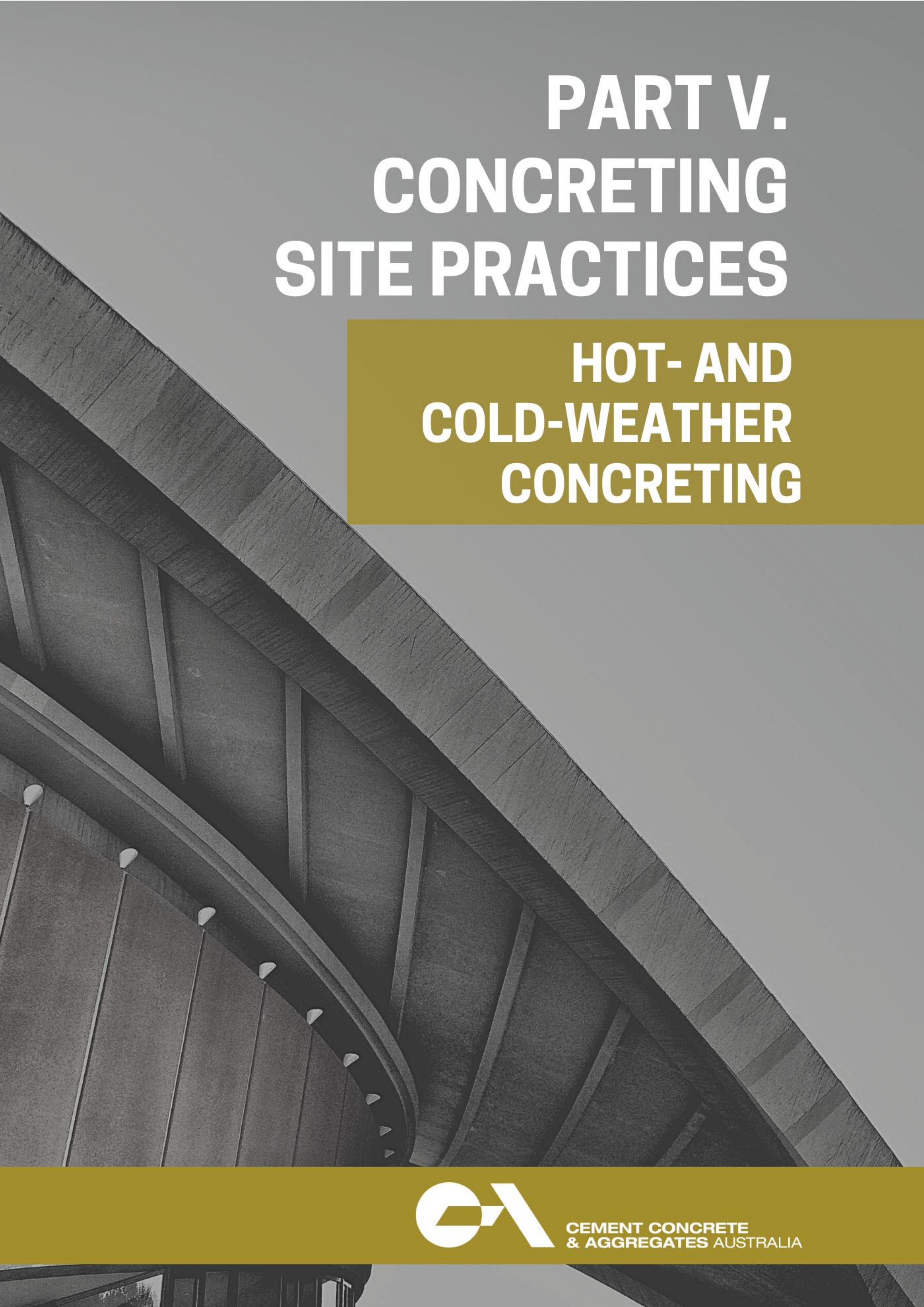

PART V. CONCRETING SITE PRACTICES

HOT- AND COLD-WEATHER CONCRETING

CEMENT CONCRETE
& AGGREGATES AUSTRALIA

This section contains information on the precautions which should be taken when concreting operations have to be carried out in either very hot or very cold weather. While what constitutes hot and cold weather is nowhere specifically defined, AS 1379 *'Specification and supply of concrete'* requires that concrete temperatures at the point of delivery be within the range 5°C to 35°C. Precautions will always be necessary when ambient temperatures lie outside this range, but may well be necessary even when they lie within it. AS 1379 suggests protective measures may need to be taken when the air temperature is less than 10°C or more than 30°C. A knowledge of the effect of high and low concrete-temperatures on the properties of concrete will enable sensible decisions to be made on when precautions are needed and what precautions are necessary.

CONTENTS

1. INTRODUCTION

It is generally well recognised that when concrete is mixed and placed in either very hot or very cold weather, it is necessary to take precautions to ensure that the concrete is not damaged or adversely affected by the ambient weather conditions. At temperatures below freezing, for example, freshly placed concrete may be damaged by the formation of ice within its pore structure. In very hot weather the concrete may stiffen prematurely preventing it from being compacted and finished properly, or the temperature of the concrete may rise to a point where thermal cracking becomes a real risk as the concrete cools.

It should also be noted that temperature is not the only environmental condition that has the potential to impact concrete performance. Strong drying conditions (created by moderate to high temperatures, low humidity and strong winds) can cause major problems for plastic concrete – the most important being plastic shrinkage cracking.

