The concrete for slipform pavers may be deposited on the formation from end-tipping trucks or discharged into a spreading device in front of the machine. It is then struck off approximately level across the slab by various means, e.g. shuttle spreaders, auger screws and transverse paddles. Compaction to its maximum density by a battery of immersion vibrators, supplemented as necessary by surface vibrators, follows. As the machine moves forward, a conforming plate or other levelling device is passed over the highly fluidized concrete and causes it to take up the shape of the slab. When a conforming plate is used, the amount of concrete passed below the plate will depend to some extent on the head of concrete in front; thus the level at its rear may be subject to slight variations. The action of oscillating screeds, on the other hand, is to strike off excess concrete or to make good deficiencies with concrete carried in front of them. For this reason there may be some technical advantage in using a machine with oscillating screeds rather than a long conforming plate.

It is often preferred to lay concrete road slabs on a very accurately prepared base of cement- or lime-stabilized material, asphalt, sand - asphalt, lean concrete, etc., which will be adequately strong to carry the weight of the paving equipment. When this is done, the paver works at a fixed height above the base tending, by virtue of its long track base, to smooth out irregularities thereon. Direction has to be controlled by means of a line sensor on the machine but apart from this all levels of the finished road slab are dictated by those of the base on which it is being built.

Slipform pavers are best suited to laying unreinforced concrete slabs built without joints but subdivided - when the concrete has been laid a few hours and hardened sufficiently to resist damage - into short lengths by gang saws. However, by deploying other machines such as spreaders and mesh depressors, it is possible to build slabs which are, to all intents and purposes, the equivalent of our reinforced concrete slabs. When this type of road is built, the basic simplicity of slipform paving is lost and the train of equipment becomes not unlike that used for rail-mounted work as previously described. The capital cost of the machines employed is much higher than for rail-mounted equipment but its potential throughput is also much higher.

In America the final running surface behind a slipform paver is often trued-up to a very regular profile by a tube finisher. This simple device consists of a 200 mm diameter tube of length about 1.5 times the slab width, mounted on a wheeled chassis which straddles the newly laid concrete slab.

The profiles of concrete slabs finished by either a slipform paver or a combination of slipform paver and tube finisher are generally very uniform and hence should comply adequately with specification requirements.

Although there do not appear to be any insuperable technical problems associated with the successful operation of slipform pavers, there are those of logistics. These are mainly that the machines operate most economically with high throughputs of concrete. Under normal conditions in Britain this necessarily involves stockpiling large amounts of concrete aggregates and perhaps special arrangements for the supply of corresponding amounts of cement. Building and drawing from stockpiles are expensive operations and significant reductions in construction costs have to be achieved to effect the desired savings in overall costs.

37.7 Concrete floors

37.7.1 Construction procedures

There are many types of toppings and surface finishes that are applied to concrete ground-floors and the choice will depend on the specific requirements in each case. However, in the majority of cases, good finishing techniques on the basic concrete itself will be perfectly adequate.

Floors can be laid in the same way as concrete paving for roads and airfields, although it is customary to see manual or semi-manual methods being used as opposed to machine methods. The latter are limited for economic reasons to the construction of large floors where uninterrupted lengths of at least 80 m are required.

A traditional way of laying concrete floors has been by the 'chequer-board' method of construction in which individual bays are cast alternatively within stop-ends forming the joints. Infill bays are usually specified to be placed no earlier than 7 days afterwards, the basis of this requirement being to allow a considerable proportion of the shrinkage movement of the earlier bays to occur. Since, however, shrinkage of concrete takes place over a period of several months, it is now recognized that this latter requirement is of dubious value. Moreover, this method of working is not efficient and access for constructing the infill bays is poor.

A more modern method of floor construction which has found favour is the so-called 'long-strip' procedure which is basically the same approach as that adapted for concrete road construction. Alternate strips - usually not more than 4.5 m wide - are first laid continuously the full length of the floor area and divided into bays by means of induced joints. These joints may be formed either in the plastic concrete or by sawing shallow slots in the surface 2 or 3 days after the concrete has been laid. The infill strips of concrete are placed a few days later when the first strips of concrete have hardened sufficiently to withstand the effects of the compacting beam without damage to the edges.

Again, as in the case of roads, reinforcement is often provided in the slab near the top surface. This entails laying the concrete in two courses.

37.7.2 Finishing techniques

For many industrial applications, the concrete used for the floor slabs can be directly finished to provide a suitable wearing surface. A 28-day strength of 30 N/mm² or more should be specified for the quality of the concrete and it is also desirable that the concrete should have a cement content of at least 330 kg/m³ in order to provide good durability and resistance to abrasion.

Traditionally, concrete floors are finished by hand trowelling using steel trowels. Each trowelling operation follows the previous one after an interval of about 1 h (during which time further moisture will have evaporated from the concrete surface).

This trowelling process has become mechanized in recent years and it is now usual to see the concrete finished by mechanical means using power floats and power trowels. The former uses a rotating solid circular disc whereas the latter is provided with three or four rotating blades. However, the terminology for these processes varies and the term 'power float' is often taken to cover both power floats and power trowels.

Power floating and power trowelling can, with care, produce very good finishes. In comparison with hand trowelling they enable the work to be done up to 6 times more quickly and their use permits a slightly drier concrete to be used (with consequent advantages in enhanced strength and resistance to wear). However, it is still necessary to resort to hand trowelling in small confined areas, such as floors of domestic dwellings, where it is not practicable to use a power float efficiently.

