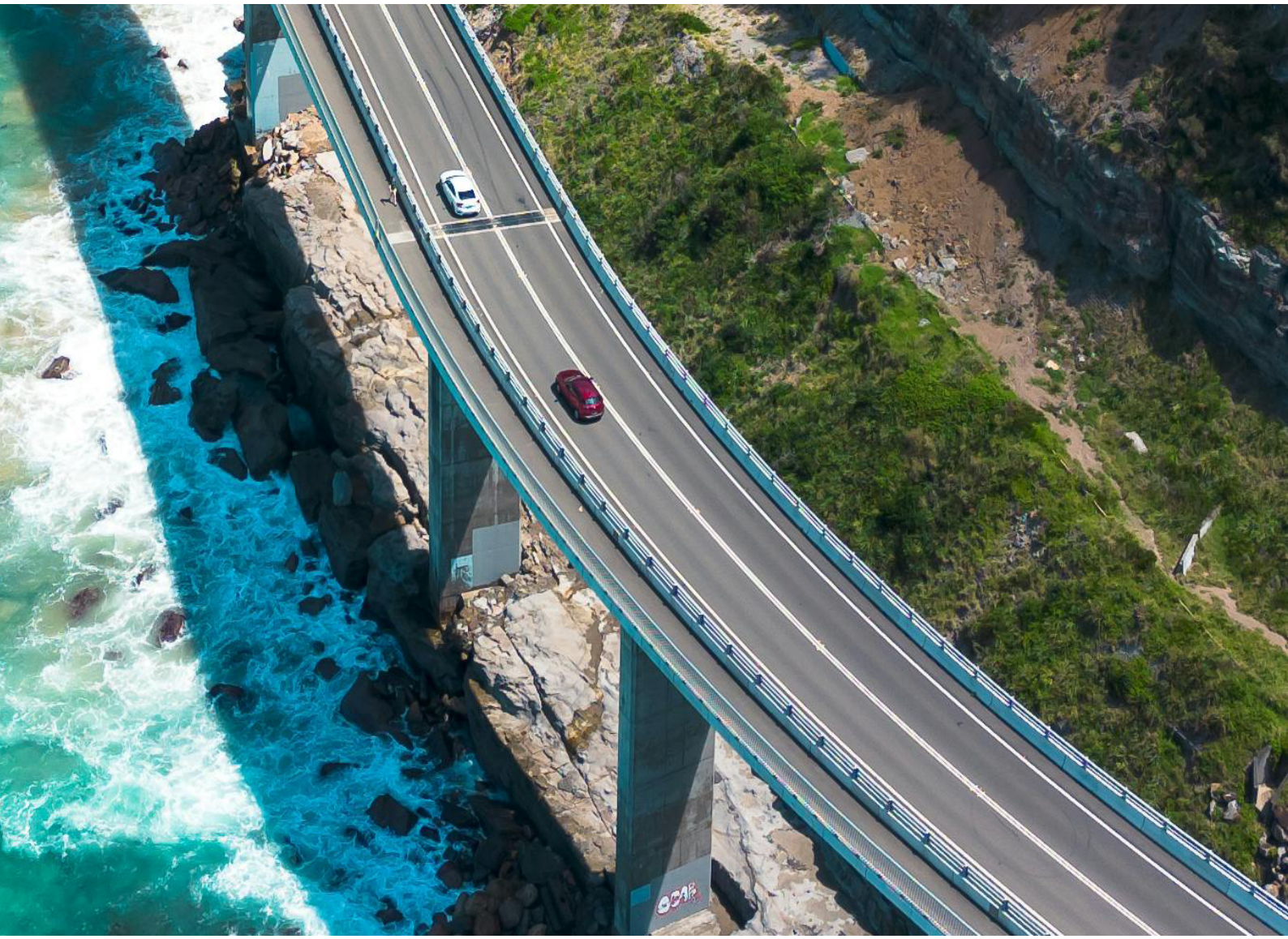
GUIDE

CEMENT CONCRETE & AGGREGATES AUSTRALIA

Guide to Concrete for Housing



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CCAA T53

Guide

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& AGGREGATES AUSTRALIA

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Cement Concrete & Aggregates Australia

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Cement Concrete & Aggregates Australia is a not-for-profit organisation established in 1928 and committed to serving the Australian construction community.

CCAA is acknowledged nationally and internationally as Australia's foremost cement and concrete information body – taking a leading role in education and training, research and development, technical information and advisory services, and being a significant contributor to the preparation of Codes and Standards affecting building and building materials.

CCAA's principal aims are to protect and extend the uses of cement, concrete and aggregates by advancing knowledge, skill and professionalism in Australian concrete construction and by promoting continual awareness of products, their energy-efficient properties and their uses, and of the contribution the industry makes towards a better environment.

Cement Concrete & Aggregates Australia
ABN 34 000 020 486

CCAA OFFICES

SYDNEY OFFICE:
Level 6, 504 Pacific Highway
St Leonards NSW Australia 2065
POSTAL ADDRESS:
Locked Bag 2010
St Leonards NSW 1590
TELEPHONE: (61 2) 9437 9711
FACSIMILE: (61 2) 9437 9470

BRISBANE OFFICE:
Level 14, IBM Building
348 Edward Street
Brisbane QLD 4000
TELEPHONE: (61 7) 3831 3288
FACSIMILE: (61 7) 3839 6005

MELBOURNE OFFICE:
2nd Floor, 1 Hobson Street
South Yarra VIC 3141
TELEPHONE: (61 3) 9825 0200
FACSIMILE: (61 3) 9825 0222

PERTH OFFICE:
45 Ventnor Avenue
West Perth WA 6005
TELEPHONE: (61 8) 9389 4452
FACSIMILE: (61 8) 9389 4451

ADELAIDE OFFICE:
Greenhill Executive Suites
213 Greenhill Road
Eastwood SA 5063
POSTAL ADDRESS:
PO Box 229
Fullarton SA 5063
TELEPHONE: (61 8) 8274 3758
FACSIMILE: (61 8) 8373 7210

EXTRACTIVE INDUSTRIES OFFICE
PO Box 243
Henley Beach SA 5022
TELEPHONE: (61 8) 8353 8151
FACSIMILE: (61 8) 8353 8151

TASMANIAN OFFICE:
EXTRACTIVE INDUSTRIES OFFICE
PO Box 246
Sheffield TAS 7306
TELEPHONE: (61 3) 6491 2529
FACSIMILE: (61 3) 6491 2529

WEBSITE: www.concrete.net.au

EMAIL: info@ccaa.com.au

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Glossary of Terms

Admixture

A substance other than water, aggregates or cement that is added to a concrete or mortar mix to improve or modify some of the properties of the mix, or of the resulting concrete or mortar.

These include pigments (colouring agents), modifiers to slow or accelerate the setting time, plasticisers to increase workability, water proofing and water-reducing agents.

Aggregates

The granular ingredients of a concrete or mortar mix: natural sand, gravel and crushed rock. Aggregates make up to 80% of the volume of concrete.

Aliphatic alcohols

Aliphatic alcohols are a type of evaporation retarder. These products slow the rate of evaporation of water from the concrete surface to enable all bleedwater to rise to the surface without premature drying of the surface and possibly drying shrinkage cracking during hot weather conditions. They do not affect the concrete's structural performance, or limit the choice of finishing techniques. They should not be confused with curing compounds.

Cement

All types of portland and blended cements conforming to AS 3972.

Cement Paste

The mixture of cement and water

Compaction

Removal of entrapped air in order to consolidate the concrete mix: to fill the forms, surround the reinforcement and to achieve the strength, durability and quality of finishes specified.

Curing

Keeping the surface of concrete, mortar or render continuously damp, after placement, to slow evaporation and to ensure enough moisture for optimum hydration and subsequent hardening. Proper curing during the early life (7–10 days) of concrete improves its strength and durability, and reduces cracking and dusting of surfaces.

Efflorescence

Deposits of soluble salts that form on the surface of building materials such as bricks, mortar, and concrete. The salts may be present in the material or groundwater and migrate to the surface during evaporation.

Flatwork

Concrete floors and pavements.

Hydration

A series of chemical reactions after cement is mixed with water, resulting in the formation of new compounds that bind the aggregates within the concrete together. During hydration the concrete, mortar or render progressively gains in strength as the cement paste hardens.

Laitance

A layer of weak, non-durable material brought to the surface by bleeding, and exacerbated by overworking the surface of wet concrete when finishing.

Matrix

The mixture of cement paste and fine aggregate (sand) that binds the coarse aggregates.

Plastic settlement cracking

Surface cracking caused when concrete settles over an embedded object, for example reinforcing mesh or service pipes, and at a change in depth of concrete. The crack usually appears on the surface parallel to the restraining object. It often happens in concrete containing too much water, and receiving insufficient compaction.

Plastic shrinkage cracking

Surface cracking caused by premature moisture loss from the surface of plastic concrete: usually in hot and windy conditions.

Pozzolans

Siliceous, or alumino-siliceous materials that have little or no cementitious properties but will, in the presence of lime and water, react with calcium hydroxide to form compounds with cementitious properties. Pozzolans are better known as ‘fly ash’ and ‘silica fume’

Segregation

An uneven distribution of fine and coarse aggregates in the concrete. The causes include excess water in the mix; concrete falling more than two metres into place; cement paste leaking from formwork; and poor (too little or too much) compaction.

Slump (slump test)

A standardised measure of the consistency of freshly-mixed concrete. It gives an indication of the water content, and the workability of the mix. Slump is one of the properties specified when concrete is ordered.

Water-cement ratio

The ratio of the mass (a scientific measure of the weight) of the water in the concrete to the mass of the cement in the concrete, mortar, render or grout. Adding water to a mix increases the water-cement ratio. The higher the water-cement ratio, the lower the strength and durability.

Workability

The degree of ease of handling, placing and finishing concrete or mortar. The greater the slump or water-cement ratio (see both terms above), the greater the workability.

Preface

This guide is written, primarily, as a reference guide for house builders and tradespeople working with concrete, mortar and render. TAFE students and their instructors will find it a helpful reference; and design professionals will find it informative. It updates and supersedes the earlier publication *The Housing Concrete Handbook*, June 2000.

It gives practical information about the use of concrete, mortar and render in the construction of houses and other small buildings, including floors, driveways, paths, and patios.

It covers the essential topics in enough detail to give house builders all they need to know about good quality concreting, and to alert them to poor practices.

More comprehensive technical information about the use of concrete in all forms of construction can be found in CCAA's *Guide to Concrete Construction* (T41). Further information on specific applications can be found in a number of publications produced by Cement Concrete & Aggregates Australia and generally available free on CCAA website **www.concrete.net.au**. Relevant ones applicable to the subject areas covered by this publication are listed in **Appendix B**.

CAUTION

Remember when working with cement, concrete, mortar and other cement-based materials or prefabricated products, always follow the manufacturer's instructions, and seek advice from the manufacturer, WorkCover or Worksafe Australia about working safely with these products.

If you have any doubts about working with concrete or cement-based materials contact Cement Concrete & Aggregates Australia before starting the work; or if you are unsure about the statutory approvals you will need contact the HIA before starting work. Useful information can be found in the following leaflets available from CCAA website **www.concrete.net.au**:

- *Working Safely with Wet Concrete*
- *Working Safely with Dry Concrete Materials*
- *Concrete Safe Site Delivery*

Concrete Properties

01

Concrete is a versatile material with many uses. Good concrete, that which achieves its specified properties, depends first of all on the careful selection and proportioning of its constituent materials, and on effective methods for its handling, placing, compacting, finishing and curing.

In its basic form, concrete is a mixture of cement, water, fine and coarse aggregates, which is plastic (can be worked and moulded) when first mixed, and hardens to a solid mass.

The properties of concrete, in its plastic and hardened states, are affected by the physical characteristics, the chemical composition, and the proportions of the ingredients in the mixture. In its hardened state concrete must be strong enough to carry the loads imposed on it, and durable enough to resist wear, weather and chemical attack. In its plastic state it must suit the methods of handling, placing, compacting and finishing.

The cement paste (cement and water) in the mixture lubricates the aggregates and allows them to move freely while the concrete is being placed and compacted. Generally, the more cement paste in the mixture, the more workable the concrete. It is important that concrete delivered to site is sufficiently workable for it to be placed and compacted by the means available. If it is not properly placed and compacted, concrete will not achieve its potential strength and durability.

Addition of water increases the workability, but dilutes and weakens the cement paste. In this respect, cement paste is like any other glue: dilution will weaken it. It is the aim of concrete mix design, or proportioning, to strike a balance between the need for workability, so that concrete can be placed and finished, and the need for it to be strong and durable. Workability can also be improved by the use of chemical admixtures such as water reducers (plasticisers).

Many of the characteristics of concrete, particularly its strength and durability, depend on the development of chemical and physical bonds: of the cement paste itself as it hydrates (see glossary), and between the cement paste and the aggregate particles as the concrete hardens. The chemical reaction between cement and water (hydration) takes time. Concrete must therefore be kept continuously moist (cured) for a time to ensure that hydration continues and that the concrete achieves its potential strength and durability.

Technologists use a range of materials other than cement, water and aggregates to modify the properties of concrete. These include pozzolanic and other cementitious materials, chemical admixtures, and special aggregates.

Concrete Materials

02

2.1 CEMENTS AND SUPPLEMENTARY CEMENTITIOUS MATERIALS

The term 'cement' covers a wide variety of organic and inorganic binding agents. By far the most widely used are those known as portland cements: finely ground inorganic materials that have a strong hydraulic binding action. These binders, when mixed with water, will harden in the absence of air to produce a stable, durable product.

Hydraulic cements manufactured in Australia fall broadly into two classes, namely portland cements and blended cements, both produced to AS 3792.

Type GP – General purpose portland cement

Type GP cement is used as a general-purpose cement suited to all types of construction, including major construction projects and in precast concrete product manufacture. Type GP cement may contain up to 5% of approved mineral additions (ie limestone, fly ash and ground granulated blast-furnace slag).

Type GB – General purpose blended cement

Type GB cement incorporates supplementary cementitious materials (such as fly ash and slag) used at rates greater than 5%. Typically 10–40% for fly ash, up to 65% of slag and up to 10% for amorphous silica. Due to the blending of ingredients, Type GB cement has a wide range of applications for residential construction in concrete, grouts, mortars and renders. Type GB cements gain strength at a lower rate than Type GP cements but 28-day strengths may be similar.

Masonry cement

Masonry cement is a finely ground mixture of portland cement clinker, gypsum and suitable inorganic materials such as hydrated lime, limestone and pozzolans. It is characterised by producing mortars of high workability and high water retention, but which have a lower rate of strength development than those made from portland cement. These characteristics make masonry cement especially suitable for masonry work but unsuitable for any form of structural concrete.

Off-white and white portland cements

The grey colour of portland cement is due mainly to the presence of iron. By lowering the iron content, light coloured cements can be produced. Off-white and white cements are used principally for architectural applications. Off-white cement is produced in Australia to meet the general requirements for Type GP cement while white cements are imported. If a 'white' concrete is required, using off-white cement with a white titanium oxide pigment in lieu of the more expensive imported white cements should be considered.

Supplementary cementitious materials (SCMs)

SCMs are defined as fly ash, ground granulated blast-furnace slag and amorphous silica, which are added to concrete to improve its characteristics and properties. These additives are sourced from industry by-products.

Fly ash is the fine residue extracted from the flue gases at coal-fired power stations. These particles are of spherical shape with a glassy appearance and are processed to meet the requirements of AS 3582.1.

Ground granulated blast-furnace slag (slag) is a non-metallic material produced simultaneously with iron in a blast furnace and which is then granulated by the rapid quenching process. It possesses latent hydraulic properties of its own which are activated by an alkaline material such as portland cement, thus producing additional cementitious materials. Slag is processed to meet the requirements of AS 3582.2.

Amorphous silica is a very fine pozzolanic material composed mostly of crystalline silica. Either naturally occurring or a byproduct of producing silicon metal or ferrosilicon alloys (silica fume), for residential applications its main use would be in shotcrete mixes for swimming pools. A more economical alternative which is increasingly being used is ultra-fine fly ash. Amorphous silica is processed to meet the requirements of AS 3582.3.

How do SCMs work in concrete?

When portland cement reacts with water, calcium hydroxide is produced. This material is soluble and adds little to the strength of concrete. Fly ash and amorphous silica, however, react with the calcium hydroxide to form insoluble cementitious compounds similar to portland cement. Slag is activated by calcium hydroxide and the alkaline environment within concrete.

Potential benefits of SCMs

- Improved workability
- Lower water demand for constant workability
- Reduction in bleeding
- Enhanced concrete durablity
- More cohesive mix
- Longer setting period
- Higher ultimate strengths
- Reduced heat of hydration.

2.2 ADMIXTURES

Admixtures are classified by the characteristic, or principal, effect on the concrete. Most concrete is described by the supplier as either a 'summer-mix' or a 'winter-mix', and will include admixtures that affect setting times to suit the prevailing conditions. Admixtures are produced in Australia to the requirements of AS 1478.1.

Air-entraining admixtures are added to concrete to improve its workability and cohesiveness and to reduce the water demand, thereby reducing bleeding and material segregation. Excessive amounts will reduce potential strengths. AS 1379 allows up to 5% air entrainment.

Set-retarding admixtures slow the setting of concrete. They are useful during warm to hot weather conditions, and when a concrete mix must be transported long distances.

Set-accelerating admixtures reduce the setting times of concrete. They are often used during cool to cold weather conditions.

Water-reducing admixtures disperse the cement particles and improve the workability of the concrete without the addition of water.

High- range-water-reducing admixtures (Superplasticisers) increase the fluidity of the concrete; improving the workability for easier placement where, for example, reinforcement is congested or the formwork makes placement difficult. Working time depends on the type and dosage. Using superplasticisers does not remove the need for proper compaction.

2.3 WATER

Most concrete specifications simply require that mixing water shall be potable, ie fit for drinking; or that it be clean and free from impurities harmful to concrete. Generally, water drawn from reticulated town-water supplies is suitable for making concrete. The requirements for mixing water and limits for impurities are given in AS 1379.

Specifying, Ordering and Testing

03

3.1 SPECIFYING

3.1.1 General

Australian Standard AS 1379 sets down a number of ways of specifying and ordering concrete to promote uniformity, efficiency and economy in production and delivery.

It refers to two classes of concrete:

- **Normal-class**, which is intended to cover most of the concrete delivered to house building sites and is used mainly for structural applications. Its specification and ordering has been simplified as far as practicable.
- **Special-class**, which allows the purchaser to incorporate into the project specification any special requirements for the project. Special-class concrete is typically specified for high-strength/high-performance concrete, architectural off-form finishes and other decorative applications where the requirements for the concrete are generally more specialised.

3.1.2 Normal-class concrete

Normal-class concrete is specified by reference to basic parameters which describe the characteristics of concrete suitable for most purposes:

- the strength grade (N20, N25, N32, N40 or N50)
- the slump required at the point of delivery (20–120 mm)
- the nominal maximum size of the coarse aggregate (10, 14 or 20 mm). If not specified, 20 mm will be the default nominal maximum aggregate size.
- the level of entrained air (if required).

In addition, the order for concrete should specify:

- the intended method of placement (as pump mixes are different to those placed by chute or other means)
- if project assessment (testing on site) is to be carried out by the supplier.

3.1.3 Special-class concrete

In general terms, special-class is specified where the concrete properties are outside those of a normal class concrete. It will be specified where specific performance characteristics are required such as in harsh environments, particularly where corrosive elements are present (such as air-borne pollution or corrosive ground waters) or where the concrete will be used in the construction of liquid-retaining structures designed for holding substances that require a special, resistant concrete. The requirement for inclusions such as pigments, special aggregates, particular cements or colour control necessitates the specification of a special-class concrete. Therefore, most architectural concrete should be special-class concrete.

3.2 ORDERING

For most housing projects, normal-class concrete is adequate, and the ordering of it is simple. A typical specification is:

Strength	20 MPa
Aggregate size	20 mm
Slump	100 mm (recommended).

It should be noted that if the slump is not specified concrete with 100 mm slump will be supplied. The increased workability of a 100-mm-slump concrete will allow easier placement, particularly when manual placement is necessary because of restricted access to parts of a project; or when an 80-mm slump might prove difficult to work, for example around congested reinforcement. Increasing the slump by the addition of excess water on site will result in reduced strength and concrete properties that may not meet the requirements for durability.

To produce a suitable mix, the supplier should always be advised of the task being undertaken, eg footings, floor slabs or driveways. For example it would be essential to order a ‘block-fill’ mix (high slump and suitable aggregate sizes) in the case of a project that entails core-filling of blockwork.

The timing of deliveries should be carefully planned. Traffic or site delays can result in several trucks waiting to discharge loads if successive deliveries are too close together. It may be possible to alter the timing of the deliveries (or some properties of the concrete, notably slump) if, after placing has started, the original specification is found to be unsatisfactory.

3.3 TESTING

3.3.1 General

Builders will find it beneficial to have an understanding of the reasons and procedures for testing concrete. This section explains why and when tests are carried out.

Concrete supplied for floor slabs and driveways in particular, should be tested for slump and compressive strength in accordance with the relevant parts of AS 1012.

A slump test is carried out on plastic (freshly mixed) concrete, whereas a compression test is carried out on hardened concrete, usually at 28 days after placement. The slump test measures the mix consistency and workability, and gives an indication of the amount of water in the mix, which will affect the eventual strength of the concrete (see **Section 1** *Concrete Properties*). The compression test measures the compressive strength of hardened concrete and is done in a laboratory using a concrete sample made on site from a cylinder mould. Testing is a specialised procedure and should be carried out by experienced and qualified people.

Builders have the choice of taking responsibility for testing or they can order pre-mixed concrete from a manufacturer who undertakes testing. Many suppliers of pre-mixed concrete have quality assurance systems that, among other checks, make periodical tests of the grades of the concrete they commonly supply. If builders order from a pre-mixed concrete manufacturer who undertakes testing it is important that they examine the delivery docket (referred to as an Identification Certificate in AS 1379) to ensure it matches their specifications. They should be sure that the docket indicates the four main attributes of a specification, namely class, strength, aggregate size and slump. They should retain this documentation for their records.

Builders taking responsibility for testing are advised to engage a testing laboratory accredited by the National Association of Testing Authorities (NATA).

For builders who want to undertake their own testing (or witness the procedure and be sure that it has been done properly), the slump and compression test procedures are summarised below.

3.3.2 The slump test

Pre-mixed concrete manufacturers generally proportion the concrete mix with consideration to the travel time and ambient temperature so that the concrete meets the specification at the time of delivery. They are not required by AS 1379 to carry out a slump test on site, unless water is added to the mix during the discharge of the concrete, in which case the concrete must be thoroughly re-mixed in accordance with the Standard and a slump test carried out on the remainder of the batch to ensure it remains within the tolerances of the specified slump. The tolerance for a slump up to 80 mm is ±15 mm and from 80 up to 100 mm ± 20 mm. The amount of water added to the mix should be recorded on the delivery docket. As stated above, the ordering of a higher slump initially (100 mm) should eliminate the need to add water on site and hence the requirement to carry out slump testing on site.

If a builder has serious concerns that the concrete mix does not have the specified slump, an on-site slump test should be requested. If the builder undertakes the slump testing, samples should be taken on site from concrete discharged directly from the concrete truck.

The slump test is covered by AS 1012.3.1.

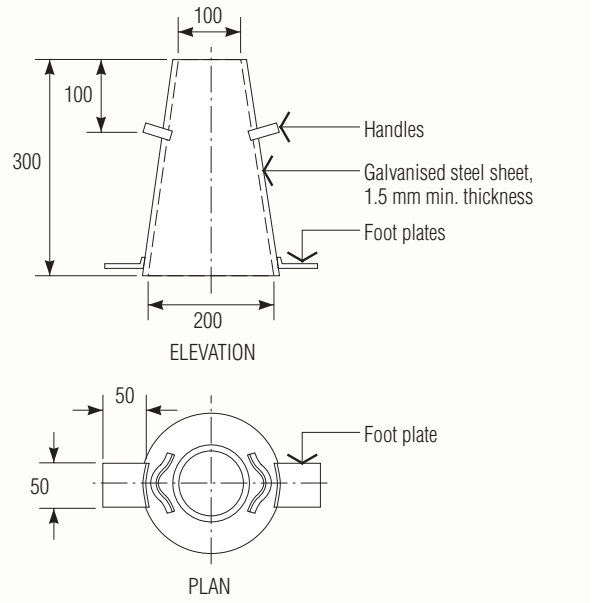


Figure 3.1 Typical cone for slump test

The tools used are:

- Standard slump cone **Figure 3.1**
- Small scoop/shovel
- Bullet-nosed rod (600 mm long x 16 mm diameter)
- Ruler
- Steel float
- Slump plate (500 mm x 500 mm).

The procedure (**Figure 3.2**) is as follows:

1. Dampen the clean slump cone with water and place it on the slump plate. The slump plate should be clean, firm, level and non-absorbent.
2. Collect a sample from the batch of concrete. If a number of sample increments are taken (required for batches over 1 m^3) these should be mixed and the sample ready for testing within 20 minutes from the time the first increment was taken. Samples should not be taken from the first or last 0.2 m^3 of the batch/load.
3. Stand firmly on the foot plates of the cone and fill 1/3 the volume of the cone from the sample. Compact the concrete by 'rodding' 25 times. Rodding involves pushing a steel rod in and out of the concrete to compact it into the slump cone or cylinder mould. Always rod in a uniform manner over the entire area.
4. Now fill to 2/3 and again rod 25 times, just into the top of the first layer.
5. Fill to overflowing, rodding again, this time just into the top of the second layer. Top up the cone until it overflows.
6. Level off the surface with the steel float. Clean any concrete from around the base and top of the cone; push down on the handles and step off the footplates.
7. Very slowly lift the cone straight up, making sure not to move the sample.
8. Turn the cone upside down and place the rod across the upturned cone.
9. Measure the average distance to the top of the sample.
10. If the sample is outside the tolerance (ie the slump is too high or too low), another must be taken. If this also fails, the batch should be rejected.
11. If the slumped shape is unacceptable (**Figure 3.3**), the test must also be repeated.
12. Complete the slump test within 3 minutes of commencement.

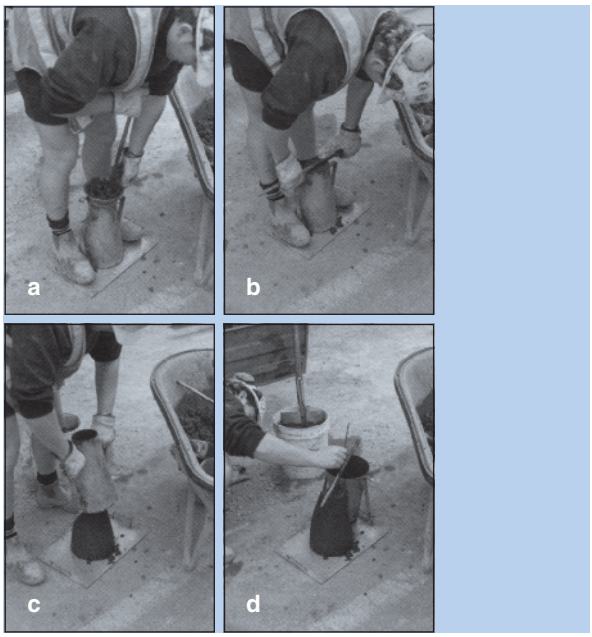


Figure 3.2 Slump test
(**a**) placing and compacting sample in cone
(**b**) leveling off the top surface
(**c**) removing slump cone
(**d**) measuring average slump

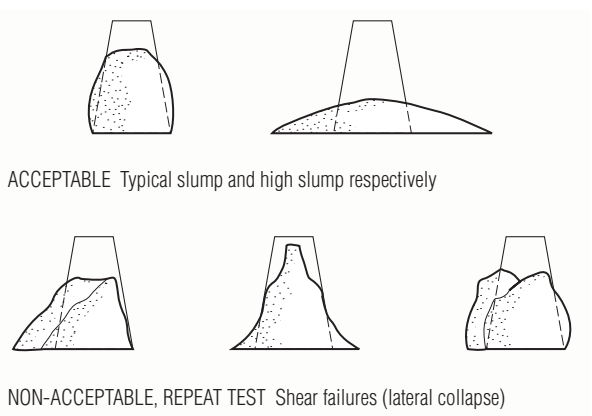


Figure 3.3 Examples of slump

3.3.3 The compression test

Compression testing may be a part of either production assessment or project assessment as described in AS 1379. Production assessment requires the pre-mixed concrete supplier to take samples for testing at a designated frequency, and that records and reports of test results for each grade manufactured are retained by the testing organisation for at least 12 months. The supplier must make available certified copies for examination by the customer, namely the builder.

