## Concrete Society Digest No. 2

# Mass concrete

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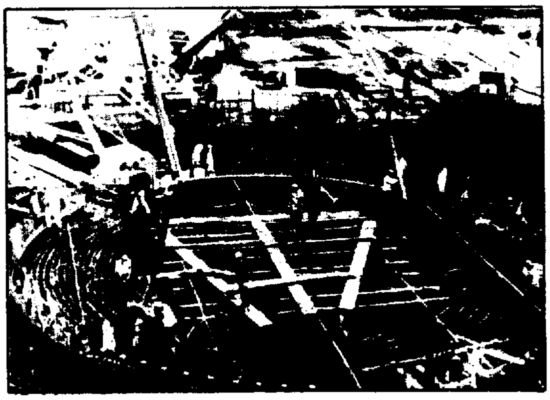


*Figure 1: Casting the foundation for a prestressed concrete pressure vessel at Heysham II Nuclear Power Station. Two boom pumps were used to complete the 500 m³ pour.*

Benefits of mass concrete pours:
- fewer stop ends;
- faster construction;
- monolithic units.

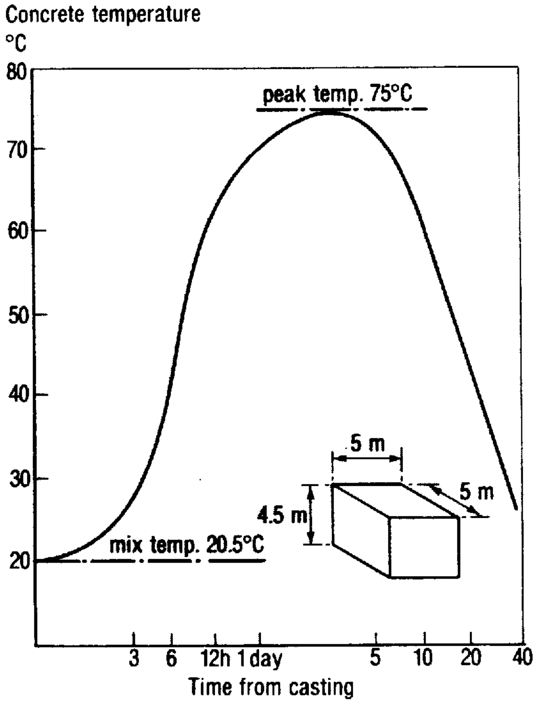


*Figure 2: Temperature recorded in the centre of a 4.5 m deep pour with 400 kg/m³ OPC.*

This Digest gives details of the special considerations associated with mass concrete construction together with basic information on selection of materials, concrete mix design and planning for mass pours.

## Introduction

In the past mass concrete was associated largely with dams. Low cement content mixes (150–250 kg/m³) were used to provide weight rather than load-bearing capacity. More recently, however, large pours using higher cement contents have become increasingly common for structural applications, such as raft foundations, nuclear pressure vessels, walls, and suspended slabs.

## What is a mass pour?

A mass pour is considered to be one of sufficient size to demand special attention to be given to logistical and technical considerations such as:

- concrete supply;
- casting sequence;
- cold joints;
- plastic settlement;
- heat of hydration.

There can be no strict definition of a massive pour in terms of dimensions or volume. As a general guide, special considerations may need to be taken in relation to heat of hydration for pours in excess of 500 mm thick. Special planning may be required where the pour volume is large in relation to those normally being placed on site.

## Benefits of mass pours

The main advantage of this form of construction is the saving in cost resulting from both reducing the number of stop ends and speeding up construction. In addition, the elimination of potential cracks at construction joints results in a monolithic unit.

Continuous casting takes advantage of the ability of ready-mixed concrete companies to supply concrete at high delivery rates and the rapid placing rates which can now be achieved using pumps.

## Special considerations

The successful construction of a massive pour is dependent on the following:

1. Consideration of technical factors which include:
    - plastic settlement;
    - heat of hydration;
    - selection of materials and mix designs.
2. Realization of the consequences of the in situ temperature cycle on strength and durability.

3. Planning to ensure that the concrete can be delivered, transported, placed and compacted within the allocated timescale and in such a way as to avoid cold joints.

In smaller pours the logistical problems are less onerous, but heat of hydration must still be considered when the cement content is higher than about 350 kg/m$^3$. Other technical problems include bleeding and plastic settlement which can result in voidage beneath the top mat reinforcement and surface cracking.

With careful planning and an awareness of the likely technical problems, mass pours can be successfully completed.

## Heat of hydration

One of the main concerns with mass pours is heat of hydration. The hydration of cement is an exothermic reaction and the heat developed during hydration can result in a temperature rise in excess of 50°C (see Figure 2). Associated with this temperature rise are thermal stresses generated by restraint to thermal movement. This restraint may be either internal or external.