The power float does not, as is sometimes thought, provide compaction of the concrete. The concrete must have been compacted and screeded to level before the power float is used.
The time at which the power float is brought into use on the floor surface depends on various factors, notably the ambient temperature and the workability of the concrete. It is recommended that under average conditions it should be used about 1 h after the concrete has been laid. A good guide which can be used to determine the time at which to use the power float is the depth of the impression left on the surface when a man stands on it; if the footprints are about 2 mm deep, the concrete is ready for treatment.

In cool conditions, there may be a considerable delay before the power float can be brought on to the concrete and this may entail overtime working by the operators. To avoid this, a vacuum dewatering process is sometimes applied to the concrete surface soon after it has been compacted and has received its initial surface finish. The process involves the use of a flexible vacuum mat, provided with a fine filter sheet, which is connected to a vacuum generator. When the mat is laid on the concrete surface, a vacuum is created underneath the mat and this causes water to be drawn out of the concrete. The vacuum is usually applied for about 20 min after which the concrete will be sufficiently stiff to receive the first surface treatment with the power float.

### 37.7.3 Surface hardeners

The use of surface hardeners on concrete floors is rather a controversial subject. On the one hand, a properly laid concrete floor should give a satisfactory performance without any further treatment. On the other hand, the quality of many concrete floors, when laid, is far from perfect and a surface hardening treatment can be beneficial in these cases. However, in the case of weak concrete floors, a surface hardening treatment will not be effective at all.

It follows that the use of a surface hardener should not be regarded as a substitute for producing a good-quality concrete in the first place.

The most commonly used surface hardener is sodium silicate which combines with the lime in the concrete to form a hard glassy substance. Magnesium silicofluoride and certain other salts are also used as surface hardeners.

### 37.8 Other forms of concrete construction

#### 37.8.1 Dam construction

Circumstances arise from time to time in the construction of reservoirs for either water supply or hydro-electric schemes when it is advantageous to build a concrete dam rather than an earthen or rock-fill embankment.

The design and specifications for the dam will give details of the lengths of each section of the dam, the depth of each lift and the interval which must lapse between the concreting of successive lifts; it will also place a limitation on the depth of concrete which can be poured in the lifts and time interval between adjacent monoliths.

Section lengths are generally of the order of 15 to 18 m and joint planes will normally be at 1.5 to 2 m.

Where it is intended that several monoliths in the same area be brought up together, this can be done provided an adequate gap is left between each for subsequent infilling. Gaps of about 2 m have been used and filled some time after the main lengths of the wall, when major drying and thermal shrinkage of the main blocks has taken place. Proper provision for water bars must be left in each side of this gap so that the method involves somewhat heavier expenditure on joint preparation and sealing.

A number of factors have to be taken into account in deciding the method of construction to be adopted.

First will be the duration of the contract and the likely time to be spent on preparation of the foundations before dam construction can begin. Another major factor will be the profile of the valley across which it will be built. In Britain, the sites on which long and high dams can be built are very few so that a contractor is usually faced with building either a small number of high monoliths or a larger number of low ones.

The required number and dimensions of the monoliths will determine the method by which concrete will best be handled into place. Where a long, low dam is required to be built across a shallow valley, it might be considered to carry the concrete from a central mixing plant in crane skips mounted on flat-bottomed lorries or trailer units, thence into the work via a crawler or other type of crane. Flat-bottomed bogies carried on a narrow-gauge rail track along a low-level gantry might also be considered. To build a shorter but higher dam across a narrow steep-sided valley it might be thought preferable to handle concrete in crane skips via a series of derrick cranes mounted on temporary concrete pillars. These could well be sited on the upstream side of the dam, since the greater volume of concrete will be there.

All possible ways of handling concrete are discussed in a previous chapter and the contractor, in preparing his scheme for the work, will make decisions on the rate of concreting and the means by which it is to be placed in position.

It is common practice to build the main mass of a dam wall with a low cement content and hence fairly low-strength hearting concrete, but to use a higher quality having greater durability at the upstream and downstream faces. This facing must be placed within a short period of placing the hearting concrete so that there shall be a complete bond between the two.

Probably the easiest method is to build up the hearting in a 400 to 500 mm lift over the whole area to within about 400 to 500 mm of the dam faces – or whatever thickness surfacing concrete is called for in the design. The facing is then filled in to the same depth between hearting and the shuttered upstream and downstream faces. The richer concrete is not normally required to be poured against the shuttering to transverse joints.

Rock suitable for good-quality concrete aggregates is often available at the site of work and is generally quarried as required to make concrete on site. Since sections are normally large and there is a need to keep cement contents low, aggregate up to 150 mm maximum is often used. The production of lean and sufficiently workable mixes for low-strength hearting concrete is facilitated by using large-size aggregate. However, the use of plungs or displacers is not economic – nor is it good practice.

In some instances where only poorer qualities of rock – as regards their suitability as aggregate – are to be found at site it might be necessary to import the better-quality material for exposed concrete but to use the inferior aggregate for the mass of low-strength concrete in the hearting. Proper mix design and placing techniques are quite capable of producing concretes satisfactory for this work from the most unlikely materials.

A disfiguring feature of many dams in the past has been the tendency to seep water through transverse joints and, more rarely, along horizontal joint planes. The former faults can be avoided by proper detailing of joints to facilitate their building according to the intended design. With horizontal joints it is essential to avoid the presence of laitence, downward joggles and deep indentations which will hold water. Laitence can be removed by air-water blast when the concrete is hardened sufficiently to avoid damage. Treatment of concrete with water sprayed on to hessian strips will ensure its proper curing and avoid any shrinkage cracks which might contribute to failure; it will also keep the whole area clean for subsequent operations.

