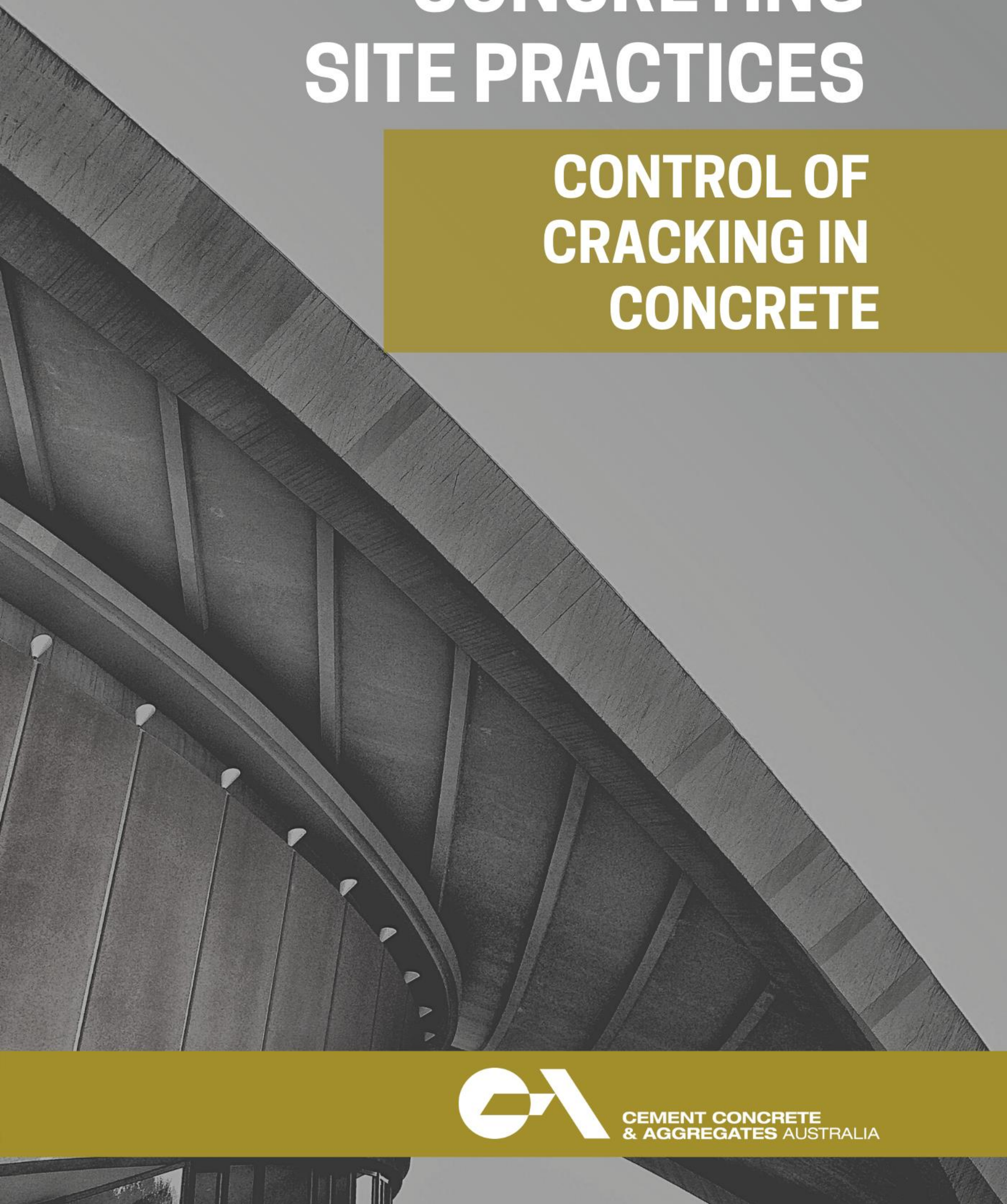
PART V. CONCRETING SITE PRACTICES

CONTROL OF CRACKING IN CONCRETE



CEMENT CONCRETE
& AGGREGATES AUSTRALIA

CONTENTS

1. OUTLINE

Cracks form in concrete construction for a variety of reasons and at different times – sometimes before the concrete has hardened, sometimes long after. This Section summarises information on the various types of cracking which may be encountered, the principal causes of cracking and methods used to minimise or prevent cracking. Information is also provided on repair techniques which may be used if cracking occurs.