There are few fixed rules, therefore, on what constitutes 'hot' or 'cold' weather with respect to concreting operations. AS 1379 requires that concrete temperatures at the point of delivery be within the range 5°C to 35°C. Precautions will always be necessary when air temperatures lie outside this range.

Precautions may well be necessary at air temperatures within the 5-35°C range and care may be required with ambient temperatures of <10°C or >30°C. In the lower temperature environment, the concrete is in no danger of freezing but it may take an excessively long time to set and to gain its specified strength. In the higher temperature environment, particularly if accompanied by hot dry winds, premature stiffening and plastic shrinkage cracking of the concrete may occur.

This section will provide guidance on (a) the effects of high and low temperatures on the properties of concrete; and (b) in light of these effects, on precautions which should be taken when air temperatures fall outside the 'normal' range (say 10°C to 30°C), or when strong drying conditions prevail.

2. CONCRETING IN HOT WEATHER

High ambient temperatures, particularly when combined with strong dry winds, can affect the quality of both fresh and hardened concrete in a number of ways:

- By heating the constituent materials, notably the aggregates, they can increase the temperature of the freshly mixed concrete to the point where slump loss, increased water demand, and reduced setting times may occur;
- By causing the surface of the plastic concrete to dry prematurely, cracking (known as plastic shrinkage cracking) can occur when stresses induced by moisture loss and consequent shrinkage exceed the tensile capacity of the plastic concrete;
- By accentuating the temperature rise in concrete caused by the hydrating cement, particularly in massive sections, they can lead to thermal shrinkage or shock-induced cracking when the concrete subsequently cools.

2.1 EFFECT OF HIGH CONCRETE TEMPERATURES

As the temperature of concrete rises the hydration reactions are accelerated where (a) the setting time is reduced, and (b) the time available in which to place, compact and finish the concrete is also reduced. More water is often added to the mix to maintain or restore workability with a consequent loss in both potential strength and durability. Where water is not added, the reduced setting time increases the dangers of incomplete compaction, or the formation of cold joints or poor finishes (**Figures 18.1** and **18.2**).

Even when potential strength and durability are maintained, by the addition of cement to the mix for example, the final strength of the concrete may be reduced because of the higher temperatures (**Figure 18.3**). It should also be noted that, whereas increased early-age concrete temperatures result in an increase in the early strengths and rate of strength gain, in the longer term, concretes cured at the lower temperatures achieve higher ultimate strength (see also **Figure 18.7**). Curing concrete at temperatures between 10°C and 25°C tends to achieve optimum results.

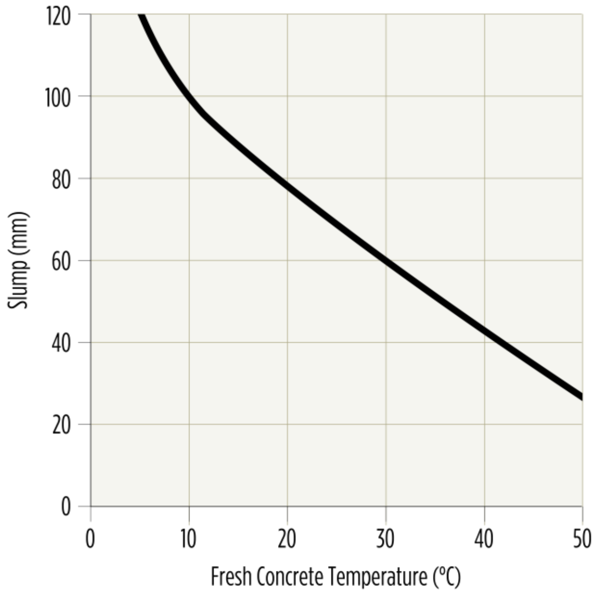

Figure 18.1 – Decrease in Workability of Plastic Concrete (measured by slump) as Temperature Increases – at Constant Water Content

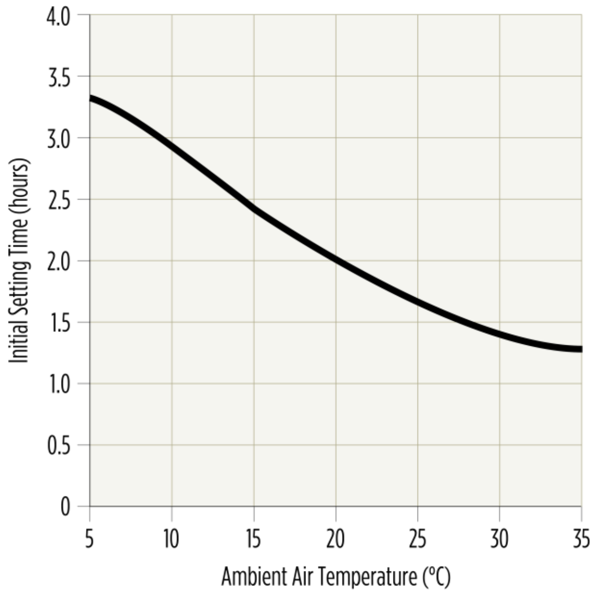

Figure 18.2 – Influence of Air Temperature on Initial Setting times of Concrete made with Type GP Cement