A recent development is the use of ‘rolled concrete’ for dam
construction (referred to as ‘Rollcrete’ in the US). The concrete in this case has a low cement content and has a relatively dry consistency which permits compaction by rolling. It may be compared with the dry lean concrete which has been used successfully for the construction of road bases, but the concrete mix used for dams benefits from the inclusion of a fairly high proportion of PFA, the proportion of which has generally ranged from 30 to 75% by volume of cementitious material. The use of rolled concrete for dams has the advantage that conventional earthmoving plant may be used for handling and compacting the concrete and that therefore large outputs can be quickly and economically achieved. Construction can proceed in layers, about 200 to 300 mm thick, laid continuously from one side of the dam to the other.

37.8.2 Tunnel linings

In situ concrete linings may be called-for in hard-ground tunnels to give support to rock which will deteriorate in the course of time or to improve hydraulic characteristics.

The dimensions of the tunnel — length, diameter, number of access points and other factors — will need to be taken into consideration in deciding the method to be used and the order in which work is to be carried out. Mention has already been made of the use of pneumatic placers but concrete pumping is coming to be more widely favoured. A variety of methods for getting the concrete to the working face have been used in the past and new ideas coming from time to time are adequately described in technical literature.

37.8.3 Mass plain and reinforced concrete sections

Concrete will be placed into sections of this type, which will most frequently be found in power stations, foundations to large buildings and other heavy work, by various combinations of methods already described. The sizes of bay to be concreted will be dictated by the output of the batching plant available for the particular operation in hand. Owing to the complexity of shuttering work in reinforced concrete it might be found advantageous to restrict the depth of pour so as to increase the area to be concreted at any one time — shuttering costs are then likely to be rather lower.

In heavily reinforced concrete foundations there is a strong financial incentive to dispense as far as possible with costly construction joints and to place the concrete continuously in large pours. Placing of volumes of concrete of the order of 200 to 300 m³ is quite common for such foundations and very much larger pours of the order of 3000 m³ have been placed where the plant facilities and access have permitted such a large-scale approach.

In unreinforced concrete foundations, however, where there is no steel reinforcement to restrain the subsequent shrinkage of the concrete, it is necessary to restrict the areas of concrete cast in one pour in order to avoid cracking resulting from the concrete shrinkage. Due to the absence of reinforcement, the provision of shuttering for the construction joints will be relatively straightforward in these circumstances.

The tendency to crack when the concrete contracts is related to the value of the maximum temperature reached by the concrete soon after it has been placed. The cracking is, of course, caused by the subsequent cooling down to ambient temperature. In large foundation slabs, where cooling is generally in a vertical direction, the maximum temperature rise attained is related to the lift height. However, due to a combination of self-insulating effects and the reduction in the adiabatic rate of heat generation after 24 h, increase in lift height above 2 m causes very little further increase in the maximum temperature reached.

37.8.4 Vertical construction with sliding formwork

For many years, certain types of vertical construction in concrete, e.g. materials storage silos and the service cores of tall buildings, both of which have either a constant cross-section throughout their height or only a small number of variations in wall thickness, have been carried out by using formwork which was moved continuously upwards as the concrete was placed within the forms. The infrequent changes in plan have been accomplished by altering the dimensions of the moving shutter as required; this has involved completion of a section and re-erection of one or both faces of the shutter before work recommenced.

More recent developments have seen modifications to the original conception of moving formwork to allow slight and gradual changes in cross-section as the work proceeded upwards. The construction of reinforced concrete chimneys and the erection of tall towers serving as supports for TV aerials and amenity buildings are examples of work in which both external dimensions and wall thickness have decreased as the height above ground increased.

Sliding formwork, though now widely used, particularly by companies who have become specialists through mastering the techniques involved, is not a new art, there being reference to such work as long as 60 years ago. However, as the use of the method has become more widespread so have improvements been made in the mode of operation.

Basically the method consists in continuously raising formwork of the correct plan dimensions into which concrete with the designed amount of reinforcement is placed in a series of narrow bands up to 150 to 200 mm depth, proceeding over the whole plan area. The formwork to the inner and outer faces is connected at close intervals by a series of straddling yokes, each having a device by means of which the yoke and the attached shutter can be moved upwards in relation to jacking rods at each point. These jacking rods are carried from bottom to top of the structure and are located in circular cavities formed within the walls by tubes which surround the rods below the jacking points.

Apart from the external and internal shutters and the jacking systems and their control, it is necessary to provide a working platform which will generally cover the whole plan area of the structure. From this men can operate and on it can be stored such materials as reinforcement and blocking-out pieces for door openings, etc.

Concrete will normally be raised by a hoist or tower crane and distributed around the outside of the structure by hand barrows, light skips, monorail or other devices considered appropriate.

An essential feature of a sliding form is a platform connected with and below the inner and outer faces of the main shutter, from which operates can carry out work to impart a sufficiently high standard of surface to the concrete emerging from the shutter. Occasionally, when faults have developed in the work, these will be corrected from the same platforms.

In the earliest examples of sliding formwork, raising of the shutter with reference to the jacking rods was carried out by hand-actuated screw jacks. However, the specially designed jacks used now are almost universally hydraulically operated from a central control panel. The mode of operation is basically that the jaws on the jacks grip the jacking rod firmly whilst the body of the jacks, attached to the yoke, are moved upwards in about 12 mm intervals, the rate of travel varying between 150 and 500 mm/h according to circumstances.

The forming of the narrow cavity round the jacking rods ensures that whilst adequate support is given against buckling under vertical loading as they are lengthened, the rods can be recovered for re-use after completion of the slide.

To ensure success of sliding operations it is essential to
provide a high standard of control over the quality of the concrete used and the rate of sliding so that when it emerges from the shutter the concrete is capable of self-support without slumping. The concrete must also be amenable to surface floating, etc., to remove minor blemishes.

