the supplier. In this way the panels will follow the line of, and fit tight to, the previously cast kicker. Large areas of panels do need considerable bracing to render them capable of being crane handled without wracking and consequent damage and the supplier should be consulted prior to such use. Where panel assemblies are crane handled particular attention must be applied to the lifting connection and the use of spreader bars.

Ply faced panels simplify the attachment of cast in components and even the passage of projecting steel. The supplier will, however, charge for repair of excessive marking or deformation, so that panel layouts should be carefully planned to minimise cutting or drilling. Some systems cater for the support of infill sheathing which can be pierced or sawn as required. The supervisor intending to use panels to form walls must carefully study the manufacturer’s recommendations regarding tie location and spacing and must install a suitable check prior to concreting to ensure these recommendations are followed.

Flexible panels

Mention should be made of flexible steel panels available to the constructor. These panels, ribbed with standard angles as are the plane panels to simplify construction, are used in conjunction with waling members to form single curvature. The tubular waling members can be purchased rolled to requirements and the whole panel thus produced provides an economic means of casting radiussed work where there is considerable re-use and not too demanding a Specification regarding surface appearance. Proprietary systems exist which allow a ply or steel facing to be sprung into shape by the use of screw adjusters bearing against straight strongbacks, an extremely economic means of dealing with curvature.

Pre-shaped panels

Special panels are available for casting the more usual geometrical shapes encountered on site, such as silos and bins. Of course, non-standard configurations can also be cast by building up special pre-shaped panels from ply set up on infill angle.

Proprietary props

Props can be divided into two main types—system props and steel supporting props. For the purpose of definition it may be stated that system props are designed to be used in conjunction with braces, lacers, ties or struts forming a systematic supporting arrangement. In many instances, system props incorporate fixings for such accessories and the use of the accessories determines the correct line spacing and plumbing of the props. Supporting steel props are purely individual items of plant, generally adjustable in height over a predetermined range of sizes. The props are intended to support a specified load when this load is applied axially to a prop which has been properly plumbed. The prop will need support against rotation and dislocation and this is best achieved using ties, lacers and diagonal braces of tubular steel, the props being spiked to sole plates and the loads being applied through forkheads or onto plateheads, which are in turn secured by wedging and spiking.

The use of system props provides added assurance as they are simple to erect, easy to line and the spacing can be readily checked. There are, however, many instances where simple props must be used due to the configuration of the confining walls or availability of support from previously cast slabbing. The supervisor should carefully study the storey heights in his structure and from these determine the most useful size of prop. It must be remembered that it may be necessary to change props in the course of a job where storey height reductions are greater than the reductions which can be achieved by normal adjustment in length of prop. The overall thickness of the sheathing joist and runner system must be allowed for when considering the lower storey heights.

The supervisor should watch for the use of defective props and any props which are incomplete. Props which have become bent through misuse are extremely dangerous and should be isolated from the general supply and returned to the supplier for refurbishment. The pins provided are fitted pins of special steel—loss or removal has resulted in the use of sub-standard pins of mild steel, or even bundles of nails, with dire results. Forkheads ensure axial loading when suitably wedged. Misuse of props with bent base plates or head plates, which, as well as allowing movement of form members, will result in a loss of bearing in use. The supervisor should check the plumb of props—this is an essential part of the pre concrete and in-concrete check.

Strongbacks and soldiers

These items of proprietary equipment are used both with standard form equipment, proprietary systems and in conjunction with traditional form arrangements. They basically serve to collect the forces from the sheathing and the first layer of the carcass and transmit these forces into the ties in an economic manner. There is a balance to be achieved between the size and span of strongback and the number of ties in a system.

It can be argued that provided lifting equipment capable of handling forms built on large Strongbacks is available, the labour in tie fixing can be reduced as well as saving being affected in a reduced amount of nonrecoverable ironmongery being used. As with all economies, however, there is a breakeven point which, in this case, is determined by the weight and depth of the strongback and the deflections at the form face as tie spans are increased. The type of strongback which reproduces the twin member of traditional formwork arrangements has much in its favour, particularly as it can be used in confined spaces without encroaching upon working space. In general terms, Strongbacks allow the casting of deep lifts with reduced numbers of ties, they simplify the construction of large crane handled parts as well as providing the essential continuity of line.

Some proprietary systems incorporate integral soldier members which are cast in actual contact with the concrete. These are helpful in maintaining plumb. The intermediate sheathing is stripped, lifted and re-fixed to these static members which remain tied to the previously cast concrete.

Push-pull props or shores

Although adjustable props are frequently used, or misused, as bracing members inclined to the back of the form from some part of the excavation or from a kicker or previously cast part of the structure, this practice is dangerous. A poor footing or bad attachment to the form can result in accidental displacement or movement at the time of placing concrete. A whole series of shores is commercially available specifically designed for the alignment and bracing of formwork panels. These shores have thread adjusters which allow the accurate placing of a panel whilst the specially designed head and foot members can be speedily and positively located onto bolts in slabs or fixings on the carcass of the form. The supervisor should check the inclination of such shores in practice as, apart from the increase in load which will develop in steeply sloped shores, a shore which is too sharply inclined tends to lift the form away from the kicker as load develops. Fixings can be made to cast in studs, quickset anchorages or loops, and where no concrete base or slab is within reach it is feasible to use kentledge blocks dropped into position by crane. On isolated work it may be advantageous to excavate holes locally when plant is available for later use as static kentledge, filled with concrete.

Telescopic and adjustable centres

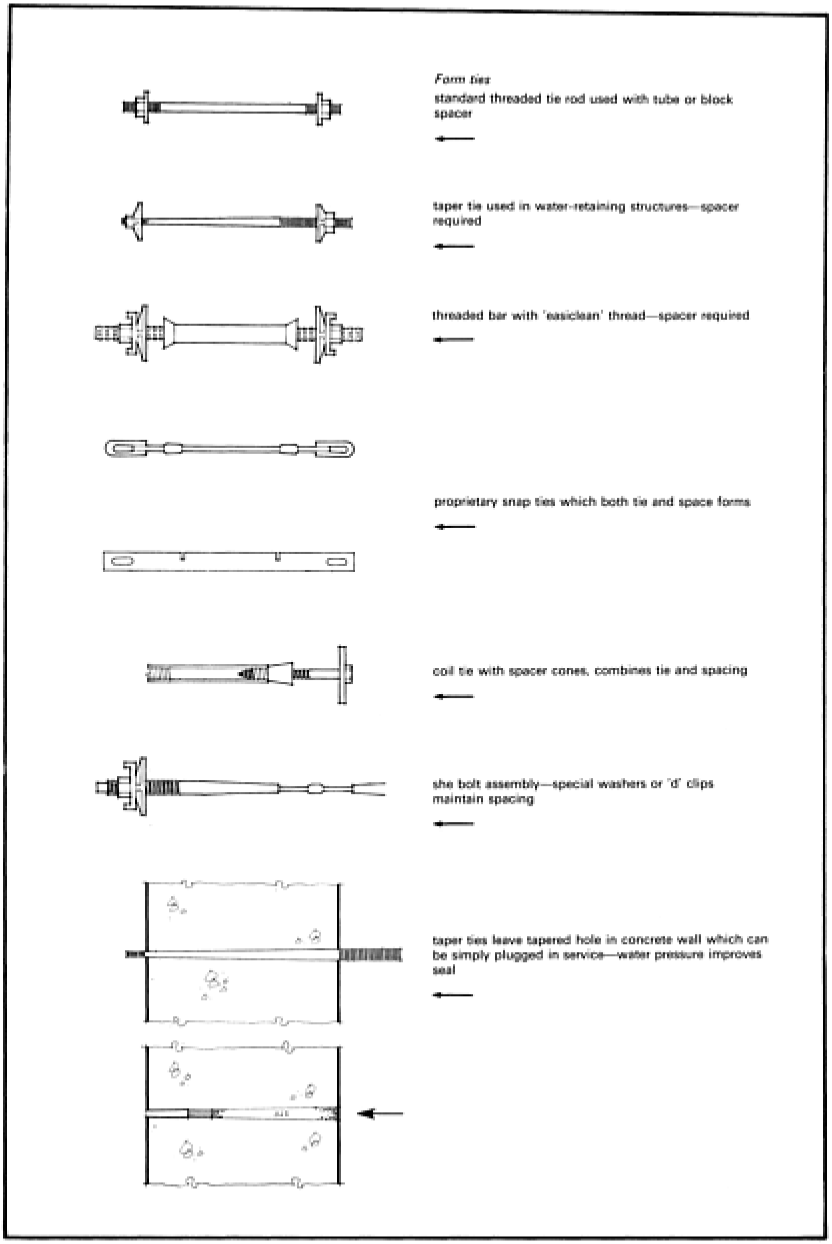
Centres provide a direct means of forming soffits for both plane and geometrical work. The basic telescopic centre, obtainable in a range of sizes, can be used, bearing either on forms or previously cast concrete to support a variety of sheathing materials. Care must be taken to control the deflection of the centre, or at least to arrange the centres to minimise the effects of camber or deflection resulting from the construction of the centre, it being difficult to take up all slack in the system by tightening the locking bolts. It is also essential that the bearing, where support is taken from beam form sides, is of sufficient area and that the beam sides are sufficiently braced to avoid rotation. The construction of beam side members must also be such that noggings or inserts prevent the bearer or backing member from being dislodged or twisted from the sheathing with dire results. With lattice type centres or lattice extensions, the supervisor must avoid the insertion of intermediate props which can cause failure of the centre.

The supervisor planning the use of telescopic centres must remember that, whilst these can be simply dropped into position at the time of formwork erection, their removal after the concrete has been placed is a different matter. Men must work overhead and the units are heavy to handle, especially on temporary stagings. Provision of standing supports enables the centres to be slid from below the freshly cast slab and into a position from which they can be handled away by crane. Where work is to be carried out in confined spaces, a simple trolley or traveller capable of moving a group of centres will prove invaluable.

The adjustable centre is extremely useful in the formation of any arched or vaulted slab. In these cases the supervisor should have a template of the concrete profile prepared, remembering to allow for the sheathing and bearer thickness where appropriate. Centres can then be set to this template before erection, or the template can be used to check setting out in situ. It is advisable to re-check the profile in the course of construction, adjusting as necessary.

Column clamps

An extremely versatile, and certainly labour-saving device, the column clamp, can be quickly assembled around the carcassing of a column form. Wedges are driven into place and the form is then ready for plumbing or filling. It is advisable to alternate the location of the legs of clamps to prevent spiralling of the form. The clamps can be used with either traditional or system forms, provided that they are not buckled by excessive pressures and that the clamp itself bears against sufficient timber in the case of traditional formwork, to maintain the bearing stress in the timber at a permitted level. It is dangerous to use column clamps as beam hangers as the leg of the clamp is easily put into bending and may suddenly buckle.


Form ties
standard threaded tie rod used with tube or block spacer
taper tie used in water-retaining structures—spacer required
threaded bar with 'easiclean' thread—spacer required
proprietary snap ties which both tie and space forms
coil tie with spacer cones, combines tie and spacing
she bolt assembly—special washers or 'd' clips maintain spacing
taper ties leave tapered hole in concrete wall which can be simply plugged in service—water pressure improves seal

System formwork for slabs

Whilst so far the individual components of formwork have been discussed, it should be understood that complete systems have a great deal to offer in terms of speed of erection and cost economy. These systems depend upon a braced system of props—and many incorporate a beam member which provides a seating for the form panel and reduces the prop spacing. Also available in most systems is a double-headed prop or so called quickstrip arrangement, which allows early removal of the sheathing elements whilst maintaining a standing support arrangement in contact with the concrete. Quickstrip arrangements allow a reduction in the quantity of formwork which must be supplied to cast a given area of concrete slab and their use can make drastic cost savings. It is essential that the use of a quickstrip arrangement is discussed with the engineer responsible for the design of the structure, as the concrete is stressed at an earlier age than in the case of some standard formwork arrangements. The arguments supporting the use of quickstrip arrangements are based on the fact that using the standard quickstrip arrangement, floors, for example, are only called upon to span 1/6 th of their eventual designed span, whilst the concrete has developed as much as 2/3 of the strength it is required to achieve at the time of being put into service supporting dead and live loads. The reader is referred to the section on formwork striking times for further discussion on this topic.

Trough and waffle formers

Design economies can be achieved in reducing the weight of floor slabs and roofs by the formation of recesses in the soffit. The recesses can be continuous troughs or a pattern of recesses which produce a waffle floor. A variety of proprietary formers have been used to form such recesses. The materials employed include ply, card, grp, grc and expanded polystyrene. Formers currently available utilise grp and coated expanded polystyrene, also injection moulded formers in polypropylene. Standards have been devised for the dimensions of troughs and waffles which have enabled suppliers and manufacturers to stock formers for hire or sale. Where special configurations, particularly large formers, are required, these have been formed using grp, grc permanent forms or coated expanded polystyrene.

The use of trough and waffle formers in conjunction with system supports results in a speedy method of constructing large span floors, the quickstrip method allowing the early removal of the expensive formers. Problems have been experienced due to high thermal expansion properties of certain of the plastics used in waffle manufacture. This, coupled with low modulus of elasticity and high creep characteristics, has rendered waffle formers difficult to strip, particularly in hot climates. Regarding supports for waffles, there are various techniques, some depending on an open framework of system supports and others on a close sheathed soffit. The close sheathed soffits are probably most desirable from the point of view of safety as dislodgement of a former does not mean the loss of footing for operatives or form leakage.

Table forms, L forms and special configurations such as tunnel forms

In construction where extremely high numbers of uses can be obtained from forms, it is sensible to handle these forms in the fewest possible number of pieces. Initially table forms, now a sophisticated method of casting large areas of concrete, consisted of assemblies of traditional forms set into scaffold frames, handled by slinging from the tower crane. As the value of the assembly has become apparent, techniques have evolved which facilitate the removal of the complete table form from beneath the freshly cast concrete, with specially fabricated hooks or hangers being used to reach into and under the table to allow its removal after striking. The very large tables (or flying form systems) are presently handled out of their casting location on special rollers located on or adjacent to the columns or walls of the structure. The incorporation into the system of a wall form or forms result in what are known as angle forms, or in the case of complete wall and floor forms, tunnel forms.

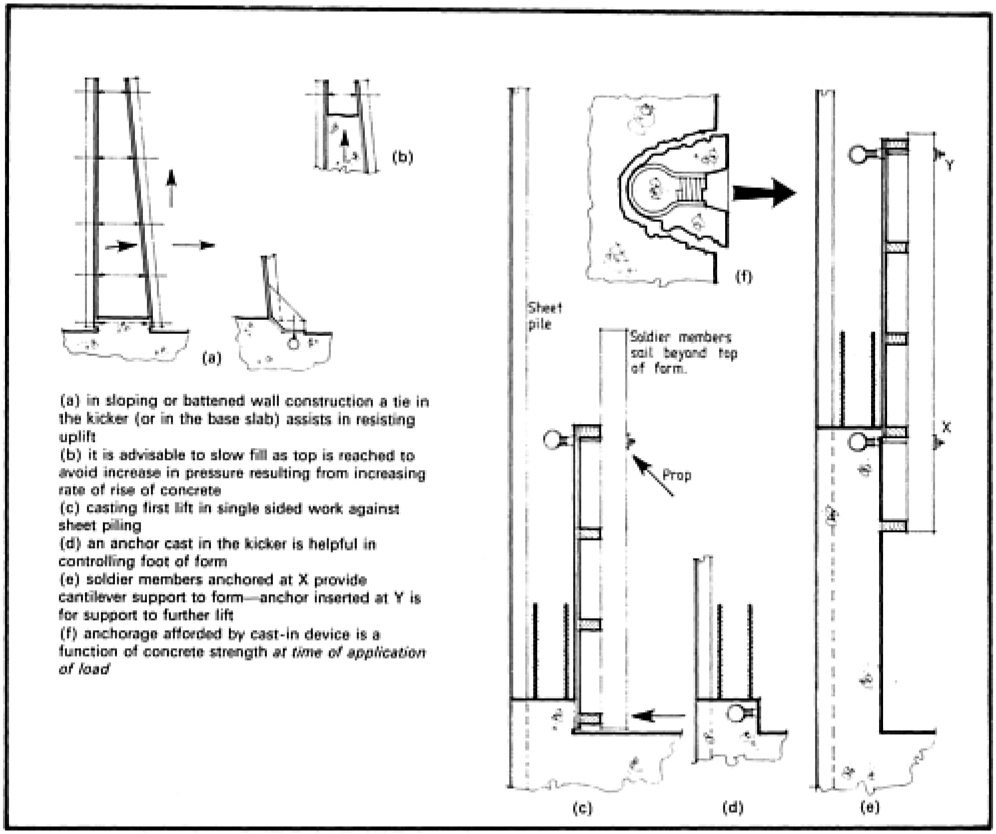
The various configurations of forms are generally used in conjunction with accelerated curing techniques which, by the adoption of heating arrangements, allow early release and removal of the forms to the next casting location.