*Internal restraint* arises from differential thermal strains which occur, for example, when the surface of a massive pour cools to atmospheric temperature whilst the centre remains hot (Figure 3a).

*External restraint* is that which is imposed on the pour by its immediate environment which may be a rigid base, groundrock or an adjacent pour. This form of restraint is particularly significant and most common in walls cast onto rigid foundations (Figure 3b).

## Temperature rise

Numerous factors influence the extent to which the temperature will increase due to hydration of cement (see Table1).

### Cement content

In the centres of massive concrete sections in excess of 2 m thick, the temperature rise will be nearly proportional to the cement content. In smaller pours, less than 500 mm thick, heat is more readily lost to the environment and the temperature rise is, therefore, affected by the rate at which the heat is developed. Figure 4 shows the relationship between the temperature rise (°C per 100 kg of cement) and minimum dimension. The rate and quantity of heat generated by Portland cement can vary considerably depending on the fineness and chemical composition. It is difficult to quantify the effect of any single factor, but there is a tendency for cements with a high $C_3A$ content to hydrate more rapidly and to develop the highest adiabatic temperature rise. The use of sulphate-resisting cement with a low $C_3A$ content will, therefore, tend to result in a lower temperature rise in situ.

Whilst the most direct way to achieve lower temperature rise is to reduce the cement content, this is not always possible within a specification which demands sufficient cement for both strength and durability. Admixtures, described later, may help in this respect. Other options include:

- using OPC replacement materials such as fly ash or blastfurnace slag which react more slowly and reduce the rate of temperature rise;
- reducing the pour thickness to enable heat to be lost more easily;
- reducing the mix temperature to slow down the rate of temperature rise.

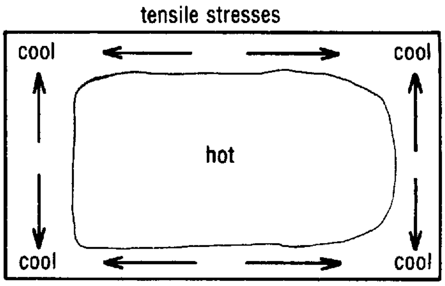


*Figure 3a: Internal restraint.*

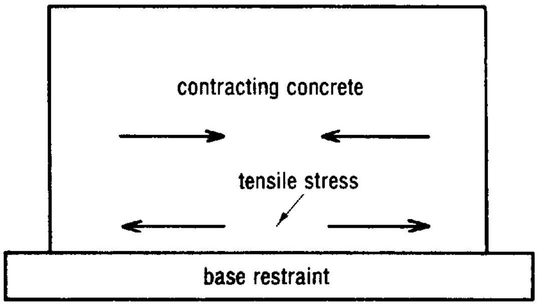


*Figure 3b: External restraint.*

**Table 1: Factors influencing temperature rise.**

| |
|---|
| Total content of cementitious material. |
| Type and source of Portland cement. |
| Alternative materials such as fly ash and blastfurnace slag and the proportions in which they are used to replace OPC. |
| Size of pour, particularly minimum dimension. |
| Type of formwork. |
| Temperature (ambient and concrete). |

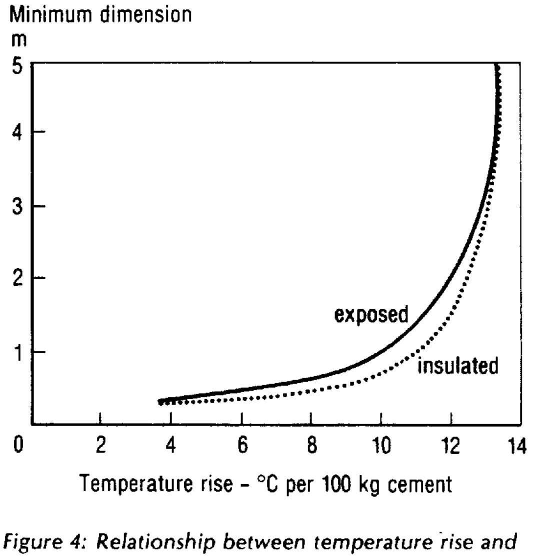


*Figure 4: Relationship between temperature rise and minimum pour dimension derived from site data.*