Cracks may occur in concrete construction for a variety of reasons. For example, drying shrinkage occurs when hardened concrete loses moisture. Being a brittle material with a low tensile strength, if this shrinkage is restrained the concrete is liable to crack as it shrinks, unless appropriate measures are taken to control this (such as the provision of control joints).

Cracks may occur due to settlement of the concrete, movement of the formwork before the concrete member is able to sustain its own weight, or due to changes in the temperature of the concrete and the resulting thermally induced movement.

Appropriate measures will at least minimise, if not prevent entirely, these forms of cracking.

2. PREHARDENING CRACKS

2.1 GENERAL

Cracks which form before concrete has fully hardened (e.g. in less than eight hours) are known as pre-hardening cracks. There are three main types:

- Plastic shrinkage cracks;
- Plastic settlement cracks;
- Cracks caused by formwork movement.

All occur as a result of construction conditions and practices although, obviously, faulty formwork design may lead to its movement and/or failure. Pre-hardening cracks are usually preventable by the adoption of good construction procedures.

Plastic Shrinkage Cracks

Plastic shrinkage cracks are formed in the surface of the concrete prior to the concrete setting and hardening. It is common that these cracks are barely visible until after the concrete has hardened and the surface has started to dry. They are due to the too-rapid loss of moisture from the surface of the concrete and generally result from concrete placing and finishing processes during hot, dry or windy conditions.

Plastic shrinkage cracks normally form without any regular pattern and may range from 25 mm to 2 m in length. These cracks vary from a hairline to perhaps 3 mm in width. Since they occur most often in hot weather, they are discussed in Section 18 *'Hot- and Cold-Weather Concreting*' in this Guide, to which reference should be made for further information and for guidance on procedures to prevent their occurrence.

Plastic Settlement Cracks

Most concrete, after it is placed, bleeds (i.e. water rises to the surface as the solid particles settle). The bleed water evaporates at the exposed surface and there is a loss of total concrete volume (i.e. the concrete has 'settled'). If there is no restraint, the net result is simply a very slight lowering of the surface level of the concrete. However, if there is some restraint near the surface such as a reinforcing bar, which restrains part of the concrete from settling while the concrete on either side continues to drop, there is potential for a crack to form over the restraining element (**Figure 17.1**).

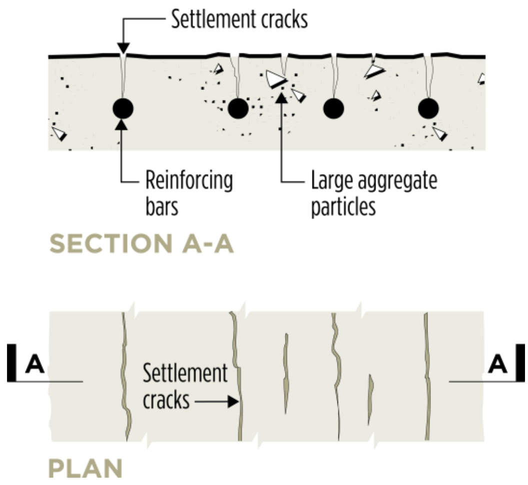


Figure 17.1 – Settlement Cracking

Differential amounts of settlement may also occur where there is a change in the depth of a section, such as at a beam/slab junction (**Figure 17.2**). Settlement cracks tend to follow a regular pattern replicating the lines of restraint, usually the reinforcement, or a change in section. Generally, the cracks are not deep but, because they tend to follow and penetrate down to the reinforcement, they may reduce the durability of a structure.