Tunnel form systems are highly productive, serving as they do to provide a quickly erected workplace for the several trades employed in cross-wall types of construction.

Ties

There are a variety of ties available for use with both system and traditional formwork. Very often a contractor uses a type of tie "because they have always been used" and it would appear that these are treated as disposable items with many ties or parts of the system lost in the concrete as work proceeds. Coil ties remain embedded and the central portion of both snap ties and she-bolts remain cast in. These are the expensive parts of the tie arrangement and, unless some value can be taken from the further fixing that they provide, it may be that some saving can be achieved by re-thinking the tie arrangement.

Tie selection is an important aspect of formwork and the supervisor is advised to consider what he will expect to achieve from a given type of tie. Firstly, the tie collects the forces and pressures from the carcassing members and transmits them either to the opposing section of the formwork or into some anchorage within previously cast concrete. It must be capable of sustaining these forces with an appropriate factor of safety. The embedded part of the tie system should meet the requirements of cover and any marks at the concrete surface where the tie passes through the concrete member should be simple to repair. The tie may be required to provide an anchorage or



(a) in sloping or battened wall construction a tie in the kicker (or in the base slab) assists in resisting uplift
(b) it is advisable to slow fill as top is reached to avoid increase in pressure resulting from increasing rate of rise of concrete
(c) casting first lift in single sided work against sheet piling
(d) an anchor cast in the kicker is helpful in controlling foot of form
(e) soldier members anchored at X provide cantilever support to form—anchor inserted at Y is for support to further lift
(f) anchorage afforded by cast-in device is a function of concrete strength *at time of application of load*

support for some succeeding operation, it should cause the minimum obstruction to the passage of concrete during the casting operation and should also be simple in operation, vibration-proof and compatible with the variety of form materials with which it will be used. It is helpful to the contractor if the tie spaces the forms apart as well as tying them together.

Types of tie available include: coil ties; she-bolts; snap ties; plain rods threaded with nuts; tapered rods; heavily indented rods; windlassed wire and hanger ties.

Coil tie systems

The coils are specially wound rods connected by two further rods, the whole assembly being jig-welded. Some coil ties incorporate a disc or plate water bar to prevent moisture or vapour penetrating along the line of the tie. The system is completed by plastic cones which space the form and provide a tapered recess which can be neatly filled after striking the formwork. Tie bolts and connectors used with coil ties have rolled threads of a special configuration which mates with the coil and yet is easy to clean. Anchors are supplied utilising the coil nut arrangement and looped wires for embedment in previously cast concrete. Hangers which can be looped over steel joists are also available using a similar configuration.

Coil ties with their associated cones provide a simple, direct means of tieing forms. The cones space the forms and provide decent recesses into which mortar fill can be punched. The system is readily understood by the operative on site. Secondary fixings can be achieved by reentering bolts into the buried coils, although care must be taken to avoid putting these bolts into a bending situation. One problem with coil ties is that of finding the coils with the tip of the bolt. When assembling the second side member in deep forms it is necessary to use a long thin bar with a hooked end and have an operative locate each one as the bolts are inserted *blind* through the form. Correct depth of thread engagement must be ensured and attention given to the correct installation of washer plates under the bolt head. Coils can be used with connectors to cope with thick walls and where tapers occur. In the case of tapers, care must be taken to avoid bending the coil or leaving the assembly in such a fashion that bending can occur in the tie assembly as the load is taken up during concreting. Where coil arrangements are used as anchorages in previously cast concrete, it must be realised that their loadbearing capacity is dependent upon the maturity of the concrete into which they are set. The manufacturer's literature will give guidance based on temperature and time. Coil ties can be used with system formwork or traditional formwork. Care is necessary in traditional formwork application to cater for the varying thickness of carcassing members which will be encountered on site.

She-bolts

Initially she-bolts were mainly used for heavy duty applications, for instance in civil engineering. The system proved so versatile, however, that new she-bolts of smaller diameter are now used with many of the proprietary panel systems. Developments have included "c" washers, or clip pins, which ensure that the she-bolt spaces the form as well as tieing it. She-bolts consist of tapered bolts with internal threads at the tapered end and substantial threads, some buttressed, at what might be termed the "shank" end. Means are also provided to avoid rotation of the she-bolt whilst it is being tightened, using large nuts, butterfly nuts or level nuts. The considerable length of external thread allows the inclusion where necessary of tilting washers to accommodate batter in form arrangement.

The buried, or lost, component of the she-bolt assembly, that which remains in the concrete, is a relatively small and cheap piece of steel and the she-bolts proper, being tapered, leave a neat and simply packed hole in the concrete. The cast in tie is crimped to avoid rotation in the green concrete and may be obtained, if necessary, with a water bar welded into place. A major point of safety is to ensure the correct engagement of the thread of the crimped tie rod into the internal thread of the she-bolt. She-bolts provide a major advantage in practice in that the complete assembly can be made up and then passed through the carcassing, then through holes drilled in the formwork face, waler nuts being installed once this operation has been carried out. The manufacturers of shebolt equipment also provide anchors in the form of deformed bars (pigtail anchors), which can be cast into mass concrete, kickers or previous lifts of concrete, to provide a fixing for forms as in cantilever construction or dam structures.

Tie rods

These are the simplest form of tie. They normally consist of a mild steel rod which is threaded at one or both ends used in conjunction with nuts and washer plates. The length of the thread allows a variety of wall thicknesses to be cast, although long threads tend to get clogged with concrete. A spacer must be introduced to maintain the correct wall thickness—this may be in the form of a timber spacer at the top of the form or a concrete or plastic block or tube within the form. These latter arrangements are not easily filled on completion of the work and moisture or vapour can easily penetrate the wall. Plastic settlement of the concrete and the accumulation of bleed water from the mix can also cause channels through which moisture will move. Setting these latter considerations aside, the simple tie rod provides economies for general structural concrete works and provides many re-uses. The diameter of the rod should not be less than 12 mm to avoid bending and damaged ties, the washer must be sufficiently large to transmit the bearing stresses from tie loads. The nuts used are often winged and a short length of bar welded to a standard nut serves the purpose of providing leverage as well as preventing the nut unwinding during the vibration of the concrete.

Tapered bolts of bright steel are commercially available which strip easily provided they are pulled in the right direction. The taper also serves to allow for caulking with mortar and the production of watertight walls in which case the larger diameter of the tie is placed to the waterresisting face of the concrete and the making good is carried out by plugging followed by caulking with dry mortar mix.

Plain tie rods

There are a number of wedging devices which combine washer plates and grip wedges—the action of driving the wedge or washer device grips the rod and thus ties the form. These various devices are appropriate to structural concrete applications, although their action appears to result in various degrees of grip or tightness which could allow variations in wall thickness. In general, the gadgets allow for speed of fixing and removal and are best used by people with some skill or expertise.

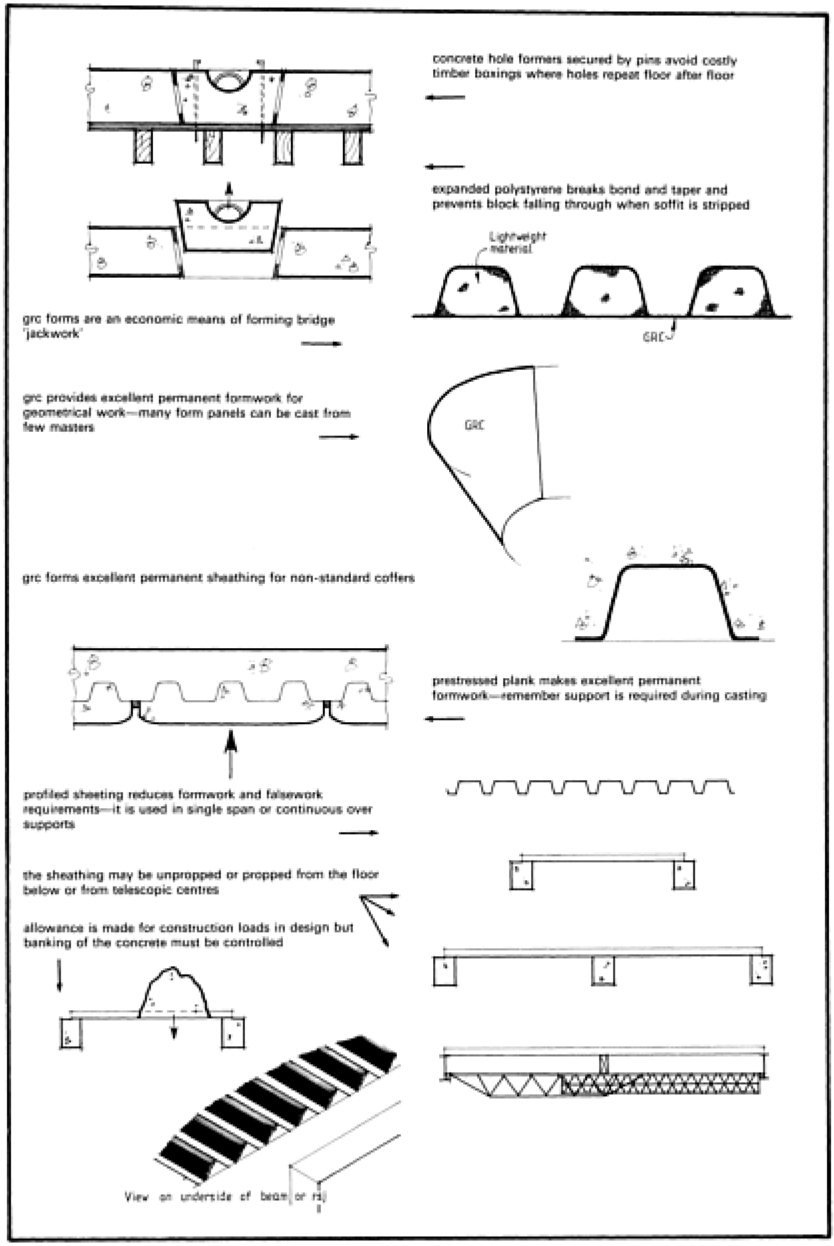
Wire ties

Wire was the traditional material used for many years and many small contracts are still carried out using windlassed wire ties. At best, however, the tie arrangement cannot be as reliable as the simplest of commercial ties, as there is always some degree of form movement as concreting proceeds.

Snap ties

The simple snap tie meets most of the demands imposed by modern construction—those of speed of installation, the capability of spacing forms and meeting the requirements regarding ties, loads and cover.

Snap ties are available in a variety of configurations, mainly designed for use with one or other of the systems, although snap ties or rod forms can be used with standard traditional construction. Snap ties originated in proprietary system formwork and were largely used where form panels were individually placed and tied. Due to their small sectional area it is necessary to insert more snap ties for a given loading than would be necessary with other ties. Snap ties are generally inserted into the joint between commercial panels and thus there can be a tendency for leakage at this point. It is possible to obtain snap ties with double slots which permit the formation of piers within the run of standard panels. There are also



small accessories which enable snap ties to be snapped off any considerable time after concreting or where particularly high strength concrete is being used. It is advisable to leave the ends of snap ties projecting from the concrete until adjacent operations are completed as it is often possible to take support for plates or forms. As a precaution when any considerable force is applied, a block, plate washer and wedge should be inserted on the far side of the wall. This precaution is particularly necessary where loads are applied to ties embedded in fresh concrete.

Special formwork

Where there is considerable repetition, where there is some particularly demanding requirement regarding accuracy of finish or where opportunities exist for a high degree of mechanisation, special formwork can be used to advantage. Special formwork is the produce of specialist suppliers who have considerable capability in manufacture. Whilst special formwork is generally produced in steel, there are some specials produced in grp and even in heavy timber. A recent development, where a relatively small number of a complicated nature of forms are to be cast, utilizes plastic sheet supported by expanded polystyrene. Special formwork frequently incorporates gantries and handling equipment, much of which uses hydraulics or fluidics. Recent developments in special formwork include casting machines for segmental bridge construction and equipment for slipforming operations and tunnel lining.

The concrete supervisor is likely to meet special formwork when there is a high degree of re-use to be obtained from a form, where there is any degree of complexity or sections which demand generation of exceptional geometry, where the accuracy required is particularly stringent, and in cases where some degree of mechanisation can be built into the system in the form of a traveller or in terms of pneumatic or hydraulic activation. It is advisable, where possible, to visit the works of the special formwork manufacturer to determine how the equipment is assembled and what are the key points in using it. A check should be made on the capability of the form in terms of containing concrete and the intended method of placement of the concrete, particular details of connection to previously cast concrete, the provision of hold down, kentledge and so on. The size of individual components of the special form should be checked in terms of transport and access to the site. Where there is any special control system or jack involved, the supervisor should ensure that he understands the principles involved and so on and, in case of emergency, can work them himself. He should also be familiar with points of maintenance, the topping-up of the hydraulics, checks on hoses, and so on, so that he can make spot checks to ensure that equipment is being serviced satisfactorily.

Other form materials

As well as those falling within the main divisions of timber and timber derived materials and proprietary equipment, there are a whole range of materials used in forming concrete—many on the face of it unlikely for use in form construction. Such materials include paper, rubber, plastic sheeting, casting resins (both rigid and flexible) and indeed such materials as expanded metal lathing. The following brief notes give some indication of the properties of these materials and some typical applications.

Aluminium

Whilst there have been some instances where reaction between alloy and concrete have caused problems and sticking, aluminium has been used for many years in casting pipes and pipe shells. Special moulds for featured panels have been cast in aluminium and latterly extruded aluminium has been used increasingly in formwork systems for strongbacks, walings and joists.

Card

Card has been used to fabricate waffle formers, bolt boxes and also cone formers, both square carton type formers and cylindrical or tubular formers. Card tubes are slipped over tie rods to facilitate their withdrawl from the hardened concrete.

Casting resins

Casting resins, either precast or supplied in a cast-ityourself pack, have been used quite extensively for manufacturing not only mats to impart surface finishes to concrete but also to case complete moulds or mould parts where accuracy and considerable re-use are required. The resins can be formulated to provide moulds which are completely rigid or partially flexible. The resins, with some small proportion of extender such as fine sand, will follow the most intricate details of the master upon which they are cast, thus allowing extreme accuracy.

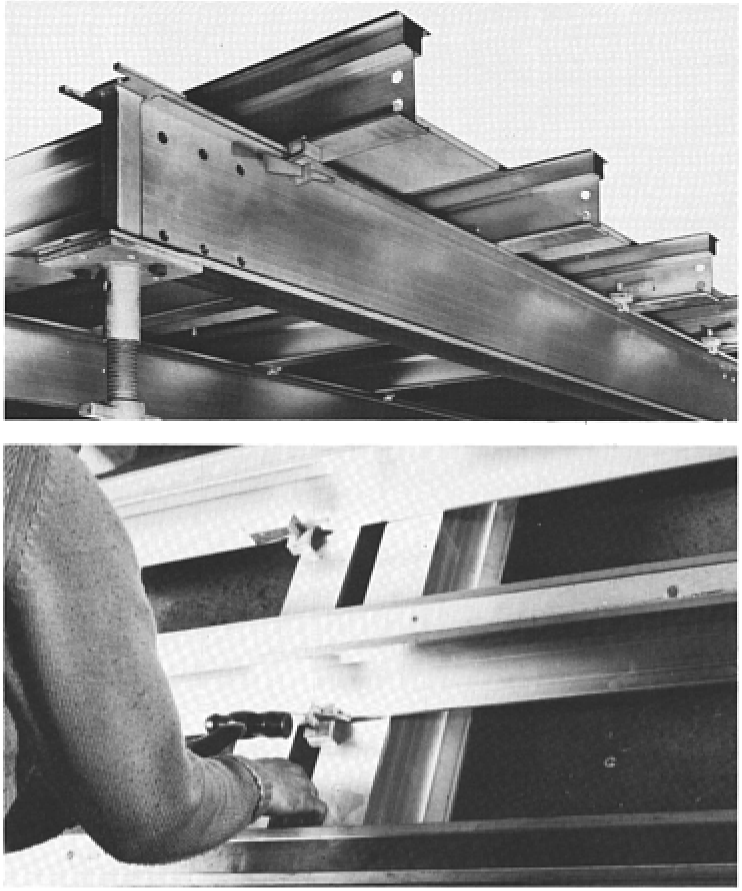
Fabric

Plasticised fabrics and synthetic fibres can be used in a variety of ways to simplify construction and simplify what are very difficult operations. Fabric moulds or mattresses can be laid above or below water level and then filled with mortar. The water is expelled as the mortar fills the mattress and the resulting layer of material is extremely dense and thus of high strength. The configuration of the fabric mould determines the concrete profile. Fabric has been used in this way in forming canal banks and dock walls, one of latest examples of which is the lining of the dry dock for the construction of the precast sill units for the Thames Barrier project. A further use for fabric has been found in the repair of concrete structures exposed to tidal range. The nylon forms are zipped into position and mortar pumped into place. The lightness of the material allows divers to place the forms underwater with mini mum difficulty. This relatively new use of fabric has a great deal to offer in terms of each of repair and protection.