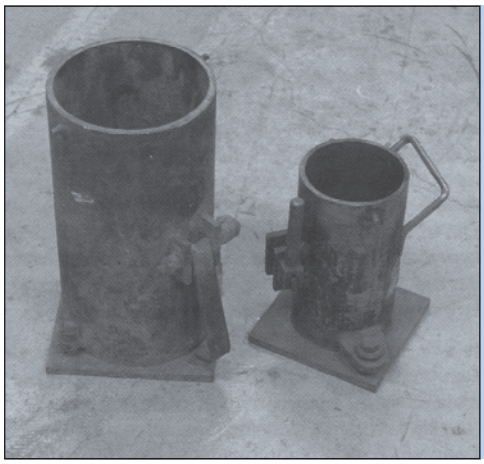


Figure 3.4 100 and 150-mm-diameter compression test cylinder moulds

AS 1379 also provides for builders who want to receive production assessment information from their supplier. Their project is registered with the supplier and reports relating to the concrete supplied during a particular production interval are sent to the builder or his nominee.

In the case of project assessment, the builder takes responsibility for testing and reporting, and makes reports available to the supplier. Samples are taken from each 50 m^3 of concrete at the project site before handling.

The making of compression-test cylinders is covered by AS 1012.8.1 and testing by AS 1012.9.

The tools used are:

- Cylinders either 100-mm diameter x 200-mm high or 150-mm diameter x 300-mm high. The smaller cylinders are used for most testing because they are lighter but the maximum aggregate size is limited to 20 mm **Figure 3.4**.
- Small scoop
- Bullet-nosed rod (600 mm long x 16 mm diameter)
- Steel float
- Steel plate.

The procedure is as follows:

1. Clean the cylinder mould and coat the inside lightly with form oil and place on a clean, level and firm surface, ie the steel plate.
2. Collect a sample from the batch of concrete. Complete moulding of the cylinder within 20 minutes of taking the sample.
3. Fill the mould with concrete.

   For 100-mm-diameter cylinders, fill the cylinder in two equal layers, compacting each layer by rodding 25 times. At least the first 10 strokes should extend just into any previous layer.

   For 150-mm-diameter cylinders, fill the cylinder in three equal layers, compacting each layer by rodding 35 times. At least the first 10 strokes should extend just into any previous layer.

   Other compaction methods are also available, eg vibration, ramming.
4. Fill the cylinder to overflowing with the last layer.
5. Level off the top with the steel float and clean any concrete from around the mould.
6. Place cap on cylinder, clearly tag the cylinder and put it in a cool, dry place to set for at least 24 hours.
7. After the mould is removed, the cylinder is sent to the laboratory where it is cured and crushed to test compressive strength **Figure 3.5**.

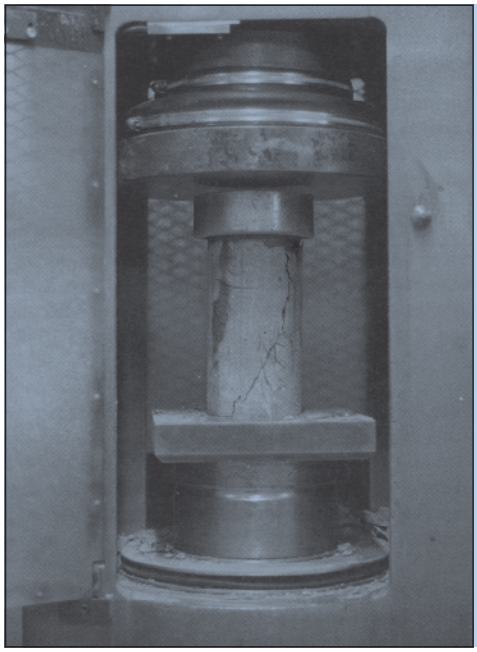


Figure 3.5 Compression testing of concrete cylinder

From Batching Plant to Finished Concrete

04

4.1 TRANSPORTING

4.1.1 General

When water is added to cement it triggers hydration, setting begins and the concrete mix begins losing workability with time. Delays in deliveries from the batching plant, on the road and on the site, should be avoided. Delays reduce the amount of time to place concrete while it is still workable. Additional mixing of the concrete may be necessary on site, further delaying placement. Note that AS 1379 requires discharge of the concrete within 90 minutes from the commencement of mixing, or before proper placement and compaction of the concrete can no longer be achieved, whichever comes first.

The setting process is also accelerated in high temperatures. To avoid premature setting and difficult placement, the following procedures should be adopted:

- Select a pre-mix supplier close to the site to reduce traveling time.
- Provide good access for trucks to enter, and clear space for turning and manœuvering, to allow for the quick discharge of the load.
- Ensure that adequate labour is on hand to minimise the unloading time for the concrete.
- Always try to finish the placement of all reinforcement, erection of formwork and site inspections at least 24 hours beforehand.
- Check that all mechanical appliances (eg vibrators, screeds) are in working order the day before placement to allow time for replacement or repair if needed.
- When pumping concrete, plan delivery schedules with enough time between loads to avoid delaying trucks.
- Consider using a pump if the weather is unpredictable. Overnight rain can limit access to the site and reduce the amount of time for placement.
- When access through a neighbouring property is necessary, ensure authorised passage beforehand to prevent delays arising from misunderstandings.
- Check that all underground services have adequate loadbearing cover to prevent damage from trucks and subsequent rectification work.
- Where trucks must be driven over trenches, provide strong bridging to carry a fully laden vehicle. A loaded concrete truck bogged in a trench will cause long delays.
- If the bearing capacity of the soil is in doubt, do not bring trucks in: pump only.
- Have all tools, equipment and materials at hand to avoid disruption.

4.1.2 The addition of excess water

Concrete will lose many essential properties if excess water is added to it on site. The addition of excess water will alter the water-cement ratio (see glossary), diluting and weakening the cement paste, which is the essential ingredient that binds the aggregates together. Many concreting contractors mistakenly assume it is acceptable to add water on site to improve workability. However, if the amount added is in excess of that required by the mix design, it will affect the performance of the concrete.

The need to add water is often due to incorrect specification of the concrete mix or ordering details. As mentioned previously, specifying a 100-mm slump to provide greater workability is recommended to avoid the common practice of adding excess water on site. A 100-mm-slump concrete is specially designed to provide increased workability while maintaining the required water-cement ratio for strength and other performance requirements.

Adding unspecified amounts of water on site should thus be avoided. The correct way to adjust this is to add water and cement at rates that maintain the specified water-cement ratio. If the workability of the concrete is inadequate, always discuss these matters with the supplier.

In certain situations, the addition of fibres (polypropylene or steel) or other materials (pigments) on site may reduce both the slump and workability of the concrete. Such additions need to be discussed with the pre-mixed supplier to ensure the appropriate concrete is supplied.

The properties affected by the addition of excess water are summarised in **Table 4.1**.

Table 4.1
Properties affected by the addition of excess water

Property/performance	Effect
Slump	Increased
Workability	Increased
Compressive strength	Decreased
Risk of shrinkage cracking	Increased
Risk of surface dusting	Increased
Risk of segregation	Increased
Volume of bleedwater	Increased
Benefit of compaction	Decreased
Benefit of curing	Decreased
Durability	Decreased
Permeability/absorption	Increased

4.2 PLACING

4.2.1 General

Common placement methods (other than chute placement and pumping) require barrowing the concrete into position or manual shovelling; usually in successive placements. Barrowing concrete over reinforcement is often necessary. Displacement of the reinforcement should be prevented by providing running boards supported above the reinforcement on blocks.

It is important not to over-handle the concrete as this can lead to segregation of materials (see glossary) and result in poor finishes.

To minimise the risk of segregation, concrete should be placed vertically and as near as possible to its final position. When it must be moved, it should be shovelled into position and not be left to flow into position.

Other techniques for avoiding segregation during placement depend on the type of element being constructed and on the type of distribution equipment being used. For flatwork and slabs incorporating ribs and beams (shallow forms) the techniques shown in **Figure 4.1** should be adopted. For walls and columns (deep, narrow forms), problems occur when the concrete is dropped from too great a height and ricochets off the reinforcement and form-faces, resulting in segregation. The means of avoiding this vary with the type of distribution equipment being used **Figure 4.2**. The use of a tremmie could prove the most practical solution; however, the size of the element and spacing of reinforcement must be able to accommodate the chute or tremmie.

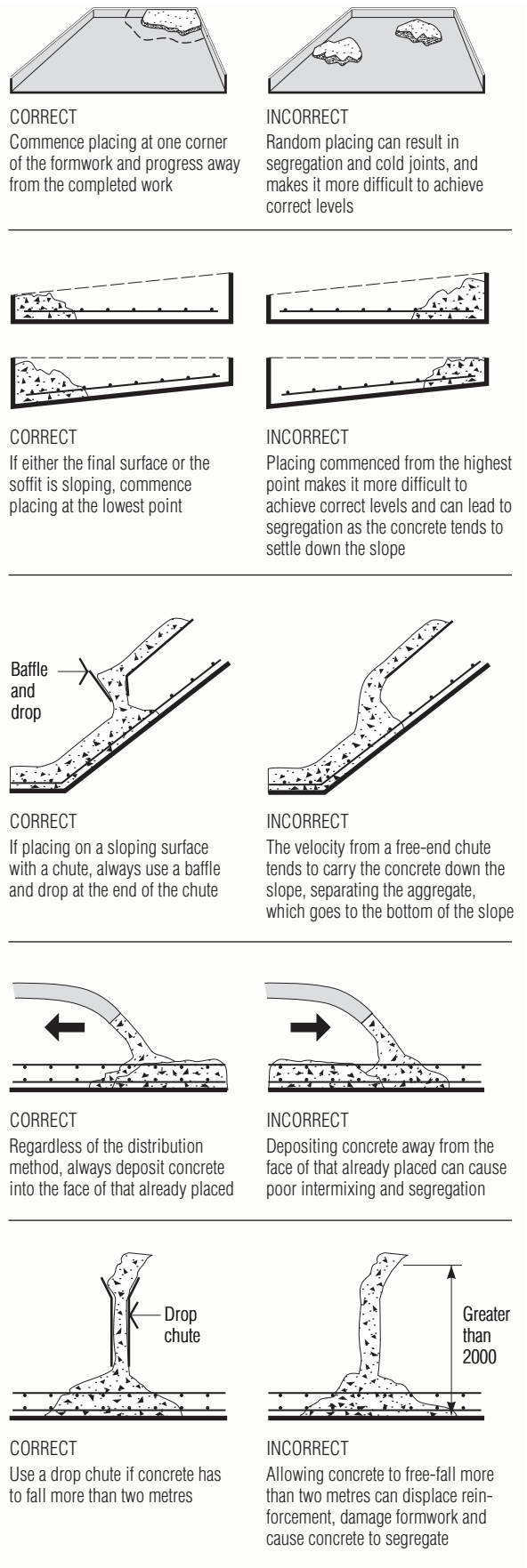
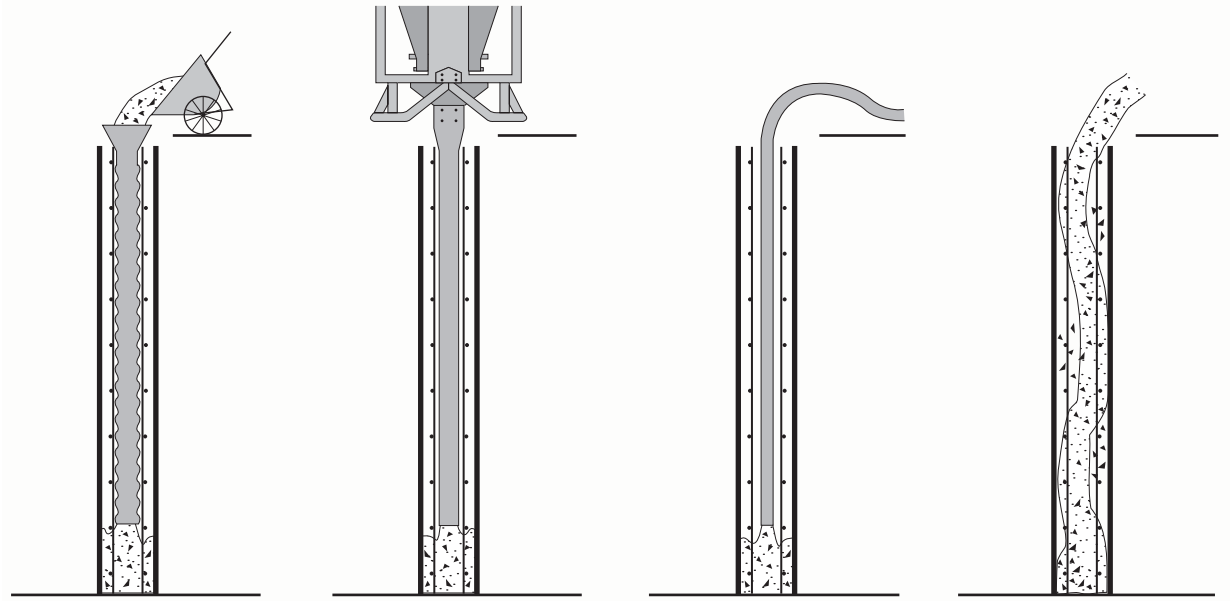


Figure 4.1 Placing techniques for flatwork



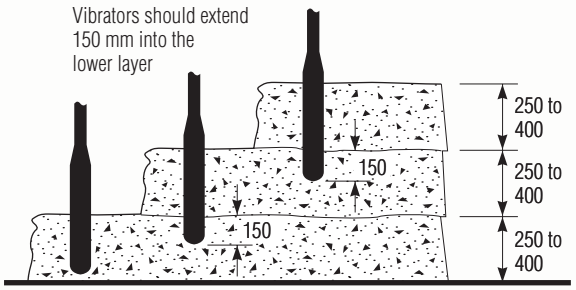
CORRECT
When placing from chutes and barrows, discharge concrete into a hopper leading to a light, flexible drop chute

CORRECT
When placing with crane and bucket, use a flexible drop chute connected to a collector cone which is permanently attached to the bucket frame

CORRECT
When placing with a concrete pump, extend the hose to the bottom of the form and withdraw as the form is filled

INCORRECT
Long uncontrolled drops cause segregation as the concrete strikes against the forms and aggregates ricochet off reinforcement. Mortar is also left on the form faces and reinforcement

Figure 4.2 Placing techniques for walls and columns



Concrete to be placed in uniform layers and of a thickness to match the 'power' of the vibrator (usually between 250 and 400 mm)

COMPACTION BY IMMERSION VIBRATORS

Figure 4.3 Compaction of concrete placed in layers

4.2.2 Placing in layers

In deep sections such as walls, footings and large columns, concrete should be placed in 300-mm layers to improve compaction. Immersion (poker) vibrators should extend about 150 mm into the previous layer of fresh concrete to meld the two layers together and avoid 'cold-pour' lines on the finished surface. Depending on the compaction equipment, thicker layers may be possible. Layers that are too deep make it virtually impossible to adequately compact the concrete (**Figure 4.3**) leaving entrapped air which will result in voids (and blowholes at the surface of the concrete) and prevent it achieving its potential durability and strength.

4.2.3 Cold joints

Placing concrete in a continuous pour, if practicable, avoids the formation of cold joints. Cold joints are formed when fresh concrete is placed against the face of concrete that is about to set. The cracks resulting from cold joints will pass through the full depth of the slab.

Cold joints can be avoided by working new concrete into existing, which skilled paviours can do with enough labour at hand. When cold joints could occur (due to hot or windy weather, or delays for example) it is good practice to blend the faces by re-vibrating the concrete or to compact the joint with a shovel in a tossing motion to re-blend the faces.

Cold joints often occur when temporary internal formwork must be removed, which is common practice for internal step-downs and set downs. Good planning of formwork will avoid this.

4.3 COMPACTION AND VIBRATION

4.3.1 General

Compaction of concrete is undertaken to improve its overall performance. Compaction is the process that expels entrapped air from freshly placed concrete thus increasing its density. It is important that compaction continues until no further air bubbles can be seen emerging from the surface of the concrete.

The most common form of compaction is vibration, undertaken with poker vibrators or surface vibrators such as vibrating screeds. Other methods of compaction include form (external) vibration, tamping and rodding.

Adequate compaction of concrete will:

- significantly increase its strength and density and thus allow the design strength to be achieved;
- enhance the bond to mesh and bar reinforcement plus any inserted structural anchors and hold-downs and thus provide anchorage;
- increase the abrasion resistance of the surface and thus reduce wear from traffic;
- increase the general durability and thus provide longer life;
- decrease the permeability and thus limit penetration of water and other aggressive substances (both air-borne and contained in ground water);
- reduce the risk of plastic settlement cracking over deep beams and mesh/bar reinforcement (plus other restraints within the concrete) as well as long-term drying shrinkage cracking;
- improve the quality of off-form finishes by ensuring concrete completely fills the forms.

Adequate compaction of slabs up to 100 mm thick can generally be achieved through the placing, screeding and finishing operations. For deeper elements, additional compaction will be required by one of the methods outlined below.

4.3.2 Methods of compaction

Vibration Vibration reduces internal friction between aggregate particles in the concrete and will thus liquefy the mix and obviate the practice of adding excess water to improve workability.

Three basic types of vibration can be used: immersion, surface or form (exterior).

- **Immersion (poker) vibrators** The most common immersion vibrator for residential work is the poker vibrator **Figure 4.4**. Smaller sizes are often referred to as needle vibrators. They are typically driven by petrol motors, although diesel, electric and compressed air are alternatives. They are good for expelling entrapped air in deep forms such as beams, columns and walls, and allow easy placement of concrete.

Figure 4.4 Use of immersion (poker) vibrator

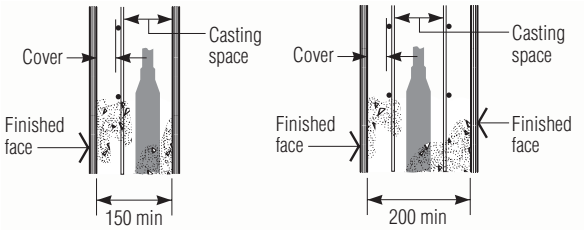


Figure 4.5 Provide sufficient clearances to allow compaction

For the sizes typically used in residential work, **Table 4.2** gives guidance on the radius of concrete that can be effectively compacted. The radius is dependent essentially on the diameter of the head/casing and the frequency and amplitude of the vibration caused by the rotating eccentric weight contained in it. The effective radius determines the insertion pattern that should be adopted to ensure adequate compaction of all concrete.

Poker vibrators should be inserted vertically into concrete, as quickly as possible, and held stationary until air bubbles cease to rise to the surface. They should then be slowly withdrawn to avoid grout pockets. They should not be dragged through the concrete or over reinforcement as this may cause segregation of the mix.

For honed finishes where the aggregates will be exposed, care is required to compact consistently over the entire area to ensure uniform exposure of the aggregate.

For deeper elements such as walls and columns, adequate space between the reinforcement or to the form face should be provided to allow use of the poker vibrator. Generally, the vibrator should be kept about 50 mm clear of the form face. Damaged form faces will result in streaks and colour variations in the surface, while inaccessible areas will result in inadequate compaction and possible honeycombing **Figure 4.5**.

- **Surface vibrators (vibrating screeds)** Figure 4.6
  Surface vibrators are applied to the top surface of the concrete with the vibration acting downward to compact the concrete. The intensity of vibration, and hence the amount of compaction achieved, decreases with the depth from the top surface. Depending on the size and operation of the unit used, the effective depth of compaction will vary from 100 to 200 mm. For slabs thicker than 180 mm immersion vibrators should be used to supplement the surface vibration.

  The available types of surface vibrators include vibrating-roller screeds, vibrating-beam screeds and also hand-held vibrating screeds. Hand-held equipment is used mainly to assist with finishing the surface rather than compacting the full depth of concrete. Larger types compact as well as aid with levelling and finishing the surface.

  This method is often the most effective and economical option for long, continuous pours and allows lower slump concrete to be used. Care may be required along edges due to the effectiveness of compaction decreasing in the vicinity of edge forms or adjacent slabs. This is because edge forms and adjacent slabs tend to dampen the vibration at the extremities of the beam. It is therefore recommended that compaction by vibrating beams be supplemented by immersion vibrators alongside edge forms and adjacent slabs to ensure adequate compaction Figure 4.7.

- **Form (external) vibration** Form vibration is useful for complicated members or where the reinforcement is highly congested. It can be done simply (where other methods cannot be used) by using a hammer to tap the form or boxing. The concrete in contact with the form is vibrated and compacted, thus improving the surface finish.

Table 4.2
Effective radius of action of poker vibrators

Diameter of head (mm)	Effective radius of action (mm)
25	75–150
35	150–200
45	250–300
55	≈ 350
65	≈ 400

Figure 4.6 Use of a vibrating screed

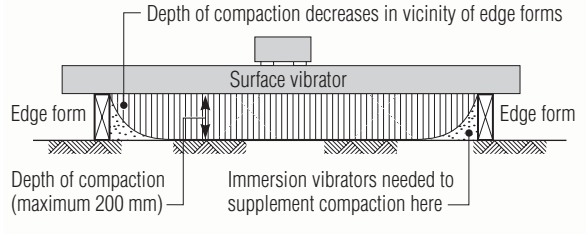


Figure 4.7 Degree of compaction varies across width when surface vibrators are supported off edge forms

Tamping For thin ground slabs, tamping with the screed board is an effective method of compaction. In certain situations, tamping with wood floats and surface working closes up some types of cracking.

For honed finishes, tamping may locally settle the coarse aggregate resulting in 'sand' streaks or lines where less aggregate is exposed in the finished surface. If this occurs, additional honing will normally be required to expose the coarse aggregate that has settled further from the surface.

Rodding Rodding with a purpose-made rodding tool or equivalent is effective for compacting piers or where poker vibrators cannot be inserted, especially where mesh reinforcement is congested and space is limited. Shovels can be used for rodding at beam edges, around pipes and penetrations and at placement joints to re-work the old and new concrete to prevent cold joints.

4.3.3 Vibration hints

Under-vibration may cause serious defects in concrete and is the most common problem. Inadequate compaction from under-vibration will adversely affect structural properties such as strength, bond, abrasion resistance and durability (through increased permeability). Other properties such as the quality of the surface finish may also be affected.

Over-vibration is generally not a problem with well proportioned mixes. Use of grossly oversized equipment for an excessive length of time with poorly proportioned mixes or those to which excessive amounts of water have been added may cause problems. Adding excess water to the mix can cause a problem with vibration, possibly leading to material segregation, and to dusting and flaking later.

Revibration is the compaction of concrete which has been compacted some time earlier. The practice is not widely used, partly due to the difficulty of knowing just how late it can be applied. A good rule of thumb is that revibration may be used as long as the vibrator is capable of sinking into the concrete under its own weight. Revibration can be used to: bond layers of concrete into previous layers; blend cold joints; close plastic shrinkage and plastic settlement cracking; improve the surface finish at the tops of columns and walls; increase the potential strength and wear resistance of floors; and improve bonding to reinforcement.

4.4 FINISHING

4.4.1 Screeding

Screeding is the operation of levelling the concrete after it is placed in the forms and roughly distributed with shovels. It is done by hand, or by means of vibrating-beam screeds, which work off the forms or guide rails. It should be done before bleedwater rises to the surface.

Hand screeding involves the use of a screed board (or beam) to strike off the concrete to the required height either off forms of by use of a level. The striking surface of a screed board should always be straight and true. The surface is struck off by pulling the screed board forward, while moving it back and forth in a sawing-like motion across the top of the edge forms/concrete. A small roll or surcharge of concrete should always be kept ahead of the screed. Surface hollows created by aggregate 'roll out' or insufficient surcharge in front of the screed should always be filled immediately to ensure a flat surface.

4.4.2 Floating

The purpose of floating is to make the surface even and open in texture, ready for finishing.

Floating is working the surface of concrete with bullfloats, hand floats or with rotary finishing machines fitted with suitable floats or shoes. Generally, it should not begin until all bleedwater has evaporated from the surface, or has been carefully removed with a hessian drag or garden hose; and the concrete is hard enough to withstand foot traffic with only minor indentations in the surface. These indentations are removed by the floating operation. Floating:

- embeds large aggregate particles beneath the surface;
- removes slight imperfections and produces a surface closer to a true plane;
- compacts the concrete and consolidates mortar at the surface, preparing it for finishing; and
- closes minor surface cracks, which might appear as the surface dries.

Bullfloating The bullfloat (**Figure 4.8**) is a large float on a long handle, which is worked back and forth on the concrete in a direction parallel to the ridges formed by screeding. Bullfloating is useful as an initial floating operation to smooth the concrete surface immediately after screeding, and should be completed before bleedwater appears on the surface. A second use of the bullfloat may be required but care must be taken not to overwork the surface.

Floating by hand Three types of hand float are in common use: wooden, magnesium and composition. The hand float is held flat on the surface and moved in a sweeping arc to embed the aggregate, compact the concrete, and remove minor imperfections and cracks **Figure 4.9**.

The surface may sometimes be floated a second time (after some hardening has taken place) to impart the final texture to the concrete.

Floating by machine Float blades are wider than trowel blades and are turned up along the edges to prevent them digging into the surfaces in the flat position. For this reason, floating with a trowelling machine equipped with normal trowel blades should not be attempted. The power float should be operated over the concrete in a regular pattern, leaving a matt finish. Surfaces near to obstructions, or in slab corners, that cannot be reached with a power float should be manually floated before power floating.

Figure 4.8 Bullfloating

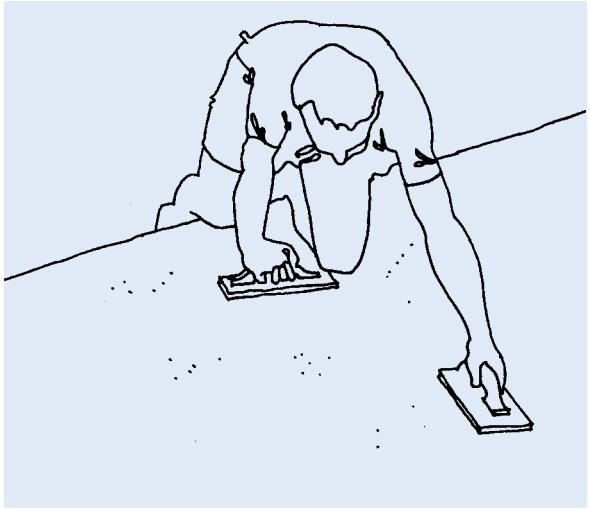


Figure 4.9 Hand floating with wooden floats

Figure 4.10 Hand trowelling with steel trowel

4.4.3 Trowelling

Trowelling is carried out some time after floating. The delay is to allow some stiffening to take place so that aggregate particles are not torn out of the surface.