Factors which may contribute to plastic settlement include:

- Rate of bleeding and total bleeding;
- The time over which settlement can take place, e.g. time before the concrete begins to set;
- The depth of reinforcement relative to total thickness of the section;
- The ratio of the depth of reinforcement from the concrete surface (i.e. concrete cover) to size of bar;
- The constituents of the mix;
- The concrete slump.

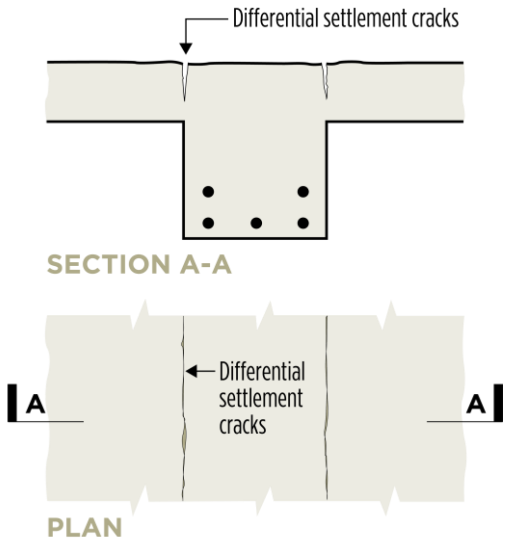


Figure 17.2 – Differential Settlement Cracking

Prevention of Plastic Settlement Cracking

Plastic settlement cracks may be prevented, or rather reduced, by re-vibrating the concrete after bleeding and settlement is virtually complete and the concrete has begun to stiffen. Re-vibration closes the cracks and enhances the surface finish and other properties of the concrete. Careful timing is essential to ensure that the concrete liquefies under the action of the vibrator and that the cracks disappear. Applying vibration before the concrete has begun to stiffen may allow the cracks to reopen. Applying it too late may damage the bond with reinforcement or reduce its ultimate strength (see Sections 13 and 14, *'Compaction'* and *'Finishing Concrete Flatwork',* in this Guide).

Other procedures which may help reduce plastic settlement cracking include:

- Using lower slump mixes;
- Using more cohesive mixes;
- Using an air entraining agent to improve cohesiveness and reduce bleeding;
- Increasing cover to the top reinforcement bars.

Where there is a significant change in section, the method of placing may be adjusted to compensate for the different amounts of settlement. If the deep section is poured first to the underside of the shallow section, this concrete can be allowed to settle before the rest of the concrete is placed. However, the top layer must be well vibrated into the bottom layer.

Avoiding the use of retarders is sometimes suggested as a way of speeding up concrete setting and so reducing bleeding and plastic settlement cracking. In the case of hot-weather concreting, the advantages of retarders generally outweigh the disadvantages.

Cracks Caused by Formwork Movement

If there is movement of the formwork, whether deliberate or unintentional, after the concrete has started to stiffen but before it has gained enough strength to support its own weight, cracks may form.

Such cracks have no set pattern. To avoid cracking from this cause, 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.

Some guides for the stripping time of formwork assume that Type GP cement is being used. Concretes incorporating supplementary cementitious materials (such as fly ash and ground slag) may take longer to gain strength and allowance should be made for this.

3. CRACKS IN HARDENED CONCRETE

3.1 GENERAL

Cracks occur in hardened concrete for three principal reasons, namely:

- Volume changes in the concrete;
- Chemical reactions within the body of the concrete that produce expansive reaction products that may cause cracking of the concrete;
- Cracking as a result of designed loading on the structure or overloading (structural cracking).