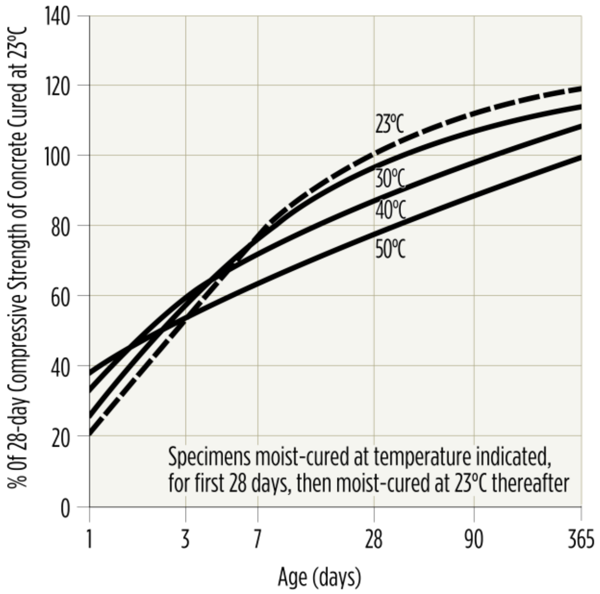

Figure 18.3 – Effect of High Curing Temperatures on Concrete Compressive Strength

2.2 CONTROLLING CONCRETE TEMPERATURE

Estimating the Temperature of Fresh Concrete – The temperature of fresh concrete may be estimated from the following equation:

$$T = (T_aW_a+T_cW_c+5T_wW_w) / (W_a+W_c+5W_w) \quad \text{.....}\textbf{Eq.18.1}$$

Where:

- T = temperature of the freshly mixed concrete in (°C);
- T_a = temperature of the aggregates in (°C);
- T_c = temperature of the cement in (°C);
- T_w = temperature of the mixing water in (°C);
- W_a = mass of aggregates including free moisture (kg);
- W_c = mass of cement (kg);
- W_w = mass of mixing water (kg).

NOTE*: This equation gives approximate results only but is sufficiently accurate for most practical purposes. For more accurate results knowledge of the specific heats of the constituent materials is necessary.*

By substituting typical mix proportions in the above equation, it can be seen that the aggregates (and their temperature) have a dominating effect on the temperature of freshly mixed concrete – since they are (by mass) the dominant material. Next in importance is the temperature of the mixing water. The cement has a relatively minor effect unless its temperature is much higher than that of the other materials. The effect of higher cement temperatures can be easily calculated.

Aggregates – As the temperature of the aggregates has the most significant influence on concrete temperature, measures taken to limit aggregate temperatures have the greatest effect in minimising the temperature of freshly mixed concrete. Shading stockpiles from the sun and/or keeping them moist with sprinklers are commonly used means of reducing aggregate temperatures. Storage in bins (painted white) can also assist.

Water sprays, continuously applied as a fine mist (for evaporative cooling), are particularly effective and serve also to suppress dust in hot, dry and windy conditions. Adequate provision for drainage and/or recycling of the water must be made to prevent the storage site becoming problematic. A continuous spray is preferable to intermittent spraying to maintain a constant moisture content in the aggregates and thus minimise variations in concrete water/cement ratio.

Water – The temperature of the mixing water may have a significant effect on the temperature of the concrete. If water is stored on site in tanks unprotected from the sun it may become quite hot. Conversely, if cooled by refrigerating the mixing water or by adding crushed ice to it, it will serve to lower the temperature of the concrete and help offset higher temperatures in the other materials.

Typically, water will be drawn from town water supplies. In such cases, reticulation lines should be shaded and lagged to protect them against solar radiation. Intermediate surge or storage tanks should be similarly protected. If bore water is being used an awareness of any temperature variability in this water source will assist in management of concrete temperatures.

Cement – The temperature of cement does not usually contribute significantly to the temperature of freshly mixed concrete because of its low specific heat combined with its relatively small mass in the mix. Nevertheless, temperature rise can be avoided by painting silos white (or other reflective colours).

The type of cement will affect the properties of the freshly mixed concrete and advantage of this may be taken in some situations. Blended cements and low heat cements may provide additional time for placing and finishing, depending on the proportion of fly ash and/or slag used in the mix.

The use of rapid-hardening cement should be avoided except where very rapid strength gain is necessary.

Admixtures – Admixtures are very helpful in offsetting the effects of hot weather and high concrete temperatures. They may be used to improve and maintain the workability of the concrete without the addition of extra water and also be used to retard setting.

There is a growing reliance on admixtures to manage plastic concrete properties. It is still appropriate though to manage the temperatures of other constituent materials and to maintain good practices in the transporting, placing and curing of the concrete.

Ice Addition – A proportion of the mixing water can be replaced with crushed or flaked ice. Ice is typically added manually to the truck during batching where the concrete temperature needs to be limited, commonly on mass or large concrete pours. Ice addition can also be directly fed to the agitator truck or mixer from flaked ice plants, however these are uncommon in Australia and have only been used on large projects. The amount of ice that can be used is limited by the water content of the concrete.

Liquid Nitrogen Injection – For large and important pours where temperature control is critical, cooling may be achieved by injecting liquid nitrogen directly into the mixer or agitator truck (**Figure 18.4**).