Trowelling by hand A trowel for hand finishing has a flat, broad steel blade and is used in a sweeping arc motion with each pass overlapping the previous one **Figure 4.10**. For trowelling to be most effective, the timing of the operation calls for some experience and judgement, but in general terms, when the trowel is moved across the surface it should give a ringing sound.

For the first trowelling (often referred to as 'breaking'), the trowel blade should be kept as flat against the surface as possible because tilting, or pitching, the trowel at too great an angle can create ripples on the surface. More trowelling increases the smoothness, density, and wear resistance of the surface. Successive trowelling operations should be made with smaller trowels at increasing pitches. This increases the pressure at the bottom of the blade and compacts the surface.

Later trowelling, after further hardening, will increase the density of the surface concrete, making it more wear resistant. Successive trowelling operations should be at right angles to each other for best results.

Figure 4.11 Trowelling by machine

Trowelling by machine Figure 4.11 The trowelling machine (power trowel or 'helicopter') is a common tool in Australia for all classes of work and consists of several (generally four) steel trowel blades rotated by a motor and guided by a handle.

Trowelling by machine should be carried out systematically over the concrete in a regular pattern. Corner areas, areas close to obstructions and small irregularities should then be 'touched-up' with a hand trowel.

Machine trowelled surfaces may or may not contain trowelling marks. If trowelling marks are not acceptable then a surface free of trowelling marks should be specified. A burnished finish is often specified to avoid trowelling marks, but burnishing refers to a surface that is so highly trowelled that it takes on a lustre of its own. The additional work and expense are generally not warranted for residential slabs unless special decorative finishes have been specified.

Edging Edging provides a quarter-round arris along the edges of footpaths, patios, kerbs and steps. It is achieved by running an edging trowel along the perimeter of the concrete. Edging trowels are steel and incorporate a quarter-round forming edge. They are available in a variety of widths and with various diameter quadrants. Edging improves the appearance of many types of paving and makes the edges less vulnerable to chipping.

4.4.4 Other finishes

For other finishes such as honed, abrasive blast and acid etched, refer to **Section 9**.

4.5 CURING

4.5.1 General

Curing is retaining moisture in concrete for a reasonable time to allow cement hydration (see glossary) which occurs when water and cement are combined to form cement paste. Since the hydration of cement takes some time (days, and even weeks rather than hours) curing must be undertaken for a reasonable period of time if the concrete is to achieve its potential strength and durability. Curing will:

- improve compressive strength;
- reduce the incidence of drying shrinkage cracking;
- reduce surface dusting;
- improve durability and hence the protection of reinforcement;
- improve the hardness of the surface, and consequently its resistance to abrasion.

Curing should be maintained for a minimum period of 3 days for all types of residential concreting and possibly 7 days depending on the environment (eg near coastal and/or exposed to salts), properties required of the concrete, the purpose for which it is to be used and the prevailing weather conditions. It should begin as soon as possible but no more than 3 hours after finishing, or the benefits will be markedly reduced.

4.5.2 Curing methods

Curing methods are designed to keep the concrete continuously moist and fall into two broad categories:

- Preventing excessive loss of moisture by:
  - applying curing compounds to the surface by spray or roller;
  - placing and securing polythene sheeting over the surface;
  - leaving formwork (edge beams, sides and face panels) in place;
  - use of internal curing compounds (admixtures);
  - a combination of such methods.
- Continuously wetting the exposed surface by:
  - ponding water on the concrete surface where practicable;
  - spraying the surface with water (often a hessian or sand covering is also used to help retain the water on the surface).

In cold climates and particularly where freezing conditions may occur, curing can also involve controlling the temperature to prevent freezing of the surface, and raising the temperature of the concrete to increase the rate of strength gain.

4.5.3 Curing compounds

Liquid membrane-forming curing compounds (commonly known as curing compounds) are liquids that can be sprayed, brushed, or squeegeed (usually sprayed **Figure 4.12**) directly onto the concrete surface, and which dry to form a relatively impermeable membrane that limits the loss of moisture from the concrete. Their properties and use are described in AS 3799.

Some points to note about the use of curing compounds include:

- They are easy to apply with either spray or roller. The type or grade of curing compound should be matched to the application method.

- They allow construction to continue unhindered.
- They can be applied immediately after finishing. Curing compounds should be applied as soon as the free water on the surface has evaporated and there is no water sheen visible. Applying too early dilutes the membrane and too late results in it being absorbed into the concrete and the film not forming.
- They may contain fugitive dyes to assist in assessing coverage. The rate of application should be uniform. If possible, two applications at right angles to each other will help ensure complete coverage. Pigmented compounds may also help the concrete surface reflect rather than absorb heat.
- The rate of coverage is affected by the actual surface finishes, eg rough or broomed surfaces will require more as there is greater surface area.
- The compatibility of compounds with intended adhesives should be checked as some compounds may require removal for glued-down floor coverings such as direct stick carpet and vinyl, epoxy or polyurethane coatings and ceramic tile adhesives.
- Adequate ventilation and other necessary safety precautions should be provided when using solvent-based products, particularly in enclosed spaces.

Figure 4.12 Spraying on a curing compound

4.5.4 Plastic sheeting

Plastic sheetings, or similar materials, are effective in limiting water loss, provided they are kept securely in place and protected from damage. Their effectiveness is reduced if they are not secured and wind can lift them from the surface.

Some points to note about the use of plastic sheeting include:

- Plastic must be placed over the concrete and sealed and secured at the edges as soon as possible (without damaging the surface) after finishing.
- All wrinkles should be smoothed out to minimise the mottling effects caused by uneven curing, particularly for decorative finishes. An alternative may be to suspend the sheeting just above the surface by using small timber battens (softwoods) or metal tubes (eg scaffolding components), taking care to avoid staining of the surface from these components, ie rust from metal tubes or stains from hardwoods.
- Plastic must be lapped and sealed to prevent exposure to the drying effects of heat, wind or low humidity. For vertical work, the member should be wrapped with sheeting and taped to limit moisture loss. Where colour is important, the sheeting should be kept clear of the surface as above.
- Plastic sheeting may be clear or coloured. White or lightly coloured sheeting will reflect the sun's rays in hot weather and keep the concrete cooler during the summer. Clear or orange plastic is generally recommended for exterior work to limit heat absorption by the concrete and minimise problems due to curling. Black plastic, however, which absorbs the heat, could be used in cooler regions, or in the winter months, to accelerate strength gain by raising the concrete temperature.
- There is generally no need to add water under the sheeting.

4.5.5 Formwork

Leaving formwork in place is often an efficient and cost-effective method of curing concrete, particularly during its early stages. In very hot dry weather it may be desirable to moisten timber formwork to prevent it drying out during the curing period, thereby increasing the length of time that it remains effective. Note that when vertical formwork is eased from the concrete surface its effectiveness as a curing method is significantly reduced.

4.5.6 Water curing

Water curing is carried out by supplying water to the surface of the concrete in a way that ensures that it is kept continuously moist.

Some points to note about the use of water curing include:

- Water should not be more than about 5° cooler than the concrete surface. Spraying warm concrete with cold water may cause 'thermal shock' and cause/contribute to cracking.
- Water curing helps to reduce/control the temperature of the concrete in hot weather.
- The practice of intermittent wetting down in the morning and at night is not regarded as curing. This may result in greater harm to the concrete by causing expansion and contraction, and contributing to surface crazing and cracking.
- If sprinklers are used, they may be operated by a timer, but the frequency of wetting must ensure the surface is kept continuously moist. Also, fine sprays may be affected by windy conditions and care should be taken under such conditions to ensure the surface is kept continuously moist and alternate wetting and drying does not occur. To limit water use, runoff could be collected and recycled.
- Flat surfaces may be cured by ponding, but care must be taken to avoid leaks and ensure the shallow pond created does not empty or dry out through evaporation. Note that an adequate supply of water is required and ponding may interfere with subsequent construction activities
- Covering materials such as hessian and sand, should be pre moistened and should not be allowed to dry out as they can act like a wick and draw moisture out of the concrete. For fabrics, this can also result in the fabric texture being negatively absorbed into the concrete surface.
- If colour is important, care should be taken that the surface is not stained from impurities in the water or any covering material that is used. New fabrics can leach fabric stains, pre-washing is therefore generally essential. Sands can also contain minerals that will stain the surface.

4.6 EFFECTS OF WEATHER CONDITIONS

4.6.1 General

In Australia, weather conditions can vary from freezing cold to very hot. Experienced paviours are always aware of the effects that weather can have on concrete. Low workability, early setting times or plastic shrinkage cracking are not symptomatic of hot weather conditions alone but can occur at any time of the year. Low temperatures do not just occur during the winter months either, but can be experienced throughout the year.

Water is very important for hydration of cement. Maintaining the correct amount of water and workability of concrete in all weather conditions is important to allow proper placement, compaction and finishing of the concrete, and full hydration of the cement to achieve, ultimately, the properties of good concrete.

When the final finish does not meet expectations, the product (concrete) is often wrongly blamed; when the most likely cause is a failure to adopt concreting practices suitable to the conditions. By considering appropriate concreting practices in both hot and cold weather, the risks involved with placing in these conditions should be reduced and the construction of good quality concrete made possible.

The effect of weather conditions on concrete properties is summarised in **Table 4.3**.

4.6.2 Hot-weather concreting

While hot weather conditions are commonly encountered in summer, any combination of high temperatures, winds and low humidity could result in conditions leading to problems with concrete placement and finishing at any time.

AS 1379 places a 35°C limit on the maximum concrete temperature at the time of delivery. However, when the air temperature is above 30°C, it is usually recommended that precautions be taken, particularly if there is also a hot dry wind. Firstly to ensure an acceptable concrete temperature at the point of delivery, and secondly, to avoid problems with plastic shrinkage cracking and early stiffening of the concrete.

Effects of hot weather conditions

- Setting time is decreased, allowing less time to place, compact and finish the concrete. Usually, a set-retarding admixture is added to compensate for high temperatures. Alternatives include

controlling the concrete temperature by using, for example, iced water in the mix, using a cement type with lower heat of hydration or limiting the amount of cement to that required to provide strength and durability.

- Workability and slump are reduced making placement, compaction and finishing more difficult. Adding excess water to the mix to improve the workability is not recommended as this will reduce the strength and durability. The use of a plasticiser or admixture to increase the workability is preferred.
- Increased plastic shrinkage cracking. If the rate of evaporation is greater than the rate of bleeding, surface drying will occur, resulting in shrinkage of the concrete and possible cracking.

Precautions in hot weather conditions

- Plan the job to avoid delays once placement of the concrete has started.
- Place concrete during the coolest time of the day.
- Provide sunshades and wind breaks to work areas.
- Protect the surface of concrete slabs at all stages against excessive evaporation and premature drying by using an evaporation retarder such as aliphatic alcohol. These products reduce the rate of evaporation and control the premature drying of the surface, while allowing bleedwater to rise to the surface of the concrete. Note that these products are not curing compounds.
- Dampen the subbase/subgrade before placement of concrete (but do not leave surface water). Also dampen side forms for slabs and walls.
- Use a set-retarding admixture.
- Commence curing as soon as possible and continue for a minimum of 3 days; 7 days is preferable. If plastic sheeting is used for curing, it should be clear or light coloured, not black.

  Note that the Building Code of Australia (Volume 2 Housing Provisions: Clause 3.2.3.1d) states that 'In hot (above 30°C) and windy conditions concrete must be cured by covering with plastic sheeting, spraying with a liquid membrane curing compound or ponding of water on the top surface'.

4.6.3 Cold-weather concreting

Temperature ranges experienced in winter can present problems with concrete placement that need to be managed. AS 1379 requires concrete temperatures at the point of delivery to be within the range 5 to 35°C. When the air temperature falls below 10°C, while the concrete may be in no danger of freezing, it is usually recommended that precautions be taken. Firstly to ensure the minimum concrete temperature at the point of delivery, and secondly, due to the increased time required for the concrete to gain strength.

Low temperatures have a number of effects on the behaviour of concrete, most of which are related to the reduction in the rate of cement hydration.

Table 4.3
Effect of weather conditions on concrete properties

	Weather conditions		
Property	Hot	Cold	Dry/Windy
Slump	Decreased	Nil	Decreased
Setting time	Reduced	Increased	Nil
Strength gain			
Short term	Increased	Decreased	Nil
Long term	May be decreased	Increased	Nil
Workability	Reduced	Nil	Decreased
Risk of plastic shrinkage cracking	Increased	May be increased	Increased
Risk of drying shrinkage cracking	Increased	Nil	Increased
Risk of cold joints	Increased	Decreased	Increased
Period required prior to removal of formwork	Reduced	Increased	Nil

Effects of low temperatures

- The rate of cement hydration is reduced, resulting in longer setting times. Usually a set-accelerating admixture is added to compensate for low temperatures. Alternatives include increasing the amount of cement in the mix, using high-early strength cement, lowering the water content, using hot water for mixing or a combination of these measures.
- Slower strength gain resulting in longer stripping times for formwork.
- Cracking may be increased as a result of the lower concrete strengths being unable to resist the drying shrinkage stresses.
- Water in the concrete may freeze and expand causing damage to the pore structure of the cement paste and a reduction in strength. As a general rule, concrete must be protected from freezing for at least 24 hours after placement. Incorporating an air-entraining admixture into the concrete may assist in minimising damage.

Precautions in cold weather conditions

- Protect the concrete from the cold, including cold/frozen ground, winds and frosts. Concrete should never be placed on frozen ground.
- Insulate formwork and/or cover the surface with insulation for the first 24 hours. Hydrating cement generates a significant amount of heat which, if retained within the concrete, will protect it from freezing.
- Delay stripping of formwork as long as possible to protect concrete from frost.
- Use a suitable method of curing as moist or water curing is generally inappropriate during freezing conditions. The concrete should be kept warm during curing where this is practical.
- The temperature of surfaces should always be allowed to fall slowly to avoid thermal cracking due to temperature differences between the cold exterior and warm interior of the concrete.

Formwork and Reinforcement

05

5.1 FORMWORK

5.1.1 General

Formwork is the temporary structure which moulds concrete into the desired shape, and holds it in the correct position until it has hardened sufficiently and/or is able to support the loads imposed on it. Formwork should have sufficient:

- strength to resist the pressure of the fluid concrete without damage or excessive deflection;
- stiffness to avoid bows/bulges outside the tolerances specified for the work;
- accuracy of construction to ensure correct surface levels and dimensions/shape;
- watertightness to prevent the loss of cement paste and/or matrix from the concrete (this can cause ragged edges, hydration staining and honeycombing, which in turn can affect strength, durability and result in poor off-form finishes);
- robustness to allow repeated stripping, storing and erection.

Formwork should be coated with a form release agent to improve concrete finishes, aid in the removal of the formwork and thus minimise possible damage to the concrete face from the stripping operation. There are two basic types of release agents: barrier products which simply separate the concrete from the formwork, and the more common reactive products which react with the concrete constituents to form soap-like products that prevent the concrete from adhering to the formwork. A release agent suitable for the type of formwork and finish required should be selected.

Formwork is left in place, primarily, to protect the edges of the slab from mechanical damage during site works (while the concrete is hardening), and to avoid damage from the premature removal of the formwork itself. Formwork is also an effective means of curing when it is left in place. If the formwork is stripped before 3 days have elapsed, it is advisable to continue curing exposed surfaces with one of the methods described in **Section 4.5** *Curing*.

5.1.2 Basic ground forms

Basic ground forms are suitable for paths and driveways on firm ground, up to 150 mm thick. The correct method of fixing forms to pegs is shown in **Figure 5.1**.

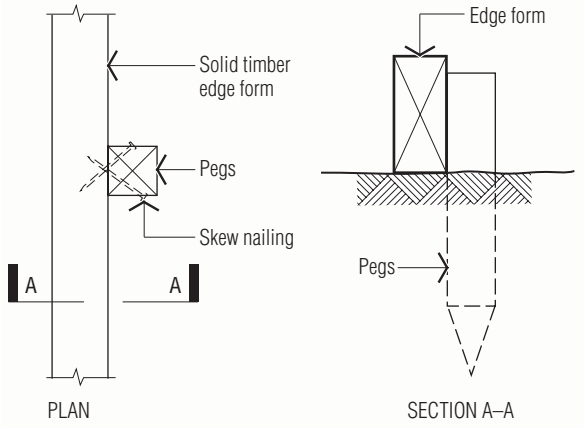


Figure 5.1 Basic ground forms

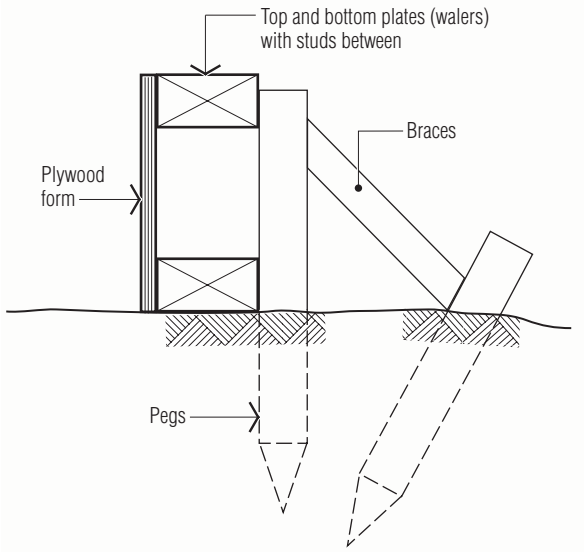
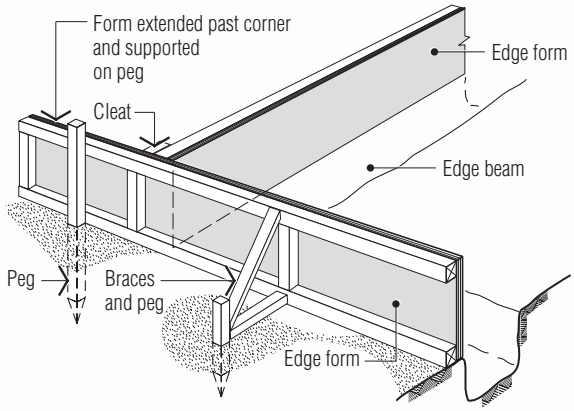


Figure 5.2 Braced formwork for slabs more than 150 mm thick

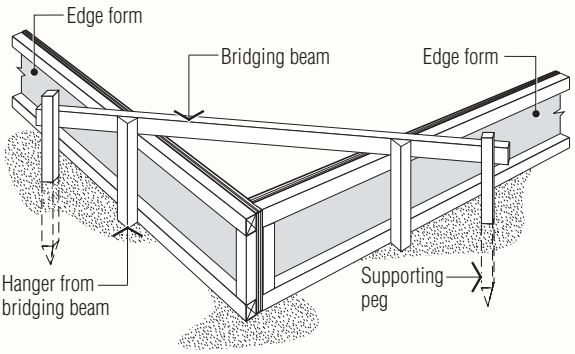
5.1.3 Deep edge forms

Formwork up to 300 mm in height is often required for slabs where the ground level varies. Where the height of formwork exceeds 150 mm, it should be braced as shown in **Figure 5.2**. Deep edge forms can be constructed from clean-faced ply with top and bottom walers. If solid timber forms (minimum 38 mm) are used, the bracing and formwork will be different. When depths exceed 200 mm, solid timber forms should be a minimum of 50 mm thick.

Illustrated in **Figure 5.3 (a) and (b)** are simple solutions to common problems when using deep edge forms.



(a) CARRY ONE EDGE FORM PAST THE CORNER



(b) HANG EDGE FORMS FROM A BRIDGING BEAM

Figure 5.3 Solutions to common problems with deep edge forms

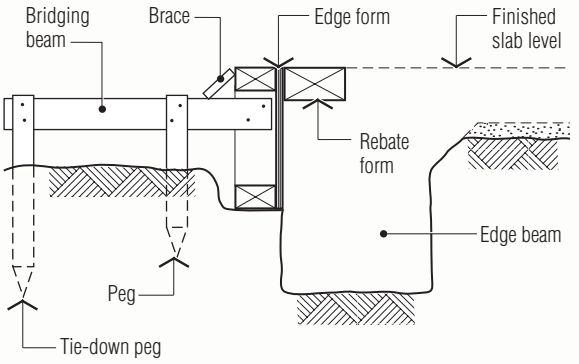


Figure 5.4 Formwork for raft slab with rebate

Figure 5.5 Edge rebate formwork with brackets and edge board

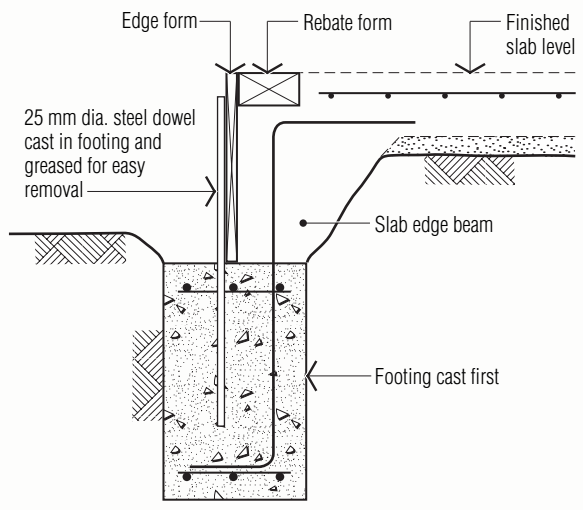


Figure 5.6 Formwork for footing slab

5.1.4 Edge forms with rebates

Many house slabs have rebates at the slab edge to allow an external skin of brickwork to sit on a damp-proof course (DPC) below the floor level. **Figure 5.4** shows a typical construction method with timber formwork for raft slab construction: the rebate form can be either solid timber, or more commonly consist of brackets with a timber edge board along the inside of the rebate **Figure 5.5**. For footing slab construction, an alternative to providing braced edge forms similar to **Figure 5.3 (a)** is shown in **Figure 5.6**. With this formwork method, edge forms are secured to greased 25-mm steel dowels placed into footing beams and removed after the slab has set. The holes are filled with grout once the dowels have been removed. The external leaf of masonry is constructed off the footing with a gap to the slab edge; and the internal wall is constructed off the slab and aligned with the slab edge.

5.1.5 Cantilevered formwork

A wider step-down is sometimes required, for example to accommodate steps at the slab edges. These are best constructed as shown in **Figure 5.7**.

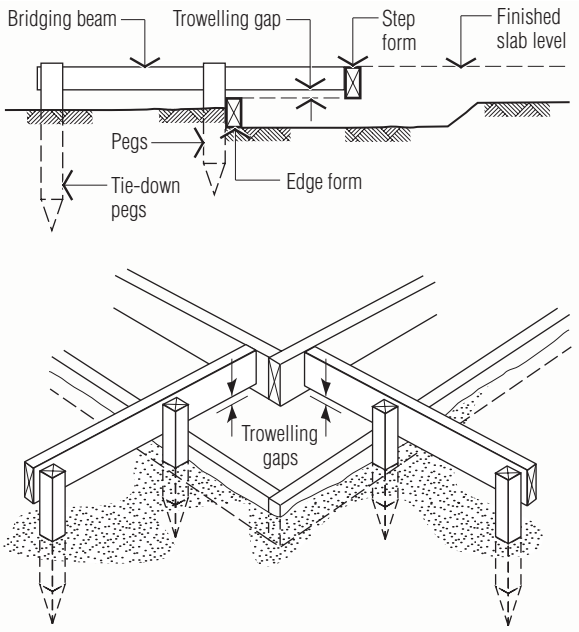


Figure 5.7 Cantilevered formwork

5.1.6 Other types of ground forms

Fabricated metal forms and other proprietary formwork systems speed up ground slab construction and can be re-used. Several telescopic metal form systems are available and can be effective for highly repetitive construction. Ply and metal composite forms are suitable for applications with repetition and heavy working loads (deep beams).

5.1.7 Masonry formwork

Masonry formwork (brick or block) maintains the same face material below natural ground. It removes the need for a formworker but requires a two-part slab construction, ie footing slab **Figure 5.8**.

5.1.8 Construction joints

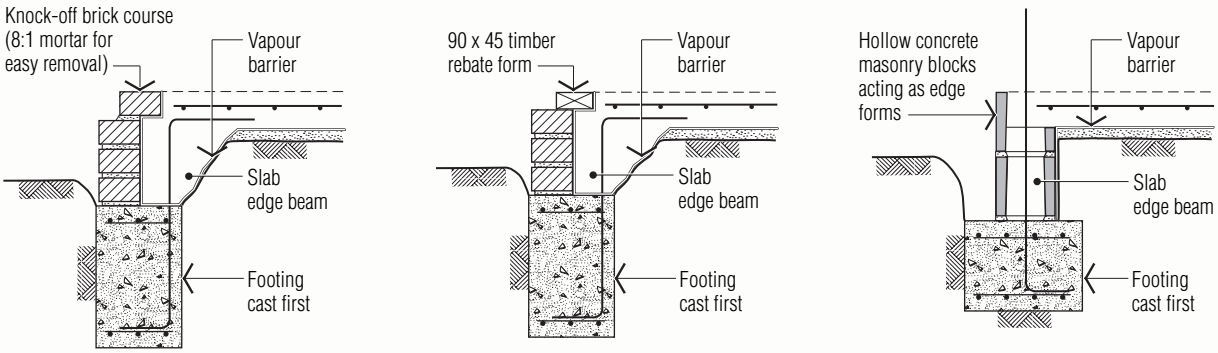
At construction joints, where continuity of reinforcement is required, two-piece formwork is suitable for both mesh and bars as shown in **Figure 5.9 (a)**. This is to enable adequate compaction and finishing of the concrete along the joint.

Although primarily used for control joints, proprietary metal key-forms or timber forms are also suitable for use as construction-joint formwork. While the reinforcement can not be continuous, the key allows load transfer between adjacent slab panels **Figure 5.9 (b)**.

5.2 PURPOSE OF REINFORCEMENT

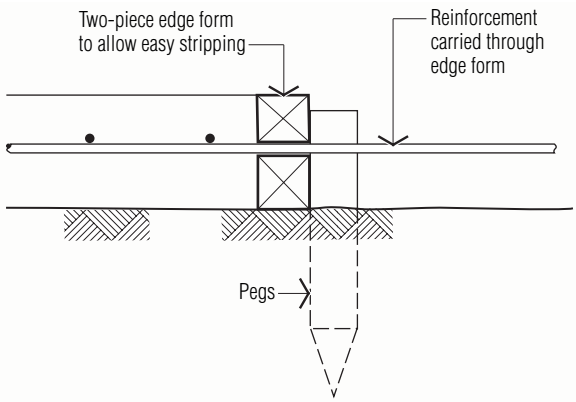
Concrete has high compressive strength but low tensile strength. Steel, on the other hand, has a very high tensile strength (and a high compressive strength) but is much more expensive than concrete. Combining steel and concrete makes use of both the high tensile strength of steel and the relatively low-cost compressive strength of concrete. **Table 5.1** lists some of the main characteristics of both concrete and steel.

It is important to understand that incorrectly positioned reinforcement can reduce both the strength and durability of reinforced concrete, and greatly reduce the ability of reinforcement to control shrinkage cracking. It is recommended that a structural engineer be engaged for the design of reinforcement.