Volumetric movement in concrete cannot be prevented. It occurs whenever concrete gains or loses moisture (drying shrinkage) or whenever its temperature changes (thermal movement). If such movements are excessive, or if adequate measures have not been taken to control their effects, the concrete will crack.

Chemical reactions within the body of the concrete, which can cause it to expand and crack, include reinforcement corrosion and sulfate attack (see Section 25 *'Properties of Concrete'*), and alkali aggregate reaction (see Section 3 *'Aggregates'* in this Guide). Provided adequate care is taken in the selection of materials and good quality concrete is properly placed, compacted and cured, these reactions should not occur except in extreme environmental conditions.

Crazing on Concrete Surfaces

The word 'Crazing' describes the very fine (spider web-like) cracks which appear on the surface of concrete after it has been exposed to the atmosphere for some time. It can occur on both trowelled and formed surfaces but is more noticeable on trowelled surfaces, particularly when the surface has been wetted and allowed to dry out. It occurs when a thin, paste-rich layer on the concrete surface expands and shrinks during alternate cycles of wetting and drying, or as it carbonates and shrinks during long exposure to the air. The shrinkage and expansion in the thin surface layer are restrained by the mass of the concrete below it – resulting in craze cracking.

The use of cement-rich mixes on the surface of the concrete, adding dry cement powder to the surface during finishing exacerbates the problem, as does overworking (bringing excess paste to the surface) or trowelling bleed water back into the surface.

On formed surfaces, crazing tends to occur on smooth faces cast against low-permeability form-face materials.

Prevention of Crazing
To avoid 'crazing' on trowelled surfaces:

- Avoid very wet mixes;
- Do not use dry cement powders on the concrete surface during finishing;
- Do not overwork the concrete surface during finishing;
- Do not attempt finishing while bleed water is present;
- Do not steel trowel the concrete surface during finishing until the water sheen has gone and setting has started;
- Commence continuous curing promptly;
- Do not subject the surface to wetting and drying cycles.

On formed surfaces, very wet and over-rich mixes should be avoided, and curing should be continuous. The concrete should not be subjected to wetting and drying cycles during curing.

3.2 DRYING SHRINKAGE CRACKS

Hardened concrete shrinks or reduces in volume as it loses moisture due to:

- The hydration of the cement;
- Evaporation.

The shrinkage caused by moisture loss is not a problem if the concrete is completely free to move. However, if it is restrained from movement in any way, then tensile stress will develop. If that stress exceeds the ability of the concrete to carry it, the concrete will crack.

A number of factors influence the drying shrinkage of concrete, in particular the total water content. Other factors include:

- The content, size and physical properties of the concrete aggregate used in the mix;
- The relative humidity of the surrounding air;
- Admixtures used in the concrete, especially any containing calcium chloride;
- The curing methods used on the exposed surfaces of the concrete after finishing.

The cement content of concrete influences drying shrinkage to the extent that it may influence the amount of water used in a mix at a particular W/C ratio.

In order to reduce the total shrinkage of concrete:

- The water content of the mix should be minimised (consistent with the requirement for placing and finishing);
- The amount of fine material used in the mix should be minimised;
- The highest possible coarse aggregate content should be used in the mix design (consistent with the requirement for placing and finishing);
- The largest possible maximum aggregate size should be in the mix design (consistent with the requirement for placing and finishing);
- Good curing practices should be adopted.

Simply reducing the drying shrinkage of a concrete will not necessarily reduce cracking since it is also influenced by the restraint, detailing, geometry, construction practice etc.

Preventing Cracking due to Drying Shrinkage
The prevention of uncontrolled cracking due to drying shrinkage starts with the designer. Appropriate design and detailing are essential. Attention should be given to the following:

- Adequate reinforcement to distribute the tensile stress caused by drying shrinkage must be provided. This is particularly important in floors, slabs-on-ground, and similar applications where reinforcement may not be required for load-carrying or structural reasons;
- The provision, location and detailing of joints to isolate restraints and permit movement between discrete parts of the construction.