The quantity of liquid nitrogen used is adjusted to the temperature of the constituent materials and, in this way, effective (but expensive) control of concrete temperature can be maintained. Injection lances, storage tanks, etc are available from the suppliers of industrial gases. Generally, liquid nitrogen injection is only used in large volume projects where good temperature control is required. A common use in in mass concrete pours where concrete temperature management is critical.

Figure 18.4 – Injection of Liquid Nitrogen into an Agitator Truck to lower Concrete Temperature

2.3 BATCHING, MIXING AND TRANSPORTING

To minimise the effect of high ambient temperatures on the concrete during the batching, mixing and transporting operations, a number of simple precautions can be taken:

- All handling equipment such as chutes, conveyors and pump lines should be either enclosed or alternatively shaded and painted white (or in a reflective colour);
- Site mixers themselves should be shaded and/or painted white;
- Transport from the mixer to the site, and on the site itself, should be planned carefully to minimise transport time and avoid unnecessary delays. Transit mixer trucks should be discharged as quickly as possible after the water has been added to the mix. Prolonged mixing should be avoided.

Fortunately, these precautions tend to coincide with the need (in urban areas at least) to minimise noise and dust pollution of the environment.

2.4 PLACING AND COMPACTING

Formwork and Reinforcement – Wherever possible, subgrades, formwork and reinforcement should be shaded to minimise surface temperatures and should also be cooled by (carefully) spraying with water prior to concrete being placed. A fine mist spray is well suited to this purpose, but care must be taken that water does not collect on the subgrade or in the forms. Surfaces at the time of concreting should preferably be damp – but not wet.

Placement – As far as is practical, concrete placement should be carried out in the cooler parts of the day. For most of Australia this is in the early morning. This permits the concrete to be finished before the hottest part of the day and makes it easier for curing to be commenced immediately.

In very hot areas night-time pours may be advantageous, particularly for mass concrete structures.

Because the time during which the concrete remains workable is generally reduced in hot weather, the provision of stand-by equipment and/or additional manpower to eliminate any delays (e.g. due to breakdowns) becomes more crucial in these environments.

Placing of slabs should be organised so that a 'minimum' front is employed to which fresh batches of concrete are added. Concrete walls and deep beams should similarly be placed in shallow layers to avoid any 'cold joints' which might occur when fresh concrete is placed against concrete already stiffened.

2.5 FINISHING AND CURING

Finishing – Two separate (albeit related) problems may be experienced in finishing concrete during hot, dry and windy conditions.

First, the time available in which to finish the concrete is generally reduced under these conditions. Finishing operations should therefore be carried out promptly once the water sheen has disappeared from the concrete surface and it is strong enough to support the weight of a person. Temporary sunshades and windbreaks will assist to lengthen the time during which finishing can be done.

*(**NOTE**: Care needs to be taken when starting finishing operations to ensure that the concrete has actually reached initial set and that the surface has not simply dried out leaving the lower sections of the slab still in a plastic state.)*

The second problem which may occur in hot, dry, windy conditions (or even at moderate temperatures when there are strong dry winds) is known as plastic shrinkage cracking (PSC). PSC can occur when the surface of the freshly placed concrete is allowed to dry out rapidly, generally before the body of the concrete has had time to take its initial set and has gained any reasonable tensile strength.

Under these conditions fine cracks may open in the surface of the concrete. While they may sometimes be closed over during finishing operations, they constitute a line of weakness in the surface and the cracks will often open up again as the concrete dries out following curing operations, or later when the hardened concrete undergoes drying shrinkage. Special care is necessary in extreme weather conditions to prevent this occurrence. A range of precautions are further discussed below (see 2.6 *'Plastic Cracking'* below).

While the concrete is still plastic and unable to be cured by conventional means (see Section 15 *'Curing'*) loss of moisture due to evaporation can be minimised by spraying aliphatic alcohol onto the surface of the bleed water. (Aliphatic alcohol is available from manufacturers of concrete admixtures.) It forms a thin film on the bleed water and reduces evaporation significantly in evaporative conditions without interfering with subsequent finishing operations. This approach is particularly useful for the prevention of plastic shrinkage cracking.

Curing – Curing should commence as soon as practical after finishing to prevent moisture being lost prematurely from exposed, hardened concrete surfaces.

As soon as the concrete has hardened and finishing is complete, normal curing procedures should be commenced.

In hot, dry conditions, water curing is the preferred method because it not only ensures that the concrete is kept moist but also assists in cooling the concrete while it hardens and gains strength. The use of a wet covering such as hessian is particularly useful for this purpose as it also shades the concrete. Hessian should be kept continually wet with a fine mist of water (which minimises water usage) or more simply, with soaker-hoses. Care should be taken that the temperature of the water is not higher (nor significantly cooler) than that of the concrete. High spray water temperatures may be the result of exposed reticulation lines. Where adequate water supplies are available, and project circumstances allow, water curing should be maintained for at least seven days.

In situations where water is not readily available, or even when site conditions are not favourable, every effort should be made to water cure for at least 24 hours. It should be followed immediately by some other form of curing (e.g. the application of a suitable curing compound or the use of a protective membrane such as plastic sheeting).

Where plastic sheeting is used in hot, windy weather it is essential that it be well secured and anchored at the edges and joints or much of its effectiveness will be lost. There is always the danger that the sheeting can be torn or blown off in strong winds.