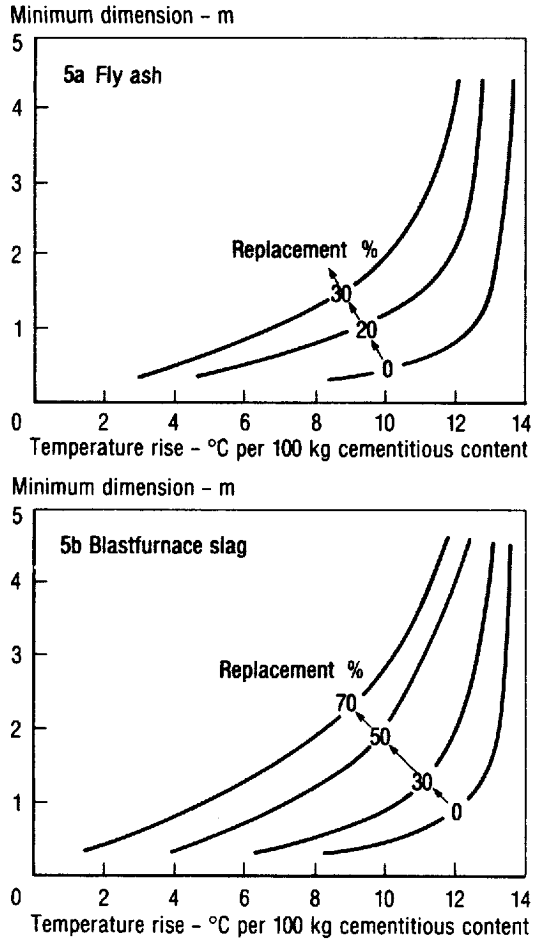


*Figure 5: The influence of partial OPC replacement on temperature rise.*

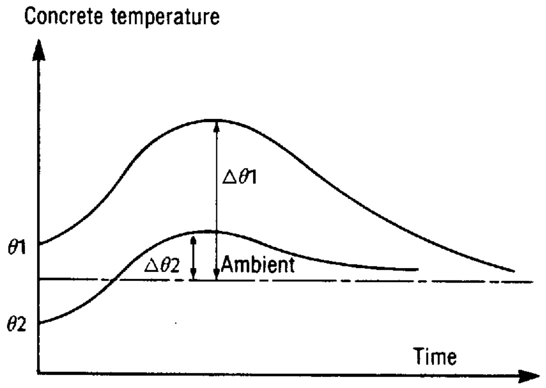


*Figure 6: The influence of mix temperature on in situ temperature rise.*

**Table 2: Typical thermal expansion coefficients for aggregate and concrete.**

| Rock type | Typical thermal expansion coefficient × $10^{-6}$/°C | |
|---|---|---|
| | Aggregate | Concrete |
| Chert | 11.8 | 13.2 |
| Quartzite | 10.3 | 12.1 |
| Glacial gravel | 10.3 | 12.0 |
| Sandstone | 9.3 | 11.4 |
| Silicious limestone | 8.3 | 10.7 |
| Granite | 6.8 | 9.6 |
| Dolerite | 6.8 | 9.6 |
| Basalt | 6.4 | 9.3 |
| Limestone | 5.5 | 8.6 |
| Lightweight aggregate | 4.5 | 7.0 |

### Cement replacements

The use of either fly ash or blastfurnace slag partially to replace OPC can result in considerable reductions in temperature rise. This is due largely to the reduced rate of hydration associated with these materials. The maximum level of replacement using fly ash does not normally exceed 35–40%. Blastfurnace slag can be used to replace up to 75% of OPC. The effect of both materials on the specific temperature rise has been monitored in pours up to 4.5 m deep (see Figure 5). It is not uncommon, with high levels of replacement using fly ash or blastfurnace slag, to achieve a reduction in temperature rise of 50%.

### Pour size

The influence of thickness on temperature rise is clearly illustrated in Figures 4 and 5. As the minimum dimension increases, the rate of heat dissipation from the centre is reduced and the temperature rise is increased. In pours thicker than about 2.5 m, the maximum temperature rise is largely unaffected by increasing pour size, but in the range 0.5 to 1.5 m the change in maximum temperature rise is considerable.

### Type of formwork

Where plywood formwork is used, insulating the concrete surface, care should be taken to avoid thermal shock when the formwork is removed. This is particularly important in winter conditions. Steel or GRP forms provide little or no insulation. When they are removed the temperature distribution is unlikely to be significantly affected.

### Mix temperature

Reducing the initial mix temperature causes a reduction in the rate of hydration. The temperature rise in smaller sections will be most significantly affected by a change of this nature. In addition to reducing the rate of hydration, the peak temperature will be reduced; hence the subsequent temperature drop to ambient will also be reduced (see Figure 6).

Various methods can be employed to reduce the mix temperature such as the use of chilled water, ice or cooled aggregates, but in the UK these measures are rarely adopted. Where lowering of the mix temperature is considered to be essential the most effective way of achieving this is by the use of crushed ice. However, care must be taken to ensure that all the ice has melted before the concrete is placed.

## Thermal strain

### Effect of aggregate type

As the combined aggregate comprises some 75% by weight of concrete, it is not surprising that the thermal expansion coefficient of concrete is dependent primarily on the aggregate type. Typical values for the thermal expansion coefficient of concrete, with a range of commonly used aggregates, are given in Table 2. To minimize the likelihood of early thermal cracking, the aggregate should therefore be selected, if practically possible, to yield a low thermal expansion concrete.