Construction practice is also important for it should ensure:

- That the concrete is properly placed, compacted and cured in order to minimise the magnitude of drying shrinkage;

- That the designer's details (reinforcement and joint locations) are correctly put in place;
- The removal of restraint by the formwork.

3.3 THERMAL MOVEMENT CRACKS

Thermal movement occurs when the temperature of concrete changes, due either to environmental changes or to the heat generated when the cement/binder hydrates.

Thermal movements due to changes in the ambient temperature are normally less of a problem in concrete structures, provided an adequate number of control or movement joints provided in slabs or long straight walls and in similar members are included; and provided isolation joints are arranged at restraints which might prevent the concrete from contracting or expanding.

Hardened concrete expands as temperature rises and shrinks as it cools. The coefficient of thermal expansion for concrete used in AS 3600 for the purposes of design is $10 \times 10^{6}/^{o}C$. Concrete that has a thicker section (typically over 500 mm minimum thickness of the concrete structure) is more susceptible to retaining heat caused by cement hydration. When this is combined with mixes containing higher cement content it can lead to a rise in temperature of up to 50°C from the initial plastic concrete temperature. Using the coefficient of thermal expansion for concrete noted above it can be estimated that the concrete in this example may go through an expansion during heating and contraction during the cooling phase of up to 500 micro-strain. In this case the early thermal movement may exceed the drying shrinkage movement over the life of the structure. Thinner structural elements and those using mixes with lower cement content are less affected by this form of movement.

Preventing Cracking due to Thermal Movement

The prevention of uncontrolled cracking due to thermal movement requires careful design of structural elements. Consideration should be given to the design of reinforcement, joints (where feasible) and the concrete mix being used.

3.4 STRUCTURAL CRACKS

When concrete structural designers are following the design principles set out in AS 3600, they will need to take account of the impacts of concrete structural cracking along with the effects of temperature movements and shrinkage. When a structural member is loaded in service it may deflect under load and zones of tensile stress will form in the member. The designer will need to consider the proportion of steel required to control the stresses resulting from all of these factors. In general, crack width is controlled to an acceptable level that meets the following needs:

- Aesthetics or the appearance of the cracks in the particular location of the member being assessed;
- Durability of the concrete and ability to maintain the service life of the structure in the service environment.

In a benign environment the visibility of cracks at the viewing distance may be of more concern and larger crack widths may be acceptable.

In environments with higher exposure classifications such as AS 3600 classifications B1, B2, C1 and C2, the design crack width will require careful consideration and typically may be limited to a maximum of 0.1 mm to 0.2 mm.

The types of members where structural cracking from design loads or overloading is a significant issue will most likely be:

- Beams;
- Suspended slabs;
- Columns (where tensile zones exist).

In members such as slabs on ground, walls or some foundations, it is probable that the effects of restraint combined with shrinkage and temperature movements will need to be designed for.

Prevention of Structural Cracking
Structural cracking control is largely in the hands of the structural designer, the construction contractor and the structure owner.

The design of concrete to avoid excessive cracking under load is controlled largely by employing adequate reinforcement in the tensile zones of structural members. The factors to achieve this control include reinforcement ratios, maximum design stress in reinforcement, location of reinforcement and reinforcement bar sizes to be used. Details of these controls in design are contained in AS 3600.

The construction contractor must ensure that the details of reinforcement positioning, quantity and bar sizes are carried out in accordance with the design. Concrete must be properly placed, compacted and cured to ensure that it achieves its potential strength as per the design. Formwork retention and propping of suspended beams and slabs must occur for sufficient time to ensure that the concrete reaches sufficient strength to avoid overloading.

The structure's owner must take steps to ensure that the design loadings on the structure are known and not allowed to be exceeded.

4. JOINTS

4.1 GENERAL

Joints in concrete construction may serve a number of purposes but are of two basic types:

- Those that do not allow relative movement of the concrete on either side of the joint; and
- Those that allow such movement.