2.6 PLASTIC CRACKING

Plastic cracking – the formation of cracks in the surface of the concrete before it has reached its initial set – may be caused in several ways:

- By drying out of the surface of the concrete before the body of the concrete has set (and gained some strength);
- By settlement of the concrete around reinforcing bars, aggregate particles or other obstructions;
- By settlement or movement of the formwork.

Cracks caused by settlement of the concrete and/or the formwork issues are discussed in Section 17 *'Control of Cracking in Concrete'.*

Plastic Shrinkage Cracking – Plastic shrinkage cracks, i.e. cracks caused by too rapid drying out of the surface of plastic concrete, most often occur in hot, dry, windy conditions but are not unknown at even quite moderate temperatures if the wind velocity is high enough and/or the relative humidity is low (**Figure 18.5**). The primary cause is the rapid loss of moisture from the surface of the concrete by evaporation. Shrinkage caused by the loss of moisture creates tensile stresses in the plastic concrete at a time (at about initial set) when the tensile capacity of the concrete (i.e. the ability to resist tensile stress) is at its lowest. Plastic shrinkage cracks are often full thickness cracks and generally do not extend to the edge of the concrete slab (due to lower levels of restraint at the edges).

Plastic Shrinkage cracking

Figure 18.5 – Plastic Shrinkage Cracking (PSC)

Figure 18.6 may be used to estimate the likelihood of plastic shrinkage cracking occurring and, hence, the need for suitable precautions to be taken. As can be seen from the nomograph, the factors which affect the rate of evaporation of moisture from the surface include:

- Air temperature;
- Relative humidity;
- Concrete temperature;
- Wind velocity.

Where these factors combine to produce a rate of evaporation of 1 kg/m^2/h or above then PSC is likely, and precautions must be taken. As has been noted, high air temperatures are not necessary for these evaporative conditions to occur – concrete temperature, wind velocity and humidity actually have greater effects. At evaporation rates of 0.5 kg/m^2/h there is a reasonable risk of PSC and precautions should be applied.

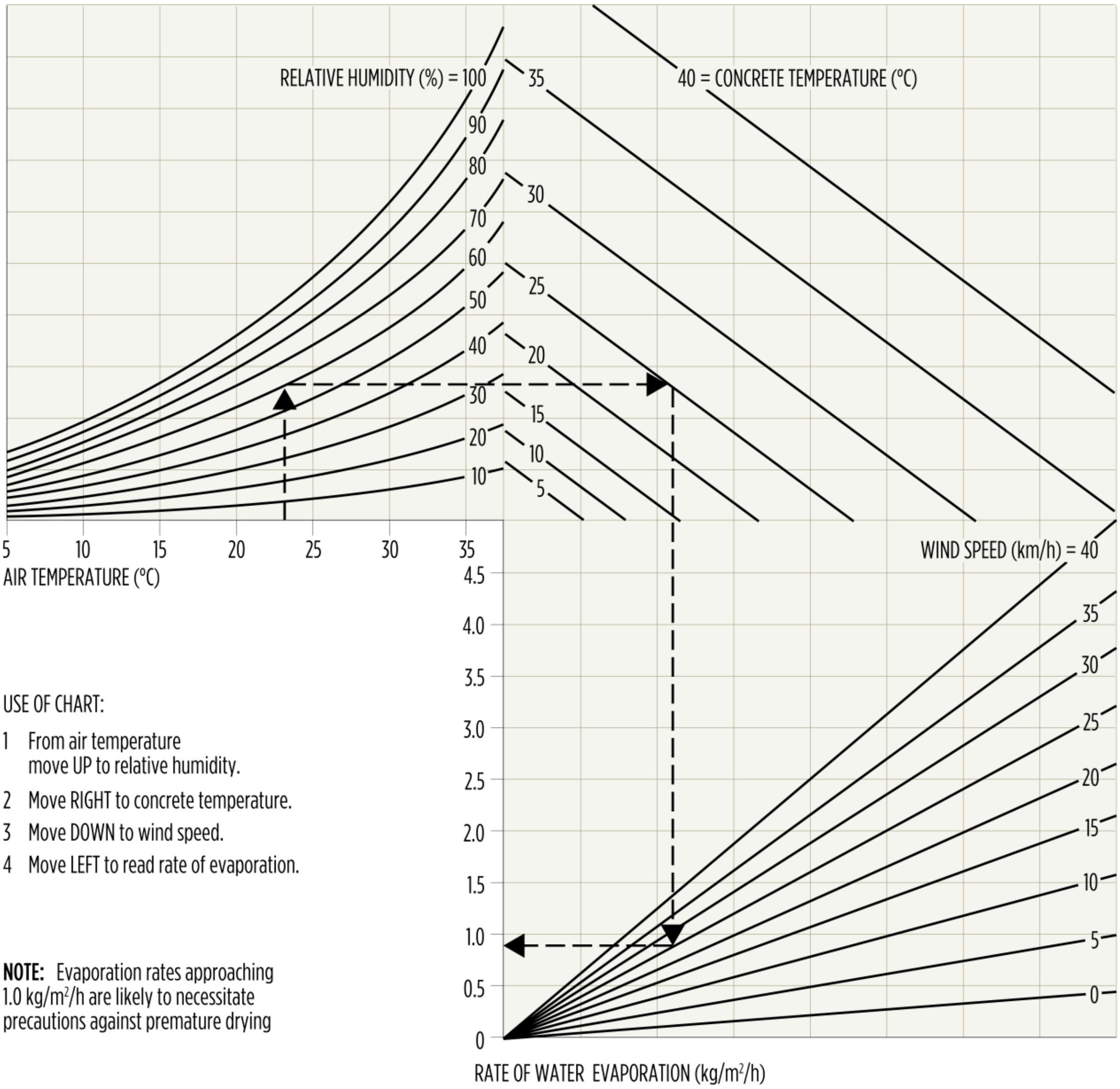

Figure 18.6 – Effect of Concrete and Air Temperatures, Relative Humidity and Wind Velocity on the Rate of Evaporation of Surface Moisture from Concrete (after ACI-305 (1999) [2])