Of the range of commonly used aggregates, limestone is particularly good in this respect. Lightweight aggregate also results in concrete with low thermal expansion coefficient.

The choice of aggregate is also significant in relation to the tensile strain capacity, or crack resistance, of the concrete. Typical values for concretes using a range of common aggregates are given in Table 3. Once again limestone and lightweight aggregates provide the best options.

The combination of low thermal expansion coefficient and increased strain capacity associated with the use of limestone and lightweight aggregate makes these materials particularly suitable for mass pours.

### Effect of cement type

Whilst the cement type has no influence on the thermal expansion coefficient of concrete it does affect the ability of the concrete to resist cracking. This is particularly so for concretes which contain either fly ash or blastfurnace slag. For a given strength, blended cement concretes tend to be less ductile (more brittle) than Portland cement concretes. This results in an increase in elastic modulus, reduced creep and reduced strain at failure. The consequence of this is that some of the advantages of reduced temperature rise are lost as the concrete will crack at a lower strain level. To achieve benefit by the use of fly ash and blastfurnace slag the level of replacement must therefore be high enough to ensure that the reduction in temperature more than offsets the reduced ductility. Recommended replacement levels to achieve this are given in Table 4.

## Restraint

The restraint to massive pours is generally small due to the relative stiffness of the pour compared to its immediate surroundings. Most of the restraint occurs internally due to temperature and strain differentials within the pour. These are caused by the surface of the pour cooling rapidly whilst the centre remains hot. In this situation surface cracking can occur. Conversely, during 'cooldown', internal cracking may occur as the core cools. The extent to which internal restraint develops is determined by the temperature distribution. For a parabolic temperature distribution in massive pours, it has been found that about 35% of the potential thermal movement is restrained.

Some typical values of external restraint which can be used for estimating the likelihood of cracking are given in Table 5.

## Estimating the likelihood of cracking

Whether or not cracking occurs is determined therefore by a range of factors:

- the temperature rise;
- the thermal expansion coefficient of the concrete, which determines the thermal strain;
- the degree of restraint which causes stress-inducing strains to be generated;
- the ability of the concrete to withstand tensile strains without cracking.

A simple equation can be used to determine the likelihood of cracking.

The equation demonstrates that to reduce the likelihood of cracking, various options are available:

1. Reduce the peak temperature in the concrete and hence minimize the temperature fall to ambient and differential temperatures.
2. Select an aggregate with a low thermal coefficient to minimize the thermal expansion of the concrete.
3. Minimize the restraint to thermal movement.
4. Increase the tensile strain capacity, i.e. the crack resistance, of the concrete.

Limiting values of temperature differential have been calculated using a value of internal restraint of 0.35 together with measured properties of concrete with different aggregates (see Table 6). For gravel aggregate concrete the often quoted value of 20°C applies. For concretes using aggregates with lower thermal expansion coefficients and higher strain capacity, this value is conservative. For example, for limestone aggregate concrete with a thermal expansion coefficient of $8 \times 10^{-6}$ per °C and a tensile strain capacity of $90 \times 10^{-6}$, a limiting value of about 40°C is more reasonable. This has been confirmed by experience of massive pours with temperature differentials of 33°C which remained free from cracks.

**Table 3: Tensile strain capacity of concrete with different aggregates.**

| Aggregate type | Tensile strain capacity $\times 10^{-6}$ |
|---|---|
| Gravel | 70 |
| Granite/crushed rocks | 80 |
| Limestone | 90 |
| Lightweight aggregate | 110 |

**Table 4: Recommended minimum levels of OPC replacement to reduce the likelihood of cracking.**

| Lift height | Minimum level of replacement percentage | |
|---|---|---|
| | Fly ash | Blastfurnace slag |
| Up to 1 m | 20 | 40 |
| 1.0 - 1.5 m | 25 | 50 |
| 1.5 - 2.0 m | 30 | 60 |
| 2.0 - 2.5 m | 35 | 70 |

**Table 5: Recorded values of restraint.**

| Pour configuration | Restraint, $R$ |
|---|---|
| Thin wall cast onto massive concrete base | 0.6 - 0.8 at base<br>0.1 - 0.2 at top |
| Massive pour cast onto blinding | 0.1 - 0.2 |
| Massive deep pour cast onto existing mass concrete | 0.3 - 0.4 at base<br>0.1 - 0.2 at top |
| Suspended slabs | 0.2 - 0.4 |
| Infill bays, i.e. rigid restraint | 0.8 - 1.0 |

For no cracking:

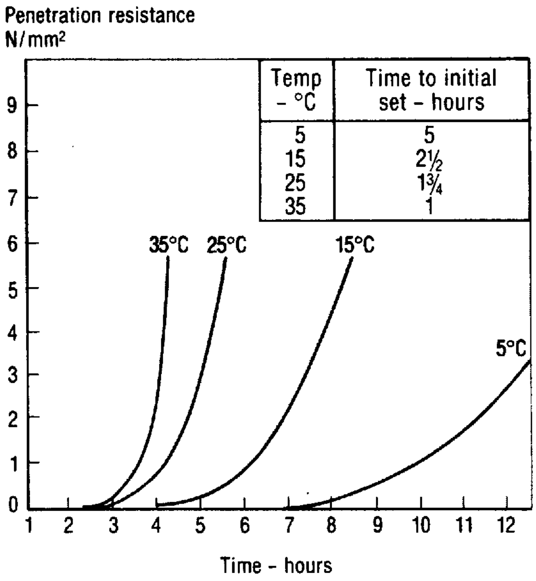
$$\varepsilon_t > 0.8\ \Delta\theta\alpha\ R \quad \text{.........(1)}$$

Where

$\varepsilon_t$ = tensile strain capacity
$\Delta\theta$ = temperature change
$\alpha$ = thermal expansion coefficient of concrete
$R$ = restraint
0.8 = factor which takes into account creep and sustained load failure

**Table 6: Limiting temperature changes and differentials to avoid cracking.**

| Aggregate type | Gravel | Granite | Limestone | Lightweight |
|---|---|---|---|---|
| Thermal expansion coefficient $\times10^{-6}$/°C | 12.0 | 10.0 | 8.0 | 7.0 |
| Tensile strain capacity $\times10^{-6}$ | 70 | 80 | 90 | 110 |
| Limiting temperature change in °C for different restraint factors: | | | | |
| 1.0 | 7 | 10 | 16 | 20 |
| 0.75 | 10 | 13 | 19 | 26 |
| 0.50 | 15 | 20 | 32 | 39 |
| 0.25 | 29 | 40 | 64 | 78 |
| Limiting temperature differential °C | 20 | 28 | 39 | 55 |



| Temp - °C | Time to initial set - hours |
|---|---|
| 5 | 5 |
| 15 | 2½ |
| 25 | 1¾ |
| 35 | 1 |

*Figure 7: Hardening times for OPC concrete measured using a penetration test.*

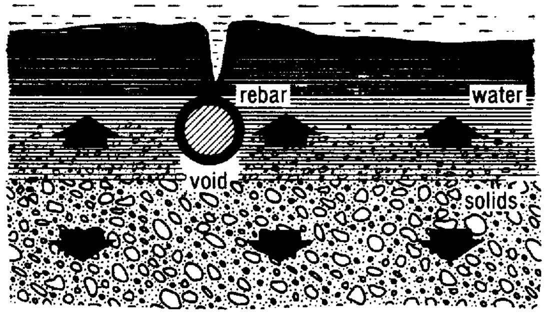


*Figure 8: Plastic settlement cracking. Void beneath the rebar will reduce bond and provide a leak path.*

## Mix design

For conventional concreting, the materials and mix proportions are selected to meet a specification for workability (usually defined by the method of placing), strength and durability. For mass pours there are additional technical considerations:

- longer stiffening time to avoid cold joints;
- higher cohesion to minimize bleed and settlement;
- lower heat of hydration to avoid cracking.

### Cold joints

A primary consideration in avoiding the likelihood of cold joints is the stiffening time of the concrete.

Stiffening time is determined primarily by cement type, fineness and chemical composition, and the concrete mix temperature. For OPC concrete with a typical mix temperature of 15°C, it is normally acceptable to leave a surface for up to two hours before placing additional concrete, providing re-vibration is undertaken. At higher temperatures, this period needs to be reduced (see Figure 7). An indication of the stiffening time can be obtained from the cement certificate, but it is recommended that tests are undertaken on site to obtain a figure for the particular concrete mix. These may involve penetration tests or simple practical tests in which samples are left in buckets and vibrated at intervals using a small poker vibrator. The mix design can then be adjusted accordingly. To increase the time for the concrete to stiffen, various options are available including:

- reducing the mix temperature;
- using OPC replacement materials such as fly ash or blastfurnace slag;
- using set retarding admixtures.

### Plastic settlement cracking

In very deep pours, plastic settlement cracking is often observed following the line of the top mat reinforcement (see Figure 8). This occurs, as the name implies, due to settlement of the concrete whilst still in its plastic state and should not be confused with plastic shrinkage cracking caused by premature drying from the exposed concrete surface. If settlement cracks occur, it is advisable to re-vibrate the top 300 mm of the concrete, providing the concrete will still respond to vibration. This will reinstate the top layer and, if the concrete has almost hardened, further settlement is unlikely to occur.

Note that the early application of moist curing will not prevent plastic settlement if the mix is prone to this phenomenon. However, the following measures can be taken to minimize plastic settlement:

- use an air entraining admixture;
- use finer sand to achieve minimum voids in the total aggregate;
- reduce the water content to an acceptable minimum for transportation, placing and compaction.