The former – construction joints – aim to bond the concrete on either side of the joint in such a way that it acts monolithically. The latter type allows movement of the concrete in a controlled manner.

Joints that allow movement include:

- Contraction joints – which allow for shrinkage movements;
- Expansion joints – which allow movement towards or away from the joint, but prevent movement in other directions;
- Isolation joints – which allow two abutting concrete faces to move freely relative to one another.

4.2 CONSTRUCTION JOINTS

Construction joints are concrete-to-concrete joints made in such a manner that the two faces are held together to prevent any relative movement across the joint. They are required whenever there is a break in concreting operations which is sufficiently long that the concrete which has been placed has hardened before fresh concrete can be placed against that face. Such stoppages (and joints) may be planned or unplanned.

While unscheduled interruptions to the placing of concrete are to be avoided as far as is possible, they do occur. Some interruptions can, however, be foreseen (e.g. at the end of the day) and should be planned carefully to ensure that the joint is placed in a position where it will have the least effect, either structurally or visually. Ideally, such interruptions should be planned to coincide with an expansion, contraction or isolation joint. This will minimise the number of joints and also the possibility of faulty construction joints.

Faulty construction joints weaken the structure and may allow moisture to penetrate into or through the joint and possibly (a) cause reinforcement to corrode, and/or (b) result in staining of the concrete surfaces.

Location of Construction Joints
The concrete structure's designer should nominate/approve the location of construction joints in structural members because they usually result in a plane of weakness. Thus, they are normally located where shear forces in the member are low (e.g. in the middle third of beams and slabs).

Suitable locations for construction joints should be shown on the design drawings and should not be changed without the approval of the designer. Nor should additional joints be made without the designer's approval.

AS 3600 requires that, unless otherwise specified, construction joints must be made at the soffits of slabs or beams and their supporting walls or columns (**Figure 17.3**). As a general rule, horizontal joints are never allowed in slabs or are vertical joints in beams or slabs near their supports because shear stresses at these locations may be high.

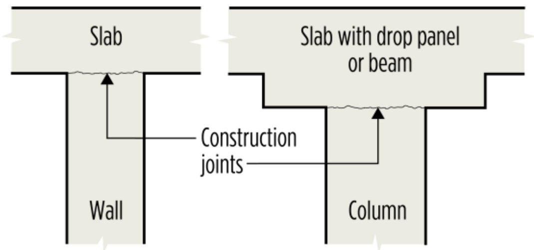


Figure 17.3 – Construction Joints between Horizontal and Vertical Elements

Vertical Construction Joints

When a construction joint has to be made in a beam or slab, a stop-end or bulkhead should be used to ensure that a vertical joint is properly formed (**Figure 17.4**). If the concrete is left free it will subside at an angle and be impossible to compact. The result will be a weak joint.

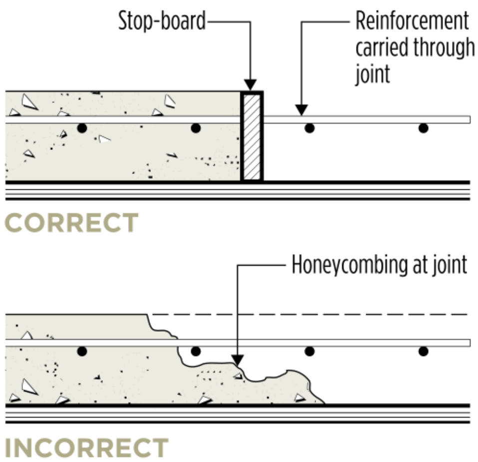


Figure 17.4 – Construction Joint in a Slab

To assist the transfer of loads across vertical joints, dowels or keyways are advisable in slabs over 150 mm in depth (**Figure 17.5**).