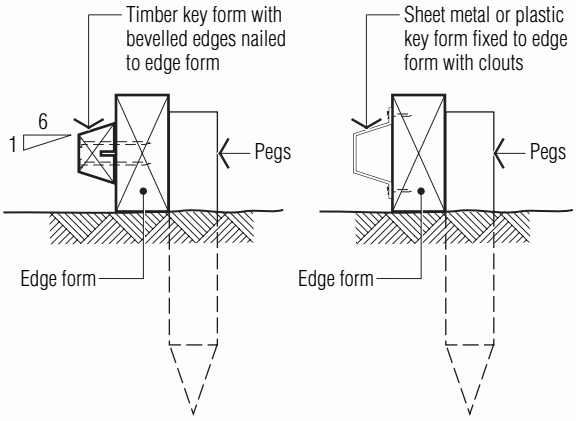


(a) BRICK COURSE USED FOR REBATE (b) TIMBER USED FOR REBATE (c) SINGLE-LEAF MASONRY

Figure 5.8 Masonry formwork



(a) TWO-PIECE FORMWORK TO ALLOW REINFORCEMENT CONTINUITY



(b) TIMBER, METAL AND PLASTIC KEY JOINTS

Figure 5.9 Formwork for construction joints

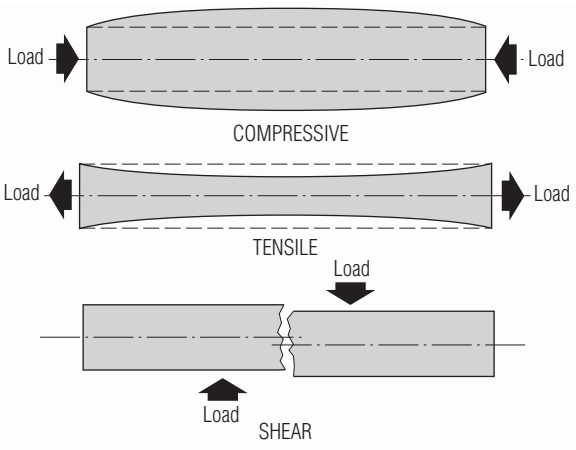


Figure 5.10 Types of stresses

Table 5.1
Characteristics of concrete and steel

Characteristics of Concrete	Characteristics of Steel
High compressive strength	High compressive strength
Low tensile strength	High tensile strength
High fire resistance	Low fire resistance
Plastic and mouldable when fresh	Difficult to mould and shape except at high temperatures
Relatively inexpensive	Relatively expensive

The combination of concrete and steel in reinforced concrete is mutually beneficial for a number of reasons including:

- Upon hardening, concrete bonds firmly to steel rods, bars and wires so that, when loads are applied, the two act as though they are one. Any tendency for the concrete to stretch or crack in a zone of tension is counteracted by the steel embedded in that zone.
- When subjected to changes in temperature, concrete and steel expand or contract by similar amounts, and therefore remain firmly bonded.
- Concrete, having a relatively high resistance to fire, and a relatively low thermal conductivity, protects the steel embedded in it.
- Concrete provides an alkaline environment which protects the embedded steel from rusting.

The principal types of stresses (**Figure 5.10**) which develop in concrete elements are:

- Compressive stresses – those which tend to cause concrete to compact and crush.
- Tensile stresses – those which tend to cause concrete to stretch and crack.
- Shear stresses – those which tend to cause adjacent portions of concrete to slide across each other.

5.3 TYPES OF REINFORCEMENT

Reinforcement is usually supplied in the firm of steel bars or steel wires welded together to form a mesh. Bars are normally associated with beams and columns, and mesh with floors and walls.

Bars can either be of low or normal ductility steel, eg L12 or N12. Normal ductility bars will elongate more under load and are the type nominated in AS 2870 for all slabs and footings where bars are required or given as an alternative to mesh. All mesh is produced from cold drawn (and therefore low ductility) wires and are prefixed with an 'L' for low ductility, eg 3-L11TM (three 11-mm-diameter low ductility wires). Mesh for slabs is typically designated as SL72, SL82, etc. The 'S' stands for square mesh, 'L' for low ductility, the first digit is the nominal wire diameter; and the second digit indicates the spacing of the wires in the mesh.

Concrete may also be reinforced with fibres, the main type being steel. Polypropylene fibres are also available but do not increase the tensile strength of a concrete member in the same way as steel bars, mesh or fibres, but will, however, provide some control of plastic shrinkage cracking of concrete.

5.4 FIXING REINFORCEMENT

5.4.1 General

Fixing is more than just tying bars and mesh together. It should ensure that once the reinforcement has been placed in its correct position, it cannot be displaced during placing and compacting of the concrete and will remain in place until the concrete has fully hardened. A number of methods are used to locate reinforcement correctly and these are detailed below.

5.4.2 Bar chairs and spacers

Bar chairs and spacers support bar or mesh reinforcement above horizontal surfaces, and provide adequate clearances to vertical formwork and/or excavation facings. They are available in a variety of shapes and may be made from wire, plastic or concrete **Figure 5.11**. They are also manufactured in a range of sizes, each of which provides a specific thickness of concrete cover.

Factors to consider in the suitability of a chair or spacer include:

- **Cover** A bar chair or spacer should be selected to provide the correct cover, not one 'close to' that required.
- **Membrane damage** Bar chairs which could puncture vapour barriers or damp-proofing membranes during placing operations should be avoided, or supported on purpose-made bar chair bases or 'saucers' (ie, flat galvanised metal plates).
- **Stability** Some types of bar chairs and spacers are easily displaced or knocked over during concrete-placing operations.
- **Spacing of bar chairs** The spacing of chairs must ensure that the reinforcement is adequately supported in the required position. Bar chairs for mesh are typically spaced at 0.8- to 1.0-m intervals in both directions. For lighter mesh (eg SL52), closer spacing of supports may be required to prevent sagging under the weight of concrete and workers.
- **Materials** Durability requirements may determine which material is suitable for use. Plastic and plastic tipped wire bar chairs may not be suitable for marine applications as the plastic tip is less than the concrete cover required to reinforcement. Also, since concrete does not adhere to plastic, the ingress of moisture is likely to occur at the interface.

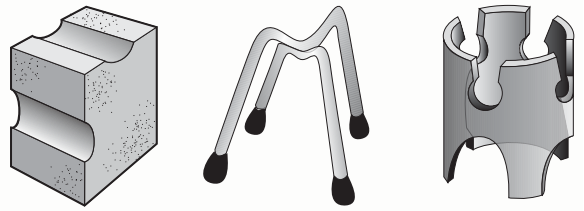


Figure 5.11 Typical spacers for reinforcement

5.4.3 Tying of reinforcement

Reinforcing bars may be tied together, or to stirrups (ligatures), to form a 'cage' that helps maintain the bars in position during the subsequent concreting operations. The cage must be strong enough to achieve this and sufficient ties used for the purpose. Note that the cage itself must be provided with spacers to ensure required covers are achieved.

5.4.4 Splicing (joining) of reinforcement

Lengths of reinforcing bar or mesh may be joined or 'spliced' together in a variety of ways. The most common method is simply to lap the bars or mesh. The lapped portion of the bars or mesh must always

be in contact and tied unless otherwise indicated on the drawings.

The following requirements are contained in Section 5.3 in AS 2870 regarding splicing/lapping of reinforcement:

- Mesh should be lapped a minimum of two cross wires so that 'the two outermost transverse wires of one sheet overlap the two outermost transverse wires of the sheet being lapped'.
- Trench mesh should be lapped a minimum of 500 mm and be tied and secured.
- Trench mesh at T and L-intersections should be overlapped by the full width of the mesh.
- Bars used in reinforced footing cages should be lapped a minimum of 500 mm. At T and L-intersections the bars should be continued across the full width of the intersection. At L-intersections, one outer bar should be bent and continued 500 mm around the corner or a bent lap bar 500 mm long provided **Figure 5.12**.

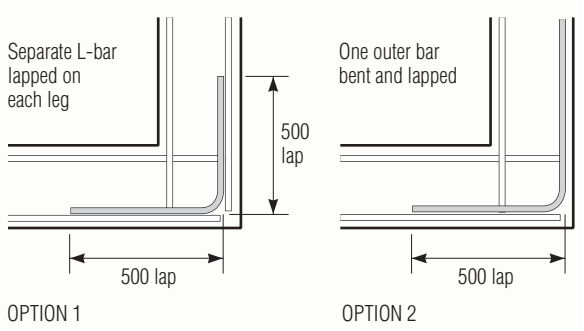


Figure 5.12 Lapping of reinforcement at corners

5.5 COVER TO REINFORCEMENT

The cover to reinforcement (the minimum thickness of concrete between the outside of reinforcement and the nearest concrete surface) is provided basically to give protection to the steel reinforcement against corrosion (rusting).

Section 5.3 in AS 2870 gives the minimum cover to reinforcement in house construction **Table 5.2**. For strip footings, generally 40 mm cover to unprotected ground or the top of the footing if exposed is required.

Table 5.2
Minimum cover to reinforcement in rafts and slabs

Situation	**Cover** (mm)
Top cover to mesh for internal surfaces	20
Top/side cover to all reinforcement in slabs exposed to weather	40
Bottom/side cover to all reinforcement in beams and slabs protected by a membrane	30
Bottom/side cover to all reinforcement in members cast directly against non-aggressive ground	40

5.6 IMPORTANT CONSIDERATIONS FOR REINFORCEMENT

Where penetrations occur, the mesh should be cut away to prevent fouling the penetration and interfering with the penetration alignment. The engineer should be asked to check whether or not extra reinforcement is required to maintain structural strength. Depending on the size of the opening in the slab, or at other re-entrant corners, AS 2870 requires that two strips of 3-L8TM, one strip of 3-L11TM or three N12 bars (minimum 2 m long) be placed diagonally across the corner to reduce the risk of a potential crack.

Horizontal penetrations to strip footings are permitted through the middle third of the footing. Localised deepening of the footing and/or additional reinforcement may be needed.

With any reinforced concrete project:

- Do not hook mesh and lift into position (use bar chairs).
- Place bar chairs for general work at maximum 1-m spacing.
- Do not 'walk' the mesh into the concrete during placement.
- Prevent mud being walked onto reinforcement. Stack materials on skids off the ground.
- Do not allow trucks to drive over reinforcement.
- Adequately splice and secure reinforcement. For mesh, a good standard is to secure each third wire lap and stagger the tying-off line. For splicing/lapping of bars, tie each end of the spliced length to adequately secure the bars.

5.7 INSPECTIONS

Items to be inspected and checked where applicable:

- Number, size and spacing of bars, or the sizes of mesh. Refer to specifications and project drawings.
- Number, size and spacing of fitments (in beams).
- Height and distribution of chairs to maintain required bottom and side covers.
- Cover to ends of bars.
- Extension length of bars and mesh past support faces.
- Location and lengths of lap splices.
- Location of service pipes, conduits, openings and outlets with respect to conflicts with bar and fitment locations.
- Trimming of bars around openings in slabs and at re-entrant corners.
- Effectiveness of tying (bars to bars, bars to fitments, lap splices, chairs to bars or mesh).
- Removal of tie wire offcuts, particularly where slab/beam soffits will be exposed.

Supports and ties are intended to support only the weight of the reinforcement, the concrete over them plus concreters and, together with tie-downs, to prevent the reinforcement being accidentally displaced during concrete placement. They are not intended to support general construction traffic. It is therefore important that, once the reinforcement has been placed, fixed and checked, independently supported plank runs are provided to keep personnel and equipment such as wheel barrows off the reinforcement. If this is not done, all the previous good work and effort in correctly positioning the reinforcement will have been wasted.

Cracks and Crack Control

06

6.1 GENERAL

Cracks can occur in concrete construction for a variety of reasons. Some cracking is inevitable because concrete, like most other building materials, moves with changes in temperature and its moisture content. Specifically, it shrinks as it loses moisture. The risk of cracking can be minimised by understanding what factors cause cracking and how to design and detail concrete work to address these issues.

Cracking in concrete falls into two basic categories:

- Prehardening cracks which occur prior to setting of the concrete
- Cracks in hardened concrete which occur after setting of the concrete.

6.2 PREHARDENING CRACKS

6.2.1 General

The two most common forms of prehardening cracks that affect concrete work are plastic shrinkage cracking and plastic settlement cracking. They occur while concrete is still in its plastic state and therefore before the concrete has gained any strength. They may not always be evident at the completion of concreting as bullfloating, bleedwater and surface trowelling can temporarily close up or conceal them. Often, with further drying of the surface, cracks that have been covered (by trowelling) with a thin layer of cement paste will reappear. A lack of adequate curing will add to the problem.

Prehardening cracks can also be caused by formwork movement.

If cracks occur they should be completely closed up by revibrating or trowelling to ensure that at completion, no initiators for further cracking remain in the concrete.

6.2.2 Plastic shrinkage cracking

Plastic shrinkage cracking **Figure 6.1** is caused by rapid drying of the concrete surface. They can occur at any time of the year, from cooler low-humidity weather conditions to, in particular, hot weather conditions involving any one or a combination of high temperature, low humidity and wind. These types of cracks occur while the concrete is bleeding and during the finishing operation. Fresh concrete may be exposed to the elements for a considerable time during these stages, causing the concrete at the surface to dry and shrink before it has any strength to resist the shrinkage forces. Concrete cracks in much the same way as clay soils.

Polypropylene fibres can be added to the concrete mix to reduce the incidence of plastic shrinkage cracking. Fibres tend to bind the surface of the concrete together and provide some strength to the plastic concrete to resist the shrinkage forces.

Methods to reduce the risk of plastic shrinkage cracking include:

- Erect wind breaks to shield the surface from drying winds.
- If vapour barriers or damp-proofing membranes are not present, dampen the ground prior to placing concrete to reduce absorption.
- Use a continuous fine mist spray to fog the surface of the concrete and prevent premature drying of the surface while bleedwater is rising.
- Spray an evaporation retarder such as aliphatic alcohol over the freshly screeded concrete surface. Surfaces can dry prematurely when the rate of evaporation is greater than the rate of bleeding. These products form a film on the surface that reduces the rate of evaporation of water, thus allowing time for all the bleedwater to rise to the surface. The addition of a fugitive dye will show the evenness of the coverage. In extreme conditions, re-application of the evaporation retarder may be necessary both before and during trowelling. These products do not affect the strength or performance of the concrete and can act as a finishing aid.
- Use physical remedies such as revibrating the concrete, vigorous wood floating over cracks or extended use of power trowelling to close up the full depth of the cracks.
- Commence curing as soon as possible after finishing.
- Delay placement if extreme weather conditions are predicted.

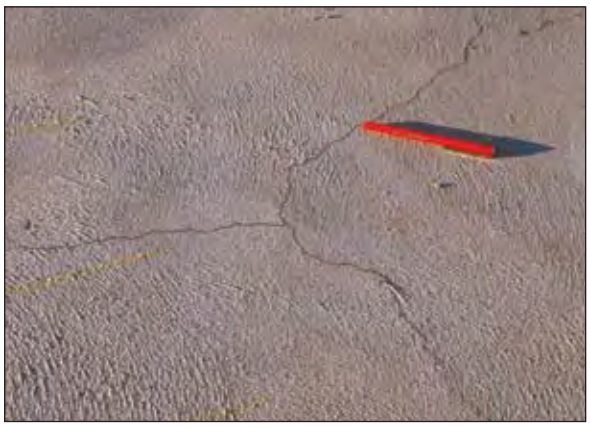


Figure 6.1 Plastic shrinkage cracking

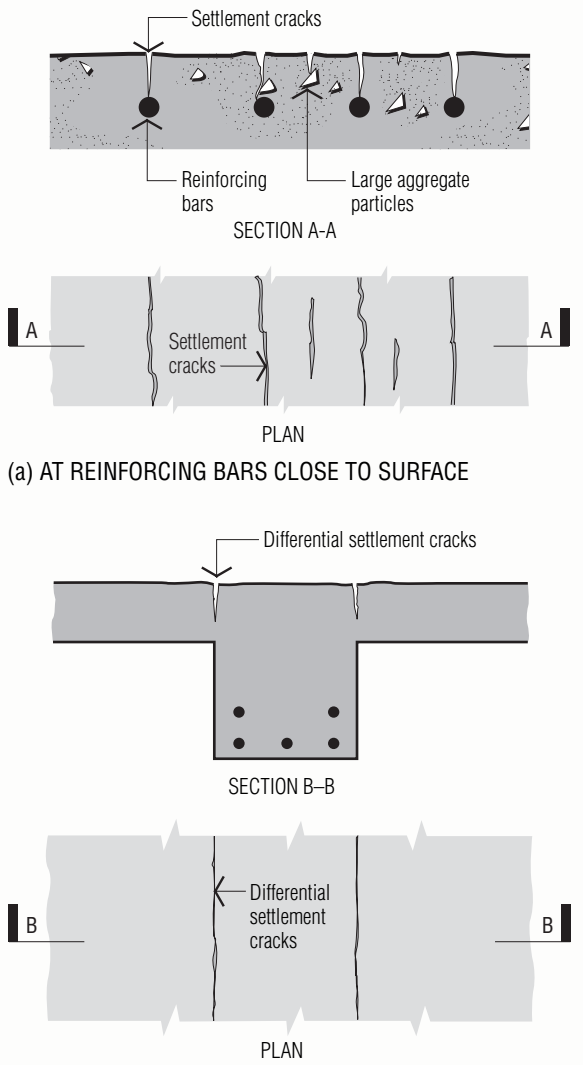


Figure 6.2 Plastic settlement cracking

6.2.3 Plastic settlement cracking

Plastic settlement cracking is caused when concrete settles under its own weight, often because of inadequate compaction. Once concrete is placed into the forms, the heavier particles (cement, sand, gravel) settle to the bottom and the lighter water is forced to the surface in a process known as bleeding. Compaction of concrete ensures that the entrapped air is expelled and particles in the concrete are packed tightly together to minimise settlement. Deeper sections such as beams are always more prone to settlement cracking as more depth is available for settlement.

If settlement occurs after placement, any restraint to the settlement will typically result in the formation of a crack in the surface above the restraint and possibly leave a void beneath it. Common restraints include reinforcement and service pipes within the concrete and even steps in formwork such as waffle rafts where the depth changes significantly **Figures 6.2 and 6.3**.

Unlike plastic shrinkage cracks which can be randomly located over the surface, settlement cracks tend to be straight as they follow the line of the reinforcing or formwork **Figure 6.4**.

Some methods to reduce the risk of plastic settlement cracking include:

- Fill any deep beam sections to the level of the bottom of the slab before placing the concrete in the slab.
- Always ensure adequate compaction.
- Revibrate the surface where there is more than a 300-mm depth of concrete below top bars.
- Ensure all formwork can withstand expected working loads and that the formwork stays in place to support the concrete until it is self-supporting.

6.2.4 Cracks caused by formwork movement

If there is movement of the formwork after the concrete has started to stiffen but before it has gained enough strength to support its own weight, cracks may form. This type of cracking has no set pattern.

To avoid cracking from formwork movement, formwork must be:

- sufficiently strong and rigid to support the weight of the concrete without excessive deflections; and
- left in place until the concrete has gained sufficient strength to support itself.

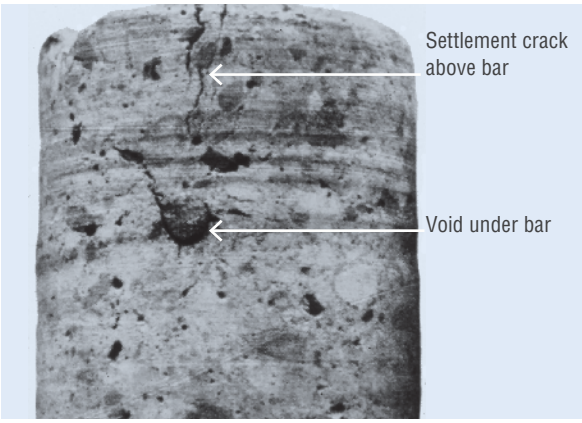


Figure 6.3 Plastic settlement crack above reinforcing bar with void under bar

Figure 6.4 Plastic settlement cracks above mesh

6.3 CRACKS IN HARDENED CONCRETE

6.3.1 General

Cracking in concrete after setting also occurs for a variety of reasons. The two most common forms of cracking in hardened concrete are crazing and drying-shrinkage cracking.

6.3.2 Crazing

This is best described as a network of very fine cobweb-like or alligator-skin cracks, which appear on the surface of concrete after it has been exposed to the atmosphere for some time. They occur in the surface cement mortar and are generally more common in surfaces with a highly steel-trowelled or burnished finish as the additional time required for finishing leaves the surface exposed for a longer period prior to commencement of curing **Figure 6.5**. Crazing does not normally extend below the top 2 to 3 mm, nor does it lead to durability or other serious problems; it generally affects only the appearance.

The main causes of this form of cracking are:

- rapid drying of the highly compacted surface (from trowelling) while the concrete is still weak (between trowelling and commencement of curing);
- the surface of the concrete expanding and shrinking during alternate cycles of wetting and drying;
- steel trowelling the concrete before the water sheen has gone and hence trowelling bleedwater into the surface of the concrete causing increased shrinkage and weakening of the surface mortar;
- using cement-rich mixes on the surface as 'driers' to remove excess water (these may create a surface layer with substantially different properties to the concrete below, eg higher shrinkage);
- overworking the surface and bringing excess mortar to the surface (again creating a surface layer that may have increased shrinkage characteristics);
- adding excess water to the mix;
- inadequate or inconsistent curing.

To avoid crazing on trowelled surfaces:

- Avoid very wet mixes and do not add excess water on site.
- Do not use 'driers' such as cement, pigments or colour hardeners to soak up bleedwater.
- Do not work the bleedwater into the surface but wait until the water sheen has gone. Excess bleedwater can be dragged off the surface with a hose.
- Do not overwork the concrete by unnecessary trowelling of the surface.
- Avoid wetting and drying cycles and excessive 'wet wiping' of the surface where water is sprinkled onto the surface to aid with trowelling.
- Protect surfaces from rapid drying during finishing.
- Commence curing promptly.

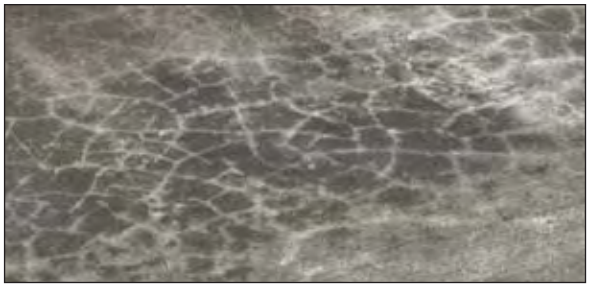


Figure 6.5 Crazing

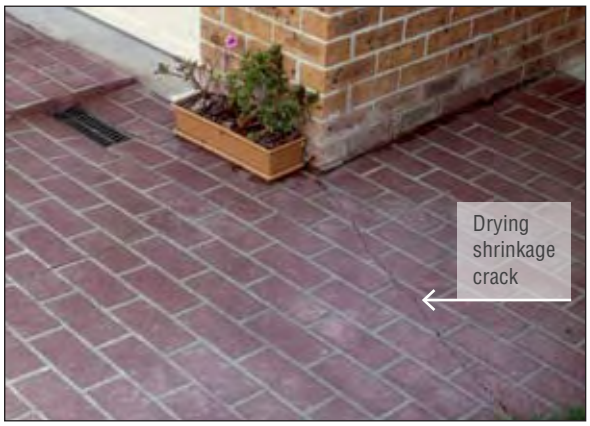


Figure 6.6 Drying shrinkage crack caused by restraint of brick wall

6.3.3 Drying shrinkage cracks

These are caused by moisture in the concrete drying out over time leading to shrinkage of the concrete. This is not a major problem if the concrete is free to move, but, if restrained, tensile stresses can develop in the concrete and, if these exceed the tensile strength of the concrete, cause it to crack **Figure 6.6**. The water content of the mix is the major factor influencing drying shrinkage. Other factors that may also affect the risk of cracking in hardened concrete include restraints, curing conditions, aggregate size and content, detailing geometry and construction practices.

Methods to reduce the risk of cracking due to drying shrinkage include:

- Do not add excess water to the concrete on site.
- Compact the concrete adequately to achieve the maximum density.
- Provide adequate curing and commence promptly.
- Place joints in correct locations, provide correct geometry (size/shape of slab panels) and ensure proper construction detailing to limit restraint of the concrete.
- Use good construction practices when placing concrete.
- Provide adequate reinforcement and ensure correct placement.

6.4 JOINTS

6.4.1 General

Joints serve a number of purposes, but they fall into two broad categories:

- Those that allow movement (isolation and expansion joints).
- Those that control cracking of the concrete (control or contraction joints).

A further type, construction joints, are used when there is a break in the concrete placement, but are rarely required in residential work because of the small slab sizes and/or distances between formed joints.

Joints of any type are rarely needed in residential floor slabs because of the amount and layout of reinforcement. AS 2870 allows slabs up to 30 m long without joints. The longer the slab (up to 30 m), the more reinforcement is required in order to control the tensile stresses caused by the concrete wanting to shrink but being restrained by the ground underneath. The standard designs in AS 2870 are intended to control shrinkage cracking so that the majority of slabs will have either no cracking or only very fine hairline cracks (< 0.3 mm in width).

If joints are provided in house slabs, both the slab and building need to be designed to allow movement at these locations as they will tend to concentrate shrinkage and ground movements. Joints are not appropriate in some slab types—this is often not understood. Providing joints in a house slab without expert advice can cause structural problems that may be expensive to fix.

A house slab is often placed directly on the ground and is therefore subject to ground movement. Without careful consideration and construction, joints can become a hinge in the slab and exaggerate ground movement, sometimes resulting in damage.

Articulation joints are commonly provided in all brick walls at slab joint locations and also in other wall linings and finishes where these are not capable of accommodating the expected movement. All joints through a house slab must also be provided with a termite barrier to prevent possible concealed access by termites.

6.4.2 Isolation joints

Isolation joints are used to separate the concrete slab from any abutting buildings, existing slabs, or rigid structures such as drainage pits, access holes or columns which may cause restraint of the slab and

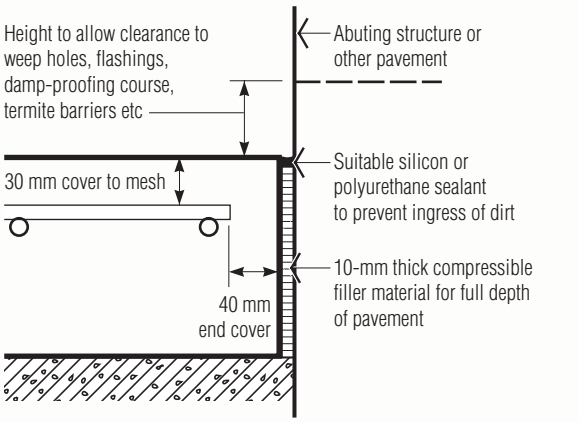


Figure 6.7 Typical isolation joint detail

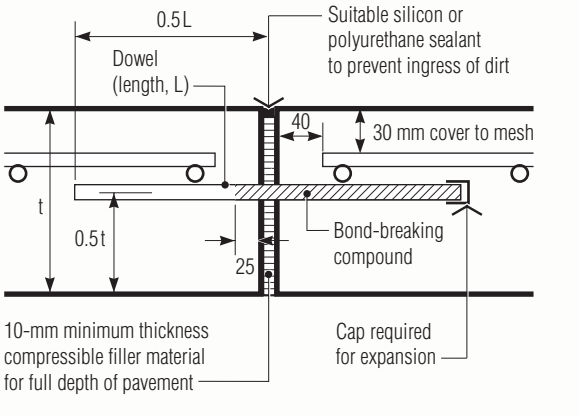


Figure 6.8 Typical expansion joint detail

thereby increase the risk of cracking **Figure 6.7**. They should allow the slab to move vertically, horizontally and to rotate. While movement from concrete drying shrinkage will normally cause the joint to open with time, temperature changes may cause the joint to close.

Compressible, cellular materials are commonly used to fill these joints and they must be sealed at the top and sides to prevent dirt entering the joint and reducing its effectiveness. Silicone and polyurethane sealants are commonly used for isolation and expansion joints.

6.4.3 Expansion joints

Expansion joints (**Figure 6.8**) are used in large areas of paving to allow concrete elements to expand and push against each other (without damage), mainly due to high temperatures in hot weather, but also changes in the moisture content. They should be provided at maximum 15-m centres.