The development of manmade fibres and sheet materials incorporating these fibres has provided the construction industry with a versatile form material. Fabric either in fabricated mattresses or used as a form container or bag has been useful in solving a variety of problems, particularly where sea defence is concerned. The containers are so devised that the fabric contains the fine materials of a mix whilst allowing the water from the mix to percolate away from the mass. The containers can be used to form fine concrete or dense structural concrete and allow the placement using pumps. Prefabricated forms are spread over the ground, river bank or sea wall, and then grout or fine aggregate concrete is placed. As the form fills so the ties in the form cause the heavily featured profile desirable in combatting scour. Tailor-made fabric forms can be used in remedial works where, for example, they are installed around defective concrete members and filled with concrete. The material is particularly useful in underwater applications and fabric bags are used to seal joints between massive concrete blocks in dock and harbour construction, when they are placed and filled under the supervision of a diver.

Paper

Craft paper or reinforced paper is used in construction to provide a parting layer between successive layers of concrete in stack casting of precast elements for example. Craft paper can also be used to line excavations to avoid contamination of the concrete. Paper is used to wrap forms or blocks to facilitate their withdrawal from within the concrete.



Aluminium forms have recently been developed. Lightweight yet immensely strong, the equipment is available for a variety of uses (SGB Ltd)

(a) as primary and secondary beams supporting ply sheathing to slabs

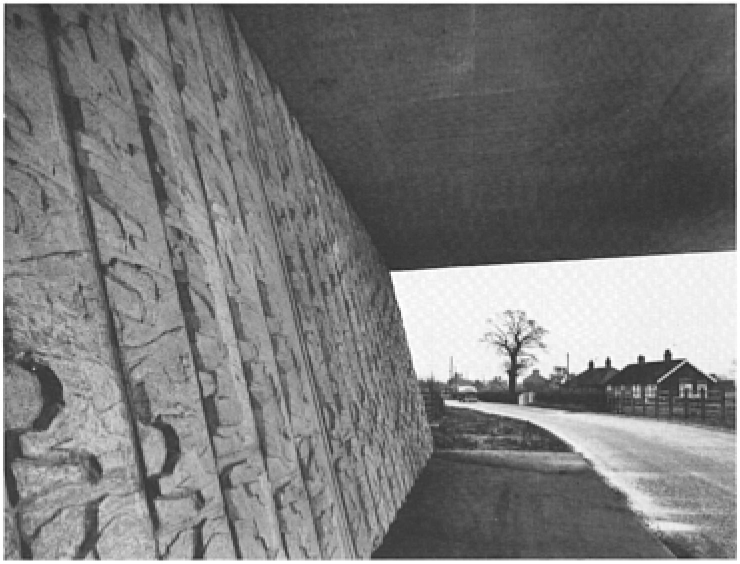
(b) as soldiers and beams in wall forming

Plastics

Plastic laminates are widely used in facing plywood and particle board and plastics form an essential part of some systems in that they can be moulded in various ways for such items as cone formers in tie arrangements. Those plastics most commonly encountered in formwork are grp, thermoplastics (PVC and ABS) and polyurethanes.

Methods of producing formers and moulds vary, but they usually require initial production of a master unit from which a mould can be taken. This master varies from a timber and plywood model in the case of grp and polyurethane, to an extremely expensive machined die for materials such as polypropylene.

Their good impact resistance, for the most part, makes plastics suitable for forming concrete. The finish on the plastic which governs the eventual texture of the concrete face can be anything from glass smooth to ease striking to difficult sections, to lightly textured to avoid surface crazing. Stiffeners can be introduced into



Re-use of formwork—the grp formers used in casting the textured panels illustrated had previously been used on a major road construction (Durham County Council)

the plastics for the purposes of fabrication into forms or for the attachment of liners to backing systems. Many plastic forms can be struck from the concrete without the use of oils or parting agents, but generally a light mist spray of chemical release agent is helpful to ensure clean striking.

Two part polyurethane and plasticised PVC can be used to cast bespoke liners for special finishes, although suppliers of liners have vast ranges of patterns and textures from which the designer may make his selection.

Polystyrene forms

A considerable amount of expanded polystyrene is used in forming blockouts, through holes and so on. Generally, this is a wasteful process, both as regards the polystyrene and the subsequent work required in its removal and the cleaning up of the concrete face. The material is used because it can be quickly and easily shaped and whilst this is the case, it is often hastily cut and jammed into the approximate location of the check out. The material is quite expensive and is usually only able to be used once in this fashion. It is better in many instances to fabricate a simple boxing in timber or ply, made to strip correctly and re-usable.

Fabricated polystyrene void formers and forms

This application of polystyrene is very economic, particularly where extremely complicated shapes are to be formed. The material is bonded into huge blocks and then wire cut and shaped to a high degree of accuracy. A plastic material is bonded to the casting face and an economic number of uses can be achieved—depending, of course, on the application. 20 or more uses from trough forms and 7–10 uses from complicated forms incorporating an internal box structure to facilitate striking, is usual.

Plastic sheet

Polythene sheet is used as a liner in some instances and as a slip layer in floor construction. Polythene supported on wires and formers has been used to form hollow cores in beams and precast elements.

Rubber and neoprene

Rubber moulds have been used for years in precasting featured moulds and panels. Rubber sheet and neoprene were used in producing patterned and textured surfaces and rubber sections are available which, when inserted into suitable grooves in the form edges, provide grouttight seals.

Concrete

Concrete has particular characteristics which are useful in mould and form work—it is readily available on most sites and in works, it is stable, easily moulded, durable and its mass and strength help to avoid damage as units are stripped from it. Plain concrete moulds are made by laying and screeding concrete prior to careful trowelling and curing to a high standard of finish. Concrete can also be cast into complicated shapes. Provided there is sufficient lead or draw allowed, concrete elements can easily be struck from such moulds. A further use for concrete as a permanent form is where complicated work or special features are precast in the form of permanent reinforced concrete panels which can be set in place prior to concreting the main structure. Glass reinforced cement has, of course, been developed as a permanent form and is used for bridge edge beams and other difficult sections. The advantage of permanent forms of this nature is that the eventual surface finish can be controlled prior to the panel installation and thus quality of the appearance of the structure can be guaranteed.

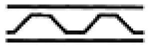
Grc permanent forms

Where there are stringent requirements on finish or where there is a considerable amount of geometry, it is worth considering the use of a glass reinforced cement permanent form. These comprise a sand, cement, glass mix, which is sprayed or hand layed into a mould in manufacture. The resulting composite is strong, durable and impact resistant and can be designed to sustain the pressures imposed by the fresh concrete in the construction process. Grc forms are valuable for work where special finishes and textures are required and provide an opportunity for pre-inspection prior to the final casting operation. In some countries grc can be taken as providing cover to the steel, although in the UK the specified cover must normally be provided over and above the 10/ 15 mm thickness of the composite facing.

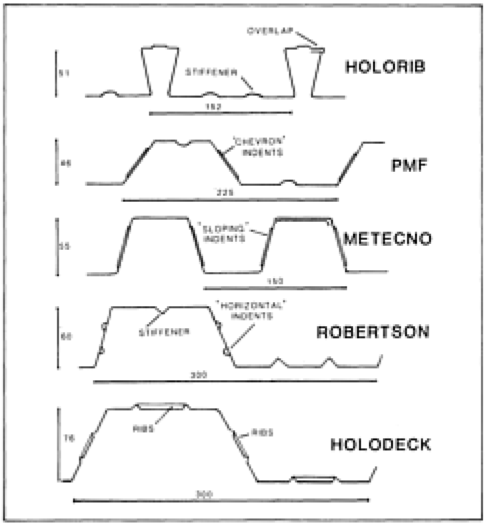
Flat plates can be supplied or plates with stiffeners, other forms can be manufactured to the profiles required for specific contracts. Grc permanent formwork has proved economic in forming cantilever edge beams to bridges, non-standard trough and waffle members and permanent forms presenting a profile finish on gable walls, retaining walls and so on.

Steel sheathing systems

Considerable use is currently made of pressed or rolled steel plate permanent sheathing. This material acts as a permanent form and in some instances can be considered as reinforcement to the structure. Plates of steel are stud rivetted or otherwise attached to concrete or steel beams, transverse steel is placed and concrete placed and compacted (the use of superplasticising admixtures promotes speedy placement).

PANEL	SECTION	TYPE CODE
SANDWICH TRIPLE SPRAY		4
RIBBED TWIN SPRAY, RIBBED SOFFIT		3b
RIBBED TWIN SPRAY, FLAT SOFFIT		3a
CORRUGATED, SINGLE SKIN		2
FLAT, SINGLE SKIN		1

Classification of grc permanent formwork



Profiles used in composite slabs in the UK

Suspended ceilings and other linings are subsequently hung into place although for industrial applications the finish of the plate is sufficient for visual purposes. Keys are provided for alternative finishes. The use of plate forms reduces the formwork and falsework requirement, although the manufacturers' recommendations regarding location and duration of support must be studied.

Circular work

The provision of circular forms, whether circular in plan or in elevation, involves much the same construction techniques. Formers are required to provide substantial grillage upon which runners or joists may be supported to generate the required sheathing profile. The main formers or ribs may take several forms (shaped timber ribs; rolled steel sections; adjustable steel centres; rolled tubular sections), each of which will be suited to a particular type of work. The selection of one of these materials will depend on the radius of the circular work to be cast as well as the normal factors of re-use, available materials and so on.

It is usual to set down a very accurate profile, full size, and to then translate this profile into templates or rods to which the materials can be shaped. Of course, due allowance must be made for the sheathing thickness and joist or support arrangement. Circular forms can be sheathed using individual timbers, ply sheet, steel sheet or combinations of these materials. If timber on ply is used the physical characteristics of the materials govern the radius to which various thicknesses can be bent. Steel sheet can be brakepressed and rolled to a very tight radii and indeed thin sheet is often pressed to shape for form accessories. Proprietary suppliers provide a variety of equipment for circular work ranging from flexible steel panels to pre-shaped interlocking extruded aluminium sections which can be used in forming small radius columns and similar work. Card and foil forms are available for forming circular columns, although the manufacturer must be consulted regarding the secondary support system required to maintain these rather flexible materials in the correct line and location. The advantage of steel and light alloy members used for supporting circular sheathing systems is the ease with which they can be re-rolled to provide further use at a different radius. The proprietary adjustable centres provide a plant item which can be hired or bought in for a particular contract. These centres are best checked against a template before each use and just prior to casting to ensure that their adjustment has not been affected by the striking and handling process.

Recently proprietary suppliers have introduced bolting arrangements which can be used in conjunction with soldier members to flex the form face to provide circular faces or indeed geometric forms. These comprise turnbuckles connecting with the strongbacks—tightening the turnbuckles reduces the radius curvature of the face which should be checked against a template as are adjustable centres.

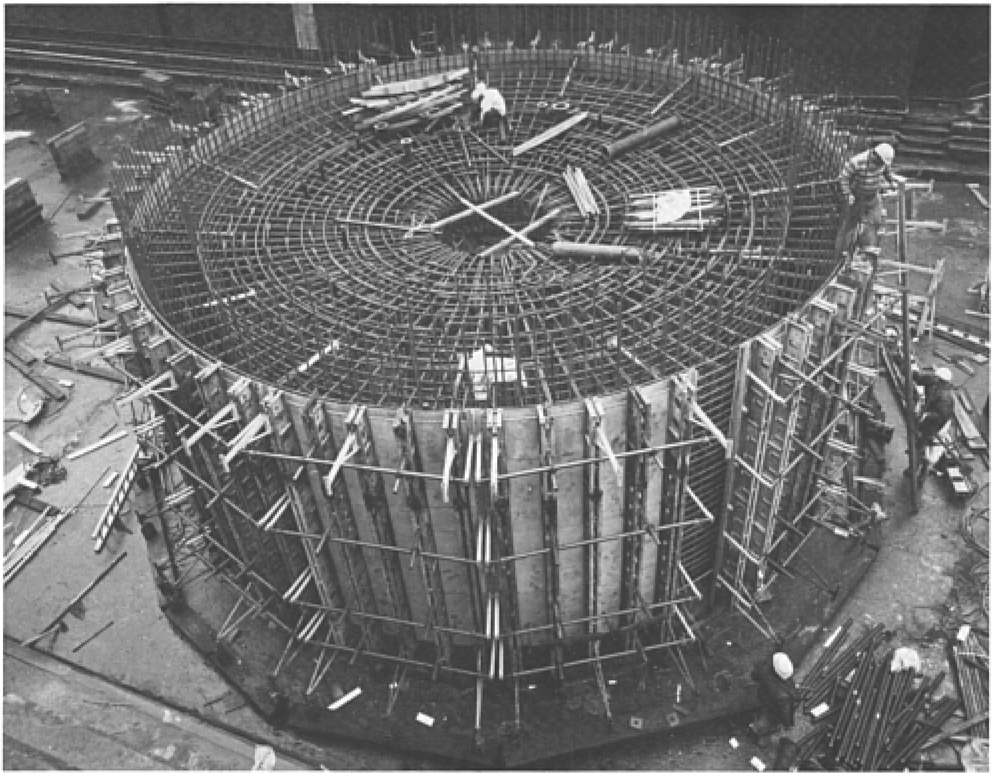
Checklist

Access

Can concreters gain unobstructed access to fill form?
Can skips or pipelines be brought to form openings?
Is there a safe scaffold platform for operatives?
Is ladder access to working platform secure?

Anchorages and bearing plates

Have correct fittings been installed?
Are duct formers securely attached?
Is position and line correct?
Are joints grout-tight?



A good knowledge of available equipment is essential—here simple screw jacks are used to curve plywood panels casting circular walling (SGB Ltd)

Ancilliaries

Have brick ties been inserted?
Is masonry slot in position?
Any other fixings and sockets?
Are through hole formers installed?
Has weather bar been fixed?

Bracing

Are all bracings securely connected?
Do braces go to sound ground or mature concrete?
Are braces angled to avoid uplift?
Are braces suitably tightened?

Carcassing

Is there evidence of wracking or distortion?

Are all connecting bolts suitably tightened?
Are the main continuity members installed?

Cleanliness

Have forms been blown out and/or any debris removed?
Has extraneous material been removed from adjacent scaffold?

Concrete

Has surface of previous lift been prepared?
Are embedded ties in mature concrete?
Has rate of rise of concrete been established?
Are screeds and tamps available?

Connections

Are brackets, sockets, plates for cladding, correctly positioned?
Are through holes or projecting loops located as per drawing details?

Cores

Are cores of correct size?
Are they correctly positioned?
Has arrangement been made to combat uplift?
Have cores been lubricated for removal?

Curing

Is curing membrane available?
Can cover be supported clear of concrete surface?
Is insulation available?

Ducts

Are ducts correctly positioned?
Are joints grout-tight?
Is there positive location against uplift?
Are tendons inserted to maintain line?
Are tell-tales attached to monitor movement?

Formers

Are formers correct size?
Are they correctly located?

Are sockets and slot formers secured to formers?
Are formers braced?
Does fixing resist side thrust and uplift?

Inserts

Are inserts correctly located and securely fixed?
Are conduits supported at correct distance from form face?
Are power boxes and switch boxes taped to exclude grout?

Level

Is level of form correct within tolerances?

Lighting

Are lights available for work after dark?
Are torches available for inspecting deep lifts?

Line

Is line of form correct?
Has camber been included?
Are continuity members installed?