Sliding operations involve 24-h working, often under very variable weather conditions, and a high standard of job organization is necessary to ensure that there is continuity of all operations involved. Breakdown of equipment which could result in long delays and perhaps in the extreme, the abandonment of a slide, is best guarded against by either duplication of vital items or constant survey to reduce the risk of untimely failure.

37.8.5 Gunite (shotcrete)

Gunite consists essentially of a mixture of cement, sand and water which is sprayed from a nozzle into the required position. In some cases, coarse aggregate of about 10 mm size may also be added. The first step in the process is the mixing of cement and sand in the required proportions. The mixture is then fed into a piece of plant called the ‘gun’ which consists of one or more chambers connected to a compressed-air supply. This gun feeds the material in a continuous flow into a pipeline, along which it is conveyed pneumatically, until it reaches the nozzle at the placing end. At the nozzle, a spray of water is introduced, under pressure, into the passing material and the resulting mix emerges from the nozzle at high velocity on to the required surface. The optimum distance between the nozzle and the surface is 1 to 1.5 m (Figure 37.16).

The condition of the sand, before mixing with cement, should be damp (a moisture content of 3 to 5% is generally considered desirable) in order that the particles can retain a coating of cement. Sand which is too wet, however, may cause a blockage to develop in the system.

The amount of water added at the nozzle is controlled by a valve operated by the ‘nozzleman’. The amount is critical since too wet a mix will result in slumping off the surface, whilst a mix which is too dry will lack cohesion and will result in a considerable loss of material due to excessive rebound off the surface.

This basic guniting procedure is sometimes referred to as the ‘dry process’ to distinguish it from the so-called ‘wet process’.

In the ‘wet process’, the materials are mixed initially, with the required amount of water (as in the case of normal concrete) before they are fed into the pipeline. The mix is forced along the pipeline by the positive displacement action of a concrete pump or, alternatively, by pneumatic means. At the nozzle end, compressed air is introduced to provide momentum to force the material out in the form of a spray.
The amount of water added in the 'wet process' is predetermined to a controlled amount and is not dependent on the judgement of the nozzleman, as in the case of gunite. However, the nature of the wet-mix process requires a mix with a higher water content than that produced in the gunite process, and accordingly, the strength and allied properties of the material will be inferior. There is also more difficulty in clearing any blockages which may occur in the pipeline.

In the US, both the 'dry process' and the 'wet process' are generally referred to as 'shotcrete'.

Gunite has been in use for about 50 years and its main application has been in the repair of deteriorated concrete structures where a layer of good-quality mortar is needed to reinstate the surface. More extensive use of the process has been limited by economics since normal concreting procedures are cheaper. It has, however, been used successfully in constructing swimming pools, culverts, retaining walls, tunnel linings, and intricate curved structures. It has also been used to strengthen existing structures by increasing the thickness of the concrete.

37.8.6 No-fines concrete
As the name implies, no-fines concrete contains no sand or fine aggregate. It is therefore characterized by uniformly distributed voids throughout the mass, which give it a relatively low density. No-fines concrete may therefore be considered to be a particular form of lightweight concrete.

The main applications of no-fines concrete are in the construction of loadbearing walls for low- and medium-rise housing. It has also been used extensively for the infilling panels on high-rise framed structures. Other uses include the provision of drainage layers in civil engineering works and the paving of free-draining parking areas.

When used for building purposes, the optimum size of the aggregate is 10 to 20 mm. It is usual to specify an aggregate of which not more than 5% is retained on a 20 mm mesh sieve and not more than 10% passes the 10 mm sieve.

In order to achieve a satisfactory cellular structure with adequate strength, it is found that mix proportions with a cement:aggregate ratio of 1:8 by volume give the optimum result. In cases where strengths higher than the normal requirements are called for, as for example, on loadbearing no-fines concrete used for four- and five-storey buildings, cement:aggregate ratios of 1:7 by volume, or even slightly richer, may be required.

Cube strengths obtained with 1:8 mixes vary from about 4 to 9 N/mm² at 28 days, the corresponding densities being about 1600 to 1850 kg/m³.
Where strength is less important, as in the case of drainage layers, cement:aggregate ratios can be reduced to 1:10 by volume or leaner.

The water content of no-fines concrete should be the minimum necessary to ensure that each particle of aggregate is coated with a shining film of cement paste. If insufficient water is used, there is a lack of cohesion between the particles giving a friable appearance and loss of strength. Too much water causes the cement paste to run and separate from the aggregate. A water:cement ratio of about 0.40 is usually satisfactory for 1:8 mixes when using dense aggregate.

The main advantages of no-fines concrete, in comparison with normal dense concrete, when used for building construction are:

1. Lightness in weight.
2. Low thermal conductivity.
3. Capillary absorption of water is virtually eliminated.
4. Light formwork can be used.
5. The open texture provides an excellent surface for the application of a rendered finish.

As a building process, the no-fines concrete construction technique has the particular benefits of being simple, economical and fast.

A further benefit of using no-fines concrete is that it will not segregate and it can therefore be readily placed in deep lifts of up to three storeys high in one operation, if required. It is important to maintain a level head of no-fines concrete in the formwork along the wall under construction, since localized full-height pouring may cause inclined planes of weakness (pour planes).

Unlike normal concrete it is not necessary to compact no-fines concrete, but some rodding should be given to it to ensure that the formwork is evenly filled. Also careful rodding should be carried out whenever obstacles such as window openings and lintel bearings occur.

No-fines concrete presents some difficulty in the fixing of various fittings and it is necessary to embed nailing blocks of timber which are attached to the formwork prior to pouring. Provision should also be made for suitable openings and chases before pouring since it is difficult to cleanly cut away the no-fines concrete for services.

### 37.8.7 Concrete diaphragm walls

During the last 15 years or so, there has been a spectacular growth in the construction of concrete diaphragm walls in the UK.