It should also be noted that actual site weather conditions may be quite different to (for example) BOM weather forecasts or data. A location on the top of a hill will have a different evaporation rate to that in an adjacent valley. Shaded or wind-protected areas in the same locale will also result in different evaporation rates. Similarly, wind-tunnel effects between adjacent buildings will result in higher evaporation rates than might otherwise be expected. It is also important to realise that evaporation rates change through the day – with wind velocity generally increasing and the sun moving overhead, both increasing evaporation potential. Where there are concerns about PSC risk, starting concrete placing as early as possible in the day is advisable.

As an alternative to using the nomograph in **Figure 18.6,** the equation shown below can be used to estimate evaporation rates. Both methods are based on evaporation from a water surface and are not applicable after bleed water disappears from the surface of the plastic concrete.

Alternative equation to calculate evaporation rate [1]:

$$E = 5([T_c + 18]^{2.5} - r[T_a + 18]^{2.5})(V + 4) \times 10^{-6}$$

…..**Eq.18.2**

Where:

- E = evaporation rate (kg/m²/h);
- r = Relative Humidity/100;
- T_a = air temperature (°C);
- T_c = concrete (water surface) temperature (°C);
- V = wind velocity (km/h).

Precautions – The most effective way to reduce the risk of PSC is to prevent rapid loss of moisture from the surface of the plastic concrete. Practices to achieve this include:

- Dampen subgrade and forms (but ensuring any excess water is removed prior to placing concrete);
- In hot weather – lower the temperature of the fresh concrete by using cool aggregates and chilled mixing water;
- Start placing concrete as early as possible in the day;
- Add polypropylene fibres to the concrete mix [3];
- Erect wind breaks to reduce wind velocity over the concrete surface;
- Spray aliphatic alcohol sprayed on bleed water to reduce its rate of evaporation from the surface;
- Commence curing promptly after finishing is complete and ensure the surface is subject to continuous curing.

Re-vibration – If PSC does become evident before the concrete has reached initial set, the cracks may be able to be closed by re-vibration of the concrete over the full depth of the cracks. The feasibility of doing this should be assessed by an experienced operator, but a good rule of thumb is to permit re-vibration of concrete only if the vibrator will sink into the concrete under its own weight. Surface re-vibration may be only partially effective as it may not close the cracks to their full depth. Partially closed cracks will almost certainly reappear as the concrete dries out.

PSC often appears immediately before initial set and in surfaces that have dried out. These conditions are not generally conducive to re-vibration.

3 CONCRETING IN COLD WEATHER

In Australia, freezing conditions are generally encountered only in the southern mountains of NSW, and in Victoria and Tasmania, although frosts are not uncommon over wide areas of inland Australia during the winter. Most often, concreting in cold weather in Australia entails operations in ambient temperatures above freezing, but temperatures still low enough to have potentially adverse effects on the progress of the work and the setting of concrete.

3.1 EFFECTS OF LOW CONCRETE TEMPERATURES

By reducing the rate at which the cement hydrates, low concrete temperatures have a number of effects on the behaviour of the concrete. Firstly, and most noticeably, the setting time will be increased, delaying concrete finishing operations (**Figure 18.2**). At low temperatures, bleeding will continue for longer and bleed water will take longer to evaporate.

Under these conditions, there is a temptation in finishing flatwork to use 'driers' (cement or mixtures of cement and sand applied to the surface of the slab) to 'mop up' excess water to allow finishing to proceed. This practice leads almost inevitably to poor abrasion/wear resistance.

Further, if the low temperatures are prolonged, the concrete will take longer to harden and gain strength, thereby requiring the removal of formwork to be delayed (**Figure 18.7**). AS 3600 (Clause 17.6.2) sets out minimum periods for which formwork and formwork supports must be left in place – periods which vary with the average ambient temperature over the period specified (**Table 18.1**).

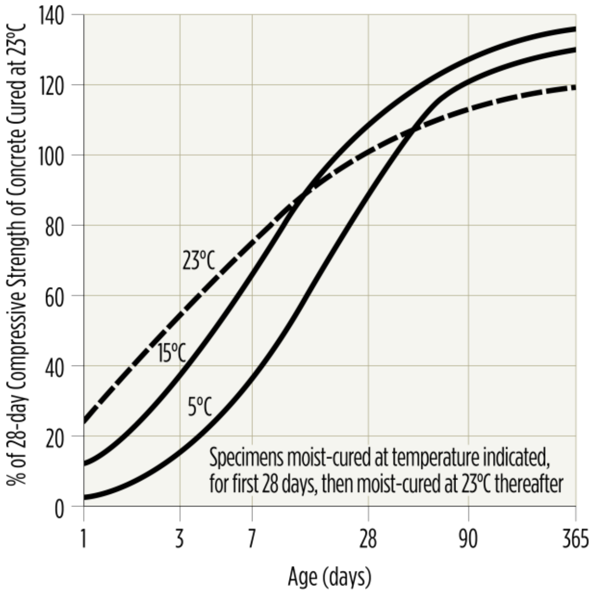

Figure 18.7 – Effect of Low Temperatures on Concrete Compressive Strength

When freezing conditions are encountered, irreversible damage may be done to the concrete while it is still plastic or when it is starting to harden (see 3.5 *'Freezing Conditions'*).