Oil and coatings

Have the correct materials been used?
Are edges of forms oiled to prevent build-up?

Power

Is power available for vibrators and equipment?
Is safe low voltage current in use?

Reinforcement

Is steel correctly positioned?
Are there positive arrangements to protect cover?
Are projecting steels suitably supported and jigged?
Is any reinforcement to be inserted as work proceeds? Is it available?

Safety

Does scaffold have sound foundation?

Is scaffold adequately tied and braced?
Is scaffold complete with toe boards and guard rails?
Are helmets, goggles, ear muffs, and so on, available?

Sheathing

Are materials appropriate to required finish? Are joints tight?
Is there sufficient lap over previous cast?
Have seals been inserted?
Is sheathing supported against previously cast concrete?
Has sheathing been oiled or coated with release agent?
Has excess material been removed?
Are features securely fixed?
Has grout check been installed?
Have all gaps and holes been filled?

Stopends

Are stopends correctly positioned and securely fixed?
Have stopends been oiled?
Has excess oil or parting agent been removed?
Have holes and gaps been effectively sealed?
Has grout check been installed?

Striking arrangements

Have stripping fillets been inserted?
Is there sufficient clearance for tie removal/form removal?
Have screw pads or jacks been adjusted and lubricated?
Is there sufficient adjustment available on rams and screws?

Supports

Are supports based on suitable foundations?
Are they correctly positioned and plumbed?
Are supports tight and restrained against movement?
Have lacers been installed?
Is external bracing in position?
Are standing supports correctly positioned?
Are forkheads wedged to ensure axial loading of props or tubes?
Have correct pins been used at adjuster?
Are secondary heads suitably tight?

Table forms

Is infill correctly positioned and supported?
Are legs jacked or casters locked?
Has bracing been properly installed?
Are runners correctly seated in forkheads?

Ties and anchors

Have correct ties been used?
Are centres correct?
Are ties suitably tight?
Have correct washer plates been used?
Are correct spacers installed?
Have correct studs or cones been used?

Washer plates

Are correct sizes installed?
Are washers square on members?
Have washers been securely wedged in tapered work?

Points of supervision

Early establishment of required quality will allow selection of appropriate method and materials
Surface finish of concrete will reflect quality of work and formwork
Butt and cramped joints avoid grout leakage
Selection of oils and parting agents is critical
A large proportion of formwork is in stopends and day joints—care and attention here will reduce costs
Economies are achieved with re-use—store and maintain forms properly
Ensure supports are plumb and set to sound footings
Always install pre-concreting and in-concreting checks
Ensure forms can be handled using available equipment
The pre-concrete and in-concrete checks ensure avoidance of movements, leakage and rework.

14. Surface finish

The process of producing an attractive surface finish to concrete begins at the drawing board in the early stage of architectural design. Whilst setting out the profile of the concrete the architect must bear in mind the environment in which the structure is to stand, the degree of exposure to the elements, such matters as exposure to aggressive chemicals in the atmosphere, moulds from the surrounding countryside and the possible influence of what are termed “mini environments” caused by the building configuration itself. The ways in which the surface reacts to these various conditions are known as *weathering characteristics*. A look at a structure where concrete has been used visually will suffice to illustrate the different gradations of tone which develop due to this weathering process. Areas where water moves quickly over the surface during rain or storm conditions tend to remain clean and of a light tone, whereas areas where water flows slowly or where the surfaces are protected from wetting and washing, tend to darken. Local vortexes of wind around corners and details also tend to cause gradations of tone. The weathering process appears to depend a great deal on the nature of the face of the concrete. The more absorbent the face, the more likely it is to collect dirt, grime or pollution from the atmosphere. The slope or inclination of a surface also reflects dirt retention, as does the actual smoothness of the surface texture. The architect must, therefore, take into account a whole range of factors when determining the profile, texture and material for the particular concrete surface.

The supervisor is advised to study a variety of concrete structures of various age and in various locations, with differing finishes, to obtain an understanding of the way in which the surfaces weather. Then, when given the opportunity of commenting on detail or at the time when drawings and detail need revision, he will be able to offer useful advice. Fortunately for the producer and the constructor it appears that the simpler, more traditional the detail, the more likely is the finish of the building to remain interesting and acceptable as it weathers.

Principle causes of uneven weathering are projections and joints, and detail such as striations which are included in the design with perhaps little attention to the manner in which they affect the flow of water over the surface. As soon as details for a particular building are received from the architect, the supervisor will be well advised to scrutinise these for any obvious problem areas with regard to surface finish. Using his experience gained from previous work, the supervisor will be able to point out such advisable details as the insertion of drips in soffits, the provision of copings and cappings and the avoidance of extremely smooth surfaces which will, in time, exhibit hairline cracks and pattern staining. Although early discussion of profile and detail will prove valuable in the eventual provision of acceptable surface finishes, there can be no substitute for the actual provision of models and samples.

Attention given to detail at the design stage will be amply repaid in consistency of finish and avoidance of damage at joints, features and detail. The designer and method engineer can do much to introduce economy into production by careful consideration of the scale of tooled features and the relative areas of tooled and textured concrete. The effort and expense of tooling can be reduced by the introduction of an intermediate stage employing retarders or textured liners, to reduce the amounts of concrete which must be physically tooled from the concrete face.

Specification covering surface finish

Generally, the specifier will have set down descriptions of the required surface, texture and materials and indeed small samples of these important details may have been prepared by contractors and precasters in establishing details of the structure. Small samples are in themselves a problem area, they are often quite unrepresentative of what can be achieved in a full scale operation and may be quite misleading by being either too high or too low a quality to be indicative of what will actually be achieved on the finished work.

The "local" specification for the concrete work will govern the finish which must be achieved on the face of the concrete. Various of the clauses used in the specification of concrete finish are standard clauses and the supervisor should be careful to understand their implications in terms of form materials and concreting technique. In this chapter the additional care to achieve *visual* concrete is discussed, the need for this extra care becomes evident once the typical clauses are examined.

The Department of Transport Specification for Road and Bridge Works is taken as the basis of much specification. The recommendations in that specification cover a range of concrete finishes (with prefix "F" for formed surface):

Class F1 calls for no greater attention to surface that the provision of forms so constructed that there shall be no loss of material from the concrete. After hardening, Fl class finish is required to be in the position and of the shape, dimensions and surface finish described in the Contract.

Class F2 specifies that irregularities in the finish shall be no greater than those obtained from the use of wrought (prepared) square edged boards arranged in uniform pattern. The finish is intended to be left as struck, but imperfections such as fins and surface discoloration shall, if required, be made good by methods approved by the Engineer.

Class F3 requires the formwork to be lined with a material approved by the Engineer to provide a smooth finish of uniform texture and appearance. The material shall leave no stain on the concrete and shall be so jointed and fixed to its backing that it imparts no blemishes. The material shall be of the same type and obtained from only one source throughout any one structure. The contractor shall make good any imperfections in the finish as required by the Engineer. Internal ties and embedded metal parts will not be allowed.

Class F4 requirements are as for class F3, except that internal ties and embedded metal parts will be permitted. The ties shall be positioned only in rebates or in other positions as described in the Contract or as agreed by the Engineer.

The recommendations continue, requiring that permanently exposed concrete surfaces to classes F4, F3 and F2 finish shall be protected from rust marks and stains of all kinds. Perhaps the most important requirement of the Department of Transport Specification governing formed finishes is contained in the Clause 1402(3), which requires:

> Unless otherwise described in the Contract, all formwork joints for exposed surfaces of concrete to class F2, F3 and F4 finish, shall form a regular pattern with horizontal and vertical lines continuous throughout each structure and all construction joints shall coincide with these horizonal or vertical lines.

What, then are the important parts of these clauses in terms of supervisory activities and workmanship?

Class F1 implies a sensible form or container, possibly constructed using reclaimed or secondhand materials. It should not be thought that the formwork of this grade is just rough shuttering. Indeed, in many instances the forms will benefit from considerable attention in the way of design for re-use and attention to access into the forms to facilitate placement and compaction as well as design for the pressures generated at the concrete face. Grouttightness should be regarded as a pre-requisite of all formwork, governing as it does the achievement of durability and a corrosion resistant enclosure for the concrete.

Class F2 is usually provided for in the provision of plywood faced forms. This is a conventional and economic form of construction using readily available materials. A specific requirement for *board* forms would imply a far more expensive surface finish in the special finish class.

Class F3 is particularly demanding and the elimination of ties calls for considerable application of design skills. Whilst generally this specification will apply to key parts of a structure, the supervisor should be careful to identify lifts of a depth greater than 1 m, where ties are excluded, as pressures increase rapidly above this depth, as does difficulty in providing external support or even achieving sufficiently sound footings for such support.

Class F4 is a finish which requires care and attention and, in this instance, as in any where approval from an engineer/architect must be obtained, the provision of samples and establishment of standards becomes critical early in the course of the contract. Once samples have been established at site and the engineer’s approval has been obtained, then everyone from the formwork carpenter to the concretor can be informed of what is acceptable in terms of performance. Failure to establish such samples can only result in constant discussion and possibly in rejection of the concrete when cast.

The word “uniform” also presents difficults—as the contractor is concerned with a range of materials exhibiting natural variability in combination with a range of skills and methods, each having their own inherent effects on variability—again the early establishment of standards by production of samples employing typical materials, labour and method, is the best solution to establishing firm guidelines for future work on site.

The Department of Transport Specification, which has been adopted as standard for much specification work, goes on to consider a series of finishes, using the prefix “U” for unformed surfaces.

These are as follows, and are self-explanatory:

Class U1. Where concrete shall be uniformly levelled and screeded to produce a plain, textured or ridged surface as described in the Contract. No further work shall be applied to the surface unless it is used as the first stage for a class U2 or class U3 finish.

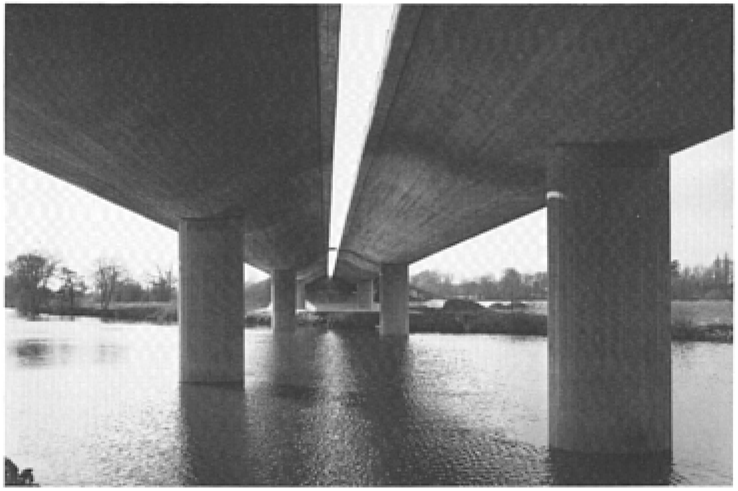
Class U2. After the concrete has hardened sufficiently, the concrete class Ul surface shall be floated by hand or machine sufficiently only to produce a uniform surface free from screed marks.

Class U3. When the moisture film has disappeared and the concrete has hardened sufficiently to prevent laitance being worked to the surface, a class Ul surface shall be steel trowelled under firm pressure to produce a dense, smooth uniform surface, free from trowel marks.

These again are sensible means of demarcation between the various types of surface finish. The word uniform can be misleading and may again lead to considerable discussion. It is advisable to establish the degree of consistency which can be achieved using normal skills and methods.

CP 110: 1972 makes recommendations regarding surface finishes for formwork or moulds and these recommendations have been brought forward in the main from CP 116: Part 2: 1969 which was the first British Standards Institution Code of Practice to make useful recommendations for classifying surface finish. The surface finishes range from Type A finish through to Type E finish and a special category entitled “Other types of finish”. These types are as follows:

Thin sawn boards were secured to a shaped ply lining, to achieve this impressive board-marked finish (Durham County Council)



Type A finish. This finish is obtained by the use of properly designed formwork or moulds of closely jointed sawn boards. The surfaces will be imprinted with the grain of the sawn boards and their joints. In addition small blemishes caused by entrapped air or water may be expected, but the surface should be free from voids, honeycombing, or other large blemishes.

Type B finish. This finish is obtained by the use of properly designed forms or closely jointed wrought boards. The surfaces will be imprinted with the slight grain of the wrought boards and their joints. Alternatively, steel or other suitable material may be used for the forms. Small blemishes caused by entrapped air or water may be expected, but the surface should be free from voids, honeycombing or other large blemishes.

(It should be noted that finishes of Type A and B do not necessarily provide a suitable surface to receive in situ concrete or applied finishes, nor do they include special board-marked finishes. Consideration should be given to the type of connection, or applied finish, and if necessary other types of treatment should be specified for the appropriate faces.)

Type C finish. This finish can only be achieved by the use of high quality concrete and properly designed forms, having a hard, smooth surface. The concrete surface should be smooth with true, clean arrisses. Only very minor surface blemishes should occur and there should be no staining or discoloration from the release agent.

Type D finish. This finish is obtained by first producing a Type B finish on thoroughly compacted high quality concrete, cast in properly designed forms. The surface is then improved by carefully removing all fins and other projections, thoroughly washing down and then filling the most noticeable surface blemishes with a cement and fine aggregate paste. Every effort should be made to match the colour of the concrete. Care should be taken in the choice of any release agent used to ensure that the finished concrete surface is not permanently stained or discolored.

Type E finish. This finish is obtained by first producing a Type C finish and then, while the concrete is still green, filling all surface blemishes with a fresh, specially prepared cement and fine aggregate paste.

Every effort should be made to match the colour of the concrete. After the unit has been properly cured, the faces should be rubbed down where necessary to produce a smooth and even surface.

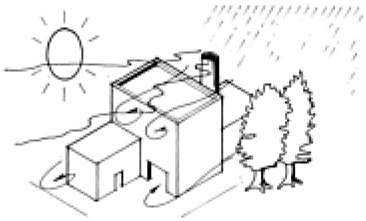
Other types of finish. These should be fully specified in each case and should, if possible, be related to samples which are readily available for comparison. Included under this heading is any finish that requires the coarse aggregate to be permanently exposed, the use of special forms or linings, the use of a different concrete mix near the surface, grinding, bush hammering, or other treatment.

CP 110 goes on to make sensible recommendations regarding the provision of samples, the avoidance of terms such as “fair-faced”, “blemish-free” and so on, and the determination of standards of finish relevant to the location of the concrete within the structure. The Code specifically mentions the control of sources of aggregate as being important in control of colour and particularly the importance of mix proportions and grading as well as freedom from impurities. One extremely practical point regarding formwork is the recommendation that the replacement of individual plywood sheets or sections of timber in large panels should be avoided. This, coupled with the importance of the selection and use of appropriate coatings and release agents, is discussed later within this Chapter.

Supervising the surface finish of concrete

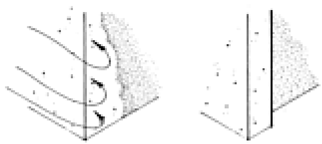
Concrete is a most remarkable material in that, whilst being a very basic mixture (it has been described as a mixture of dirt, burnt dirt and water), it can be used to achieve the most elegant surface. Architects and designers can set out dramatic profiles, massive or slender, and can choose from a variety of very attractive aggregates or applied finishes. The result can be a thing of beauty— surfaces which need little maintenance, which will withstand the ravages of weather and time and which may, if certain basic rules are observed, even improve in appearance with age.