The technique, which was initially developed in Italy to prevent the seepage of water below dams, has subsequently been extended to the construction of retaining walls and loadbearing elements at the sides of deep basements, underpasses, etc. Diaphragm wall construction is invariably carried out by specialist contractors.

The basic process consists of excavating a trench in the ground which is filled with a slurry of bentonite mud to stabilize the sides of the trench as the excavation proceeds. A reinforcement cage is lowered through the bentonite into the trench and concrete is then placed by tremie pipe, gradually displacing the bentonite as it fills the trench.

The key to the process is the use of bentonite which is a thixotropic clay. When it is mixed with water to form a slurry, it has the useful property of forming a membrane of low permeability at the sides of the excavation. The face stabilization is improved as the density of the bentonite slurry is increased but in general the aim should be the achievement of a density of between 1.02 and 1.04 g/cm³. This may be achieved with a slurry containing 4 to 6% bentonite and 1% fine sand. The gel membrane which is formed along the sides of the trench allows the bentonite slurry to exert a hydrostatic head in excess of the in situ head of groundwater and the lateral earth pressures. Additional stabilization is obtained by limited penetration of the bentonite slurry into the adjacent soil.

In the initial stages of diaphragm wall construction, it is necessary to construct concrete guide walls which are usually about 1 m deep and about 300 mm wide. These walls serve the purpose of fixing the line of the wall, controlling the direction of the trenching tool and retaining the soil near the surface.

Percussive, rotary or excavating tools may be used for forming the trench, the first two types being necessary where excavation in rock is required. Excavating tools may be of the auger, bucket, shovel or clamshell grab type which cut the soil in bulk and bring it up above ground level for discharge.

As the excavation proceeds, the bentonite slurry is simultaneously pumped into the trench. Since it is not possible to avoid the mixing of the bentonite with detritus arising from the excavation process, there is inevitably a settling of this sludge to the bottom of the trench and this must be removed before the reinforcement cage is positioned in the trench. If this is not done, it is likely that the concrete which is poured into the bottom of the trench will flow over the sludge and not displace it. Clearly, the presence of such a soft layer would seriously reduce the loadbearing properties of the wall.

After the bottom of the trench has been cleaned out the reinforcement cages are lifted into position and supported at the right level. Concrete is then tremied into the trench and the bentonite slurry is gradually displaced as the level of concrete rises. The displaced slurry is pumped into settling tanks for reuse or else removed from site.

The difference in density between the bentonite slurry and the concrete is generally enough to prevent intermixing except for a layer of about 300 to 600 mm in the interface zone. The concrete should be very workable in order that it can flow readily and the aim should therefore be a concrete having a slump of 150 to 250 mm so that it behaves like a heavy viscous fluid. The coarse aggregate should preferably be rounded gravel of 20 mm maximum size to enhance the flow properties and plasticizing admixtures are normally recommended. A cement content of not less than 400 kg/m³ is necessary to provide adequate strength in the concrete.

The degree of compaction achieved by gravity in a very workable concrete placed by tremie pipe is generally adequate. Vibration is not required and in any case would be undesirable since it would cause segregation in a very workable concrete.

Diaphragm walls are normally constructed in panels ranging from 700 mm to 1 m wide, 3 to 6 m long and 6 to 30 m deep. The length of a panel is mainly determined by the soil stability and this leads to a practicable maximum length of 6 m in practice. The distance of lateral flow of concrete from the bottom of a tremie pipe should not exceed 3 m in order to ensure a uniform flow. For long panels, therefore, two or more tremies should be used.

Continuity of concrete placing is essential and a continuous rate of at least 20 m³ concrete per hour is desirable. If serious delays occur in the supply of concrete, difficulties will arise with achieving a correct tremie technique and this can lead to undesirable trapping of bentonite slurry in the body of the concrete wall.

Since diaphragm walls are cast in a series of panels, it is necessary to ensure that the resulting joints between panels are watertight and that they provide an effective key between the panels. This is generally achieved by means of a steel tube installed vertically as a stop end at the end of a panel. This steel tube is removed after the concrete has set to leave a semicircular-shaped joint at the end of the panel.
One of the problems is the complete removal of the bentonite slurry from the surfaces of the reinforcement bars. Although the tremie technique enables the concrete to displace the bentonite slurry as a mass movement, it cannot be expected to remove completely the coating of bentonite around the reinforcement bars. Since such a coating will adversely affect the bond between the concrete and the steel, it is necessary to use deformed bar reinforcement.

In the case of diaphragm walls constructed round the perimeter of deep basements, the excavation of the ground will follow the completion of the diaphragm wall. Some form of support system will then be necessary to resist the lateral pressure of the earth behind and this may be achieved by props or by ground anchors. The technique whereby the wall is tied back with ground anchors has the particular merit of allowing a clear space free of obstructing props and struts in the excavated area.

37.9 Precast concrete

Precasting of concrete is widely practised in all branches of civil engineering but perhaps the most spectacular is in maritime work. For example, units weighing thousands of tons to be linked together to form submerged vehicle tunnels across narrow waters are frequently built in docks and made temporarily buoyant by adding bulkheads. They are then floated out to their permanent location where a number are strung together on a prepared base below the sea-bed, to make a complete tunnel.

37.9.1 Bridges

Many concrete structures can be built either in situ or by using a number of precast units which when assembled together, often by in situ work, will form an equivalent structure; here, the emphasis will be on bridge work.

Design studies carried out by the engineer and influenced in large measure by his past experience will indicate which method is the more likely to result in lower cost, simplicity and speed of building. The findings of these studies will be incorporated in the contract designs.