Expansion joints typically have dowel bars connecting the slabs to provide load transfer across the joint and avoid changes in the levels from one slab to another—known as stepping. As a guide, for 100-mm-thick slabs intended for vehicles less than 3 t gross mass (eg typical car) 12-mm-diameter dowels at maximum 400-mm centres would be satisfactory. There are many proprietary jointing systems (**Figure 6.9**) that allow easy installation and continuous concrete placement across these types of joints.

As for isolation joints, the top and sides need to be sealed to prevent dirt entering and problems such as edge spalling (**Figure 6.10**), slabs riding up and joint peaking, all of which are detrimental to slab performance and appearance. Preformed strips at the top of joints should not be relied on to provide an adequate seal as shrinkage can open up a gap that can fill with dirt and cause problems **Figure 6.10**.

Figure 6.9 Example of proprietary expansion joint

Figure 6.10 Edge spalling

6.4.4 Control joints

Control joints (**Figure 6.11**) typically form a weakened plane at which concrete will crack. Without them, drying shrinkage would result in random cracking. They should be provided at maximum 3-m centres, at any changes in shape (eg a narrow path attached to a driveway), at any changes in direction (eg around corners), and at any rigid structures that may prevent movement and increase the risk of cracking.

Control joints can be made by:

- inserting a pre-moulded (plastic or metal) strip into the concrete as it is being placed;
- use of a grooving tool immediately after the concrete has been placed;
- sawing a groove when the concrete has hardened sufficiently to prevent ravelling;
- using a proprietary pressed metal key joint.

Note that:

- Both isolation and expansion joints can be used as control joints
- If joints are saw cut, this should be done before shrinkage cracking occurs. As a guide, saw cuts should be made not more than 12 hours after finishing of the slab if temperatures exceed 25°C, and not more than 16 to 18 hours after finishing of the slab for lower temperatures. The surface is hard enough when it does not chip, spall and collapse on the cutting blade (sometimes referred to as ravelling). To avoid delays, early-age saw cutting is possible with specialised equipment. The surface should be thoroughly cleaned after cutting to remove cement paste from the surface, especially for decorative work.
- If joints are wet-formed by scoring the plastic concrete with an edging tool, care should be taken to ensure that the joint does not fill with cement slurry/mortar, making the joint less effective.
- If joints are formed with pressed metal keys, they should be fixed in position to maintain straight lines.
- While reinforcing mesh will normally stop 50 mm from control joints, it may extend across the joint to provide better control of movement on, say, highly expansive clays. In this case, 50% of the mesh should be cut to assist in the formation of a plane of weakness at the joint location. To allow some tolerance in the location of the saw cut, crack inducer or tooled joint, the ends of the cut wires should be at least 50 mm clear of the proposed joint location. **Figure 6.12**.

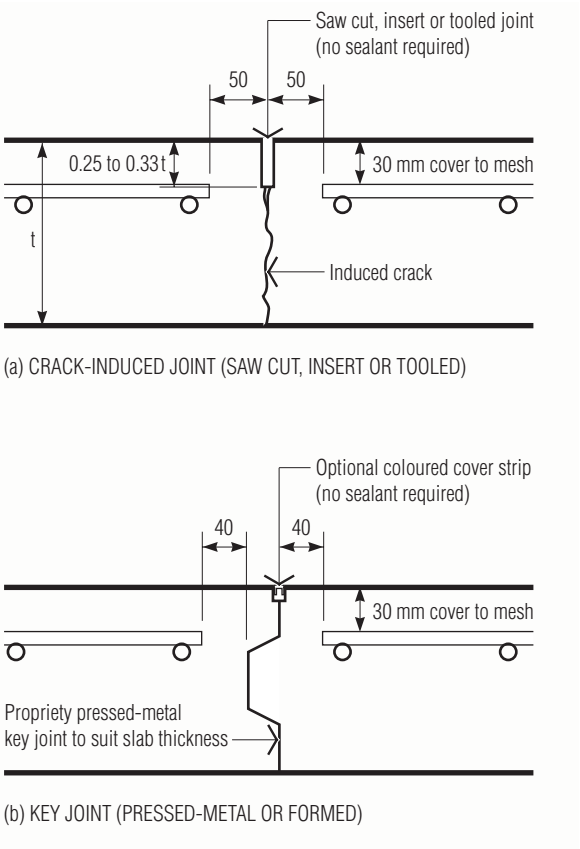


Figure 6.11 Typical control joint details

Figure 6.12 Reinforcement fixed in position and mesh being cut at control joint locations

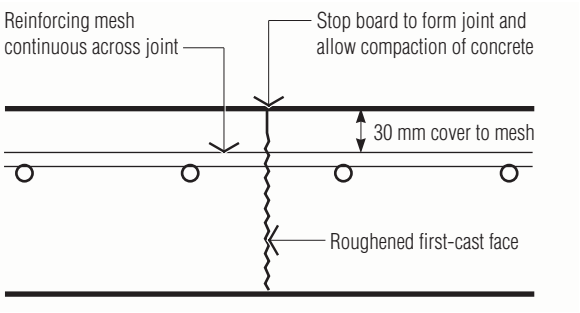


Figure 6.13 Typical construction joint detail

Figure 6.14 Joint perpendicular to slab edge

6.4.5 Construction joints

Construction joints (**Figure 6.13**) are concrete-to-concrete joints that prevent any relative movement across the joint. They are commonly used when there is discontinuous placement of concrete and successive pours are allowed to harden beyond the initial set; or at the end of the working day. They may also be necessary if unforseen events (for example delays in delivery, pump breakdown or bad weather) interrupt a pour.

Most house slabs are placed and finished in the course of a day, obviating the need for construction joints.

6.4.6 Slab proportions

Concrete slab sections bounded by joints should be as near to square as possible; the rule of thumb is that the length of the longer side should be no more than 1.5 times the length of the shorter side.

Acute angles should be avoided as these are difficult to reinforce and increase the risk of cracking and/or breaking off the tapered section of concrete even under light loads. With all joint types, the angle formed at edges and intersections of joints should not be too acute. A good detail in these situations is to keep at least 500 mm of the joint at more than 75° (and preferably at right angles) to the slab edge **Figure 6.14**.

6.4.7 Joint spacing

In unreinforced slabs, the rule of thumb is that joints should be placed at no more than 30 times the slab thickness, and as mentioned above, so that the longer dimension is no more than 1.5 times the shorter dimension. For example: 75-mm-thick footpaths should have transverse control joints spaced no more than 30 x 75 = 2250 mm apart. However, if the path is only 900 mm wide, the spacing of control joints is limited to 900 x 1.5 = 1350 mm to control the shape and minimise the risk of cracking. If the slab was 100-mm-thick, while the maximum spacings between joints could be increased to 3000 mm, the 1350 mm length would still govern the joint spacing.

When a slab is reinforced this distance can be increased slightly, depending on the type and amount of reinforcement.

Longitudinal joints are recommended when the slab is wider than 3 m, for example wide driveways or terrace pavements.

6.4.8 Joint locations

In concrete flatwork the layout of joints is very important. Wherever possible, the location of joints should be planned. Joints can be transverse or longitudinal, but are predominantly transverse in residential work such as paths and driveways due to their limited width **Figure 6.15**.

6.4.9 Joint maintenance

The long-term performance of joints is crucial to long-life pavements. Dirt must be kept out of those joints intended to allow movement. While silicon and polyurethane sealants are long lasting, some maintenance and occasional replacement will be required to ensure the joints keep performing as intended.

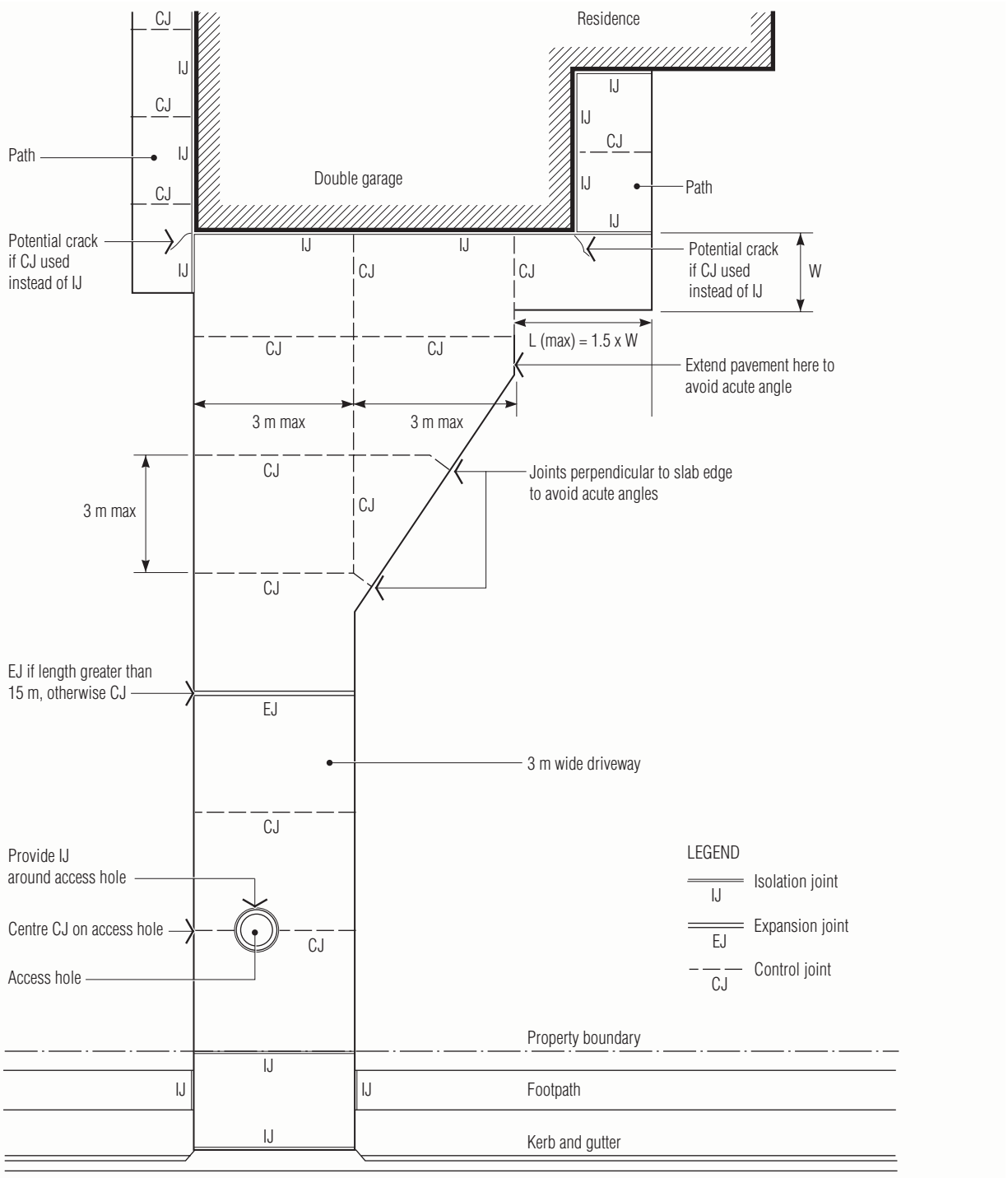


Figure 6.15 Typical joint layout

Footing Types

07

7.1 GENERAL

A variety of standard designs for footing systems are provided in Section 3 of AS 2870. The choice of footing system can be one of preference based on local experience, or it may be based on particular site conditions.

The standard designs cover various types of foundation soils including Class A, S, M, and H. Class A sites display little or no ground movement, Class S are slightly reactive sites, Class M moderately reactive sites and Class H highly reactive sites. As the reactivity (seasonal movement caused by moisture changes) of the soils increases, the footings need to be stiffer (deeper beams, more reinforcement, closer beam spacing) to enable the footing to limit the deflection of the building caused by the ground movement.

Different building materials can accommodate different amounts of deflection (movement). The more rigid the building material, the less deflection it can accommodate before cracking and hence the stiffer the footings need to be. This is why the footing system varies within each site classification depending on the type of construction used for the walling: clad frame being the most flexible and full masonry the most rigid.

For each site classification, the standard designs in AS 2870 give deemed-to-satisfy solutions to meet the requirements of the Building Code of Australia. However, the selection of a suitable design and the detailing of slabs and footings are increasingly being undertaken by geotechnical or structural engineers to ensure compliance with all detailing issues and suitability of the building to a 'standard' design. For example, many site-specific issues such as extremely reactive soils, some filled sites, mine subsidence areas and sites with abnormal moisture conditions will place the design outside AS 2870 and require special assessment, design and detailing. Buildings can also contain heavily loaded areas (eg columns, chimneys) for which the footing's suitability may need to be assessed.

The term 'slab-on-ground' is adopted in AS 2870 (and in this guide) and refers to concrete slabs supported by the ground and incorporating integral edge beams. 'Stiffened raft', 'waffle raft' and 'stiffened slab with deep edge beam' are all types of slab-on-ground footing systems included in AS 2870.

7.2 STIFFENED RAFT

A stiffened-raft floor slab (**Figure 7.1**) has the slab plus all external and internal stiffening beams placed at the same time to form a single concrete element. Internal beams must be continuous from edge to edge of the slab, located to provide continuity with edge beams at re-entrant corners and have the maximum spacing given in Figure 3.1 of AS 2870. For Class M and H sites the maximum spacing from the corner of the slab is limited to 4 m in order to control deflection (and cracking) of the walls at the corners of slabs.

A stiffened raft is one of the most common footing systems used as it offers a cost-effective solution for a wide range of ground conditions.

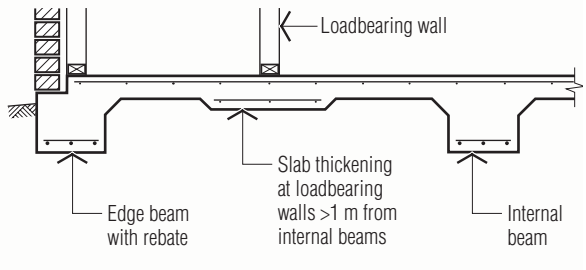


Figure 7.1 Stiffened raft

7.3 WAFFLE RAFT

Waffle rafts (**Figure 7.2**) are constructed on level sites using cardboard or polystyrene void formers to produce a closely-spaced grid of reinforced concrete ribs. Site preparation is minimized because the concrete is placed on forms rather than in excavated trenches.

This system avoids occasional, unintended, over-excavation when trenching, enabling the required quantities of concrete and reinforcement to be assessed more accurately. Construction on a level site also reduces the risk of delays due to wet weather (eg water filling trenches) and excavation. Another advantage with waffle rafts is that for one-storey houses constructed with clad frame or masonry veneer walls on Class M, M-D, H or H-D sites, the rafts may be supported on piers without further structural design of the raft being required. These advantages have been responsible for a significant increase in the proportion of these types of footings used.

However, some points need to be considered:

- The practice of joining either two or more void formers together is not covered by the standard and places the design outside the deemed-to-comply requirements. With less ribs to stiffen the footing, any alternative design should ensure that the deflection of the building/structure is appropriate for the site conditions and will still allow an acceptable performance to be achieved.
- The replacement of top mesh with polypropylene fibres in the concrete is also not covered and places the footing system outside the scope of the standard.
- As these types of footings are constructed on a level site, there is usually a requirement to backfill around the edges to raise the ground level. Backfilling should be carried out carefully to avoid water ponding at the base of the raft, particularly for moderately and highly reactive sites. This will cause edge heave (swelling of reactive soils) and may result in damage to the building through excessive movement at the perimeter of the footing.

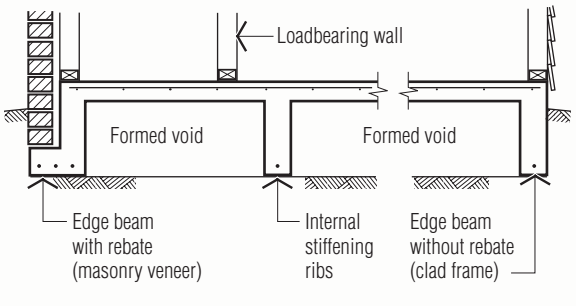


Figure 7.2 Waffle raft

7.4 STIFFENED SLAB WITH DEEP EDGE BEAM

Stiffened slabs with deep edge beams (**Figure 7.3**) are suitable for sloping sites where cut and fill excavation is not practicable, but are limited to masonry veneer and articulated masonry veneer types of walls on Class A, S and M sites. The system uses deep perimeter beams consisting of a concrete footing tied to a reinforced concrete wall above to achieve the stiffness required. The reinforced concrete wall can be formed up using two leaves of brickwork with the concrete placed between them, or by using masonry blocks which can be filled with concrete.

Any fill required under the slab has to comply with the requirements for either a controlled or rolled fill depending on the depth of fill and loads to be supported on the slab above.

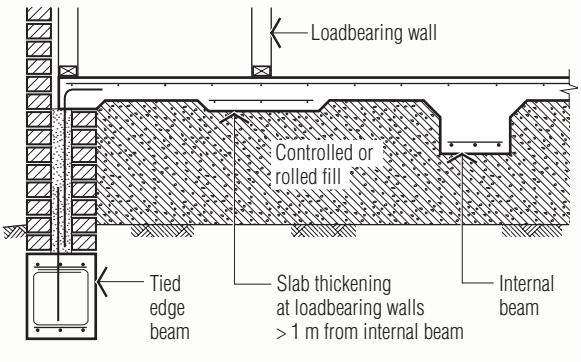


Figure 7.3 Stiffened slab with deep edge beam

7.5 FOOTING SLAB

The footing slab (**Figure 7.4**) is cast on the ground in two stages: the edge footings first, followed by the slab. Footing slabs are suitable only for Class A and S sites as moderately and highly reactive sites may cause problems with differential movement between the footings and the slab. For class A sites having little to no ground movement the tie bars between the footing and slab (**Figure 7.4**) may be omitted along with the reinforcement in the footings: footings being required only to distribute wall loads onto the foundation.

This method reduces the length of time excavations are open and does not require extensive formwork. The footing-slab system can be adapted well to sloping-site applications.

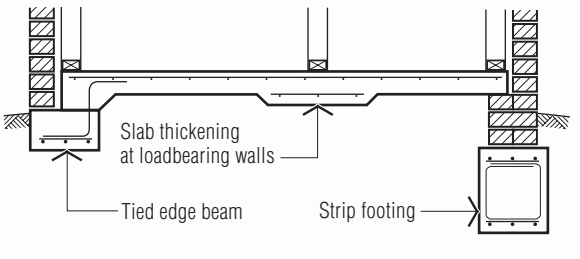


Figure 7.4 Footing slab

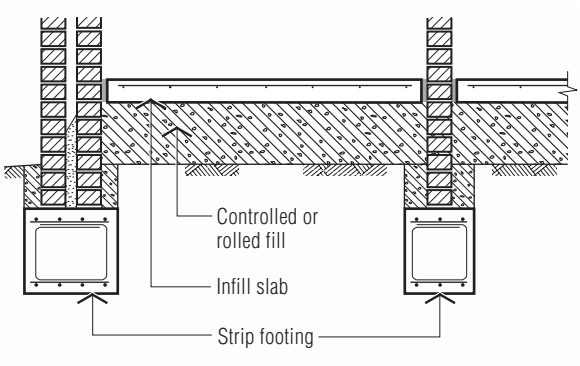


Figure 7.5 Strip footing

7.6 STRIP/PAD FOOTINGS

Strip footings (**Figure 7.5**) are rectangular in section and are used for continuous support of walls. Floor slabs between walls can be supported on controlled or rolled fill depending on the depth of fill and loads on the slab.

Pad footings are used to support piers, columns or stumps. Strip and pad footings can be used together to support a range of suspended flooring systems for sloping sites.

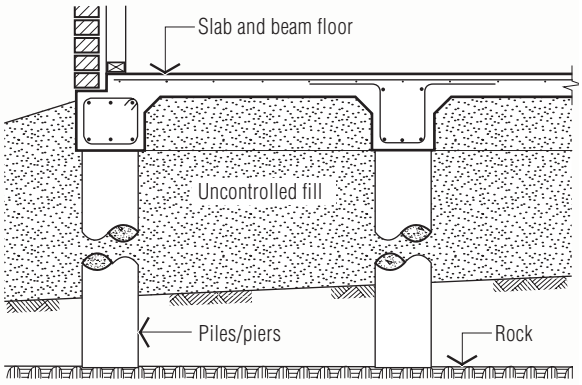


Figure 7.6 Pier/pile and slab footing

7.7 PIER/PILE AND SLAB

On extremely reactive sites, and areas of collapsing or uncontrolled fill, piers or piles can be used to support a concrete slab-and-beam floor system (**Figure 7.6**).

Piers are poured, after excavation, whereas concrete piles are driven into the ground to a specified depth or until reaching a specified level of resistance. Section 15 of AS 3600 (Plain Concrete Members) covers the design of unreinforced bored concrete piers and Appendix G of AS 2870 gives information on the design of driven timber piles. The piles are cut off at the required level to suit the floor system. For waffle raft slabs supported by piers/piles in accordance with AS 2870 refer to **Section 7.3**. For other footing types, the provision of piers/piles may change the structural concept and the footing design may need to conform with the requirements of AS 3600.

Paths and Driveways

08

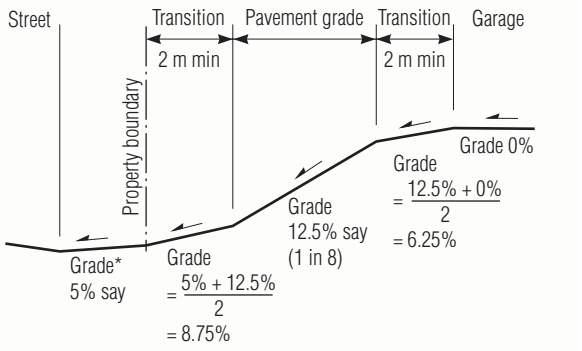
8.1 GENERAL

The primary function of concrete paths and driveways is to provide easy access onto or around a property. However, they are also important to the general appearance of the property, and the surface finish must therefore not only contribute to the appeal of the property, it must satisfy a number of functional requirements.

8.2 PLANNING

Prior to undertaking construction, a number of aspects need to be considered:

- **Pavement grades** The maximum grade allowed in AS 2890.1 for a domestic driveway is 1 in 4 (25%). For grades steeper than 12.5%, a transition zone at the top and bottom of the grade may be required to prevent the vehicle from 'bottoming' on the driveway **Figure 8.1**. For steeply sloping sites, driveway grades and details should be checked prior to finalising the level of the garage to ensure that suitable access can be provided once the house/garage has been completed.
- **Drainage** Pavements should generally drain away from the building, or where this is not possible, be provided with adequate drainage to prevent flooding of the garage/building. The minimum grade or crossfall to allow for drainage of the surface is 1 in 100 (1%) or 10 mm per metre.
- **Trees** Trees can cause soil movements by either removing moisture from the soil resulting in shrinkage of reactive soils or by roots growing under pavements and locally lifting a section of pavement. Pavements near/adjacent to trees may require some maintenance in the future to correct levels.
- **Adjacent structures** Pavements are often located next to buildings or other structures. The finished level of the pavement should not be above the finished level allowed in the BCA (relative to the floor level of the building), conceal any sub-floor ventilation holes in brickwork or weep holes above flashings/damp-proof courses, or restrict any termite inspection zones.
- **Surface finish** The surface finish should provide adequate slip and skid resistance, while being suitable for the application. For example, a highly textured surface providing excellent slip resistance may not be appropriate for barefoot traffic around a swimming pool. A relatively smooth surface having adequate slip resistance is preferable.



* The advice of the Local Authority should be sought to obtain grade requirements for the area between the street and property boundary.

Figure 8.1 Transition zones for driveways

8.3 DESIGN

Design issues relating to residential pavements are relatively simple.

- **Concrete** The loads and durability requirements of the pavement determine the concrete thickness and strength grade **Table 8.1**. A '**N**ormal' class concrete with a minimum strength of 20 MPa (ie N20 concrete) is suitable for most residential work. To assist with placement, a 100-mm slump is recommended.

  A higher strength may be necessary if freezing and thawing conditions are expected: N32 for occasional exposure to freezing, and N40 where more than 25 freezing cycles occur each year. If salinity is present in the soil, an N25 concrete is recommended for moderately saline soils, N32 for very saline soils and N40 for highly saline soils (refer to *Guide to Residential Slabs and Footings in Saline Environments* (T56) by the CCAA for more information).

- **Reinforcement** The purpose of reinforcement within a pavement is not to prevent cracking but hold tightly closed any cracks that may occur. The size of the reinforcing mesh essentially depends on the thickness of the concrete Table 8.2. Note that polypropylene fibres are no substitute for the required steel reinforcement but may assist with plastic shrinkage cracking.

  For some decorative concrete finishes, increasing the mesh by at least two sizes (ie SL52 to SL72, SL62 to SL82 and SL72 to SL92) may be an option to further reduce the width of any cracks that may occur from causes such a drying shrinkage, ground movement and tree roots.

- **Joints** Providing joints in accordance with Section 6.4 will assist to minimise the risk of drying shrinkage cracking. For decorative finishes, joints should be located to blend in with the pattern wherever possible.

- **Surface tolerances** Both the flatness and levelness of the surface should be specified. A reasonable flatness tolerance would be a maximum deviation or gap of 12 mm under a 3-m straightedge placed anyway on the pavement Figure 8.2. A reasonable level tolerance would be ±10 mm from the designed level or elevation. Note that while the general alignment and appearance of a driveway may be discussed with the concreter, levels are seldom given as they are set out by the concreter to provide a suitable alignment between the kerb and garage. Other pavement levels may be specified in relation to features such as door openings, flashings, damp proofing membranes and termite barriers.

  Note that if the flatness and levelness are not specified, the tolerances may be governed by perhaps more-stringent State or Local Government building regulation requirements.

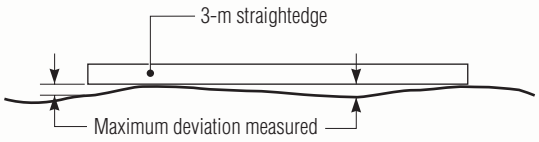


Figure 8.2 Measuring the flatness of a surface

Table 8.1
Concrete thickness/grade

Application	Concrete thickness (mm)	Strength grade
Footpaths	75	N20
Patios/garden-shed floors	100	N20
Cars and other light-vehicle traffic (less than 3 t)	100	N20/N25
Light trucks (3 to 10 t)	150	N25/N32*

** Where abrasion resistance is required*

Table 8.2
Reinforcement and joint requirements

Concrete thickness (mm)	Reinforcing mesh	Maximum joint spacing (mm)
75	SL52	2250
100	SL62	3000
150	SL72	4500

8.4 CONSTRUCTION

The main issues to consider include:

- **Planning for concreting** Before ordering concrete, careful planning will ensure the concrete is transported, placed, compacted, finished and cured in accordance with the good work practices outlined in this guide.

- **Subgrade** A reasonably uniform foundation is essential to the long-term performance of a concrete pavement. Correct subgrade preparation ensures the concrete pavement alone does not carry the service loads. An assumption that a concrete pavement will bridge over poor subgrade could lead to a false sense of security Figure 8.3. The subgrade should be prepared by first removing topsoil containing roots and grass, and levelling the subgrade. Service trenches should then be backfilled and isolated hollows or soft spots filled or built up to the required finished ground level by compacting in layers no more than

100 mm in depth. Subgrades for slabs must have adequate strength after compaction with a plate compactor or a vibrating-drum roller. Note that clay soils need to be moist for optimum compaction.

Unstable, or filled sites with inadequate compaction, should be thoroughly investigated by a geotechnical or structural engineer before design and construction.