The supervisor responsible for concrete construction has a major role to play in the achievement of surfaces to satisfy the requirements of the architect, designer and engineer. The way in which the supervisor sets up the



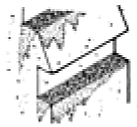
when considering the variety of conditions to which a structure is subjected, it is not surprising that different weathering patterns emerge

rate of water movement and the point of discharge are critical to consistency of weathering



the effect of 'mini-environments' are often apparent at returns in elevations and corners of the structure

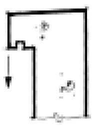
some details formalise the weathering process and add to the visual effect



horizontal surfaces allow dust to collect and upset consistency of finish

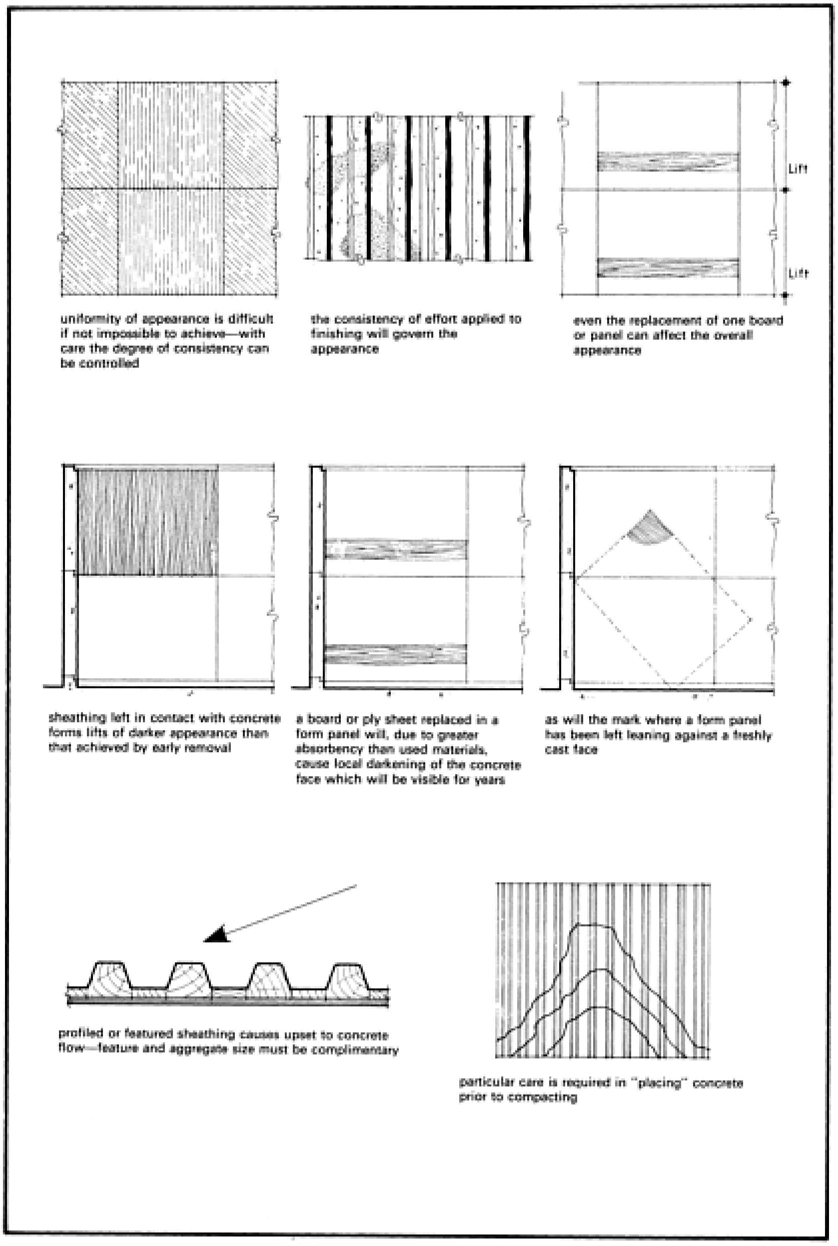
exposed aggregate and lightly ground or etched concrete have a good track record and it is advisable to make the selection on the basis of finishes which have been proved satisfactory within the local environment

reeded or striated concrete directs the water in the way the designer intends



copings and traditional drips control local weathering

quirks emphasis change of finish or texture (remember cover)



uniformity of appearance is difficult if not impossible to achieve—with care the degree of consistency can be controlled

the consistency of effort applied to finishing will govern the appearance

even the replacement of one board or panel can affect the overall appearance

sheathing left in contact with concrete forms lifts of darker appearance than that achieved by early removal

a board or ply sheet replaced in a form panel will, due to greater absorbency than used materials, cause local darkening of the concrete face which will be visible for years

as will the mark where a form panel has been left leaning against a freshly cast face

profiled or featured sheathing causes upset to concrete flow—feature and aggregate size must be complimentary

particular care is required in "placing" concrete prior to compacting

concreting operations and maintains control of the various trades and skills will determine the success of the operation. It must be remembered that many years after the contract is completed, the concrete stands as a record of the skills and abilities of all concerned in the activities of the construction. From the face and general detail, such as joint lines, arrisses and so on, of a concrete structure, it is possible to read what size the lifts and bays were, how the concrete was compacted and in what type of form, how long the form work remained in position (in the case of precast concrete, which way up the element was cast), how the aggregate exposure was achieved, and a number of other points, many of which tend to provide an answer to the question—was it done successfully?

Once he becomes aware of the specific visual requirements of the structure for which he is responsible, the supervisor has a considerable fund of valuable information which he can provide as input into the architect and engineer. Many architects, for example, have a quite limited knowledge of details of the processes from construction, concrete placement and compaction techniques, which are all essential to production of high quality surface finishes. At all stages the supervisor should be prepared to provide the necessary information, make trial mixes, construct models and produce samples with a view to simplifying the work where possible and to ensure that the work can be carried out to the required standards. It possibly goes without saying that the supervisor should question details or features which are so slender that they are virtually impossible to construct in concrete and should raise matters of detail such as treatment of arrisses and scale of detail and feature. It is an unfortunate fact that many jobs are spoiled for a lack of such feedback. Architects and engineers are often required to deal with such a wide range of aspects of construction that it is quite impossible for them to be aware of these more practical details and they will thus welcome helpful suggestions early in the course of the work.

Unfortunately the words *uniform* and *uniformity* have been used in a number of specifications in the past and have been taken too literally. Indeed, there are people in the industry who believe that it is possible to achieve absolute uniformity of finish where concrete is concerned. Unfortunately, the architect may not have had much experience of, or direct contact with, concrete and may find that the structure which he has designed does not present a uniform appearance either during construction, on completion or later in its working life. This is a disappointment for both architect and client and care must be taken to ensure that they are made aware of the likely surface appearance prior to or early in the course of the work.

A number of factors determining the appearance of concrete will be discussed in this chapter. They are many and varied and indeed take effect at different stages in the course of construction. In place of *uniformity,* with its militaristic connotations of absolute similarity, the word *consistency* will be used throughout this chapter.

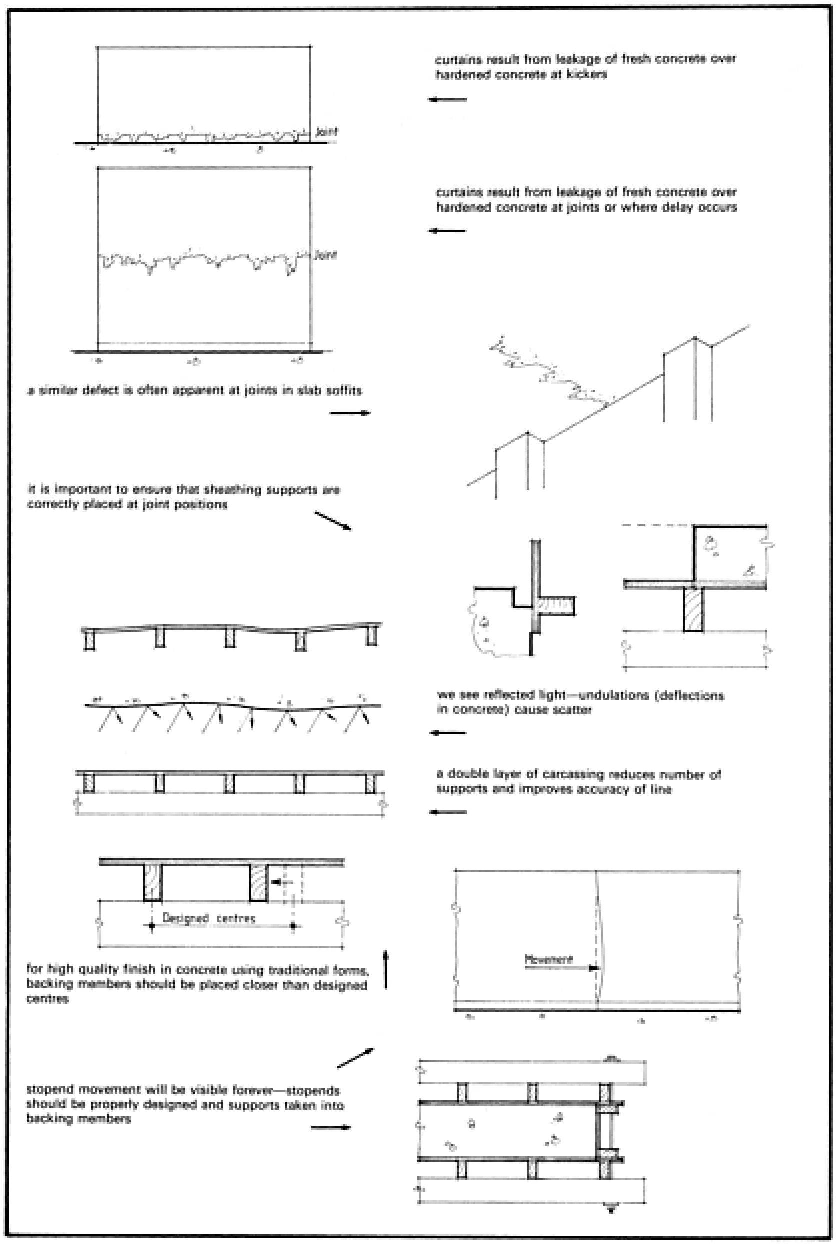
The task of the construction supervisor is to achieve consistent results, and he must thus be clear in his own mind about the meaning of the word consistency. When we talk about consistent finishes, we mean finishes which match, within acceptable limits, the standards of finish set out for the job, and finishes which exhibit an acceptable degree of variability throughout the job. The Formwork Report recommends the early establishment of standards of surface finish and these standards embrace a variety of details such as type and location of joints, colour and texture of surface, degree of exposure or exotic aggregates and similar details. Although standards of accuracy are dealt with elsewhere in this publication, the accuracy of the construction, linearity of surfaces, deflections of form face, and so on, will all have a major impact on the final appearance. As an example of this interrelationship between surface appearance and accuracy, consider the effect of "quilting" where local deflections in the sheathing accentuated by the light reflected from the surface, can render the most carefully produced and consistent surface visually unacceptable. Considering these various aspects then, this chapter is aimed at providing the supervisor with a good understanding of various processes which can be used to achieve a specific surface finish. Such is the breadth of the topic that it will be necessary to touch upon information given in other chapters, although the supervisor will be left to read these points in more detail.

Much of the achievement of consistent finishes and especially the achievement of high quality surface finishes depends upon the care and attention paid to what are the normal processes of concrete construction

—applying a rather higher standard of control to the everyday processes than is necessary for normal structural concrete production. The storage of aggregates, provision of formwork, location of steel, and so on, are discussed in other chapters, but in the case of visual concrete and special finishes rather more attention is necessary to detail. For example, whilst it is normal to store a sufficient stock of aggregate in well segregated, carefully drained bins, for special surfaces with high specification standards it may be necessary to purchase all the aggregate and store sufficient cement for a particular part of the contract from one source, at one time and to then make special provision for the storage of the aggregate up to the time of use. Another example is perhaps the use of mould oil or parting agent. Application by mist spray is normally sufficient, but where there are particular demands for visual concrete it may be necessary to mist spray the oil or parting agent and then to mop the excess off before concreting to leave the merest film on the mould or form face.

Aggregates and cement

Consistency then is the watchword and careful control must be kept on the standards of incoming materials and the way in which they are delivered and stored. Aggregates can be particularly problematic and it is advisable to keep samples of what are acceptable aggregates both as regards appearance and grading, and to constantly compare incoming loads with these known samples. The way in which the materials are loaded onto vehicles from the quarry can cause problems, particularly where layering develops as a result of taking various fractions from



different bins or silos. A point to watch for is contamination by chemicals or dust from other loads, which is not unknown in the case of contract vehicles. The materials checker must take care to avoid such contaminated loads being tipped onto stockpiles. Seasonal changes can take place in aggregates, either as a result of availability of the individual fractions or as a result of different means of making up loads.

Sometimes it is necessary for the pit to crush stone to supplement existing stocks and, whilst the concrete will be of equivalent grade once adjustment has been made to the mix design, obviously if the concrete is to be exposed then the appearance will be quite different. The location in a pit from which the material is taken can result in variations in colour which again are of little importance in plain concrete but which will become very apparent where aggregates are to be exposed. Regarding cements, provided that these are drawn from one works, then there should be little problem. However, there are differences in cement shades which can affect a change in appearance if not controlled. Again, ideally all the cement should be drawn from only one source or supplier.

Batching and workability

It goes without saying that consistency of batching and consistency of workability are essential to good structural results, but it cannot be over-emphasised that these two factors govern the chain of operations which determine the results in terms of appearance. Given an appropriate workability, the concrete can be placed and compacted satisfactorily with the optimum amount of vibration and applied effort. Provided that trial mixes have been used to establish the requirements of workability, the concrete will flow within the confines of the section around the steel and into place. Variations, either higher or lower workability, will cause problems and result in different display in terms of aggregate in the finished job. This is particularly apparent when placing into forms with featured sheathing—striated forms present considerable problems for the concretor. In this case particularly, the concrete must be placed evenly throughout the length of the form as near to its eventual position as possible to avoid the separation which is otherwise caused by the restraining influence of the striations.

Formwork and moulds

Absolute care must be taken to provide formwork of the very highest standards of workmanship—plane, accurate and close-jointed. Local distortion, deflection and leakage are the most common causes of fall off in visual standard and without a good quality form it is impossible to achieve a good quality surface finish. No amount of dressing, tooling or other remedial work can ever make good the defects arising from form problems.

The use of gaskets and seals may appear pedantic when one is dealing with such a basic material as concrete. Be warned, however, form leakage with resultant discoloration of the surface, displacement of forms and fins and curtains being formed on the face can ruin what is otherwise a successful operation as well as destroying the appearance of what may have been an acceptable piece of structural concrete. Having said this, however, we should remember that leakage from a form evidenced by fins and discoloration is difficult to assess in terms of its effect on the structural quality of that element. Honeycombing and excessive blowholes may be apparent on the surface, but without ultrasonic and/or similar tests, it will be difficult to measure the effect of such defects. Grout tight forms are essential to the production of good quality surface finishes and especially high quality surface finishes. It must also be remembered that the quality of the form face will be directly reflected in the finished work. The better the compaction, the better the concrete and the more carefully the oil or parting agent is applied, the more likely is every minute detail of the form face to be expressed on the finished surface. Points to watch are the relative absorbencies of adjacent boards, the careful application of mould oils, the condition of new boards or replacement sheets of ply which will otherwise cause variation in the appearance by absorbing greater amounts of moisture from the concrete mix.

It is advisable to close up the supporting members in the carcass of the form where visual concrete is concerned to reduce deflections, particularly where there is some likelihood of the sun shining along or across the finished surface. Reflected light emphasises variations in the plane of the form face which are made more evident by smooth or carefully produced concrete. As well as using gaskets in form joints, it is essential, wherever possible, to mask the joints by siting them in shade or by locating them within features of the structure. Features applied to the form face create recesses in the concrete and joints set into these features will not mar the general appearance of the concrete as they would on the plane of the face of the concrete. Care should also be taken when locating stopends that these should coincide with points of sheathing support, as the local deflections of sheathing will otherwise allow grout loss and resultant staining. The line of joint formers and construction joints must be true, whether vertical or horizontal, as there is bound to be some difference in tone or shade which will be emphasised by inaccuracies. Stopends require particular attention in this respect as the results of poor workmanship will be apparent throughout the life of the structure.