3.2 ADMIXTURES

The most commonly used method of offsetting the effects of cold weather is the addition of an accelerating admixture to the concrete. There is a wide variety of these, ranging from water-reducing admixtures which have had accelerators incorporated in them to chemicals whose sole purpose is to reduce the setting time and accelerate the rate of strength gain (see Section 5 *'Admixtures'*).

Accelerating admixtures increase the rate at which the cement hydrates, increasing the rate of strength gain and result in higher levels of heat generation which leads to higher concrete temperatures.

Accelerators may perform a very useful purpose, but their use should be approached with caution. Any accelerating admixtures containing chlorides should be avoided. If these must be used, the chloride content must be known and a check made to ensure that the limits on the chloride content of concrete, as noted in AS 1379, are not exceeded.

Table 18.1 – Stripping/removal Times (based on Tables 17.6.2.4 and 17.6.2.5 in AS 3600)

Average ambient temperature over the period T (°C)	**Period of time before stripping of formwork from reinforced slabs continuous over formwork supports – Normal-Class concrete with specified early-age strength (days)**	**Period of time before removal of all formwork supports from slabs and beams not supporting structures above – reinforced members only* (days)**
T > 20	4	12
20 ≥ T >12	6	18
12 ≥ T > 5	8	24

***NOTE**: * Where the average ambient temperature over the period is less than 5°C or the superimposed construction load is greater than 2 kPa these periods will need to be increased.*

3.3 HOT WATER

The use of hot water is another common method of compensating for the effects of cold weather. Its use as mixing water raises the temperature of the concrete which increases the rate at which the cement hydrates.

The temperature of mixing water should never exceed 70°C however, to ensure that 'flash setting' of the cement does not occur.

Care should also be taken to ensure consistency in the temperature of the concrete delivered to the site. Significant variations in the temperature of batches of concrete can lead to variations in the setting time of the different batches, thereby complicating finishing operations. Sufficient heating capacity should be available at the concrete plant to ensure an adequate supply of hot water.

3.4 CEMENT TYPE AND CONTENT

The type of cement and the amount used will also have a bearing on the performance of concrete in cold weather. High-early strength cements (Type HE) will tend to set more quickly than general purpose (Type GP) cements, but the difference is not particularly significant. Hardening or strength gain will proceed more rapidly with a Type HE cement.

Blended cements (Type GB) have a range of characteristics, depending on the blend, but in general will tend to set and gain strength more slowly than Type GP cements.

Of greater significance is the amount of cement used in the concrete. Whilst this has little or no impact on setting time, except with low cement content mixes, the rate of strength gain can be increased significantly with higher cement contents.

3.5 FREEZING CONDITIONS

Freshly placed concrete is vulnerable to freezing conditions both before and after it has stiffened. If allowed to freeze while still plastic, the damage done to the pore structure of the cement paste (water expands as it freezes) is such that the potential strength of the concrete will be drastically reduced. Freezing of concrete which has partially hardened will also damage it, the extent of the damage depending on its age and strength when frozen.

Precautions in Freezing Conditions – It is always desirable to take precautions against freezing when the air temperature drops below 5°C. At the very least the concrete temperature should be maintained above 5°C to ensure that setting occurs within a reasonable time and that the concrete gains strength. Damage to the concrete by any sudden and unexpected frost will thereby be minimised.

If there is any likelihood that the temperature will drop below zero and freezing conditions ensue, then additional precautions will be required.

Form Insulation – Concrete can be protected and kept from freezing – at least until it has started to harden and gain strength – by the use of insulated formwork and protective covers. During the first 24 hours, hydrating cement gives off a significant amount of heat which, if retained within the concrete by insulation, will protect it from freezing.

Timber formwork is a reasonably adequate thermal insulator and will probably suffice for moderately cold conditions. Additional insulation will be required for more severe conditions or for prolonged periods of freezing weather.

Metal formwork offers little or no insulation protection and should be insulated.

Insulating materials should themselves be waterproof or be protected by tarpaulins, plastic sheeting, or other means, to keep them dry. While materials such as straw and some insulating boards are excellent insulators when dry, they are ineffective when wet. Expanded polystyrene sheets are relatively unaffected by moisture.

Heated formwork may also be employed to protect concrete against freezing over longer periods. These systems tend to be quite sophisticated, however, and are beyond the scope of this Guide.

Heated Enclosures – In some circumstances the use of a heated enclosure to completely encase the concrete element may be a satisfactory alternative. This may take the form of light frames covered with tarpaulins or similar material; or, in some cases, larger heavier frames with sheeting covers, within which work may be carried out during very cold weather. Heating these enclosures with hot-air blowers ensures an even distribution of heat within the enclosure.

Curing – Curing poses particular problems during prolonged periods of freezing weather. While loss of moisture from the concrete due to evaporation will be greatly reduced, very cold air can be quite dry, and it may still be necessary to cure concrete to ensure that it achieves maximum potential durability.