- **Subbase** On highly expansive soils, a 100-mm-thick layer of low-volume-change soil or material (eg roadbase) is recommended to minimise moisture changes (and movement) in the expansive foundation soil. It also provides a more uniform support for the slab.
- **Reducing friction under the slab** Providing polythene sheeting or a 20-mm-thick layer of sand beneath the pavement is an effective way of reducing the friction between the slab and supporting ground and thereby minimising the risk of cracking.
- **Jointing** Joints are an essential part of any pavement to allow for movement and to control the location where shrinkage cracking occurs. Recommendations for joint types, spacing, detailing and layout can be found in **Section 6.4**.
- **Formwork** Formwork should be strong and true to line. The accuracy of the formwork will be reflected in the finished line of the hardened concrete. By placing the top edge of the form boards at the finished level of the pavement surface, screeding can be efficiently done using the form edge as a guide. Form boards should be thick enough and securely fixed so they do not bend or move when placing concrete. Formwork should be constructed with care so it is easily removed when the concrete has hardened. A light coating of form oil before placing concrete will make removal easier.

  It is good practice to leave formwork in place for a minimum of 3 days (depending on weather conditions) to allow concrete to harden and become self-supporting.
- **Reinforcement fixing** Reinforcing mesh should be located in the top half of the pavement, with a minimum 30 mm cover to the top surface. Mesh should be spliced and fixed in position, refer to **Section 5.4** and **Figure 6.12**.
- **Concrete** Factors to be considered when placing, compacting, finishing and curing concrete can be found in **Section 4**. Basically:
  - No excess water should be added to the concrete on site.
  - Any water ponding on the ground should be removed.
  - Placing should commence from one corner (usually the lowest point) and proceed continuously out from that point.
  - concrete should be placed as close as possible to its final location,
  - Concrete should not be placed in temperatures above 30°C or below 10°C without precautions being taken.
  - In hot weather conditions, especially if it is also windy, an evaporation retarder such as aliphatic alcohol should be used after screeding.
  - Concrete depths greater than 100 mm should be compacted using immersion (poker) or surface vibrators (vibrating screeds) or both.
  - Finishing should not commence until all bleedwater has evaporated from the surface.
  - Curing should commence as soon as possible after finishing and extend for a minimum period of 3 days; 7 days if located near the coast (within 1 km) and/or subject to heavier traffic. Care in selecting the curing method for decorative finishes should be taken.
- **Slip and skid resistance** Slip resistance relates to pedestrians and skid resistance to vehicles. In terms of the concrete surface, the requirements for both will be affected by the use of the pavement, its steepness, and the effectiveness of its surface drainage.

  Slip resistance for residential applications is generally specified by nominating a classification in accordance with the wet pendulum test in AS 4586. For guidance on which classification method and class of finish is appropriate, Standards Australia's HB 197 contains recommendations for a variety of applications including pool surrounds, sloping pool edges and walk-through wading pools.

  For external areas, a Class W slip resistance in accordance with the wet pendulum test is normally adequate. While caution should be exercised in selecting generic types of finishes capable of achieving a Class W finish (as each

surface can vary), finishes such as stencilled, stippled, broomed, wood float, hessian drag, exposed aggregate and honed (80 to 100 grit with penetrating type sealer) should give satisfactory results and comply with the requirements for a Class W slip resistance. Some smoother stamped finishes (slate and cobblestone) may not have sufficient surface texture and require the use of an applied sealer incorporating silica or carborundum dust, or some other type of slip-resistant aggregate.

Class W slip resistant surfaces will normally provide satisfactory skid resistance as well. Having a coarser texture for vehicle surfaces generally becomes important only at higher speeds or to provide adequate drainage during heavy rainfall.

As the slope of the driveway or pavement increases, so to will the need to provide greater slip/skid resistance. Depending on the slope, the slip/skid resistant properties of each type of finish may need to be evaluated.

Improving slip/skid resistance is relatively simple. Abrasive blasting, acid etching, grinding, application of non-slip clear sealer/coating and regular maintenance to ensure that the surface is clean are some of the options.

- **Protection against staining** Sealers, clear and tinted, prevent most contaminants penetrating the concrete surface and help with cleaning the surface. Coloured paints and other coatings, suitable for the concrete and the conditions, can also be applied to the surface. Some points to consider include:
  - For smoother finishes, a penetrating type sealer should generally be used. Depending on the slope the choice of a suitable sealer could be critical to the slip/skid resistance. A slip-resistant aggregate may need to be incorporated into the sealer.
  - Water- and acrylic-based sealers plus silicone sealers are suitable for exterior use (UV resistant) but once silicon products are used, bonding anything else to the surface will be a problem. Waxes, urethanes and epoxy products (along with acrylics and silicones) are suitable for interior applications.
  - Concrete surfaces are often subject to abrasion by vehicular and pedestrian traffic. For residential applications, most water- and acrylic-based sealers will provide satisfactory performance.
  - The use of a low-odour (water-based) sealer for confined areas or where adequate ventilation is not possible is recommended.
  - Sealers are not curing compounds, but may function in a similar way. They should be compatible with the curing compound used (if different from it) and allow for bonding of other surface coatings/treatments if required.
  - They should be applied after the curing period to enable them to penetrate into the surface without interfering with the curing process.

Figure 8.3 Poor subgrade may cause cracking of pavement

Concrete Finishes

09

9.1 COLOURED CONCRETE

9.1.1 Introduction

Colour can be provided in floors and pavements by using off-white and white cements in the concrete, mineral oxide pigments, dry-shake toppings, chemical stains, dyes and tints, a range of coloured surface coatings or by exposing the colour of the aggregates within the concrete.

Which method is used depends on factors such as the colour required and its consistency over the surface, the durability of the colour, whether patterns are required, if an existing concrete surface is to be coloured and whether the surface is vertical or horizontal.

9.1.2 Cement colour

Using off-white or white cement instead of the normal 'grey' cement can change the colour of the concrete.

Off-white cement is manufactured in Australia and is often used for architectural finishes as it tends to give a more consistent colour—not because the colour of the cement is controlled, but because any variations in the shade of off-white colour produced in the concrete are less noticeable. Note that there may be many different shades of off-white colour, so if colour and also consistency of colour is important, the use of a pigment is recommended. Also, to achieve more vibrant colours from pigments, off-white cement is usually required. Normal 'grey' cements tend to give the darker more earthy colours when pigments are added.

White cement is imported to Australia and this is reflected in the higher cost. An alternative is to use off-white cement with a white titanium oxide pigment. The pigment both brightens and gives a more consistent colour.

If off-white cement is required in concrete, the availability should be checked with the concrete supplier. Smaller plants often will not have an additional silo available to stock off-white cement, but one plant in a group of plants may have the capacity to supply off-white concrete to the region.

9.1.3 Coloured concrete (integral colouring)

Integral colour refers to the addition of pigments (colours) to the concrete or topping mix in order to colour the entire volume of concrete/topping. Pigments are available as either powders, granules which dissolve, or liquids. Powders are generally added into the concrete truck in bags which dissolve during mixing, while liquids are often used at major batching plants as they avoid dust and can be connected to automated batching equipment for accurate measurement of quantities.

Naturally occurring or manufactured inorganic mineral oxides may be used: the latter known as synthetic iron oxides. Most colours (reds, yellows, browns and blacks) are oxides of iron. Some colours such as blue, green and white may be more expensive due to the manufacturing process to produce these special metal-oxide pigments.

Pigments are ultra-fine particles a fraction of the size of cement particles. They become bound into the cement matrix in the same way as other aggregates within the concrete mix. Similar to exposed aggregate finishes where the predominant colour is that of the aggregates, pigmented concrete takes on the colour of these very fine particles (or aggregates) that are exposed at the surface of the concrete.

As pigments are made from metallic oxides or materials in their most basic form, there is no mechanism for them to degrade or change colour over time. Pigments are not affected by the sun's ultraviolet rays, are light fast (eliminates fading) and once bound into the concrete matrix they provide a permanent colouring solution. They are also insoluble (prevents leaching out), chemically inert (do not interfere with the cement reaction), alkali resistant (suitable for concrete which has high alkalinity) and harmless to the environment,

In correct proportions, oxides do not have a significant affect on the strength of concrete. The amount of oxide powder required will generally be 5–8% of the weight of the cement in the mix. For best results, a colour should be selected from a manufacturer's/supplier's colour chart and their recommendations followed regarding pigment requirements for particular mixes.

After placing, the concrete surface is screeded, floated and finished in the same way as ordinary concrete. Particular care should be taken with curing to produce the best finish.

For uniform colour, every aspect of the concrete and its method of placement, finishing and curing should be consistent, including the mixing procedure. Sample panels are useful to find the right mix, and provide the basis for quality control. Because an exact colour match from batch to batch is difficult, borders of different colours or concrete pavers, can be used to divide large areas into smaller more manageable sections which can be placed from a single batch. This helps to mask any minor colour variations, or create pleasing patterns.

9.1.4 Dry-shake toppings

Dry-shake toppings are commercially available products containing cement, sand, and pigments, and in some cases, special hardeners to increase the strength of the finished surface (they are therefore sometimes referred to as 'coloured surface hardeners'). They come in a range of colours and are often used in conjunction with stenciled and stamped pattern finishes (refer **Section 9.2**).

Dry-shake toppings can also be made on site from similar materials. The mineral oxide pigment is measured by weight in the ratio of 1 part pigment to 10 parts cement. The powdered pigment is first blended with dry cement before combining with the sand in the usual blend of 1 part cement to 2 parts sand by volume.

The dry powder is cast by hand over the surface (hence the term 'dry-shake') of the fresh concrete (**Figure 9.1**) and worked into the surface by trowelling. All traces of bleedwater must be allowed to evaporate before applying the powder. Using the powder to soak up bleedwater is bad practice, and invariably results in a much weaker surface, which will wear quickly, and may dust, delaminate or chip. The rate of application of a dry-shake topping for flatwork will typically be a minimum of 2 kg/m^2.

Coloured surface hardeners are usually cement-based products and must be finished and cured like any concrete work to achieve the potential strengths.

When using dry-shake toppings it is important to protect adjacent surfaces, with plastic sheeting for example, because splashes are difficult to remove.

The application of dry-shake toppings is as follows:

- Evenly broadcast the dry-shake topping (coloured surface hardener) over the surface in two stages to ensure uniform colour and thickness. Usually two thirds is applied for the first coat, and one third for the second, which should be applied in a direction perpendicular to the first. Each coat is thoroughly worked into the surface by trowelling.
- Apply topping colour or highlight flecking if required, while the surface is still plastic to ensure bonding.
- For dark colours such as charcoal (black), it may be advisable to apply a third coat for more even colour distribution.

Figure 9.1 Dry-shake topping being applied

9.1.5 Chemical stains

Chemical stains react with the excess calcium in the concrete to produce products that permanently colour the concrete. They typically produce a unique mottled finish due to the variability with which they penetrate into the concrete **Figure 9.2**. Two or more colours are often used to produce mottled finishes resembling stone or to create patterns **Figure 9.3**.

Because chemical staining is often considered as an afterthought, or as a solution for existing concrete, the required preparation to achieve a good-quality finish is usually missing and the outcome may be disappointing. Colouring concrete by the use of chemical stains may appear simple, but in fact requires careful planning and a high level of skill in its application to achieve a good result. Often it may be better to place a thin bonded topping (refer **Section 10**) over the existing slab and apply the stain to this as the topping and hence coloured finish from the stain will be more consistent. It also avoids having to protect the surface prior to the application of the stain.

As chemical stains react with the concrete constituents, they should not be applied until the concrete has achieved its design strength. Release agents and curing compounds can also affect the rate at which the stain will penetrate into the concrete surface.

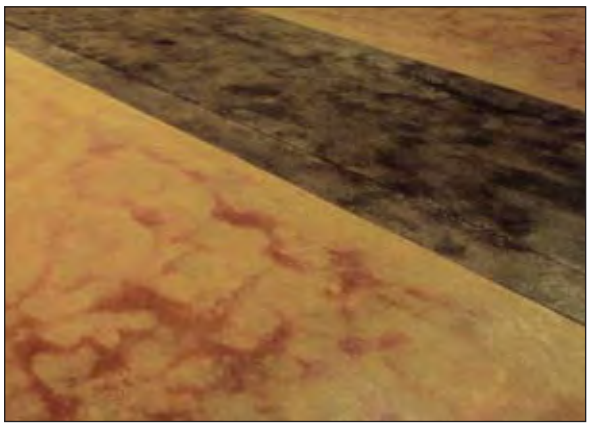


Figure 9.2 Mottled finish produced by chemical stains

Figure 9.3 Chemical stains used to create patterns

Figure 9.4 Chemical stains can pond on flat surfaces to allow good penetration

The use of chemical stains suits flatwork construction as the product can be ponded on the surface to allow good penetration into the concrete **Figure 9.4**.

Staining of large areas and those with flat or smooth finishes is best carried out using spray equipment to avoid brush or roller marks, unless specific patterns are required. Coarser textured finishes such as stamped surfaces will tend to conceal brush and roller marks.

9.1.6 Dyes and tints

Dyes and tints contain coloured particles in either a water or solvent solution and can produce colours that are not available with chemical stains, eg red and yellow **Figure 9.5**. Dyes have very fine coloured particles and will penetrate into the concrete producing mottled finishes similar to chemical stains. Tints have larger particles, are opaque and remain on the surface of the concrete: the flowers in **Figure 9.5** are an example of the opaque finish achieved.

Unlike chemical stains, dyes and tints do not react with the concrete. This makes the results more predictable and less dependent on the consistency of the concrete or the weather conditions. For this reason they can be used to correct the results from chemical staining by colouring areas where the stain did not provide the required colour, or areas where the stain created a colour that was darker or different than intended.

Dyes and tints produce strong vibrant colours and along with other colouring options, extend the palette of colours possible into a vast range of colouring solutions for both large and small projects.

The UV resistance, and hence the ability to use the product externally need to be established for each dye or tint.

Figure 9.5 Dyes and tints produce strong vibrant colours not possible with stains – red, yellow and orange. Chemical stain used for mottled green background and patterned border.

Figure 9.6 Dark blue areas are a coloured cement-based micro-topping approximately 1 mm thick trowelled onto the surface. Light blue colour is from dye washed over the surface.

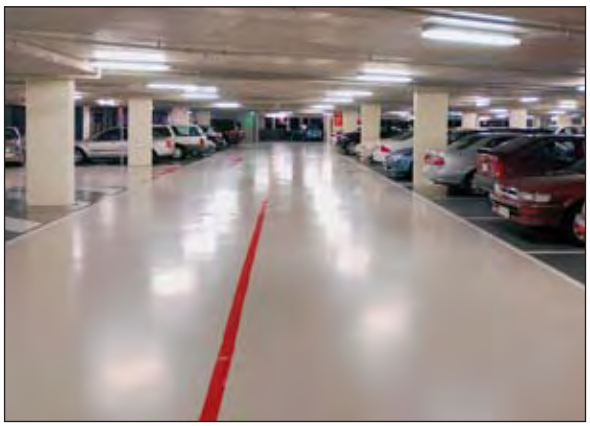


Figure 9.7 Coating used in garage area to provide uniform colour, delineate areas, protect surface and facilitate cleaning

9.1.7 Surface coatings

Coatings range from various paving paint, urethane, epoxy or other chemical sealers and products to coloured cementitious materials that provide similar results to insitu coloured finishes but with improved colour consistency. Ultra-thin cementitious coatings are often referred to as micro-toppings **Figure 9.6**.

Unlike coloured concrete finishes or the use of stains and dyes which typically give some colour variations, coatings provide a uniform colour over the entire surface **Figure 9.7**. Reasons for their use may include colour variations being unacceptable, to simplify the creation of patterns, achieve particular colours, protect the surface from abrasion or staining and assist with cleaning. With adequate thickness they will conceal the substrate and, depending on the type of product used, may provide a moisture and/or chemical barrier to the concrete. This may extend the design life of the concrete element.

If a combination of paint/coating and sealer are required, the products should be compatible. The manufacturer should be consulted to ensure that a compatible paint or coating plus sealer system is specified.

As any product applied to the surface of a concrete pavement will be subject to wear, coatings may need to be re-applied some time later to reinstate the desired appearance.

9.1.8 Exposed aggregates

The colours of aggregates (sand and stones) can provide permanent colour in exposed-aggregate finishes, but the range of colours will be limited by the available aggregates **Figure 9.8**. Exposed aggregate finishes are discussed in **Section 9.3**.

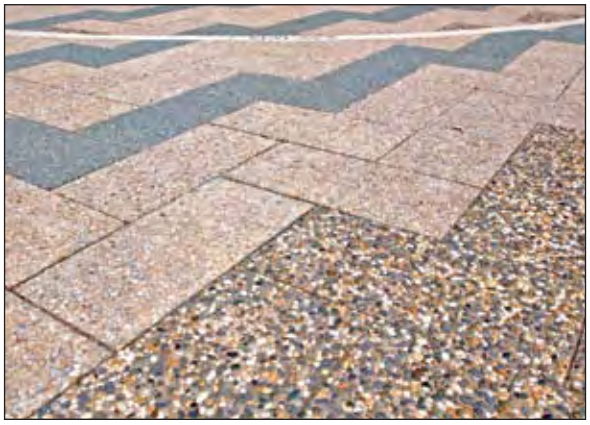


Figure 9.8 Colours from different aggregates

9.2 PATTERNED CONCRETE

9.2.1 Introduction

Stiff-bristle brooms, wood floats and sponges have been used for many years to create surface textures and patterns on concrete pavements. More recently, purpose-made rubber moulds and metal dies have been developed to stamp impressions in the concrete surface; while cardboard stencils are used to produce many patterns when dry-shake toppings are sprinkled over them.

The techniques are simple, but must be well planned to take advantage of the short period when concrete is workable. Ordering ‘low-bleed’ concrete shortens the waiting time for bleedwater to rise to the surface and evaporate, in effect giving more time for finishing. The addition of polypropylene fibres, which can help bind a mix and reduce bleeding could also be considered.

Good curing practice is crucial to the appearance, and the service of the pavement.

Figure 9.9 Placing and embedding the stencil into the 'wet' concrete

9.2.2 Stencilling

Stencilled patterns are made by altering the surface of the concrete pavement after the concrete has stiffened, but before it has hardened. The process for stencilling is relatively simple; however, the timing of each stage is critical to the success and durability of the finish.

With stencilling, cardboard stencils laid on the surface of the pre-hardened concrete (**Figure 9.9**) mask the surface from the subsequent application of the coloured material **Figure 9.1**. When the concrete stiffens the stencil is removed (**Figure 9.10**) producing a coloured pattern with grey joints—the colour of the base concrete.

There are a variety of patterns resembling brick bonds, stone or random paving. The surface finish can also be varied with brooms for example, which produce coarse textures that improve slip resistance on steep grades.

The procedure for stencilling concrete is as follows:

1 **Protect adjoining surfaces.** Stains caused by fine oxides and cement are difficult to remove. Use protective plastic sheeting to stop splashing of adjoining surfaces such as glass, aluminium or timber during placement **Figure 9.9**.

2 **Place the concrete slab.** Place, screed, bull float and trowel the concrete to its final level.

3 **Lay the stencils.** Points to note include:
   - Wait until all bleedwater has evaporated before placing stencils.
   - Features such as rosettes or motifs are normally placed first, followed by borders and finally the main stencilled area is placed and cut in around other items.
   - Carefully work the stencil into the surface with a roller or a trowel.
   - Stencils placed on concrete that is too wet may become embedded too deeply and will be difficult to remove, resulting in uneven grout or 'joint' line depths.
   - Stencils that have not been adequately embedded or are not well bonded to concrete will tend to adhere to the applied colour, leaving ragged outlines when removed. The colour may also creep underneath the stencil and stain the 'joint' lines. Evaporation retarders such as aliphatic alcohol can be used to increase working time, and help keep the surface of the concrete plastic during drying conditions.
   - When placing and aligning stencils it is good practice to lift them, rather than drag them into position.
   - Shrinkage control joints in stencilled concrete can be 'wet-formed' such as tooled joints (grooves) or key joints, or 'hard-formed' such as sawn joints (see **Section 6.4.4**). Wet-formed joints are best placed under a stencil 'joint' line so that they are not repeatedly trowelled over.

4 **Apply coloured surface hardener.** See **Section 9.1.4** *Dry-shake toppings*.

5 **Apply surface texture.** While the surface is still plastic it can be lightly textured by brooming, wood floating, sponging, or hessian-drag to give a more slip resistant finish **Figure 9.11**.

6 **Remove the stencils.** The stencil can be removed once the concrete surface has stiffened sufficiently. Note that this phase of stiffening or setting is 'drying', rather than curing. The time at which the stencil is lifted is very dependent on the weather conditions.

   After the stencil has been removed, clean off any debris with a leaf blower rather than with high pressure air and avoid walking on the concrete with heavy or industrial footwear. If necessary the leaf blower can be attached to a long pole for greater reach.

Figure 9.10 A stencil being removed

Figure 9.11 Surface texture

Figure 9.12 Sealing the surface

7 **Cure the concrete.** Curing is required to produce optimum results. While plastic sheeting and curing compounds provide the most practical methods, like other conventional curing methods (see **Section 4.5**) they may be unsuitable for this type of finish and are generally not recommended. The wrinkles in plastic sheeting can cause colour variations due to uneven contact with the surface and curing compounds may affect the adhesion of the sealer. For these types of finishes a same-day-sealer is therefore often used.

   While not as efficient as curing compounds, same-day sealers (see below) will slow down evaporation and may offer a reasonable degree of curing depending on their efficiency at retaining moisture. Same-day sealers may retain up to 70 to 80% of the moisture within a concrete slab compared to the 90% required of a curing compound. Note that curing should not be confused with drying.

8 **Seal the surface.** Sealers are applied to protect the surface from contaminants such as oil spills because they are difficult to remove without the cleaning compounds or solvents required affecting the colour **Figure 9.12**.

   Most sealers cannot be applied to moist concrete without problems such as the sealer turning a milky-white colour. Special same-day sealers are available which can be applied to the 'set' surface of the concrete while the concrete is still 'moist'. They are generally not as effective as normal sealers or curing compounds for retaining moisture in the slab, but are a satisfactory alternative.

   The use of same-day sealers should be followed with an application of the final sealer after the curing period. Although this is not the best curing regime, it minimises initial moisture and surface strength loss.

9.2.3 Stamped concrete

The procedure for stamping is similar to that for stencilling. After placing and screeding the concrete it is left to stiffen, and the bleedwater is allowed to evaporate before the application of any dry-shake toppings.

After the application of colour, the pattern is stamped in the surface with metal moulds or rubber mats. Many finishes resemble stone paving: slate-like patterns have shallow impressions, whereas those resembling natural stones or rocks have deep impressions.

To better resemble natural stone, stamped pattern concrete often combines two or more colours.

The procedure for stamping concrete is as follows:

1 **Protect adjoining surfaces** Stains caused by fine oxides and cement are difficult to remove. Use protective plastic sheeting to stop splashing of adjoining surfaces such as glass, aluminium or timber during placement.

2 **Place the concrete slab** Place, screed, bull float and trowel concrete to its final level.

Note that the thickness of a stamped concrete slab is measured from the bottom of the impression to the underside of the slab. This is important as the strength or load-carrying capability of the paving depends on the minimum concrete thickness and not the average thickness. For example, if the slab thickness needs to be 100 mm, and a 15-mm deep stamp is used, the formwork will need to be set at 115 mm to ensure the minimum thickness is achieved. This will also ensure sufficient cover and protection for the reinforcing mesh.

3 **Apply coloured surface hardener**
See **Section 9.1.4** *Dry-shake toppings*.

The use of integrally-coloured concrete as the base colour may give the paviour more time to apply highlight colours, and stamp the surface, which is helpful in drying conditions.

Evaporation retarders can be used to increase working time, and help keep the surface of the concrete plastic during drying conditions. They also have an added benefit of reducing the incidence of plastic shrinkage cracking. They should be re-applied each time the surface is worked and during extreme drying conditions. They should not affect the colour, and will generally aid in the finishing operation.

4 **Apply surface release agent** After the application of the base colours, a coloured release agent is applied **Figure 9.13**. The surface release agent has two purposes:

- It prevents concrete adhering to the stamping mould and ruining the appearance of the pattern.
- It serves as a highlight colour, creating a variety of two-tone effects.

Release agents come in a range of colours to match the base surface hardener colour. Stamping with sufficient pressure will ensure an adequate bond of the coloured release agent to the base coats, which is why the highlight effect generally occurs in deeper joints and impressions.

Note that the surface release agent is not a curing agent.

A thin film (about 1.0 mm) of clear polythene plastic can be used as an alternative bond breaker but may interfere with the stamping of some textures. It is placed over the prepared concrete before stamping, preventing the concrete sticking to the moulds **Figure 9.14**.

5 **Stamp the surface** It is always necessary to plan the stamping sequence to produce a good result where the pattern meets walls and fixtures and extends over joints. In many cases hand pads and hand-held jointing or ironing tools will be required to complete the edges.

6 **Cure the concrete** The surface release agent does not allow the use of curing compounds as it prevents them bonding to the concrete surface. To avoid colour variations in uniformly coloured stamped work, there is generally no initial curing with polythene as uniform contact between the sheeting and concrete surface is difficult, if not impossible. In these cases the release agent is removed the next day, the surface is allowed to dry, and the sealer is applied. With two-tone finishes, minor variations in colour resulting from the use of polythene are less noticeable. With two-tone finishes, cure the concrete for a minimum of three days using polythene sheeting, then remove the release coat and apply the sealer.

7 **Remove the release agent** After curing, remove the release coat using high-pressure water or by scrubbing with a detergent-based wash (taking care not to damage the surface) **Figure 9.15**.

8 **Seal the surface** Apply surface sealers evenly with a broom or brush, using two or even three coats. Glass grit, carborundum dust or fine silica aggregate may be sprinkled over the final coat to provide a non-slip finish if required.

For steep driveways the sealer may need to be thinned down to allow it to soak into and key with the concrete surface, rather than remain as a thick layer on top as this may become slippery when wet.

Always ensure that the surface of the concrete is dry before applying the sealer. The concrete may have set and appear stiff, but it may not be dry. The premature application of sealers can result in moisture being trapped under the sealer film. This often causes surface imperfections, which will detract from the appearance of the project.

Figure 9.13 Applying release agent

Figure 9.14 Stamping concrete – slate and cobblestone textures

Figure 9.15 Removing the release agent

9 Joints (Refer also to **Section 6.4** *Joints*)

Points to note:

— Plan the layout of joints so they correlate with the grooves in the pattern.

— Wet-formed control joints can be tooled after stamping is finished, while the surface is still plastic—although this is difficult if the stamping makes deep impressions.

— Form key joints before placement. Key joints may interfere with stamping of deeper patterns.

— Install isolation joints against abutting structures before placement. Installing them after will probably damage the finish.

9.3 EXPOSED-AGGREGATE FINISHES

9.3.1 Introduction

Exposed-aggregate finishes can be produced by 'seeding' the surface of the concrete with selected stones, or by ordering a special mix (for the full depth of the slab or for a topping) which contains selected stones. They are exposed when the thin layer of cement mortar at the surface is removed soon after the concrete stiffens. A number of methods are available to do this including water washing (most common), abrasive blasting, acid etching and honing.

Aggregates are available in a range of colours including white, black and green quartz, dark grey basalt, brown and red gravels. Aggregates can also have various surface textures from smooth river gravels to coarse crushed rocks and come in range of sizes from 3- and 6-mm pebbles to large stones: the choice will depend on the application. The concrete can be coloured (see **Section 9.1**) to complement or contrast with the selected stones.

Sample panels are recommended to assess techniques, surface finish, distribution of stones and, if applicable, consistency of colour.

Exposed-aggregate finishes should be done under the supervision of a paviour experienced in these techniques.