When prestressed concrete beams of various types are a feature of the design then the contractor may have to consider either buying-in or making within his own organization. He will rarely consider setting up equipment to produce long-span box-section beams designed for production by the fully bonded (long-line) system because of the high capital cost involved; but where the beams incorporate their own inbuilt anchorages for prestressing tendons it is often open to consideration whether the beams should be factory made and hauled to site by road and rail or built on the job.

In some instances, for instance where very heavy long-span beams, which could not be brought to the site because of road or rail restrictions, are required, there will be no alternative to site casting. For the smaller, readily transportable, handleable units, such factors as the cost of preparation of suitable casting beds, the cost of concrete production and of providing the high degree of supervision over production need to be considered. Quite often, bridges are built in locations where access is difficult even for small units. Here the alternatives of building on site or waiting until better access can be provided for brought-in beams and the cranes for handling them need to be considered.

Precast concrete units weighing up to about 130 t have formed a substantial part of several overhead urban road works.

37.9.2 Tunnel works

Not perhaps so much in the public eye have been schemes in which the roadways in bored two-lane vehicular tunnels have been precast and set in position somewhat below the axis of the tunnel. In this arrangement the large area below the road is used primarily for ventilation but also for services of all kinds.

Tunnel road deck units will normally be formed in lengths of up to 6 to 8 m in precasting yards at one or both ends of the tunnel, according to the number required and the time available between the completion of driving and lining and opening to traffic.

A high standard of dimensional accuracy and surface finishes is called for, particularly if the upper surface is to form the running surface of the road without recourse to an applied bituminous or further concrete finish; additionally, accurate and sufficient bedding of the units is called for to ensure good performance.

Where ground conditions are appropriate, precast concrete units may be used for lining tunnels. These units may be either solid sections which are stressed into contact with the ground (often manhandled units in the smaller-diameter tunnels), or ribbed sections, both of which are put into position with mechanical erectors. Precast tunnel linings are used as widely as possible because of their low cost as compared with that of cast-iron tubbing.

37.9.3 Cladding panels

Precast concrete cladding panels have been used extensively for the façades of buildings for many years and a great variety of shapes, sizes and surface finishes may be seen throughout the world.

The size of a cladding panel is often determined by the site cranage and the aim should be to limit the weight of a cladding unit to a value which is no more than the other site loads that the crane will have to lift. If this aim is disregarded, it will be necessary to hire-in a heavy mobile crane for lifting the cladding into place.

Although large cladding panels are more expensive to transport and handle, the merits of using them should be considered in each case. The advantages of large panels include faster construction, a reduction in the number of fixings and fewer joints. The latter is a pertinent point as far as leakage problems are concerned.

The weight of the panels will also be influenced by the density of the concrete and there is an obvious benefit in using lightweight concrete. The latter may take the form of concrete made with lightweight aggregate or it may be made from concrete having a cellular structure. An alternative approach to minimizing the weight is to use normal concrete mixes in thin panels, but this introduces problems of providing adequate cover to the steel reinforcement. The consequences of inadequate cover can be seen in the unsightly cracking and corrosion staining that has occurred in those cases where this basic requirement has been given scant attention. For very thin panels where it is not possible to obtain the necessary cover, stainless steel reinforcement should be used.

The development of glass reinforced cement (GRC) in recent years had led to this material being successfully used as a cladding material. Glass reinforced cement is basically formed in thin sheets which not only gives it the advantage of lightweight but also enables it to be provided in panels to a wide variety of shapes. One particular application is the production of panels having a light insulating material (such as polystyrene) sandwiched between two sheets of GRC.

Whatever the material used for cladding panels, dimensional accuracy is an essential requirement. Normal standards of accuracy are covered by the tolerances given in CP 297:1972, 'Precast concrete cladding'. If tighter tolerances are sought, it is
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necessary to bear in mind that costs increase dramatically as the degree of accuracy is increased.

There are various means of fixing precast concrete cladding panels to the supporting structure and the choice of a suitable fixing arrangement must, in particular, take account of adequate supporting strength, the need for adjustment to accommodate any inaccuracies and the long-term corrosion resistance of the metal used.

37.10 Concrete construction in hot arid countries

37.10.1 Introduction

Concreting in hot arid countries presents difficulties not usually encountered in areas with temperate climates. The prime difficulty is dealing with the adverse effect of the high temperatures and solar radiation not only on the concrete in the handling stages but also on the concrete in the early hardening state.

However, another factor which can be equally difficult in hot arid areas, if not more so, is the presence of aggressive salts in the ground and in sources of fine and coarse aggregates. Sources of water can also contain undesirable levels of salts and even the atmosphere contains wind-borne salts which can cause trouble.

When no allowance is made for these factors in areas of rapid development, such as in parts of the Middle East, the result has been poor-quality concrete work lacking in durability.

37.10.2 Mixing and handling concrete in hot weather

The effects of high ambient temperatures, intense solar radiation and variable humidity pose several problems when planning and carrying out concreting operations. In the Middle East, the annual temperature range in the shade generally varies from about 10 to about 50°C, the latter being experienced during the period June to September. Moreover, the problems caused by high temperatures during this period are increased by the rapid changes in relative humidity which can vary from 25 to 100% within a daily cycle.

This harsh environment influences the behaviour of concrete in both the plastic and the hardened state. In the former, the rapid loss of water by evaporation results in a corresponding loss of workability, and concrete which has been carefully designed to give the right workability at the mixer may well be too stiff for proper compaction by the time it reaches the point of placing. Allowance must therefore be made for this effect by increasing the water content at the mixer above that required. This approach calls for careful judgement since there are several factors which influence the loss of workability, not least being the method of transporting, and the distance to the placing point. It is generally considered preferable to convey the concrete in truck mixers which provide protection from the direct heat of the sun; they may be kept relatively cool by spraying with cool water. The latter should be used with discretion because there is a danger that the water content of the aggregates will become very variable and consequently cause difficulties in controlling the water content of the concrete. A fine spray of water uniformly applied two or three times during the day is probably the best approach.