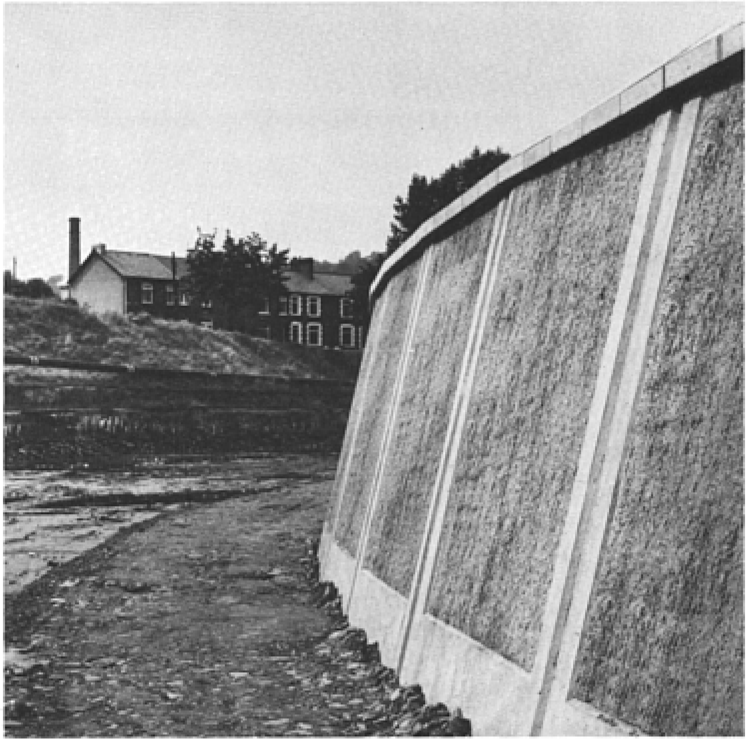
Formwork should be protected between uses to avoid scuffing, wind and similar face damage. During use, vibrators should be kept away to avoid burns or recesses which fill with paste and get progressively worse use after use. These are worst when the vibrator is allowed to penetrate between the form and steel reinforcement, and are virtually irreparable in terms of concrete finish. Where forms are to be exposed to weather for any period of time between erection and actual casting of concrete, they should be protected as far as possible. This is also an instance where sealers and chemical parting agents can be used to advantage to avoid oil absorption into the face of the form and the drain down to which mould oils are prone.

Where special features are to be cast it is likely that a new form will be bought in or constructed on site. The trades supervisor should, whenever possible, enter into discussions with the formwork designer to establish details of construction. Much of form construction, particularly where timber and timber derived materials are concerned, is based upon traditional practice proven over many years and the skilled tradesman has a lot to contribute. Even the way in which features and fillets are moulded, or joints in sheathing are formed, and the way in which the sheathing is attached to the frame or carcass is critical to the eventual appearance.

Where steel, grp and grc are used to form special concrete finishes, it is essential to consult the specialist supplier. The process of welding steel sheathing to a framework of supporting steel presents difficulties, the welds tending to distort the sheathing very slightly locally and, whilst the resulting blemish on the form face may not be very marked, the corresponding effect on the face of the visual concrete may be sufficient in the eyes of the authorities to warrant the rejection of the concrete. Glass reinforced and injected plastics and grc forms are quite flexible by nature and deflections, particularly at elevated temperatures, may detract from their performance. Whenever possible form and materials should be tried out early in the course of the construction, ideally somewhere in the structure where appearance is not critical, such as a basement wall. This provides an opportunity for all concerned to experiment with the rate of fill, period of vibration, and so on.

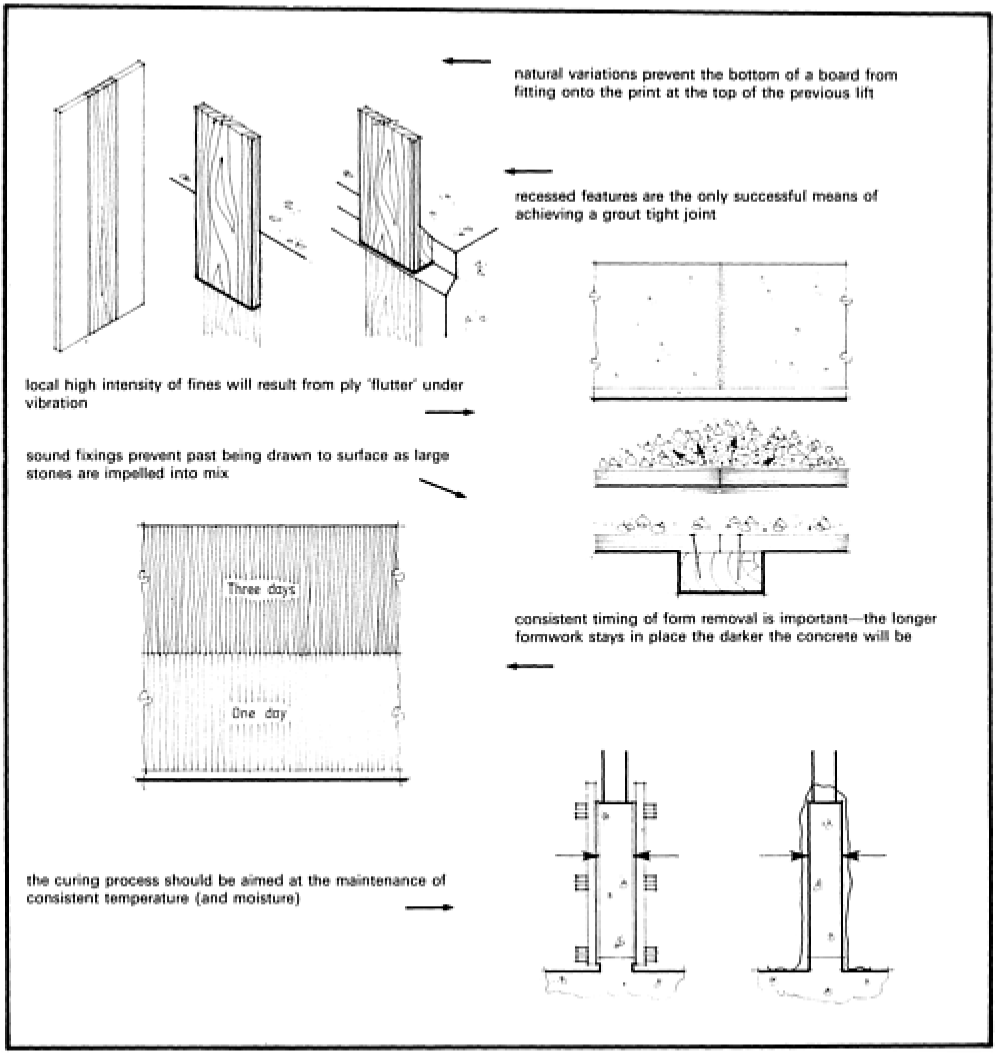
In *Chapter 2: Drawings and documentation,* the question is raised concerning intended geometry. At the early stages of discussion it is worth querying the detail, particularly where complicated shapes are generated by lines set down in accordance with the architects' or engineers' drawings. Frequently the complexity of a detail does not become readily apparent until the initial stages of setting out for steel bending or form manufacture. The form should be set down full size—this is normal practice in proprietary form and mould manufacture. In one works, for example, which produces high quality precast concrete cladding, not only is the profile of the mould and the concrete set out full size, but zinc templates are also produced for checking in their finished state. It is advisable to produce small models or sketches of each lift

These textured panels are the result of use of polyurathane form liners (Welsh Water Authority, Taff Division)



or section of concrete and to examine the intersections of arrisses, the plane of faces, the interaction between interesecting curved surfaces and similar details.

The number of uses achieved from forms and moulds become more critical in the case of high quality visual concrete. Deterioration of a form face is acceptable in normal structural concrete, marks from repairs to ply faces, where joiners or patches have been applied and so on, but this will not be the case in visual concrete and the potential number of satisfactory uses will be difficult to establish. Obviously, the number of uses will vary from material to material, but a constant check must be made and careful remedial work carried out at the first signs of any deterioration. It should not be considered that activities such as grit blasting or exposure of aggregate by tooling will mask sub-standard finishes from the form.



Even inconsistencies in the mix proportions and agglomeration of fines adjacent to leaking joints will be visible long after the forms are removed when the aggregate has been exposed.

The period of time during which the forms remain in contact with the concrete will have a considerable effect on the appearance of the surface. As a general rule, the longer the form is in place the darker the concrete surface. Differences can be observed in lift and service cores and shafts where the form has remained in place overnight or during a weekend, for example. Another example is that where, due to some associated work, the forms to a face have been left in place whilst, for instance, a return or landing has been cast—the face of that part of the work will be noticeably darker. In normal structural concrete construction, differences in shade are not important. With visual concrete, however, such variations can be the difference between acceptance or rejection of the finish.

Timing

One important aspect of concrete production from the viewpoint of the person attempting to achieve a specified degree of consistency is that of timing of operations. The whole process of concrete construction is time dependent in terms of both the macro-and micro-scale. The process of stiffening and hardening of concrete commences from the moment of addition of water to the cement and aggregates in the mixer and continues, we understand, for the next 100 years or so. The strength gain and durability developed within the early life of the concrete are dependent upon the achievement of compaction and the installation of sensible curing regimes. The time of mixing and placing are important factors in the production of good quality concrete. These factors become more important where the visual qualities of concrete are concerned. Whilst most mixers will produce acceptable structural concrete on a 1 1/2–2 minute mixing cycle, and most structural requirements can be satisfied providing the concrete is placed and finally compacted within about 1 1/2– 2 hours of the addition of water to cement, far more consistent timing must be ensured where the finished concrete is to be visually acceptable. It is recommended that the mixing time should be doubled and maintained as standard by an in-built timing mechanism in the mixer or, where necessary, against a clock set before the operation. Great care must be taken to ensure that the concrete is placed and compacted within a period of, say, one hour from mixing. The vibratory effort should be applied in the same way, for the same duration and ideally be the same person for each successive lift (or unit in the case of precasting).

There must be a carefully planned sequence for concrete placement and for complicated sections the concreting gang must be instructed in the placing of concrete into particular parts of the form. It may be necessary to introduce filling doors into the formwork to facilitate placement, although this should be avoided on the face of forms producing visual concrete. The curing time and timing of form removal must be standardised with due regard to ambient temperature and the temperature of the concrete within the form or mould. All these factors must be maintained as consistently as possible to ensure consistency in appearance of the finished work.

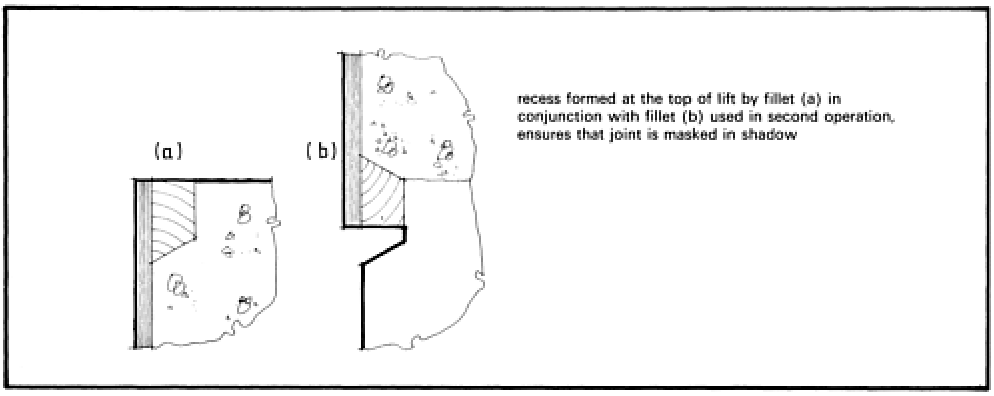
Construction joints and casting sequence

Mention is made in *Chapter 9: Joints* of the importance of joint location. Joints must be so placed as to provide a convenient junction between adjacent lifts or bays. Where visual concrete is concerned, then special care should be taken to:

mask joints in shadow or detail;
rule joints or express joints;
position joints in a way emphasising the nature of design;
ensure tight joints.

There are a number of instances where concrete profile is such as to render monolithic construction impracticable, such as where landings and flights abutt walls or where cantilever balconies have concrete parapets. Although a form can be designed to cast the whole of the concrete in one operation, the timing of the operation to avoid surge below riser boards, at cut strings and below upstands and beam forms, is critical. Apart from the possibility of the formation of dry joints where concreting operations are delayed, the whole texture of the face, important in the case of exposed aggregate, can be upset by the different amount of compactive effort applied at the various stages in construction. In these and parallel instances, great care must be taken to incorporate features to mask joints, fillets to rule joints and so break down the construction into phases so that each concreting operation is carried out in forms rigidly and accurately fixed to previously cast concrete. As an example, and to illustrate principles which apply to concrete construction generally, it is worth considering the construction of the wall, stair and parapet as sketched, and bearing in mind the same principles when considering the construction of the balcony and the landing also illustrated. Firstly, the structural designer must be consulted to ensure that the various allowable stopend and day joint locations are understood. It may be that the requirements of the design determine these positions and that some further design work is necessary to introduce a specific series of steps to the construction. The economies of additional cost of redesign versus simplified construction must be considered and, in the case of major works, the guidance of a quantity surveyor may well need to be sought. Generally, the structural designer can overcome the problems of simpler, more logical, joint locations by some small amount of re-scheduling of bar lengths, shape codes and so on, and thus free the construction from non-essential constraints.

In the case illustrated it is proposed that the spine wall would be cast onto a kicker, the kicker incorporating



loops or anchorages to ensure a sound leak-free seal. The spine wall would be cast to landing level plus kicker, say the height of one riser, to standardise joint location. The spine wall form would have at its face an indent former of the exact profile of the tread riser and waist of the stair within which the projecting steel for the reinforcement of the flight proper would be fixed during the casting operation. After striking the first lift of the spine wall form and casting the next lift, the stair flight, the landing and the parapet wall kicker would be cast bolting back the carriage to the spine wall using ties inserted in anchors located as agreed with the architect (this because the filled holes at anchorage points are bound to affect the visual aspects of the design). Suitable standing supports would be needed under the landing to enable early removal of the soffit. The next operation will be a repeat of the last, the formwork being located to a platform of scaffolding set to a predetermined datum. In the case of the operation incorporating the sloping soffit, precautions are necessary to counteract the thrust which develops as the concrete is placed and compacted. This operation will provide a sufficient kicker to allow the erection of formwork for the parapet/baluster, and this form will be clamped tightly to the previously cast kicker using ties entered into the anchors cast in as ties during the previous operation. The filling of the wall form will be carried out slowly and a cover board may have to be introduced on top of the baluster forms to avoid surge. This board would need to be very securely fixed to resist the thrust and uplift developed during this part of the operation.

This type of construction can be made considerably easier to execute under site conditions by the premanufacture of forms in a workshop, or even under tarpaulin at the corner of the site, in which case the concrete profiles can be set out full size on sheets of ply or a previously cast concrete slab and bearers and backings so spaced as to match the positions of tie bolts, which are governed by the construction joint locations, need for kickers and so on. This description has concentrated upon formwork considerations, but it must be said that in work of such a nature the careful installation of accurately cut and bent steel, located by sound ties and plastic spacers with due regard to side and end cover, is essential to the satisfactory completion of the task. It should also be noted that the location of anchors and ties is very important both as regards the achievement of excellence visually and also from the viewpoint of sound fixings for formwork. There are several options regarding the finishing of tie and anchor holes, such as:

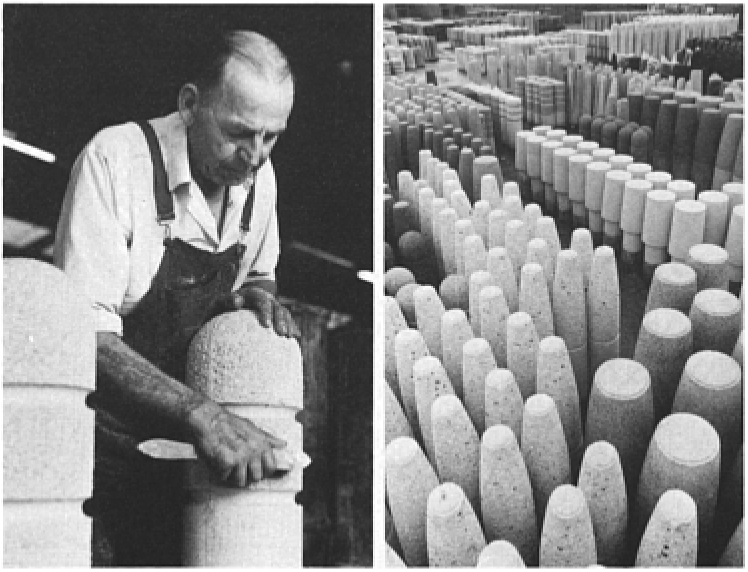
to fill flush with a mixture of sand and cement, carefully mixed with the addition of some colour if required to match the main structural element;

to fill with mortar, dry packed into the hole and in such a way that a recess of about 3–4 mm remains as a feature;

to fill with mortar to ensure that moisture will not corrode the ends of the anchors or ties and to then insert a plastic plug, again as a feature.