9.3.2 Seeded aggregates

The procedure is as follows:

- Place the concrete, screed and bull float the surface to the finished level.
- After the bleedwater has dissipated, sprinkle the selected aggregate over the surface **Figure 9.16**. An aggregate size of 8–12 mm is recommended for ease of placement although sizes up to 20 mm can be used.
- The selected aggregates are fully embedded by tamping and by repeatedly working the surface with bull or wood floats.
- Aggregate exposure begins when the surface can bear the weight of the paviour without making surface impressions deeper than 2 mm. Use a medium-bristle broom, together with a continuous water spray, to wash away the cement mortar **Figure 9.17**. Do not broom the surface repeatedly as this will weaken the matrix and dislodge aggregates. Re-trowelling of the surface may often be necessary to tightly pack the aggregate particles for a better finish and the washing process repeated.

  The use of water-based surface set-retarders could also be considered. Those that are developed especially for this technique slow the setting time of the surface of the slab to a predetermined depth without affecting the set of the mass of the concrete. This ensures consistent depth of exposure. They are very useful when drying weather conditions would otherwise limit the time available for aggregate exposure.

  No more than one third of the stone should be exposed to allow adequate bonding into the concrete.
- After exposure, cure the surface by covering it with plastic sheeting for a minimum of 3 days (7 days is preferable).
- An acid-wash treatment (1 hydrochloric acid to between 10 and 20 parts water) is usually necessary to brighten up the stones by removing the fine cement film from the surface. Thoroughly wet the surface first to prevent acid soaking into the concrete and weakening the bond to the exposed aggregates, and rinse the surface with clean water afterwards to remove all residual acid. A surface sealer may be applied if desired.

Figure 9.16 Seeding the concrete surface with selected aggregates

9.3.3 Water-washing

The procedure is as follows:

- Order the special mix of concrete from the concrete supplier, containing the required proportions of the specified aggregates (colours and sizes), and pigments.
- Place the concrete, screed and bull float the surface to the finished level, ensuring even mortar coverage over the aggregate at the surface.
- Follow the steps for exposing the aggregate and curing in **Section 9.3.2**.

9.3.4 Abrasive blasting

Abrasive blasting uses either sand or grit to erode the surface cement mortar. Typical equipment is shown in **Figure 9.18 (a)** but variations that allow for recycling of the sand/grit are available. As the process is applied to hardened concrete the opportunity to trowel the aggregates to improve the appearance is not available and typically a mixture of fine and coarse aggregates will be exposed **Figure 9.18 (b)**.

The depth of removal should be specified, but as for water washing, the exposure should not be more than one third of the aggregate size to ensure adequate bond into the concrete.

9.3.5 Acid etching

Typically carried out under factory controlled conditions (**Figure 9.19 (a)**), the process may also be used on site to remove the surface cement mortar to varying depths. Acid etching is more commonly used to slightly roughen the surface to improve slip resistance, rather than expose the coarse aggregates as shown in **Figure 9.19 (b)**. The procedure is the same as for the acid-wash treatment above. For environmental reasons, if the surface of hardened concrete must be removed, abrasive blasting or honing are the preferred methods.

Courtesy of the Portland Cement Association (USA)

Figure 9.17 Washing off the surface cement mortar (**a**) to expose the aggregate (**b**)

Figure 9.18 (**a**) Abrasive blasting and (**b**) close-up of finish

Figure 9.19 (**a**) Acid etching process and (**b**) close-up of heavy etching

Figure 9.20 Methods of honing concrete surfaces. (**a**) Dry process, (**b**) wet process and (**c**) hand tools for edges

Figure 21 Examples of honed finishes. (**a**) Patio slab, (**b**) honed finish at 80 to 100 grit and (**c**) path

9.3.6 Honing

Honing of an insitu concrete surface is achieved by grinding it with abrasives to give a smooth, low-maintenance finish with good durability characteristics **Figure 9.20**. The term 'honed finish' is used to cover a level of grinding that produces a smooth but matt surface **Figure 9.21**. Further grinding with progressively finer abrasives is needed to produce a 'polished finish'.

The factors which affect the final appearance are:

- The colour and hardness of the course aggregate exposed by the grinding. While both the aggregates and the matrix contribute to the final appearance, it is the aggregate rather than the matrix which holds the polish.
- The colour of the matrix. The matrix is typically matched in colour with the course aggregate by the addition of a pigment to the concrete.
- The quality of the concrete. Regardless of what properties may be required for structural reasons, a high-strength concrete is desirable for the honing process. High-early strength is particularly desirable to ensure good aggregate bond during honing. A minimum concrete grade of S32 (to AS 1379) is typical.
- The depth of grinding. This will determine the exposure of the coarse aggregates within the concrete.

With so many variables, it is recommended that either one of the specialist concrete mixes developed for this type of finish be used (test samples or examples are already available) or that test samples be produced to allow the finish to be assessed prior to work commencing.

Figure 9.22 Stamped and exposed-aggregate finish combined

9.3.7 Stamped exposed-aggregate

Aggregate exposure (by either the seeding or wash-off method) and the stamping technique described in **Section 9.2.3** can be combined to produce other finishes **Figure 9.22**.

9.3.8 Environmental considerations

Environmental issues, particularly water run-off containing cement or dilute acid, must be considered with coloured and exposed-aggregate finishes. Flushing cement paste, acid, coloured surface hardeners, oxides and release agents into stormwater drains affects the water quality in natural water systems and may be prohibited by local authorities.

To prevent this:

- Provide filters at strategic points using sand as a sediment-control barrier and remove from site.
- Use hessian wraps to divert run-off to surface catchment or into excavated silt traps. Overflow from silt traps can be diverted to a surface catchment with excavated channels.
- Temporarily cap all drainage inlets.
- Use raised formwork to control sediment run-off.
- Where practicable, wash off the residue from one section of a pavement onto the bare earth to be subsequently covered by an adjoining section.

9.4 SPRAY-ON TOPPINGS

9.4.1 General

Existing slabs can be sprayed with coloured and textured finishes (varying in thickness from 3–5 mm) **Figure 9.23**. However, the success of any topping depends on the bond to the substrate.

9.4.2 Materials

Spray-on toppings are available as cementitious or acrylic-based materials. They can look similar but their life expectancy may vary. Consult the supplier about suitability and performance of materials.

9.4.3 Preparation

Clean the existing pavement to remove grit, paint, oil, and other substances that will affect the bond and finish. Use high-pressure water cleaning, acid etching (a mild solution of 1:25) and (where severe surface deterioration has occurred) concrete grinding or dustless shot blasting to produce a clean, even and sound substrate.

Figure 9.23 Spray-on topping with stencilled pattern

9.4.4 Repairs to substrate

Most sprayed finishes are applied to existing concrete surfaces to improve the appearance. Any defects within the existing slab that may detract from the appearance should either be repaired or, if satisfactory repairs are not possible, a way found to accommodate them in the new pattern or design. As a last resort, some sections of the existing pavement may need to be replaced to achieve a satisfactory outcome. Note that matching finishes and colours between replaced sections and the existing slab is generally not an issue as the spray-on topping normally includes a base coat that will conceal the entire substrate. For patterned finishes where joint/grout lines are left exposed and no base coat is applied, the colour consistency of the concrete substrate may be more important.

Defects that may need to be repaired prior to spraying a topping include:

- **Cracks** can be filled with either a rigid material such as cementitious or epoxy grout if they are dormant cracks (not moving), or with a flexible material if they are live cracks (still moving). However, while live cracks can be filled and sprayed over, continuing thermal or ground movements will cause the crack to be reflected through the new topping material, albeit generally narrower and less noticeable.
- **Different levels** of adjoining slabs (caused by tree roots, expansive soils, moisture problems and subsidence) can be made flush with a topping or purpose-made levelling compound. Prepare and apply strictly in accordance with the manufacturer's specifications. The cost of levelling compounds may be prohibitive. Moreover they are not recommended externally because of the possibility of warping and delamination. Where there is a serious case of subsidence, and the slab has lost support, an alternative to replacement is the injection of grout under the slab ('slab jacking'). This is expensive but may be necessary in some cases.
- **Broken corners** can be repaired by fixing a new section of concrete to the existing. The fixing may be a reinforcing bar (or a stainless steel pin if enough concrete cover is not possible) epoxied into the existing concrete.
- **Joints** are difficult to repair because movement may cause failure of the repair.
- **Spalling** is usually caused by rusting reinforcement. Before any repair work is undertaken, the cause of rusting should be determined and eliminated if possible, to prevent further spalling. Exposed and rusting bars can be locally cut back to give the required cover, before patching with a repair mortar. Before any reinforcement is cut out, a structural engineer should be consulted to determine the implications of removing the reinforcement. Repair of spalling concrete is a specialist job, and for extensive areas it may be better to remove and replace the section of paving.
- **Surface defects** that are shallow can be filled with a spray-on topping material. A purpose-made repair mortar can be used for deeper depressions.

Note that repairs should be carried out by specialists. Also, if extensive repairs are necessary, consideration should be given to replacing the existing damaged pavement with a new slab. The total cost of repairs and a sprayed finish may be greater than the removal and replacement costs.

9.4.5 Existing joints

As a general rule, joints in a new topping or coating should correspond with existing joints. This is because joints are used to allow or control movement in the slab. If they are filled and sealed over, continued movement of the pavement could cause the joint to rupture and the topping to spall.

The location of existing joints may govern the direction of any surface patterns. If any new joints are cut into the existing pavements (eg because existing joints are too far apart or not able to adequately control movement) these should be located to suit the new pattern.

In certain situations, isolation joints may be needed to relieve stresses around structures (posts and walls) adjoining the slab.

9.4.6 Protection of adjoining structures

Protect adjoining surfaces from over spray or splatter to eliminate the risk of staining them.

9.4.7 Bonding products

Bonding agents can be used to increase the strength of the bond of the topping to the existing substrate. They are usually supplied with the application kit or incorporated into the spray material. Products should be applied in strict accordance with the manufacturer's instructions as incorrectly used bonding agents can have a de-bonding effect.

9.4.8 Base coats

A base (or primary) colour coat is applied over the bonding agent (where required); in stencilled work, this becomes the colour of the 'joints' in the stencilled pattern. Base coats are fairly workable and can be leveled with trowels, broad floats or squeegees. The condition of the slab, existing falls and depths of any depressions will, however, influence the choice of slump. After the base coat has dried (a period specified by the manufacturer) the surface is smoothed by fine sanding, light grinding or rubbing over with open-mesh rubbing blocks to remove minor imperfections. Dust and grindings should be removed from the immediate area so that they are not walked onto, or blown back onto, the pavement.

9.4.9 Stencil application

Stencils are usually self-adhesive for fixing directly to the base coat or prepared surface. They are available in a wide range of patterns, similar to those available for standard stencil applications. Stencils with special patterns can be made to order.

9.4.10 Topping coats

The final coloured coat is mixed according to the manufacturer's directions. This may include additives sold with the application kit. Varying the slump and viscosity of the topping can produce different textures. A more fluid topping (with a high slump) will produce a smooth finish; a drier mix (lower slump) is used to produce rougher textures. The slump is increased by adding both fluid and binding materials; not only fluid.

The colour can be applied through a dual-line feeder or hand-held hopper with a gravity feeder. An even application is crucial. A further, or highlight coat (with an iron-oxide fleck for example) can be applied.

After the surface is set, the stencils are removed and the residue is blown off.

9.4.11 Sealing

A same-day sealer can be applied for immediate protection; however, two coats of a high-quality sealer are recommended to ensure lasting serviceability of a spray-on surface finish.

Toppings

10

10 .1 GENERAL

Applying a topping or thin layer of concrete/cementitious material on top of the main structural concrete slab or pavement is one of the most common methods of providing a decorative finish and/or colour to concrete flatwork. A damaged or worn concrete surface can also be revitalised by the application of a topping. Other reasons for using toppings are that they:

- limit the amount of material that must be coloured, particularly with the more expensive pigments such as blue and green;
- are placed at the end of the project and therefore reduce the risk of damage to the finish from construction activities;
- allow special finishes to be achieved, particularly those that require various materials to be embedded or set into the surface of the pavement;
- can provide a decorative finish to an existing, older concrete slab;
- can be used to correct surface levels in the pavement.

Toppings can be divided broadly into two categories: those placed during construction of the slab (monolithic toppings) and those placed over an existing concrete slab (bonded and unbonded).

It is crucial to consider the locations of joints in a topping to avoid cracking. Joint locations largely depend on whether it is a bonded or unbonded topping. If bonded, joints are placed to correspond with existing joints in the slab. If unbonded, joint spacings should also correspond to existing joint locations with the maximum joint spacing complying with the recommendations for new concrete slabs (ie 30 times the topping thickness to reduce the risk of cracking). Practically, the area defined by joints should be limited to about 15 m^2 to allow time to place and finish the concrete.

Cracks in the existing concrete should be repaired, because it is likely they would appear in the topping, especially in thin bonded toppings (refer **Section 12.2**). Sometimes it may be possible to provide a pattern in the topping to conceal crack locations.

New concrete toppings may show fine surface cracks because of drying at the surface of the topping, and the bond of the topping to the existing base.

After curing, the topping can be used by foot traffic. However, heavier loads should be excluded for 28 days.

10.2 TOPPINGS PLACED DURING CONSTRUCTION (Monolithic toppings)

Monolithic toppings are surface layers which are applied after the base or structural concrete slab has been placed, and while the concrete is still in its 'plastic' or workable state. This allows bonding of the two layers as they set and harden together, effectively producing a single or monolithic element.

Dry shake toppings are the most common type of monolithic topping used to provide a coloured surface (see **Section 9.1.4**). An alternative to casting dry powder over the surface is to apply a thin layer of mortar to the surface. This can either be trowelled on or, more recently, sprayed onto the surface.

A surface layer of coloured concrete can also be placed as a monolithic topping. Because concrete surface layers/toppings have similar properties to the concrete below, there is no limit to the thickness of a concrete surface layer. Practically, the thickness is kept to a minimum to reduce pigment costs, with the minimum thickness usually governed by the maximum aggregate size used.

For exposed aggregate finishes where expensive aggregates are required, placing the mix as a topping may provide a more economical solution. The procedure for placing such a 20- to 40-mm thick exposed aggregate topping mix that allows a water-washed finish would be as follows:

- Place the base slab and screed it to a level 20 to 40 mm below the finished level.
- Prepare a topping mix in the proportions (by volume) 1 part cement: 1.5 parts sand: 3 parts aggregate (and pigments if required) and just enough water for workability. Alternatively, order a special pre-mixed concrete.
- Use a surface set retarder on large jobs (or in drying conditions) to allow more time to place and finish toppings.

- Wait until the surface bleedwater has evaporated from the base slab before placing the topping.
- Screed and float to ensure consolidation and complete bonding.
- Follow the steps for exposing the aggregate and curing in **Section 9.3.2**.

10.3 TOPPINGS PLACED OVER EXISTING CONCRETE SLABS

10.3.1 General

There are two types of toppings that can be placed over existing concrete slabs: bonded and unbonded. Bonded toppings are relatively thin layers of material that are bonded to, and rely on, the existing slab for their integrity, eg resistance to drying shrinkage and cracking. Unbonded toppings are separated from the existing slab, incorporate reinforcement and act as individual thin slabs.

10.3.2 Bonded toppings

Bonded toppings can be classified according to their thickness. Ultra-thin toppings up to a few millimetres in thickness (eg spray-on toppings) and thin toppings up to about 10 mm in thickness (eg trowel-on toppings) consist of mortar-type mixes, generally incorporating polymers and bonding agents. Pigments can also be added, or the surface chemically stained after hardening similar to any other cementitious material.

Thicker toppings in the range of 20 to 40 mm consist of concrete mixes containing coarse aggregates to better control drying shrinkage—the thickness being a function of the aggregate size used. Typical hand mixes range from 1:1:2 (heavy duty) to 1:2:4 (lightly trafficked) cement:sand:aggregate. These are mixed with a minimal quantity of water necessary for workability.

The usual maximum thickness for unreinforced bonded toppings is about 50 mm. Beyond this, the topping will behave more like a thin slab and achieving an adequate bond to the existing slab becomes even more important to guard against delamination from factors such as shrinkage and curling.

Toppings are placed on a rough surface, which is clean and sound. Old concrete surfaces, which are disintegrating, ie dusting or spalling, should be chipped until a sound surface is obtained. Smooth concrete should be chipped or scabbled to provide a key for the new topping. Water blasting or captive shot blasting is preferable, because chipping tends to produce a weak base layer. On a prepared surface the coarse aggregate should be visible.

The surface should be hosed and scrubbed with a stiff broom to remove all dust and foreign matter before placing the new concrete. A suitable bonding compound should be used.

Generally, reinforcement is not used when the topping thickness does not exceed 50 mm. However, depending on the thickness, SL42 fabric can be positioned 20 mm from the top of the slab and supported on bar chairs to help control shrinkage cracking. Polypropylene or steel fibre reinforcement may also be used.

Levelling compounds are a form of bonded topping typically less than 10 mm in thickness. They are mixed with water and screeded onto the concrete surface. They can be applied in thicknesses as thin as 1 mm. Some self-levelling products require little finishing. It is essential to follow the manufacturer's advice and instructions about the product's application.

All joints in the original slab should be duplicated in the topping slab to maintain movement control.

The topping should be cured for a minimum of 3 days, preferably 7 days.

10.2.3 Unbonded toppings

If toppings greater than 50 mm in thickness are required, then a separate unbonded reinforced topping should be considered. In reality, unbonded toppings are essentially thin new slabs but referred to as toppings because they are placed over existing concrete.

While these toppings are typically used for waterproofing applications by allowing the installation of a polythene sheet or other waterproof membrane, they also provide a useful means of topping existing timber or concrete floors. The greater thickness allows the use of a minimum 14-mm aggregate.

A plastic membrane is typically used as a bond-breaker to separate the old or existing concrete from the new. To allow cover to the reinforcement and minimise curling problems a thickness of about 70 to 75 mm is recommended. Toppings that exceed 75 mm in thickness should be regarded as new concrete slabs and designed and reinforced accordingly.

Because unbonded toppings do no rely on the substrate to control shrinkage and hence cracking, a layer of reinforcing mesh (typically SL52) needs to be provided for crack control. Note that the durability requirements may govern the concrete strength (minimum N32 with a 100-mm slump recommended) and minimum topping thickness. The topping should be cured for a minimum of 3 days, preferably 7 days.

Mortars, Renders and Roof-tile Bedding

11

11.1 MORTARS FOR MASONRY

11.1.1 General

Mortars for concrete, clay or calcium silicate masonry perform similar functions, whether veneer, double, or single-leaf construction.

The design of masonry, including the requirements for mortars, are covered by Australian Standard AS 3700.

Mortar:

- provides an even bedding for masonry units, and takes up the dimensional variation of units;
- transmits compression loads;
- bonds the units together so they resist the tensile and shear forces from lateral loads;
- seals the joints from the weather;
- holds damp proofing and flashings in place;
- is essential for optimum acoustic performance and fire resistance of masonry walls;
- can add to the appearance by providing colour;
- must be resilient enough to accommodate minor structural movements.

The bond between mortar and masonry is the most important factor and is formed by the water carrying cement particles into the surface of the masonry unit and hydration then leading to a chemical bond being formed. Some practical points to consider include:

- Ensure the mortar matches the masonry units being used.
- Use water-thickening admixtures where appropriate. These products ensure that for units having high suction, the water is not rapidly drawn out of the mortar without carrying cement particles with it.
- Joints should be completely filled, with the frog in pressed bricks laid upwards.
- To limit the moisture loss, do not place too great a length of mortar in a course before placing the bricks.
- Dampening or wetting the masonry units prior to laying reduces the suction and leads to poor bond.
- Any disturbance of the units more than a few seconds after laying should be avoided.
- Detergents, drinks, sugars and the like must not be used to improve workability as they destroy bond strength.
- Avoid overdosing with air-entraining admixtures as this reduces bond strength. The manufacturer's instructions should be carefully followed.

11.1.2 Materials

Cement For normal brick and blockwork, general-purpose cement (Type GP or Type GB) or masonry cement are suitable. Where a lighter coloured or more vibrant pigmented mortar is required, off-white cement should be used. The proportioning of the mortar, however, varies with the type of cement **Table 11.1**. To avoid on-site confusion, it is preferable if only one type of cement is used on a project.

Cement has a limited shelf life and should be stored off the ground in a dry environment.

Lime Hydrated lime or building lime suitable for hard plastering should be used. Lime is added to make the mortar creamier or more workable. It also helps to minimise cracking while the mix is drying because it provides a degree of elasticity to the hardened mortar. It is good practice to soak the lime in an equal volume of water for 24 hours prior to use to improve its performance in the mix.

Sand (fine aggregate) Sand is the fine aggregate in mortar. Fine sands are preferred. Sands with high clay content should not be used, nor should 'fire clay' or 'brickies' loam' be added to the mortar. (Loam is commonly referred to as 'fatty' sand.) Sand with a high clay content degrades the mortar, markedly reducing the bond strength and lowering the durability.

Water Water should be clean, fresh and free of impurities. Mains water or water suitable for drinking is usually satisfactory.

Admixtures Chemical additives should not be used to replace lime and should be used in strict accordance with the manufacturer's instructions.

Powdered mineral oxide pigments should not exceed 10% of the weight of cement in the mix (normally 5 to 8%) and should be thoroughly mixed with the other materials prior to the addition of water.

Table 11.1
Mortar mixes for masonry (based on Tables 5.1 and 10.1 in AS 3700)

	Mix proportions by volume				
Mortar Classification	Cement Type GP or GB	Masonry Cement	Building Lime	Sand	Water Thickener
M2	1	0	2	9	No
M3	1	0	1	6	Optional
	0	1	0	4	No
	1	0	0	5	Yes
M4	1	0	0.5	4.5	Optional
	1	0	0–0.25	3	Optional
	1	0	0	4	Yes
	0	1	0	3	No

Note these mortars are not suitable for autoclaved aerated concrete (AAC) units. For calcium silicate units use only the mixes with added water thickener.

Liquid colour additives should be measured and used in accordance with the manufacturer's instructions.

Water thickeners should be cellulose-based products suitable for the application and used in accordance with the manufacturer's instructions.

A sample of coloured mortar should be made and allowed to dry before starting work, to ensure the desired colour is achieved.

11.1.3 Mixes and applications

Mixes should be varied to suit the particular exposure conditions and location (see **Table 11.1** and **Section 11.1.6** below). Mix proportions are expressed as ratios, eg 1:1:6, meaning 1 part cement to 1 part lime to 6 parts sand by volume.

11.1.4 Site-mixed mortar

When site-mixing, it is important to carefully measure all the materials by volume in a suitable container, not by the shovelful. They should be properly mixed to ensure that a uniform mixture is obtained.

Mechanical mixing is usually done in a concrete mixer. A small amount of mixing water is placed in the mixer followed by the sand, cement and lime. Water is slowly added to create a thick creamy mixture that is just fluid enough to ensure ease of bricklaying. Each batch should be thoroughly mixed to ensure that a uniform mixture is obtained. A minimum mixing time of 6 minutes is recommended.

Hand mixing should be done in a clean wheelbarrow or on a mixing board to avoid contamination. The dry materials should be combined and mixed to an even colour before slowly adding water as the mix is constantly turned until a thick creamy mortar is made.

Mortar should be used within half an hour of mixing. Mortar that has stiffened should not be retempered by the addition of water.

11.1.5 Pre-mixed mortar

Factory-blended, ready-to-use, general-purpose mortars are available in bags from most hardware outlets. They need only the careful addition of water (and colour additives if required) for mixing. They have the advantage of ensuring a highly consistent, well proportioned mix.

11.1.6 Mortar for fireplaces and barbeques

Traditionally, the mortar used for these applications was a 1:3 or 1:4 mix by volume of lime and sand. Lime mortar which hardens slowly and has low strength is able to accommodate the thermal movements better than the stiffer, stronger mortars.

Nowadays, the recommended mix for fireplaces and barbeques is a 1:2:8 or 9 mortar by volume of cement, lime and sand, ie a weaker cement-based mortar than normally used. Depending on the exposure, the durability of this mortar should be considered.

The alternative would be the use of refractory bricks with a refractory cement mortar either made up on site in accordance with standard practice using high-alumina cement, or a mortar purchased as a proprietary product from a refractory materials supplier.

11.1.7 Mortar mixes for particular environments

Mortar mix classifications and their applications based on Table 5.1 in AS 3700 are summarised below:

M2 Typical applications include:

- Mild environments such as those remote from the coast, industrial activity or the tropics
- Above DPC in interior environments not subject to wetting and drying
- Above DPC in other than marine environments
- Above DPC and protected by a waterproof coating, flashed junctions and top covering
- Below DPC or in contact with ground but protected from water ingress by an impermeable membrane.

M3 Typical applications include:

- Interior environments subject to non-saline wetting and drying
- Marine environments (within 100 m to 1 km of a non-surf coast or 1 km to 10 km of a surf coast)
- Below DPC or in contact with non-aggressive soils
- In fresh water.

M4 Typical applications include:

- Interior environments subject to saline wetting and drying
- In severe marine environments (within 100 m of non-surf coast or 1 km of surf coast)
- Below DPC or in contact with aggressive soils
- In saline or contaminated water, including tidal and splash zones
- In especially aggressive environments eg corrosive liquids or gases.

Mix proportions for mortar classifications M2, M3 and M4 based on Table 10.1 in AS 3700 are listed in **Table 11.1**.

11.2 RENDERS

11.2.1 General

Cement-based renders, on internal and external walls improve waterproofing, fire rating and (when coloured and/or textured) the appearance.

To get the best results from a render:

- the mix should be suited to the background surface;
- it should be properly applied in the correct number of coats, and to correct thicknesses;
- it should be properly cured.

11.2.2 Materials

Cement General Purpose (Type GP or Type GB) cement is normally used, but where a light or coloured finish is required off-white cement may be used.

Lime Hydrated lime or building lime suitable for hard plastering should be used. Lime is added to make the render creamier or more workable. It also helps to minimise cracking while the mix is drying because it provides a degree of elasticity to the render in its hardened state. It is good practice to allow the lime to soak in an equal volume of water for 24 hours prior to use to improve its performance in the mix.

Sand Sand is the major ingredient of the mix and should be of good quality, clean and free from clay and vegetable matter. In general, coarsely graded sands are more suitable for undercoats, while a finer grading is more suitable for finishing coats. Plastering sands and finer washed concrete sands (commonly referred to as ‘sharp’ sand) are available from retail hardware and building supply outlets.

Water Water should be clean, fresh and free from impurities. Mains water or water that is suitable for drinking is usually satisfactory. Just enough water should be used to make the mix workable.

Admixtures Generally, admixtures are not required in render. However, if they are added they should be used strictly in accordance with the manufacturer’s instructions as overdosing can result in serious loss of strength and bond.

Pigments, added to colour the render, should not exceed 10% of the weight of cement in the mix and should be thoroughly mixed with the other materials prior to the addition of water. Liquid pigments should be measured consistently and added in accordance with manufacturer’s instructions.

A sample of coloured render should be made and allowed to dry before starting work, to ensure the desired colour is achieved.

11.2.3 Mixes and applications

A variety of render mixes can be used, depending on the background surface and the conditions to which the rendered surface is exposed **Table 11.2**.

11.2.4 Site-mixed renders

Render can be mixed on site in either a mechanical mixer or by hand on a board or in a wheelbarrow. Hand mixing is generally less reliable than mechanical mixing. When site-mixing, it is important to carefully measure the material by volume in a suitable container, not by the shovelful.

Note that renders should be applied within half an hour of mixing.

Mechanical mixing A small amount of mixing water is placed in a concrete mixer followed by the sand, pigment (if required) cement and then lime (if included in the mix). They are blended together until a uniform colour is achieved.

Water is slowly added until a stiff mix that will 'sit up' on a trowel is achieved. Each batch should be thoroughly mixed for two to three minutes to ensure uniform consistency.