### Admixtures

Admixtures can be used to advantage in mass concrete construction in two ways:

- to increase the setting time;
- to reduce cement content.

Set retarders influence the chemical action of hydration and thereby delay the initial set.

The British Standard Specification for accelerating, retarding and water-reducing admixtures BS 5075:Part 1:1982(2) requires that a retarding admixture increases the set by at least one hour. By increasing the dosage, however, a controlled delay in set of several hours can be achieved. Admixture manufacturers will recommend dosage rates related to cement type, temperature and required delay in set, but tests should be undertaken on site prior to commencing a mass pour.

Plasticizers are used to enable a reduction in water demand, and hence a reduction in cement content at constant water/cement ratio and workability. Typically, a reduction in cement content of 5–6% can be achieved using a standard dose of plasticizer but increased dosage rates will enable increased reductions in cement content. There may also be a commercial benefit with the use of a plasticizer, the cost of the admixture being less than the cost of the cement saved.

For greater cement reduction superplasticizers can be used. These high range water reducers enable cement savings of 25% or more. However, they are expensive, and will increase the cost of the concrete despite the reduction in cement content.

Many of the available plasticizers and superplasticizers cause set retardation as well as a reduction in water demand. These materials can be used to provide the combined benefit of delayed set with reduced cement content. It is also worth noting that certain plasticizers entrain small amounts of air. However, in general, admixtures do not in themselves cause changes in the long term properties of the concrete other than those which result from changes in the mix proportions which the admixture may have permitted.

## Planning

The successful completion of a mass pour is largely determined by continuity of concrete supply, placement and compaction. Care must therefore be taken to ensure that:

1. The concrete supplier is able to meet the demand and that alternative sources are available in the event of breakdown. Refer to Concrete Society Digest, *Using ready-mixed concrete*(3), for further information.
2. The placing equipment has sufficient capacity and back-up equipment is available.
3. The labour resources can handle the rate of concrete delivery. Refer to Concrete Society Digest, *Site organisation for concrete construction*(4).

It is also important to ensure compatibility between concrete production, transportation, placing rate, compaction rate and finishing. A deficiency in any one of these processes can lead to unacceptable delays.

Furthermore, the casting sequence and rate of supply must be such that a live working face is always maintained with the avoidance of cold joints. Refer to Concrete Society Digest, *Joints in in situ concrete*(5). With only one placer, whether it be a skip, a pump or a chute from a mixer truck, the choice of casting sequence is limited, usually to starting at one end and working towards the other. With more than one placer the options increase.

For very large pours, even with the use of several placers, it is often necessary to continue concreting beyond normal working hours. In this situation, provision must be made for night shift working as well as for continuing concrete delivery. It may, in fact, be beneficial to utilize non-standard working hours, such as weekends, to enable the concrete supplier to dedicate a particular plant to the contract. In areas of heavy traffic, casting during the night or on Sundays would allow easier access for ready-mixed concrete trucks which might otherwise be delayed during busier periods. If non-standard working hours are necessary, local by-laws should be checked.

## Methods of transportation and placing

For the large quantities of concrete normally associated with mass pours, rapid placement methods are essential. One of the

*Figure 9: A foundation slab being concreted with discharge down chutes direct from the ready-mixed concrete trucks. The concrete is transported at the foot of the chutes via conveyors. (Photograph by courtesy of Myton Limited).*

*Figure 10: Casting a large volume (1100 m$^3$) suspended slab, using four lorry-mounted boom pumps which are fed directly by discharge from ready-mixed concrete trucks. (Photograph by courtesy of John Laing Construction Limited).*

Planning considerations:
- concrete production and supply;
- plant for placing and compaction labour;
- labour;
- placing sequence;
- compatibility between concrete supply, placing, compaction and finishing;
- by-laws if working non-standard hours.

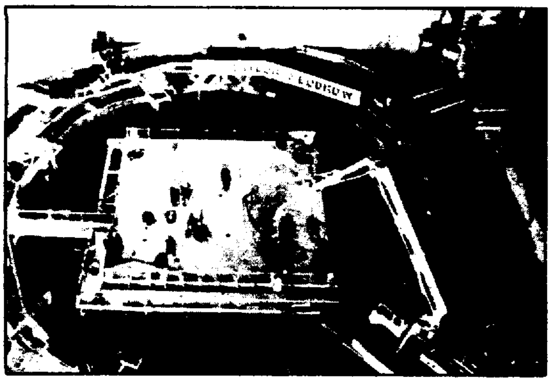


*Figure 11: Casting the top cap of a prestressed concrete pressure vessel using pumps and tremie pipes. The concrete contained a 50:50 blend of SRPC and blastfurnace slag.*