Concrete placement

To ensure that the planned sequence of concreting operations can be carried out in practice, the supervisor must arrange for the appropriate equipment to be made available. Whatever form of mixing, equipment is used, or even if the concrete is supplied readymixed, it is essential that the concrete should be available in a continuous supply. Special care must be taken to ensure that skips, dumpers, and such like are cleaned. The first batch of concrete can possibly be used in other structural locations after it has coated the plant with a layer of paste. In some circumstances the quantity of the coarse aggregate is reduced in the first batch to



The use of a retarder to produce an attractive finish and improve weathering characteristics of concrete products (Marshall Mono Ltd)

allow for this coating of equipment. Of course, this must be done under careful supervision and in consultation with the person responsible for the mix design. The equipment should be of size and design suited to the scale of the part of the structure under construction. It is useless to attempt to fill slender wall sections, for example, using a massive bottom opening skip—it is more likely that a 400 litre roll-over skip can be manoeuvred on the end of the crane into and around and fairly complex piece of construction such as this. In general terms, the larger the quantity of concrete which can be handled, the greater the likelihood of achieving consistency. This must, however, be considered in the light of pour size and accessibilty. The compactive effort in this instance will be applied by poker or immersion vibrator and a 50 mm diameter poker should be about right for the job.

Access for concretors would be best provided by some form of unit scaffold as in this way there will be no lengthy tubular standards projecting at any level to prevent access by skip. As only about 1 1/2 tonnes of concrete and skip are being handled, the crane can have a fairly substantial stand-off distance and it is likely that it would be relatively easy to obtain working headroom. Headroom and standoff distance can be as problematical as lifting capacity where mobile cranes are concerned, as often the early stages of work being *in the ground* prohibit the location of a crane close to the work. In the case of tower cranes there is little problem with headroom, but here outreach and working radius is important, particularly where static cranes are concerned. The supervisor must ensure that there is good communication between the banksman, or concrete ganger, and the crane driver, particularly where he is unsighted due to the nature or location of discharge position.

Form oils and parting agents

Insufficient attention is given to the selection of coatings and release agents, an important step in the production of visual concrete. Traditionally, the contractor's purchasing officer would place a routine order to the normal supplier for a certain number of drums of form oil at the commencement of a contract. The site used this until the stock dried up, when a further order would be issued for replacement supplies. Unfortunately, this is still the practice with many contractors (and precasters), although during the past ten years, with persistent representation on the part of suppliers, oils and coatings have come to be selected, and indeed occasionally specified, for particular contracts. The supervisor would be well advised to take the time to consult with several suppliers, to experiment with samples and to determine for himself what are the most satisfactory treatments for forms and moulds for different applications on his site. In the larger concern possessing a research and development section, or where formwork is centrally designed, there are probably directives and in-company information sheets available to the supervisor. Failing this, or where there are special requirements, the supervisor should consult the relevant section of *The Formwork Report,* from which the accompanying table has been reproduced.

The following observations result from the author's own experience with particular materials and should be of assistance to the supervisor in formulating his ideas and making a selection for a particular task:

Whenever possible, the form material should be sealed—proprietary products, lacquers and paints, are generally acceptable, although care should be taken to ensure that these materials are applied to dry form faces.

One part applications are generally the most suitable, relying on the evaporation of solvents or reaction with moisture in the atmsophere for achieving a *cure*.

Shellac is excellent for timber and ply surfaces which will not receive abnormal amounts of heat. Orange shellac in methylated spirit hardens timber and plywood and renders them impervious to moisture.

Where possible, coatings with some degree of elasticity are desirable to cater for the normal movements of the material to which they are applied.

Particular care should be taken to seal end grain and timber and the edges of ply panels.

Some degree of *build* is essential to ensure that minor discrepancies in the face are filled to avoid grout infiltration.

An excellent coating for really first class work is a film of glass tissue laminated into place with resin, the slightly matt surface being helpful in reducing tendency to crazing.

Coatings should be applied in the best available conditions—it will not do to just coat them out of doors and hope for the best.

In all cases forms must be properly set up with adequate access to allow consistent applications of paints, oils or retarders—as has been stated this is an important part of the concrete process which will make or mar the finished concrete structure, particularly where visual concrete is concerned.

There can be little doubt that the most useful and, in the end, most economical, treatment is the chemical release agent. Whilst initially of greater cost than oils, provided it is applied in the finest spray, just enough to leave a film which is greasy to the touch, it ensures good release. Care must be taken to avoid over-application because of its action as a mild retarder at the concrete face. Where there are objections to the mist spray as a method of application, there is no reason why the release agents should not be brush or roller applied and subsequently removed using a sponge or absorbent cloth. Cream emulsions are useful for run-of-the-mill work, although care is required to ensure correct dilution in the mixing stages.

It should be noted that whichever mould treatment is used, the most critical aspect is the application to the form which should be carried out systematically and as an inbuilt part of the production process, just as is the cleaning operation. Form oil application is used in some instances as part of the cleaning process and, indeed, some oil is helpful in removing paste residue from the form face. Where the work is critical, however, a further application and sponge removal should be carried out to leave the slightly greasy film required to achieve striking without stain or plucking at the face.

Recommended release agents

Type of form face	Plain surface finishes		Special surface finishes	
Pre-treatment	Subsequent applications	Pre-treatment	Subsequent applications	
Timber—sawn	2	2	6	2 or 5
	3	3	2	2
	5	5	5	5
	6			
Timber—planed	2	2	6	2 or 5
	3	3	2	2
	5	5	5	5
	6			
Plywood—unsealed	2	2	6	2 or 5
	3	3	2	2
	5	5	5	5
	6			
Plywood—sealed	None required	2	None required	2
Plastics—grp, polypropylene plain or textured	None required	5	None required	5
Steel	None required	2	6	2
		5	[5 can be used to prevent rust]	5
Concrete	6 [wax]	2		
	6 [wax]	5		
		6		

Main types of release agent: 1—neat oils*, 2—neat oils with surfactant (wetting agent); 3—mould cream emulsions (water in oil); 4—water soluble emulsions (oil in water)*; 5—chemical release agents; 6—paints, lacquers and other impermeable coatingst†; 7—was emulsion (not included as insufficient data available).
*=Not recommended/not included in table; †=these are pretreatments only.

Retarders (surface-acting)

During the past 15 years or so, the producers of retarders have improved their products beyond recognition. Retarders were once a source of concern as being fugitive in their early forms and could be transferred to steel reinforcement, thus upsetting the bond between steel and concrete. Present day retarders, which are lacquer based, are extremely reliable. Painted onto a prepared form, they can be used (by selecting the correct grade) to achieve surface retardation and exposure of the aggregate over a range varying from an equivalent surface to that achieved by acid etching to an exposure of 10–15 mm depth.

Retarders should be applied to a dry, pre-treated surface, either a sealed surface or one treated with a release agent (not oil or chemical) which is formulated to provide a base for the retarder, yet allow the transfer of the retarder and retarded paste from the form to the concrete mass at the time of striking. In this way build-up on the form face is avoided. Recently introduced heat and rain resistant retarders have overcome many of the problems faced by the contractor attempting to achieve a high quality result in the field. As with oils and release agents, the application of retarders should be made using tools suited to the scale of the work and the size of the features incorporated in the concrete surface.

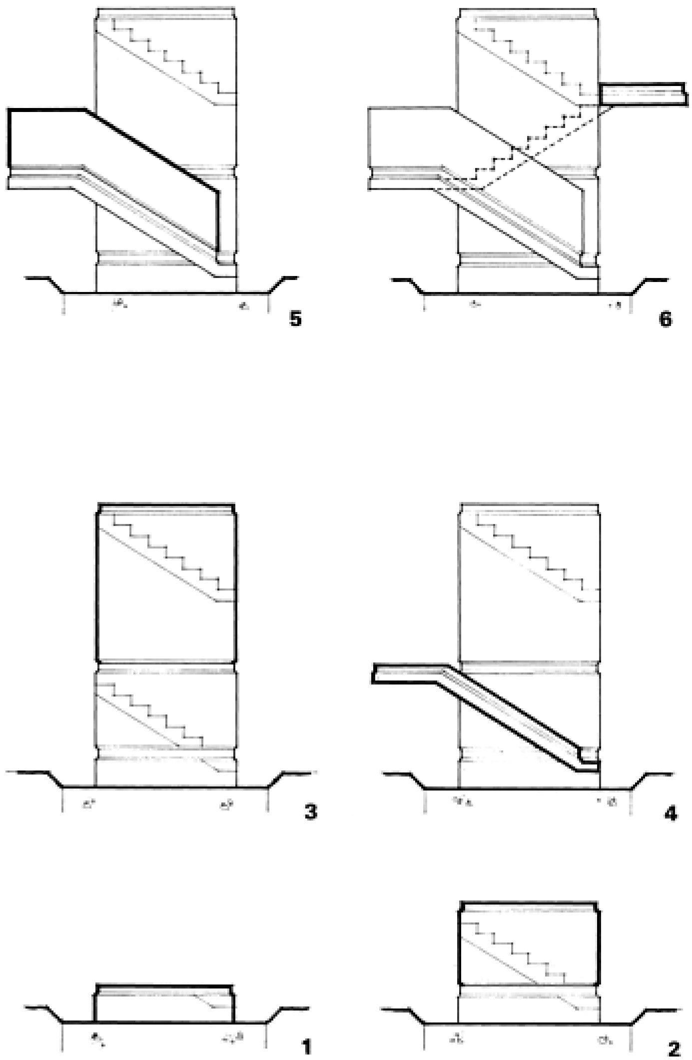
Regarding the removal of retarded face fines, this should be carried out in a consistent manner, and the timing of the operation should be such as to allow the same men to do the work each time, after the same time from striking. Brushing should be with a wide brush— from the top downwards in overlapping strokes. Waterjetting or air and water-jetting serves the purpose of cleaning the face as well as removing retarded material, although care is required to achieve consistent results.

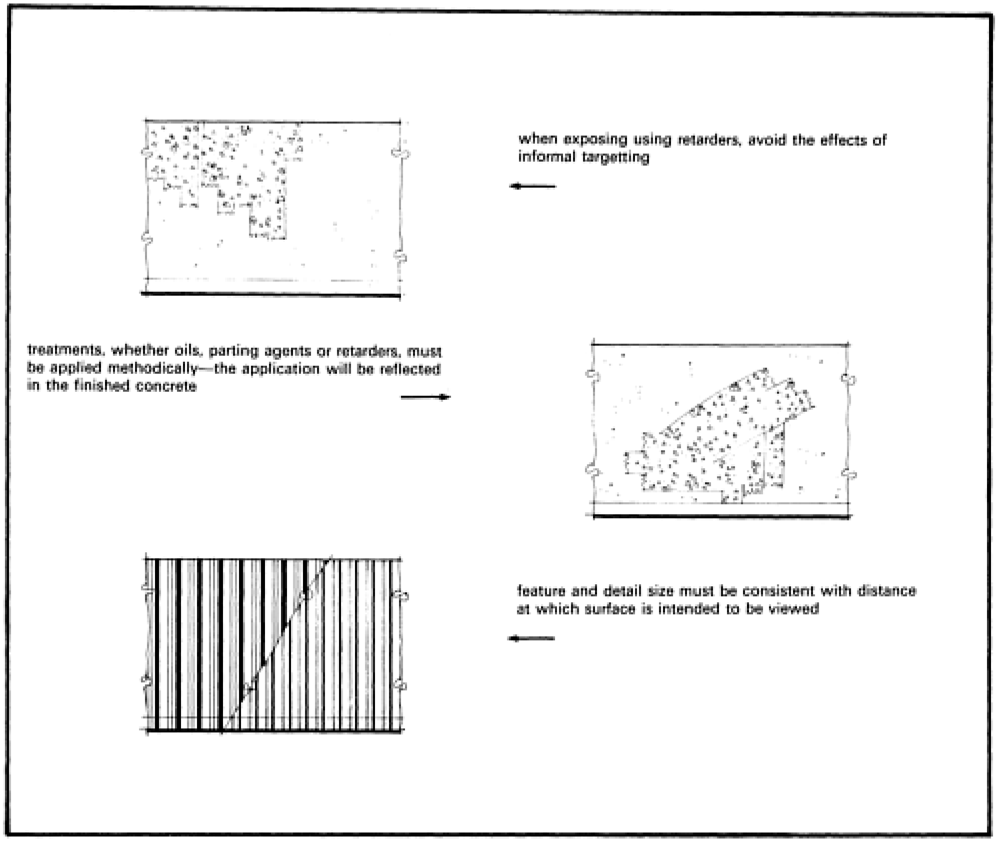
The consideration of detail in production of visual concrete

Architectural details indicate the general profile and texture of the concrete finish eventually required. They also indicate minute but important detail such as the location of drips, treatment of arrisses, position of quirks and profiles. All such detail have an impact on the form and mould details, the means by which compaction is achieved and the way in which the external structure weathers in practice. Such a small detail as the shape and location of a drip former can introduce difficulties into the striking operation which may result in local damage, the need for remedial work and, in the case of special work such as exposed aggregate work, rejection of part of the structure or of a precast element.

Stair construction

Casting sequence of stair tower in visual concrete





It is worthwhile considering the factors governing form design and concreting technique which result from some apparently minor design details. In the instance of the detail indicated, it is possible to construct a groove in the concrete face with parallel sides as drawn, although at the time of striking there would probably be plucking and damage as the form was struck from the concrete. The variation indicated would be far more sensible as a moulded fillet of timber with lightly rounded corners could be attached permanently to the face of the form. A rectangular groove, if essential, could be achieved by the early removal of a steel former from a slot in the face of the formwork. The formwork would thus retain the concrete at *x* and *x,* as the parallel sided fillet was prized out from the concrete. In a precast mould it would be possible to drive the fillet out in the direction of the long axis of the mould side.

One important point in the production of visual concrete particularly, but which is also important to all formwork operations, is that of provision of lead or draw on features. The drip form indicated is securely attached to the form panel and thus the panel will, after casting, be restricted to removal in the direction indicated by the arrows and dictated by the lead. If, for striking purposes, the form must be removed in another way, then the drip fixing detail should be modified as shown. It is important that all external fixings, whether bolts or screws, should be removed prior to the striking operation to avoid plucking from the concrete face. The features, fillets and so on can be removed as a secondary operation. *Any* detail can be achieved but the cost of the detail will considerably vary with the selected profile. In the case of such a detail, care must be taken to ensure that the depth of the groove or drip does not detract from the cover of concrete to the steel reinforcement. The distance between the bottom of the feature and the top of the kicker onto which the upstand is being cast should be considered. Too small a space will preclude the entry of aggregate and resultant trapping of stones will negate the compactive effort and result in honeycombing. The problems of congestion are aggravated in profiled work. They exist in normal construction where, for example, the combined effect of sharp external corners and restrictions on aggregate flow are imposed by the position of steel reinforcement. In geometric work and featured work, particularly in precast concrete, the space for ingress of concrete is often more restricted and, whilst the normal structural concrete can be flowed into place under the influence of suitable compactive effort, special aggregates perhaps of larger size or chosen for their shape, will not flow. The result will be a feature or corner which is composed mainly of paste or fines. The corners of concrete elements, whether in situ or precast, are vulnerable so that the incorporation within the form or mould of a fillet to provide a bullnose or chamfer serves two purposes: the resulting corner is less likely to be damaged by impact and, provided the aggregate is of appropriate size, there is less likelihood of the high incidence of fines which would detract from the appearance of the exposed concrete.

Where the aggregate in concrete is exposed by gritting, tooling or the use of a retarder, it is advisable that the section of the member as cast is increased by some amount to compensate for the material or matrix to be cut or brushed away. Very deep exposure can encroach on the cover to steel necessary to the durability and performance of the finished concrete. The effect of vibration on the appearance of the concrete is another factor which must be considered when aiming for good visual results. This factor is most important in precasting, where the way-up or orientation of the unit within the mould will determine the way in which the larger particles of aggregate move under the influence of the energy imparted by the selected method of compaction. Provided that the concrete mix is nicely graded with sufficient aggregate content and provided care is taken in the handling and placement of the concrete to avoid separation of the larger particles by a roll-out, and as long as the concrete is placed as close to its final position as possible and is not flowed into position by poker for example, then if the compactive effort is properly applied, an even distribution of aggregate within the matrix will result at the finished face of the concrete. Concrete should be placed in layers and vibration used to ensure that these layers knit together. The workability should be such that the concrete flows around the steel and between steel and form face. Workability aids are helpful here to ensure that workability can be achieved without the introduction of amounts of water which would detract from the durability of the concrete. Whenever possible, poker or immersion vibrators should be used to energise the concrete, the size of vibrator being matched to the available space for its immersion.