Hand mixing All the required dry materials for the batch should be measured into a wheelbarrow or onto a board. The dry materials should be combined and mixed to an even colour before the addition of water, which is slowly added and mixed in until a stiff creamy mix that will 'sit up' on a trowel is achieved. Turning and mixing should be continued for a couple of minutes to ensure all the sand is uniformly coated with paste.

Render mixes which have stiffened, making them difficult to apply, should be discarded and not re-tempered by the addition of water. The more water used, the weaker the mix and the greater the likelihood of shrinkage which may lead to bond failure or cracking.

11.2.5 Pre-mixed renders

Factory-blended, ready-to-use, general-purpose and special-purpose renders requiring only the addition of water are available in bags from most hardware and building supply outlets and decorative-coating manufacturers.

11.2.6 Applying render

Surface preparation The background surface should be free from paint, oil, dust and any dirt or other loose material that may prevent a good bond. Proprietary bonding agents, applied in strict accordance with the manufacturer's instructions, can also be used to improve adhesion.

Table 11.3 indicates the preparation treatment necessary for a number of background surfaces prior to rendering.

Surface dampening After initial preparation, the background surface should be dampened and allowed to dry back to a surface-dry condition immediately prior to rendering. This reduces excessive suction but still enables a bond to be achieved in the case of weaker and open-textured backgrounds.

Dash coat Dash coats are used to provide a adequate bond between the background and the subsequent render coat. Site-mixed dash coats have the ratio of 1 part cement to 1 to 2 parts sand (by volume). The dash coat is flicked and splattered over the background to produce a rough finish. This open-textured layer is not trowelled level or smoothed out, but left rough to 'key' with the render.

Number of coats The number of coats will depend on the condition and the evenness of the background, the conditions to which the render is exposed, and the type of finish required. Usually, one or two coats are all that is required. Single coats should never exceed 15 mm in thickness.

A minimum of three days should be allowed between coats.

Undercoats Undercoats are normally applied by trowel to a minimum thickness of 10 mm and a maximum of 15 mm. When the render is firm, it should be raked or scratched to provide a key for the next coat.

Final coats Final coats are normally applied by trowel to a maximum thickness of 10 mm over the undercoat.

Decorative finishes A variety of decorative effects can be achieved using different finishing techniques on the final coat.

Table 11.2
Render mixes and their application

Mix (Cement:lime:sand by volume)	Internal/external	Application
1:0:3	Internal	Single coat, undercoat work (two part)
1:0:5	Internal	Finish coat work (two part)
1:0.5:4.5	External	Strong mix for strong backgrounds
1:1:6	External	Moderate strength mix for porous and weaker backgrounds
1:2:8	External	Final coat for weak backgrounds in sheltered situations

Table 11.3
Background preparation

Background		
Material	Properties	Preparation
High-strength concrete	Strong/smooth	Scabble surface and apply dash coat or fix metal lath clear of surface
Fibre-cement sheet	Strong/smooth	Fix metal lath clear of surface
Standard bricks, concrete blocks, concrete	Strong/porous	Rake joints (if appropriate) and apply dash coat
Lightweight concrete, render undercoat	Weak/porous	Dampen surface

The application of decorative render finishes can be difficult and specialist application by competent tradespeople is recommended. The types of finishes possible include:

- **Trowelled** Achieved by skimming the final coat with a wood float to produce a smooth, dense surface or using notched trowels to produce a variety of patterns.
- **Bagged** A bagged or patterned finish is obtained by rubbing a ball of damp hessian into the surface, the pattern being dependent on the action used.
- **Sponge** Achieved by mopping or sponging the unhardened surface with a damp sponge. Water should not be allowed to run down the wall.
- **Rough cast** The final coat is thrown and flicked onto the surface and no retouching is done.
- **Textured** Textured surfaces can also be achieved by the use of coarser aggregate in the final coat.

11.2.7 Control joints

Cement-based renders may crack for a number of reasons, common ones include the result of shrinkage as the render dries and movement in the background material. With the careful placement of control joints, cracking can be minimised.

Control joints should be formed in the render to coincide with all joints in the background and locations in the structure where movement is likely to occur. Joints in the background should not be filled with render, while weep holes should be carried through the render.

11.2.8 Curing and protection

All render coats, including undercoats and dash coats, should be kept damp for 3 days or until the next coat is applied. Render should not be allowed to dry out quickly and should be protected from hot weather, drying winds and rain. Rendering in direct sunlight or exposed windy areas should be avoided.

Clear or lightly-coloured plastic sheeting should be used to protect fresh render for the first 3 days after application. The plastic sheet should not be allowed to touch the finished surface if colour is important as it may lead to discolouration. Instead, it should be spaced just off the surface.

Protection is not normally necessary for internal renders if the building provides protection from drying weather conditions.

11.3 ROOF-TILE BEDDING AND POINTING

11.3.1 General

Ridge and hip cappings should be laid on a mortar bed. Mixes recommended by AS 2050 are:

- Cement mortar for bedding
  1:4 by volume of cement and sand.
- Cement mortar for pointing
  1:3 by volume of cement and sand.

Measurement of the ingredients should be made using a gauge box or bucket not a shovel. A good bricklayers' sand (see **Section 11.1.2**) should be used.

11.3.2 Bedding and Pointing

Bedding and pointing cappings provides a weather seal. The use of wet mixes prone to excessive shrinkage cracking should be avoided.

Bedding and pointing of the joints between ridge and hip cappings should be done using a 1:3 mortar by volume of cement and sand.

Where tiles converge at a valley (or steep roof pitches), it is often essential to point under the cut tiles in the valley line to prevent the up-wash of roof water under the opposing tile edge.

Pigments are usually added to pointing mortars to match the colour of roof tiles. Some trials will be required to achieve a good match. In all cases, the pigment used should be no more than 10% by weight of the cement in the mix. Pigments should be used strictly in accordance with the manufacturer's recommendations.

When bedding or pointing, the mortar should be lightly brushed or wiped after the initial set to remove loose particles. All tiles adjacent to the ridge tiles should also be cleaned and brushed free of loose mortar particles.

Troubleshooting and Repairs

12

12.1 DEFECTS – PREVENTION AND REPAIR

12.1.1 Dusting

Dusting is a condition where a fine powder comes off the surface of the concrete.

CAUSE The most common causes for a weak surface that is prone to dusting are the addition of excess water to the concrete, premature trowelling of the surface (working bleedwater into the cement matrix at the surface thereby increasing the water-cement ratio) and inadequate curing of the concrete. Any one of these three will weaken the concrete surface, and if two or more are combined will almost certainly cause problems. Other possible causes include rainwater either diluting the surface cement matrix or washing out the cement binder, applying dry cement to the surface to soak up water (eg after rain), freezing of the surface during or just after setting, using the wrong concrete strength for the application (ie too weak) and inadequate compaction.

PREVENTION Avoid adding excess water to concrete. Do not work the surface too early while bleedwater is present but allow all bleedwater to evaporate before finishing. Do not overwork the concrete because this will also bring fine material to the surface. When rain or freezing conditions threaten, take precautions to protect the surface. Use the correct concrete strength for the application and do not attempt to broom the surface when wet because this will drag away the cement matrix and create rutting in the surface. Always initiate a good curing procedure as early as possible.

REPAIR Dusting can be rectified in the majority of cases by the application of a chemical surface hardener or dust inhibitor that penetrates the concrete and reacts with the hydration products in the concrete to form compounds that assist in strengthening the surface layer. They also bond the thin, weak layer on the surface to the base concrete below and are generally applied after 28 days. More-severe cases will require the complete removal of the weak surface layer by grinding, installation of a topping or providing an appropriate floor covering.

12.1.2 Crazing

A crazed concrete surface is a network of very shallow fine cracks across the surface. They are obvious when the concrete is damp.

CAUSE Crazing is caused by the drying shrinkage of the thin mortar layer that is created during the finishing of the surface, or alternating wetting and drying of the surface. Other contributing factors include the mix being too wet and the lack of adequate curing. Crazing also results when driers such as neat cement are used to soak up excess water and are trowelled into the surface.

PREVENTION Take precautions during hot weather conditions and adopt a good curing regime, starting as early as possible. Do not use cement (or coloured surface hardeners) to soak up water, and limit the trowelling of the concrete. Avoid the addition of excess water to the concrete. Do not work the surface too early when bleedwater is present.

REPAIR Repair may not be necessary because crazing usually will not weaken concrete. If it is visually unacceptable, then a surface coating of paint or other overlay sealer can be applied to cover and/or conceal the cracks. With adequate curing, most cracks should heal themselves.

12.1.3 Blistering/flaking

Blisters are hollow, low-profile bumps on the concrete surface filled with either air or bleedwater. Under traffic (both vehicle and foot traffic) these blisters crack and the surface mortar breaks away, exposing the concrete underneath. Flaking is similar but over a larger area.

CAUSE The concrete surface was sealed too early by trowelling, trapping bleedwater which continued to rise underneath the now compacted surface (from trowelling). As the water accumulates it forms a layer that de-bonds the compacted surface from the concrete below. Depending on the extent of the problem it may resemble an isolated blister, or large flakes will lift from the surface. This can occur particularly in thick slabs or on hot, windy days when the surface is prone to premature drying and hence finishing.

PREVENTION The use of an evaporation retarder in hot, dry or windy weather will reduce this problem by allowing sufficient time for all bleedwater to reach the surface prior to finishing. Other means of reducing rapid drying include windbreaks and sunshades, and placing at cooler times of the day. If blisters are forming during finishing, delay trowelling as long as possible and take steps to reduce evaporation. Avoid using driers such as cement on the surface.

REPAIR Grind off the weakened layer to an even finish and apply a sealer. Applying a topping layer or epoxy coating to remedy badly damaged surfaces could also be considered.

12.1.4 Uneven colour of plain concrete

There is sometimes colour variation in adjoining sections of concrete, and sometimes in the slab itself.

CAUSES Factors leading to colour variations in concrete include:

- Variable amounts of water in the concrete
- Changing the strength of the concrete
- Changing the supplier of the concrete
- Changing the type or brand of cement used in the concrete
- Finishing practices such as early trowelling of wet surfaces and extended hard trowelling
- Inadequate, inconsistent or different curing methods can result in mottled surfaces. Curing compounds that are not evenly applied, and plastic sheeting that is not fully in contact with the surface may also cause colour variations.

PREVENTION Adopt a standard and consistent procedure for ordering, placing and finishing. Do not add excess water, use the one supplier, trowel after bleedwater has dissipated, trowel the surface evenly and implement good and consistent curing techniques.

REPAIR The application of a stain or dye available from most decorative concrete product supply companies may lessen the colour variations. A trial, on a concealed section of the slab, is advisable.

12.1.5 Rain damage

CAUSES Heavy rain while concrete is setting, or rainwater being allowed to run across the concrete surface.

PREVENTION Prevention is far better than any cure in this case. If caught out, cover the concrete and channel run-off away from freshly laid concrete.

REPAIR If concrete has not hardened and damage is only slight, the surface can be re-floated and re-trowelled, taking care not to overwork excess water into the surface. If concrete has hardened, it may be possible to grind or scrape away the surface and place a topping layer of new concrete, or repair compound, over the top. This may not always be possible and should be done only with expert advice. Avoid the use of driers such as cement to soak up the water as this may cause other problems.

12.1.6 Efflorescence

Efflorescence is the formation of salt deposits, usually white, on or near the surface of concrete after it has been finished and causing a change in the appearance. Light-coloured concrete shows the deposit much less than darker coloured concrete. With time, efflorescence becomes less extensive and should eventually cease to occur, unless there is an external source of salt.

CAUSES Efflorescence is usually caused by a combination of the following factors:

- One or more of the constituents of concrete may contain salts
- A high water-cement ratio resulting in a more porous concrete that allows movement of water and salt solutions
- Inadequate curing which may leave un-hydrated products near the surface of the concrete
- Exposure to rain or other water sources (moisture allows salts to be transported to the surface where they accumulate as the water evaporates)
- Slow rate of evaporation of water allowing time for salts to permeate to the surface (this is why efflorescence tends to be more of a problem during the winter months; in summer, high temperatures may cause evaporation and hence depositing of salts within the concrete rather than on the surface)
- Variability of concrete (eg from compaction or curing) can result in localised problems where water can permeate more easily through the concrete.

PREVENTION Measures to prevent/control the occurrence of efflorescence include:

- Use ingredients containing as little soluble salt as possible.
- Use waterproofing admixtures to reduce permeability of concrete/mortar. Note that as some of these products may cause efflorescence themselves (eg water-soluble soaps) always check with the manufacturer.
- Use a denser concrete, again to reduce permeability. However, this may increase the shrinkage.
- Use cement:lime:sand mortars no stronger than required for the application to minimise possible soluble salt levels.
- Lime should be hydrated lime free from calcium sulphate.
- Avoid premature drying.
- Apply curing compounds or same-day sealers to reduce exposure to wetting.
- Protect hardened concrete from exposure to moisture by maintaining surface sealers and site drainage, and from rising groundwater by placing a plastic membrane under slabs.
- For masonry, ensure flashings, damp-proof courses and copings are detailed correctly, cover the top course at the end of each day's work, tool joints with a 'V' or concave shaped jointer to compact the mortar at exposed surfaces, provide wide eaves and avoid wetting from sources such as sprinklers.

REPAIR (REMOVAL) Prior to removing efflorescence, the things that may be causing the problem should first be corrected so as to limit or reduce the risk of re-occurrence.

Soluble salt deposits can be removed with a stiff-bristle broom. Note that all brushed-off material should be totally removed by vacuum cleaning or other means. If the result is not satisfactory, scrub with clean water then lightly rinse the surface. Note that adding water may result in further deposits. Repeated dry brushing as the deposits appear is probably the best treatment.

Insoluble salt deposits (hard, white, scaly or crusted) cannot be removed by water washing, although the use of a high-pressure water jet is effective. The application of a dilute acid solution (1 part hydrochloric acid to 20 parts water) is also effective in most cases, and in some cases, may be the only way (refer **Section 12.3.3** for procedure). Note that washing with acid may cause colour variations and alter the surface texture. For coloured finishes a more dilute acid solution (2% or 1 part acid to 50 parts water) may be required. A small trial area should be done first to assess the results.

12.1.7 Honeycombing

Commonly occurring on vertical faces of edge beams, stair and verandah soffits, it appears on the surface as a coarse texture of interconnecting voids and stones.

CAUSES One or more factors including incorrect placement of the concrete, delays between placement of concrete layers, inadequate vibration, and the loss of cement paste and/or mortar through unsealed formwork joints. Surface voids may also indicate a mix that has segregated because of the addition of water, or concrete that has been dropped into place from a height greater than two metres. Poor surface formwork, poorly oiled forms, or damaged form faces restrict the movement of the concrete during placement and prevent adequate consolidation.

PREVENTION Compact and vibrate as close as possible to formwork and, if necessary allow for external vibration of forms. Vibrate more frequently. Use good formwork that has not been damaged. Do not add excess water to the concrete. Do not drop the concrete into forms from excessive heights. Ensure that all formwork joints are tight (tape joints if necessary) to avoid paste/mortar leakage. Place all concrete continuously and ensure that when placed in layers, concrete in one layer is vibrated to blend with the lower layer.

REPAIR Honeycombed surfaces can be rendered. If honeycombing is much deeper than the surface layer, it may need to be removed and replaced with a repair mortar. If colour is important, the repair mortar should be made from the same materials used in the concrete, with up to 40% of the grey cement replaced with off-white cement to better match the colour. A trial patch should be carried out to assess the results and colour.

12.1.8 Blowholes

Blowholes are individual, spherical voids in the surface, usually less than 10 mm in size.

CAUSE Air voids are trapped against the form face, usually because insufficient vibration (compaction)

has not brought them to the surface. Blowholes often occur with impermeable forms.

PREVENTION Ensure forms are rigid, with a thin, even coat of form release agent/oil. The workability of the mix should be suitable for the application. Ensure careful and thorough compaction of the concrete.

REPAIR Use repair mortars. If colour is important, refer recommendations for honeycombing above.

12.1.9 Wavy or uneven surfaces

CAUSES Common causes include:

- Poorly built formwork that has uneven guide rails for screeding
- Improper methods of screeding and trowelling
- Loading a slab with workers' foot-traffic and power trowelling machines before it has adequately hardened, resulting in humps and hollows in the concrete. Paviours, intent on finishing the surface, can be deceived about the hardness of the slab when hot weather conditions dry out the surface prematurely, while the concrete mass underneath is still plastic and can be deformed.

PREVENTION Always keep a uniform surge of concrete ahead of the screed board and take accurate levels. To avoid the premature set of the surface, use evaporation retarders to control rapid drying. Maintain a constant slump; do not add water, which will vary the set of different concrete loads/batches.

REPAIR Use self-levelling floor compounds or repair mortars. Alternatively, grind the surface evenly.

12.1.10 Spalling

Spalling is when fragments of concrete are detached from the concrete surface.

CAUSES Heavy loads or blows from a hammer. Corrosion of reinforcement, which forces off the surface concrete. Entry of hard objects such as stones into joints can cause spalling when a slab expands and pushes against the object. Poor compaction of concrete at joints is another cause.

PREVENTION Ensure sufficient concrete cover to reinforcement. Remove formwork carefully, to avoid hammer blows or point loads to new concrete. Design joints carefully. Keep joints free of debris. Keep heavy loads away from the joints and edges until they have properly hardened. Ensure proper compaction.

REPAIR Scrape, chip or grind away the weak areas until sound concrete is reached. Then refill area with new concrete or repair mortar. Make sure the old concrete is brushed clean of any loose material. Compact, finish and cure the new patch carefully. For larger areas, seek expert advice.

12.1.11 Coloured decorative concrete defects

Stamped concrete

Defects and their causes include:

- Colour appears to be lifting, exposing a pale, tinged concrete base. This is caused by the incomplete removal of the release coat.
- The depth of the stamped impression tapers down to a minimal imprint. This is the result of undertaking the stamping when the concrete has hardened too much.
- The surface has small craters over much of the pattern. Often the concrete has been too wet when stamping begins, or the concrete was re-wetted (or 'wet wiped') to make imprinting easier, and the excess surface water has created suction on the stamping mould.
- The colour is 'fading', although it is not in a high-traffic area. The colour applied was not sufficient, or only one coat of base colour was applied and the release coat was applied at the same time as the second colour. Colour may have been poorly worked into the concrete.
- The coloured surface has cracks at the edges of deeper depressions. This is known as crusting and is caused by the surface layer drying out prior to stamping and then cracking when deformed by the stamping tool.
- Surface delaminates and flakes off. Causes include the use of cement or a dry-shake topping to mop up bleedwater, premature finishing of the surface or the application of the colour topping after the concrete has set, resulting in a poor bond with the base slab.

Stencilled concrete

Defects and their causes include:

- The edges of the 'joints' of the pattern are rough and variable. The stencil was not fully embedded in the concrete, consequently the colour topping has stuck to the stencil and been torn away when the stencil was removed.
- The joints are stained with colour. The colour has bled under the stencil due to poor adhesion with the surface. The stencil was not sufficiently worked into the surface, or the concrete had begun to dry when the stencil was placed, resulting in a weak bond.
- The depth of the joints varies. The stencil was placed too early, when the concrete was too wet, and was embedded too deeply in places into the soft surface.
- The pattern is out of alignment. The alignment of stencils was unplanned or the project was comprised of separate pours and care was not taken to align stencils.
- The pattern is distorted. This is often caused by dragging the stencil into alignment across the surface. When aligning stencils, always hold them off the surface and lay down into position.

12.2 CRACK REPAIR

12.2.1 General

The following factors should be taken into account:

- Before any repair is undertaken the cause of the cracking must be established (if possible). This may require the services of a suitable expert or consultant.
- Whether the crack is live or dormant. Will it continue to move (open or close) or has it stabilised?
- The width and depth of the crack.
- Whether or not appearance is a factor.

Dormant cracks are usually repaired by cutting a groove over them and filling with a cement grout or mortar. Other materials are also available for crack repair.

Live cracks are filled with a flexible sealant to allow movement. A wide variety of purpose-made materials are available.

In the scope of this guide, it is not possible to give detailed instructions about the use of the large range of repair products available. The following is only a guide, detailed information should be sought from the manufacturers of any products being considered.

12.2.2 Live cracks

Live cracks should be sealed with a flexible material that allows movement, particularly in seasonal cycles.

Flexible epoxy resins allow a small amount of movement but mastic sealants, such as silicone and polyurethane, are more commonly specified for pavements. Cracks are repaired by cutting a groove (or chase) over them and filling with the sealant.

If appearance is important, simply fill the crack with a matching coloured sealant using a caulking gun, rather than highlighting it any further by cutting a groove at the top. Care should be taken to avoid spreading sealant over the surface adjacent to the crack.

12.2.3 Dormant cracks

Dormant cracks range in width from 0.05 mm (crazing) to more than 5 mm. The materials and methods for repair depend on the width of the crack.

Very fine cracks, for example crazing, are very difficult to repair effectively. In many cases it is best to do nothing. If the problem is one of appearance (dirt collecting in very fine cracks accentuates them), a solution may be to rub down the surface with a carborundum stone before applying a sealer to the surface.

Fine cracks (up to about 1 mm in width) can often be sealed against water penetration by simply rubbing in a cement grout or slurry. Injecting an epoxy-resin into them can also seal them.

Repairing fine cracks is often unnecessary and can sometimes detract from the general appearance of the surface finish.

Epoxy grouts are widely used because:

- they adhere strongly to both fresh and hardened concrete;
- formulations are available which will adhere to most surfaces and harden even under wet conditions;
- they have good mechanical strength and low shrinkage; and
- they are resistant to a wide range of chemicals, including the alkalies in concrete.

For cracks wider than 2 mm, a cement grout may be the most satisfactory, and is often preferred because of its total compatibility with the parent material, and its ability to maintain an alkaline environment around reinforcement.

Other materials, such as polyester resins and synthetic latexes, have also been used satisfactorily to seal fine cracks. They can have lower viscosities than epoxies and hence can penetrate more easily. However, they may not achieve the same bond strengths and may be less reliable in damp or wet conditions.

Always refer to the information supplied by the manufacturer of the products to be used in a particular situation.

12.2.4 Wet-crack repair

In some situations, a crack in a concrete slab can allow moisture to rise through to the surface, possibly due to hydrostatic pressure. Often, moisture is present from seepage or a broken or damaged water pipe under a slab. As the concrete may be very dry, the slab acts as a wick and can draw up any moisture present. Products are available which react with the moisture present to seal cracks in a moist environment.

12.3 GENERAL REPAIRS

12.3.1 General

Concrete needs minimal maintenance if correctly placed. However, minor repairs may be necessary in some instances to improve its appearance and performance. Serious defects may require a complete topping over the whole concrete surface. Some of the simpler repairs are outlined below.

A variety of purpose-made products are available for repair and treatment of concrete. It is essential to obtain the manufacturer's advice and instructions on the product's application.

12.3.2 Mortars

The filling of chips or gouges is best done with a repair mortar available from concrete product supply companies. A variety of products are available and the product selected should suit the particular application. The manufacturer's instructions should be followed carefully.

12.3.3 Acid etching/cleaning

Acid etching is an effective method in some instances to clean or lightly texture concrete surfaces.

Extreme care is required when handling acids. When diluting hydrochloric acid always add the acid to the water, never the reverse. Ensure good ventilation and avoid contact between the acid and the reinforcement.

Use only diluted acid to clean the concrete surface. The recommended proportions are 1 part hydrochloric acid to 20 parts water. Always saturate the surface with water before applying the dilute acid solution. When applying the solution, ensure that the surface is moist but without any free water being present.

The applied solution should be allowed to react on the concrete surface for 10 to 15 minutes. The surface should then be thoroughly rinsed and scrubbed with lots of clean water. Repeat rinsing at least twice or until all traces of the acid solution have been removed.

The process may be repeated if necessary to produce the required surface finish.

12.3.4 Slippery concrete surfaces

Smooth concrete surfaces that have become slippery may be made coarse by using a high-pressure water blaster or by acid etching the surface.

If a high-pressure water blaster is used, it should be capable of delivering pressure between 7 and 8.5 MPa (about 1000 and 1200 psi). The use of such equipment to achieve surface texturing can be difficult and specialised use by a competent tradesman is recommended. If the clean concrete surface is sealed (once dry), it will resist dirt and grime.

Referenced Australian Standards

A

AS 1012 Methods of testing concrete

AS 1012.3.1 Determination of properties related to the consistency of concrete – Slump test

AS 1012.8.1 Method for making and curing concrete – Compression and indirect tensile test specimens

AS 1012.9 Determination of the compressive strength of concrete specimens

AS 1379 Specification and supply of concrete

AS 1478 Chemical admixture for concrete, mortar and grout

AS 1478.1 Admixtures for concrete

AS 2050 Installation of roof tiles

AS 2758 Aggregates and rock for engineering purposes

AS 2758.1 Concrete aggregates

AS 2870 Residential slabs and footings – Construction

AS 2890 Parking facilities

AS 2890.1 Off-street car parking

AS 3582 Supplementary cementitious materials for use with portland and blended cement

AS 3582.1 Fly ash

AS 3582.2 Slag – Ground granulated iron blast-furnace

AS 3582.3 Amorphous silica

AS 3600 Concrete structures

AS 3700 Masonry structures

AS 3727 Guide to residential pavements

AS 3799 Liquid membrane-forming curing compounds for concrete

AS 3972 Portland and blended cements

AS 4586 Slip resistance classification of new pedestrian surface materials

HB 197 An Introductory Guide to the Slip Resistance of Pedestrian Surface Materials *(available from Standards Australia)*

Relevant CCAA Publications

B

AVAILABLE FOR PURCHASE from Standards Australia

Guide to Concrete Construction

AVAILABLE FOR DOWNLOADING (FREE) from www.concrete.net.au

Applications

Houses for Bushfire-prone Sites

Polished Concrete Floors (Briefing 5)

Concrete Retaining Walls

Concrete Panel Homes Handbook

Guide to Off-form Concrete Finishes

Guide to Residential Slabs and Footings in Saline Environments

Residential Concrete Driveways and Paths

Concrete materials, properties and construction

Hot-weather Concreting

Cold-weather Concreting

Curling of Concrete Slabs

Compaction of Concrete

Curing of Concrete

No Fines Concrete

The Specification of Honed Concrete Finish

The Specification of Burnished Concrete Finish

Sealers for Exposed Concrete Flatwork

Colouring, Stencilling and Stamping Concrete Flatwork (Briefing 1)

Exposed Aggregate Finishes for Flatwork (Briefing 2)

Thermal Benefits of 'Solid' Construction

Articulated Walling

Joints in Concrete Buildings

Tolerances for Concrete Surfaces

Concrete Slabs as Barriers to Subterranean Termites

Slab Edge Dampness and Moisture Ingress

Moisture in Concrete and Moisture-sensitive Finishes and Coatings

Energy Efficiency in Building Regulations and the use of Concrete in Housing

Slip Resistance of Polished Concrete Surfaces

Slip Resistance of Residential Concrete Paving Surfaces

Skid Resistance of Residential Concrete Paving Surfaces

Avoiding Early Cracking

Avoiding Surface Imperfections in Concrete –

- Flaking Floors
- Blowholes (bug holes)
- Honeycombing
- Popouts
- Efflorescence

OnSite – Dusting Concrete Surfaces

OnSite – Plastic Shrinkage Cracks

OnSite – Beware of Excess Water

Removing Stains from Concrete

Cleaning Concrete

Masonry

Durability of Masonry Mortar

Masonry Bond Strength

Durable Masonry Specification Checklist

Mortar Mixes for Masonry

Mixing Mortar for Masonry

Constructing Durable Masonry

Bond Strength in Masonry Construction

Removal of Mortar

Render

Guidance on Render for Simple Projects

Information on Selection, Construction and Finishes using Render