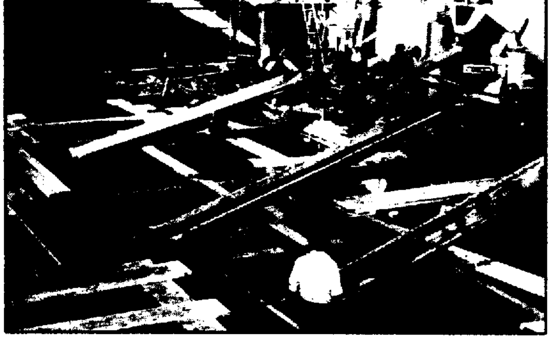


*Figure 12: Placement of a mass pour using chutes and high flow concrete.*

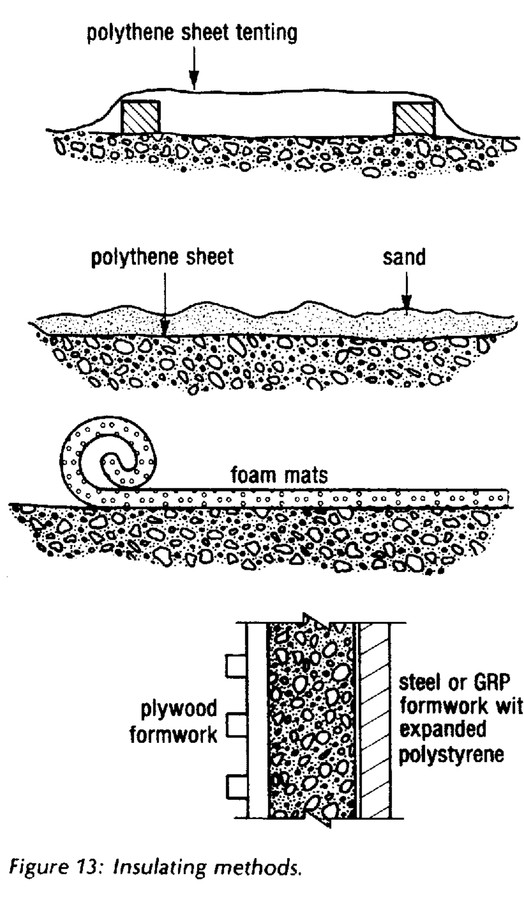


*Figure 13: Insulating methods.*

most common methods is to pump the concrete using one or more lorry-mounted boom pumps. Refer to Concrete Society Digest, *Pumping concrete*[6], for further information. With a single pump typically delivering in excess of 40 $m^3$/hour, the use of say four pumps will enable pours of the order of 1000 $m^3$ to be placed in a six hour shift or 4000 $m^3$ in a 24 hour period. Placing at this rate will require one ready-mix truck every two minutes. To achieve this, supplies from more than one plant will almost certainly be necessary.

Boom pumps also provide access over a large area, and mobility; using several pumps, the options for placing sequence are numerous. Working from each corner is common, but there are many variations depending on the size and configuration of the pour. Whatever the sequence, the aim should be to keep the advancing faces live, avoiding cold joints.

Other placing techniques are more common in smaller pours which can be reasonably placed within the normal working day. If access is available the simplest method is to chute the concrete directly from the mixer truck. Skipping is probably the slowest method of placing. Unless a number of cranes are available, it is only suitable for relatively small pours or if there are other constraints on the rate of concreting.

## Insulation

If the most suitable concreting materials are not available and it is expected that the temperature differentials will be excessive and cause cracking, insulation can be applied. This prevents rapid heat loss from the surface and hence minimizes the temperature differential between the surface and the core.

Various forms of insulation are available ranging from quilts, normally used for winter concreting, to simple tenting. The precise measures to be taken will be determined by the extent to which the surface temperature must be raised in order to bring the temperature differential within the acceptable limit for the particular concrete.

If only modest insulation is needed, tenting may be sufficient. In its simplest form, this will consist of polythene sheeting laid on the surface and fixed in such a way as to prevent evaporative cooling. To increase the insulating value, the sheeting can be raised on timbers, but care must be taken to ensure that the system is windproof.

For more effective insulation, quilts or foam mats, or soft board or sand laid on polythene sheets are all methods which have been employed. Quilts or foam mats are probably the easiest to apply and remove and allow greatest flexibility.

The insulation should remain in place until the centre of the pour has cooled to a temperature level which is low enough to avoid the limiting differential being exceeded even if the surface should cool to ambient. This period will vary with the size of pour and mix used. Some typical values are given in Table 7 for OPC concretes used in pours of different sizes. For mixes containing OPC replacement materials, the period of insulated curing will be reduced.