On horizontal surfaces, which eventually form the soffit of a structure, care should be taken to place and spread the concrete in small amounts rather than dumping concrete in skiploads onto the form. The latter practice leaves a patchy appearance where the concrete tends to scour away the mould oil or retarder.

Precast surfaces

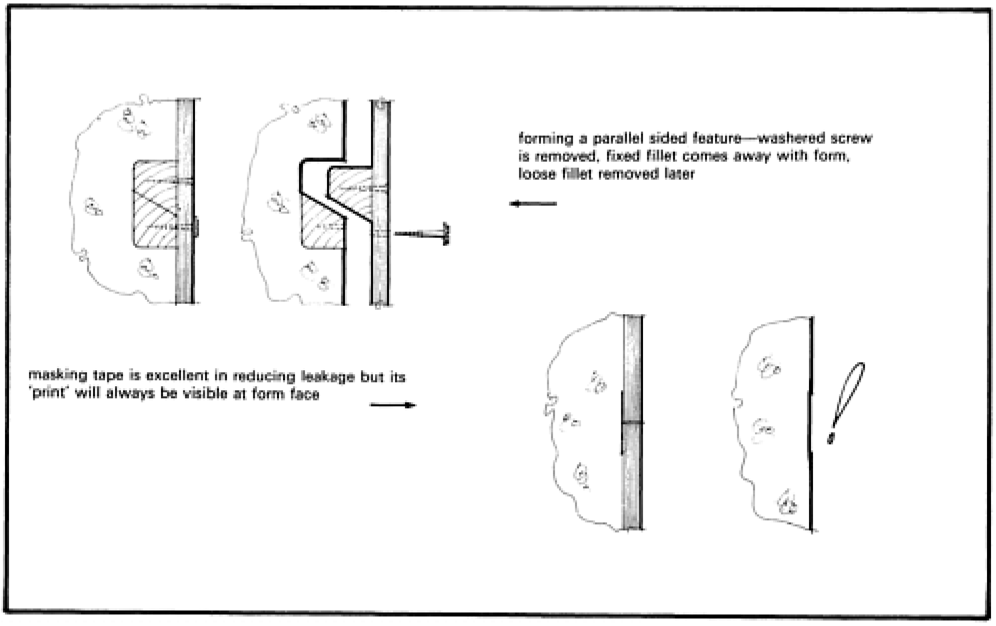
Where the precast element is concerned there is a marked difference between the appearance of the concrete face as cast in either of the following:

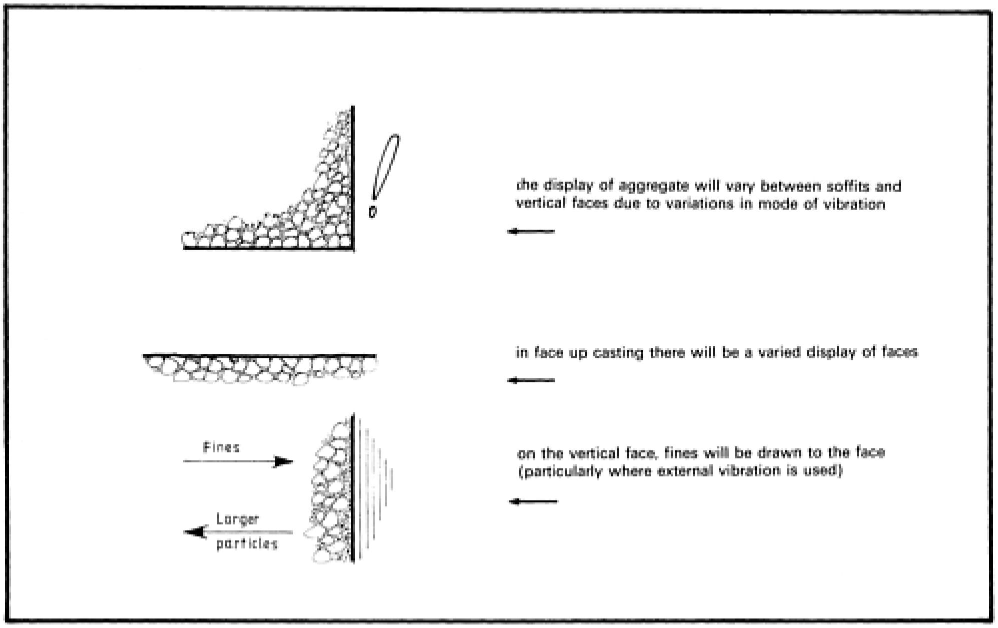
where face down casting is employed, the larger particles orientate themselves in such a way that the larger, flatter faces lie against the mould face;

in face up casting there may be a mixed exposure of flat faces and edges and corners of crushed stone;

where concrete is cast against the sides of the mould (equating to the face of vertical formwork) there will be a mixed appearance of flat faces, larger rounded faces and corners of crushed stone.

There will also be a considerable amount of fine material at the face due to the tendency for larger particles





to be propelled by vibratory effort into the mass of the concrete, these particles being replaced by fines. On a small scale this is the cause of what is often known as *aggregate transparency,* where flexible forms or forms receiving considerable energy from external vibrators cause similar movement within the concrete.

A most difficult fill is that where the surface is formed below a top form or under an inclined form. The casting technique here is identical to that used for structural concrete. That is, a slow fill of medium workability concrete placed in such a way as to expel air as the fill proceeds. Where the inclined form can be omitted, the problem of entrapped air will be avoided, although the timing of the operation becomes critical as does the control of workability. The success of the concreting operation now depends upon the ability of the trowel hand and the geometry is no longer controlled by the form face. Where the fill continues after the inclined face, then timing and workability are critical to avoid surge. This problem can be overcome by the introduction of a surge board or sheet and indeed in the production of larger flanges this is often practised to ensure good compaction and to avoid pockets of entrapped air where the reinforcement or prestressing ducts restrict the flow.

Superplasticisers can be used to assist concrete placement into congested parts of the structure, although the visual affect of the exposed aggregate can, to some extent, be spoiled by the high intensity of small particles which flow to the face.

Visual concrete using tooling to texture the surface or expose the aggregate

Despite the fact that tooling is generally a labour intensive means of producing visual concrete, these techniques are still in general use. For many, consideration of the use of tooling to produce visual effects at the concrete face brings to mind a process involving massive plant and equipment with workers dressed, for reasons of safety, like invaders from space, and processes which are noisy, dusty and time consuming. Indeed, for many years this has been the case—today’s techniques and equipment, however, employing as they do new generations of hand tools and compact power supply, offer a direct and controlled means of producing surface texture. Tools such as the needle-gun, scaling hammer and similar relatively lightweight pieces of equipment, capable of being powered by small compressors and generators, can be handled easily at and to any location on the site with safety. The smallness of available equipment promotes improvements in the final product as operator fatigue is minimised. In production, for example, in the precast works, the use of balancer rigs and the adoption of mechanisation can speed and thus simplify the process.

Once standards are established (as previously discussed), then men can be set to work to tool the concrete. The supervisor in his capacity as controller of labour, should be aware of the number of aspects of work which, unless considered and catered for, will result in unacceptable standards of work. The majority of tooling operations depend upon the worker to maintain the standard, depth of exposure, amount of matrix removed, and so on, and although in the main the operations are simple, they are repetitive and in some instances demand considerable effort. All these points tend towards the production of surfaces which lack consistency. The aspects of noise, danger and fatigue are worth study, and the supervisor would be well advised to obtain from any library a book on ergonomics or, in simple terms, man's ability to work physically and using mechanical equipment. The supervisor can do a number of things to improve the consistency of the product or concrete face by providing the following:

ready reference to standards and samples;
good access;
tools and equipment in good working order;
safety wear and equipment;
protection from weather;
suitable and adequate rest periods.

The illustrations accompanying this chapter indicate some problems of tooling and texturing and suggest some solutions. The main task, of course, is to ensure that workers understand what is expected of them in terms of quality. Jigs, gauges, and templates will all assist in ensuring that performance matches these standards and the supervisor should watch for the following details:

Ideally the same man/men should carry out the same task at or about the same time from initial casting on each successive lift or bay.

Men should be given complete access to avoid kneeling or reaching to deal with part of the surface. Quite apart from the fact that a man will rapidly tire and be able to apply less effort, it is likely that output will fall off as he thinks perhaps more about his safety than the job in hand.

The angle of application of a tool, frequency of application and direction of work are all apparent on the finished face. Straight lines of tooling are often evident where a man has outlined his target for the next work period—differences in depth of tooling are apparent in work done at the beginning and end of a shift.

Randomness is extremely difficult to achieve and often work which is apparently random, when viewed close up, reveals patterns or areas of extremely different texture when viewed from a greater distance.

Any operation which relies on the cutting or shattering of concrete or aggregate demands particular attention as regards safety—goggles, masks, gloves, aprons, and so on, are obvious necessities.

The equipment used, if electrically powered, must meet the regulations and be of low voltage supplied from suitably protected transformers.

The provision of margins of plain concrete at arrisses or adjacent to recesses and openings will avoid damage and spalling of concrete at these points. The operative will also be more likely to maintain the uniformity of depth of exposure right up to the edge of the tooled surface.

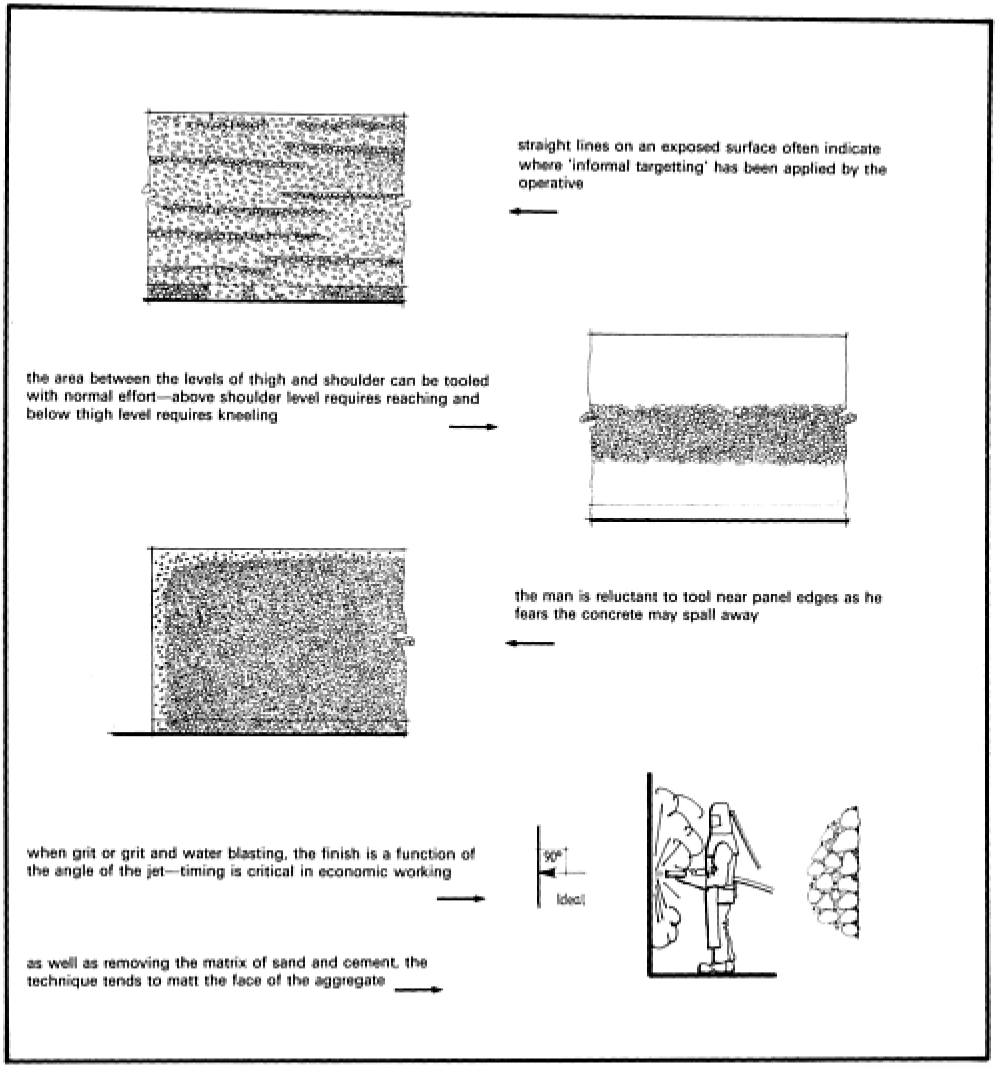
A quirk or groove will serve to maintain a tidy junction between exposed work and plain or textured surfaces.

Long before the tooling stage, the process begins with the introduction of a high degree of control into the activities of mix design, to ensure the inclusion of adequate quantities of rock or stone in the mix for visual effect. Control of placement and compaction is vital to provide a sound face, free from blemish and defect, such as bugholes and layers formed by different batches of concrete. No amount of tooling will overcome the problems of poor concreting techniques, which can hinge upon such detail as complete access for placement and the use of appropriate vibratory equipment. Since concrete is to be removed in the process it is essential that the cover of concrete over steel is of sufficient thickness to present the required minimum cover *after* tooling. Curing is important as is the timing of cutting operations, the latter determining the economy of the process and vitally affecting tool wear, operator comfort and so on. Tools include electrically and pneumatically driven guns used in conjunction with pointed tools, roller combs, chisels, needles and other cutting equipment, each of which provide a distinctive surface finish and a unique shade of colour to the concrete. Each of the available tools tend to shatter and cut the aggregate and matrix in a different way, and quite attractive results in terms of light, shade and texture can be achieved at the surface.

Regarding tooled finish, there is a lot to be learned from the study of the play of light and shade on the concrete surface, and the various effects resulting from such influences as the direction of application of tool, type of tool, operator skill, operator fatigue, the informal programme imposed by the workshift and refreshment breaks, timing of the operation relative to the curing cycle and gain of concrete strength. There is more to tooling than just cutting concrete and the old adage emanating from the bench joiner—*"think twice and cut once",* has a great deal to offer the designer intending to employ tooling as a means of achieving visual effect. Care must be taken to ensure that features, carefully formed by the form face or liner, are maintained in their intended crisp and pristine form and are not cut away away by overapplication of effort in the tooling operation.

Abrasive blasting

Abrasive or grit blasting is becoming an extremely popular technique being perhaps less time dependent in terms of difficulty of exposing aggregate by abrading a hard matrix. Various grades of exposure can be achieved, although of course, early treatment eases production of deeper exposure. Again the finish is sensitive to the angle at which the stream of abrasive material is applied and ready access is essential. The abrasive material is generally a finely crushed, extremely hard aggregate which provides sharp cutting edges. The operator must, of course, be instructed in the safe operation of the equipment and again must be provided with protective clothing and a mask incorporating a supply of fresh air. The combined grit and water guns are extremely effective and do present less of a health hazard. Masking can be carried out using ply or sheet metal plates where margins and plain areas are to be preserved on the concrete face.



Efflorescence and lime bloom

Efflorescence, or the build up of a white deposit on the concrete face, usually results from the movement of moisture within the hardened concrete. Generally speaking, efflorescence lightens the concrete face or occurs in patches on coloured concrete. The lime which causes the white appearance results from the hydration process. The material migrates through damp concrete to the surface and then, in contact with the atmosphere, forms crystals which result in the patches of white or lightening of the surface.

"Bloom", as it is known, can appear at any time, although rain and damp, foggy days tend to promote its formation. Where water passes through concrete, then local build up of salts at the surface may result in the growth of crystals. The best treatment for bloom is continued washing with soft water. Acid (dilute hydrochloric) can be used on wet concrete to remove the lime. Subsequent washing with water is essential to remove any last traces of acid. As concrete matures, there will be less tendency for lime bloom to occur, although should cracks develop, then water passing through the concrete may cause build-up of crystals at the surface, which will need to be chipped off and action taken to seal the concrete to prevent the ingress and passage of water through the mass.

In precasting, care must be taken in the stockyard to ensure a flow or air between units in the stack. Where units are in direct contact, trapped water or water drawn between the units by capillary action, provides an environment in which lime bloom can develop.

Points of supervision

Establish required standards of finish and supply samples on site
Check on supply of special materials
Ensure suitable storage facilities, bins, silos and covered space
Examine special equipment requirements
Produce special form details
Ensure supply of required oils/release agents
Train operatives in use of equipment and safety measures
Maintain checks on standards as work proceeds
Ensure adequate protection of the finished work

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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