The temperature of the concrete when it is first produced at the mixer will depend on the temperatures, the specific heats, and the proportions of the constituent materials. The temperature of the fresh concrete can be estimated from the following formula:

\[ T_c = \frac{(t_c + AT_w + 5Wt_w)}{(1 + A + 5W)} \]

where \( T_c \), \( t_c \), \( t_w \) and \( t_w \) are the temperatures of the concrete, cement, aggregate and water respectively, \( A \) is the aggregate: cement ratio, and \( W \) is the water: cement ratio.

This formula is based on a specific heat for water of unity and on a specific heat for cement and aggregates of 0.2 (this figure being used for simplicity instead of the more correct figure of 0.22).

This formula indicates that the initial water temperature may be more important than the aggregate temperature since water has a high specific heat. It is therefore important to keep the water cool and consequently it should preferably be stored in tanks below ground; if this is not done, the tanks should be shaded and painted white. All supply pipes should be buried in the ground and insulated.

In severe conditions, the use of ice will cool the water very significantly. However, ice is frequently not available in the quantities required and also it can be expensive. Ice-making plant or refrigeration equipment is sometimes installed at concrete-mixing plants which provide large quantities of concrete. Generally, it is not considered that ice is really necessary, although it may be desirable in some cases to add blocks of ice to the tank(s) of water early in the morning well before concreting starts.

37.10.3 Maximum temperature of the concrete

To ensure that good-quality concrete is produced, many specifications impose a maximum temperature on the concrete produced. Based on experience in the hot arid zones of the US this maximum temperature is often stated at 32°C.

The practical limitations of this value in the Middle East have led to a more realistic approach there as more experience has been obtained. Depending on circumstances, the maximum temperature allowed in the concrete is now usually between 35 and 38°C. Certainly, a very considerable amount of good-quality concrete has been placed with a maximum temperature requirement of 38°C. However, it must be added that it would not be prudent to relax the temperature requirement to more than 40°C since loss of workability, handling difficulties and the tendency of the concrete to crack after placing increase very significantly above this temperature level.

Clearly, there is no one unique value for a maximum concrete temperature since the behaviour of the concrete will be influenced by the relative humidity and amount of wind as well
as the temperature. In some of the coastal regions of the Middle East, the high relative humidity will tend to alleviate the drying effect of the high temperatures. Conversely, where relative humidity is low, it is preferable to be cautious and limit the concrete temperature to a relatively low value, especially where drying winds are prevalent.

The concrete temperature can, of course, be influenced by the time of day during which the construction work takes place. Ideally, it is best to start work either in the early morning or early evening and avoid concreting during the high midday temperatures. Apart from the effect on the concrete, there is the important benefit that the operatives will be able to work more efficiently during the cooler parts of the day. Working at night is sometimes a way of avoiding high daytime temperatures, although it may not be so popular and, moreover, surveillance is generally not as good as that in daylight.

37.10.4 Protection and curing of the concrete

Once the concrete has been placed, compacted and finished, adequate protection from the sun and adequate curing is essential. This aspect of the work certainly requires far more attention in hot climates than in temperate ones.

If exposed concrete surfaces are not protected from the sun directly following the finishing operations, continuing evaporation of water is likely to lead to plastic shrinkage cracking. This type of cracking on paved areas is characterized by a series of cracks parallel to each other, often running at about 45° to the line of greatest slope. Although they are usually relatively shallow, they may well penetrate to the steel reinforcement and provide a path for corrosive salts to reach the reinforcement with a risk of consequent steel corrosion.

More severe cracking can occur subsequently in the first 2 or 3 days if the concrete is not protected and is allowed to reach a high temperature before it eventually cools and tries to contract.

The risk of cracking is related to the initial concrete temperature and this adverse effect is one of the main reasons for specifying a maximum concrete temperature at the time of placing, as mentioned above.

The Portland Cement Association has produced a chart (Figure 37.17) which enables the rate of evaporation of water from the concrete to be determined from known values of air

![Figure 37.17](image-url)
temperature, relative humidity, concrete temperature and wind speed. If it is found that the rate of evaporation approaches 1 kg/m²/h, precautions against plastic shrinkage working are deemed necessary for paving work. These precautions invariably will be required when working in areas with hot arid climates.

Curing procedures in hot conditions are the same as those already described in earlier sections for concrete work in general. However, for hot climates, curing should be started earlier and be applied more diligently. Exposed surfaces, such as paving, should not be left exposed for more than 20 min and preferably less. Curing membranes which are sprayed on to the fresh concrete surfaces should contain a pigment to reflect solar radiation, and two coats should be applied in very hot conditions. It may also be necessary to provide covers or suitable shading over the concrete for several hours to protect it from the excessive heat of the sun. It is important that provision is made for adequate ventilation under these covers.

Where damp hessian is used to cover concrete for several days after placing, the water which is sprayed periodically on to the hessian should be relatively free from salts. If it is not, the repeated application will build up chlorides in the concrete which may reach a level where corrosion of the reinforcement will be initiated. This is an important point to watch in hot arid regions where suitable water supplies are limited. In coastal areas, the temptation to use seawater for curing reinforced concrete must be firmly resisted.

**37.10.5 Strength development in hot weather**

It is well known that concrete which is placed and cured at high temperatures will achieve higher early strengths than concrete at standard laboratory conditions of 20°C. At an age of 28 days, however, the situation is reversed, and concrete which is maintained at a temperature of 40°C will have a 28-day strength which is nearly 20% less than concrete maintained at 20°C.