Plywood formwork is also a good insulator and, if left in place, will allow the surface temperature to increase by 20°C or more thereby decreasing the temperature differentials. If this system is adopted, however, care should be taken not to remove the formwork when the pour is at its peak temperature after 48 hours or so. This could lead to rapid surface cooling and cracking. If the formwork has to be removed, it is best to loosen the shutters initially, but keep them in place for a period of, say, 24 hours. This allows the surface to cool slowly, resulting in less severe thermal gradients. When the shutters are removed altogether, they must be replaced by insulating drapes to maintain the temperature differential within the acceptable limits.

## Temperature measurement

To determine when insulation or formwork can be removed, it is advisable to cast in thermocouples to measure directly the in situ temperature (Figure 14). This is relatively cheap and simple, and gives a direct measurement of temperature differentials. The thermocouples should be located at the centre and at the surface to measure the temperature extremes and hence the maximum differential. Monitoring can be either manual or automatic.

## Durability

The durability of concrete is determined primarily by the performance of the cement paste. The permeability of the paste and the nature of the cement are particularly important.

The way in which the temperature affects the strength gain of concrete is the same regardless of the cement blends used. The early strength is accelerated but the long term strength gain is impaired. The use of fly ash or blastfurnace slag does, however, lessen the extent to which the long term strength is affected. It is also worth noting that the use of these materials provides increased resistance to sulphate attack, although where sulphate concentrations in excess of 1% $SO_3$ occur, only sulphate-resisting Portland cement is recommended.

The consequences of the in situ heat of hydration cycle, and the selection of materials to minimize its detrimental effects, must therefore be considered in relation to both structural performance and durability.

**Table 7: Minimum periods of insulation to avoid excessive temperature differentials.**

| Minimum pour dimension (m) | Minimum period of insulation (days) |
|---|---|
| 0.5 | 3 |
| 1.0 | 5 |
| 1.5 | 7 |
| 2.0 | 9 |
| 2.5 | 11 |
| 4.5 | 21 |

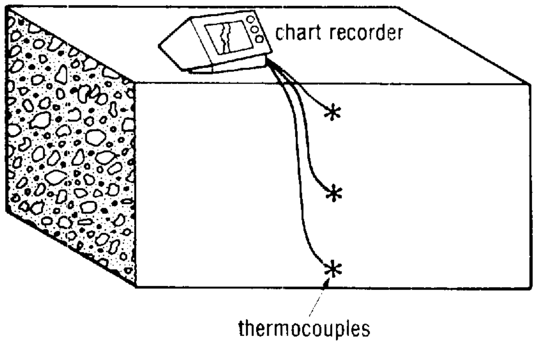


*Figure 14: A typical arrangement of thermocouples in a mass pour to determine both the maximum temperature and temperature differential.*

## References

1. BAMFORTH, P.B. *Early age thermal cracking in concrete.* Slough, Institute of Concrete Technology, 1982. Tech. No. TN/2.
2. BRITISH STANDARDS INSTITUTION. *Specification for accelerating admixtures, retarding admixtures and water-reducing admixtures.* London. 16pp. BS 5075:Part 1:1982.
3. GRANT, M. *Using ready-mixed concrete.* London, The Concrete Society, to be published 1985. Concrete Society Digest.
4. MANSFIELD, C.E. *Site organization for concrete construction.* London, The Concrete Society, to be published 1985. Concrete Society Digest.
5. BLUNDELL, R. and O'LEARY, E. *Joints in in-situ concrete.* London, The Concrete Society, to be published 1985. Concrete Society Digest.
6. LAING DESIGN AND DEVELOPMENT CENTRE. *Pumping concrete.* London, The Concrete Society, 1984. 8 pp. Concrete Society Digest No. 1. Publication 53.045.

## Further reading

BAMFORTH, P.B. In situ measurement of the effect of partial Portland cement replacement using either fly ash or ground granulated blastfurnace slag on the performance of mass concrete. *Proceedings of the Institution of Civil Engineers,* Part 2, Vol. 69, September 1980. pp.777-800.

BIRT, J.C. *Concrete pours – a survey of current practice.* London, Construction Industry Research and Information Association, 1974. CIRIA Report 49.

FITZGIBBON, M.E. Large pours for reinforced concrete structures. *Concrete,* Vol. 10, No. 3, March 1976. p.41. Current Practice Sheet No. 28.

FITZGIBBON, M.E. Large pours – 2. Heat generation and control. *Concrete,* Vol. 10, No. 12, December 1976. pp.33-35. Current Practice Sheet No. 35.

FITZGIBBON, M.E. Large pours – 3. Continuous casting. *Concrete,* Vol. 11, No. 2, February 1977. pp.35-36. Current Practice Sheet No. 36.

HARRISON, T.A. *Early-age thermal crack control in concrete.* London, Construction Industry Research and Information Association, 1981. CIRIA Report 91.

THE CONCRETE SOCIETY West Midlands Region. Proceedings of Symposium, *Large pours for RC structures.* University of Birmingham, September 1973. London, The Society. 91pp.

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