Moist or water curing is rarely appropriate for obvious reasons.

Where the concrete has been placed in insulated formwork, covering the top surface of the member (preferably with an insulated covering) will serve to retain moisture within the member. When the formwork is removed, the member should be further cured by covering it with plastic film or waterproof tarpaulins, properly lapped at joints and secured to ensure wind-tightness. On no account should concrete released from insulated formwork or heated enclosure (and therefore warm) be saturated with cold water.

When protective measures are discontinued, care should be taken not to suddenly expose warm concrete surfaces to freezing conditions. With formwork, insulation and forms may be eased from the surface of the concrete but allowed to remain in place while the temperature of the surface falls slowly. With heated enclosures, the air temperature should be reduced slowly.

When hot-air blowers are used to heat enclosures, it should be noted that the air will be very dry unless humidified. Either (a) the use of fine mist sprays within the enclosure, or (b) placing trays of water in the path of the moving air, are advisable to prevent the concrete from drying out.

3.6 STRIPPING FORMWORK

Concrete that has been kept warm in an enclosure or with insulated formwork will quickly reach a strength (about 2 MPa) which will allow it to resist frost. At this point, vertical formwork may be removed. However, unless the formwork is required elsewhere, it will be advantageous to leave it in position as this will accelerate the hardening process and shorten the time to removal of soffit boards and props. By maintaining a record of the curing temperature of the concrete an assessment of its strength can be made at a later time to assist in determining when it is safe to remove loadbearing formwork.

As was noted above, in stripping forms care should be taken not to expose warm concrete to low temperature conditions too suddenly. Care should be taken also to prevent too great a temperature differential developing between the external surfaces and the interior of a concrete section. This is of particular significance with massive structures which may take some time to cool down. Even after forms have been removed it may therefore be desirable to continue to insulate the concrete.

In the absence of more specific information such as a record of the temperature of the concrete, guidance on permissible stripping times may be obtained from **Table 18.1**.

4 SUMMARY – CONTROLLING THE EFFECTS OF HOT AND COLD WEATHER

Aspect	In hot weather	In cold weather
Pre-planning	• Pre-plan carefully to avoid delays at all stages; • Have standby equipment and manpower available for all stages; • Pay particular attention to speed of application, effectiveness and duration of curing arrangements; • Schedule night-time placement if possible, or early morning.	• Pre-plan carefully to ensure adequate equipment and manpower available especially if there is a likelihood of temperatures below 0°C.
Concrete	• Use water-reducing retarding admixtures in the concrete; • Reduce the temperature of the concrete by (in order of effectiveness): – Reducing temperature of aggregates; – Using liquid nitrogen injections in the mixed concrete; – Reducing temperature of mixing water (chillers or ice addition); – Using cement with lower heat of hydration; – Reducing temperature of cement.	• Reduce the setting time of the concrete by (in order of effectiveness): – Heating mixing water (maximum 70°C); – Using (chloride-free) accelerating admixture; – Using higher cement content; – Using high early-strength cement.
Batching, mixing and transporting	• Shade batching, storage and handling equipment or at least paint with reflective paint; • Discharge transit mixer trucks as soon as possible.	• Ensure an adequate supply of hot water (if being used) to ensure consistency between batches.
Placing and compacting	• Shade reinforcement, formwork and subgrades if possible and spray with water; • Ensure that slabs have minimum 'fronts' to which concrete is being added; • Place concrete in walls and deep beams in shallow layers; • Use burlap covers if there is any delay between load deliveries.	• Thaw frozen subgrades and heat frozen forms (particularly steel) before placing concrete; • Warm, insulate or enclose handling and placing equipment; • Avoid delays in handling and placing.
Finishing and curing	• Use sunshades and windbreaks to lengthen finishing time (or if hot/dry winds are present, to control plastic shrinkage cracking); • For flatwork use aliphatic alcohol after initial screeding if hot/dry winds present; • Use re-vibration to correct plastic shrinkage cracking if possible; • Use water curing as the preferred method for at least 24 hours.	• Maintain concrete temperature until safe strength reached by means of form insulation, insulated covers or heated enclosures; • Delay striking of formwork for as long as possible; • Avoid thermal shocks and temperature variations within a member. This includes not using cold water for curing and removing thermal protection measures gradually.

5 REFERENCES

1) Uno, P., *'Plastic Shrinkage Cracking and Evaporation Formulas'*, ACI Materials Journal 95, 4 (July-August 1998), pp. 365–375
2) ACI Committee 305, *'Hot Weather Concreting'* ACI Manual of Concrete Practice, Part 2: Construction practices and inspection, pavements American Concrete Institute, Farmington Hills, USA (1999)
3) Berke, N S & Dallaire, M P *'The effect of low addition rates of polypropylene fibers on plastic shrinkage cracking and mechanical properties of concrete'*, Fiber reinforced concrete: Developments and innovations SP-142 American Concrete Institute, Detroit, USA, (1993) pp. 19–42
4) CCAA Datasheet, *'Hot Weather Concreting'*, (August 2017)
5) CCAA Datasheet, *'Cold Weather Concreting'*, (September 2004)

6 RELEVANT AUSTRALIAN STANDARDS

1) AS 1379 – *The specification and supply of concrete*
2) AS 3600 – *Concrete structures*

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