Research has shown that concrete made in the laboratory at 38°C produced cube results at 28 days which were about 15% lower than concrete made at 18°C. This reduction occurred in spite of the fact that after 1 day, all the cubes in the investigation were stored in water at 14 to 19°C before testing at 28 days.

**37.10.6 Concreting materials**

Rigorous quality control is the key to producing trouble-free concrete in hot arid areas, particularly the Middle East, and this applies to the choice and handling of materials as well as the construction process. On major projects, extensive testing is required both before and during construction and even on small projects it is advisable to ensure that the materials have been checked by some basic tests.

Aggregates are probably the main cause for concern and they should be carefully assessed by a full programme of testing before they are approved for use. Natural sands in hot desert countries, especially beach sands, can have very high salt (i.e. sodium chloride) contents and are clearly undesirable for concrete unless the chloride is removed by washing. Many cases of corroded reinforcement and cracked concrete in structures have been due primarily to the use of a sand containing too much salt.

Coarse aggregates may also contain undesirable levels of chloride, particularly some crushed limestones quarried from near the ground surface.

Sulphates must also be checked in both fine and coarse aggregates since undesirable levels can cause expansion within the concrete.

The following recommendations apply to the permissible chloride and sulphate contents of fine and coarse aggregates.

| Table 37.1 Limits of chloride content for aggregate used in reinforced concrete |
|---------------------------------|---------------------------------|
| Aggregate                        | Maximum chloride content        |
|                                 | (as CL)                        |
|                                 | (by weight of aggregate)       |
| Fine aggregate (sand)            | 0.06                            |
| Coarse aggregate                | 0.03                            |

Chlorides (for reinforced concrete)

Small adjustments may be made to these limits, if necessary, subject to the overriding requirement that the acid-soluble chloride present in the concrete does not exceed 0.30% by weight of ordinary Portland cement or 0.20% weight of sulphate-resisting Portland cement.

**Sulphates** (for all classes of concrete)

The acid-soluble sulphate (as SO₄) content of all aggregates, both coarse and fine, should not exceed a maximum limit of 0.40% by weight of aggregate.

This limit applies when using either ordinary or sulphate-resisting Portland cement. In the case of mixes with relatively low cement contents, it may be necessary to reduce this limit of 0.40% in order to comply with the overriding requirement that the total acid-soluble sulphate present in the concrete (including that present in the cement) does not exceed 4% by weight of cement.

Grading of aggregates should also be carefully checked. Dune sands and beach sands are often too fine to be used on their own as fine aggregate and therefore it may be beneficial to blend them with the fine material from crushed rock and gravel which is usually rather coarse when used on its own. The blending of sands to produce an acceptable grading is often desirable when the concrete is to be placed by pumping.

Dust content is another consideration and in some areas where water is expensive or in short supply it may be necessary to accept dust contents in the processed aggregates which are slightly in excess of BS or ASTM requirements. Although this increases the water demand of the concrete made with such aggregates, the effect is not serious.

The importance of other aggregate tests will depend on the source and type of aggregate and information on these can be obtained from specialist papers.

Apart from the tests, it is recommended that periodic visits are made to the source of the aggregate supplies to ensure that sand is being dug from the area which has been approved or that work is being quarried from suitable working faces. In the case of sandpits where excavation is taken down to water-table level, it is essential to ensure that sand is not taken from just above the water table since it is likely to be contaminated with chlorides that have been absorbed due to upward capillary movement of the water.

In some areas, the quality of cement can be very variable since supplies can be obtained from many different parts of the world. Although consignments may sometimes be accompanied by manufacturers' test certificates, it is nevertheless advisable to check the quality of the cement by tests on samples, especially if the cement has been in transit or store for some months and is no longer fresh. Some form of testing is essential whenever a
change of source of cement occurs, otherwise there is a risk of low concrete strengths being obtained if no allowance is made for a lower-quality cement.

The importance of good concreting materials and the quality of the resulting concrete has been well covered in the CIRIA Guide to concrete construction in the Gulf region.

Table 37.2, taken from information in the CIRIA guide, gives the basic requirements of the concrete as based on specifications in use in the Gulf region. These requirements are related to material exposure conditions which can be very severe in some cases. Particular attention needs to be given to ensuring that the minimum cover to the reinforcement is achieved since lack of adequate cover has been responsible for early corrosion and concrete cracking in many cases.

The recommended type of cement in these various exposure conditions depends on the amount of sulphates and chlorides present. Where resistance is needed against sulphate attack and there is no risk of chloride-induced corrosion, sulphate-resisting cement to BS 4027 or ASTM type V should be used. Where there is no significant exposure to sulphates but there is a risk of chloride-induced corrosion, cement with a medium to high C3A content is preferred (as found with ordinary Portland cement or ASTM type I). Where resistance is needed against both sulphates and chlorides, a compromise has to be made on the type of cement used. Generally a cement containing at least 3.5, but not more than 9%, C3A is preferred.

Steel reinforcing bars can also be supplied from a wide variety of sources and therefore checks on quality are advisable. In a saline atmosphere, the reinforcement must be stored under covers to prevent the deposition of salts which will cause corrosion. On important projects it is sometimes considered advisable to clean the steel by grit-blasting or rotary wire-brushing to ensure that it is free from salts and corrosion before being fixed. When reinforcement bars are left projecting from the initial lifts of concrete, they should be covered with polythene sheeting as protection from atmospheric salts if any delay in placing subsequent concrete lifts is expected.

**References**

1 American Concrete Institute (1977) 'Hot weather concreting'. ACI Committee 305. Proc. Conc. Inst. 74, 8, 317-332.

**Bibliography**