Reinforcement should not be cut at construction joints so that, where necessary, stop-ends must be slotted or fitted in sections so that they permit reinforcement to pass through them without allowing mortar leakage.

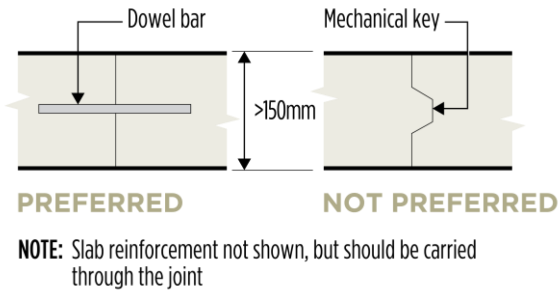


Figure 17.5 – Load Transfer across Construction Joints in Slabs over 150 mm Thick

The treatment to be given the partially hardened concrete before fresh concrete is placed against it will depend on its age. If it is less than four hours old, it is recommended to brush it with a wire brush. This roughens the surface and removes any weak material. Any residue from this treatment should be removed.

If the surface is more than four hours old at the time the fresh concrete is placed, water-blasting or other means may have to be used to expose the coarse aggregate of the concrete. The exposed surface should then be cleaned and dampened before fresh concrete is placed against it. A good mechanical keying of the coarse aggregates is important to an effective vertical construction joint shear restraint. Reliance on grouts or other 'adhesives' to provide bond is not recommended.

Horizontal Construction Joints

When fresh concrete settles or is compacted mechanically, a layer of laitance – watery grout – tends to form on the top surface. If this is allowed to harden, it forms a plane of weakness. Whenever possible, therefore, laitance should be removed as early as practicable from the surface of concrete against which a horizontal joint is to be formed. When the joint surface is not more than four hours old, this is relatively easy. Surfaces may be simply wire-brushed to expose sound concrete and all loose material removed. Fresh concrete should then be thoroughly compacted against the old surface.

Where the joint is being made against concrete more than a few hours old, additional treatment may be necessary, depending on the time that has elapsed.

Wire-brushing, the use of high-pressure water jets and even sandblasting are all methods which have been employed to expose sound concrete at the surface of a proposed horizontal construction joint. The exposed surface should then be cleaned of all loose material and free-standing water, dampened if necessary and fresh concrete compacted against it. Lengthy delays between clean-up and concreting may require the surface to be cleaned and dampened again before concreting operations are resumed.

Where a clean neat line is needed (e.g. in an exposed or rendered wall) typical formwork details are shown in **Figure 17.6**.

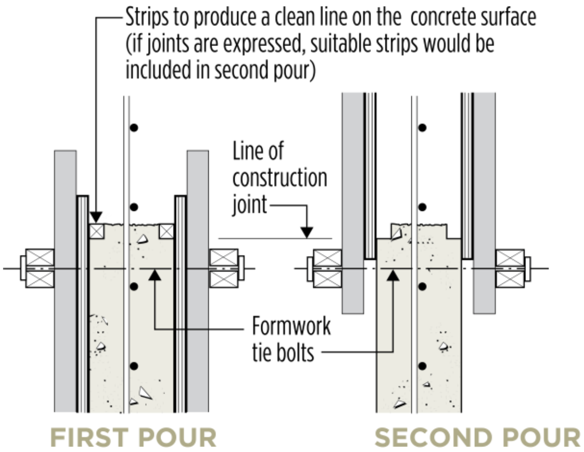


Figure 17.6 – Horizontal Construction Joint in a Wall when a Clean, Neat Line is needed

4.3 CONTRACTION JOINTS

A contraction joint is one in which the two concrete surfaces are free to move away from one another as a result of shrinkage or thermal movement. Relative movement in the plane of the joint is prevented.

As concrete hardens and dries out, it shrinks. Unless this shrinkage is unrestrained, it creates tensile stresses in the concrete which may cause it to suffer from un-controlled cracking.

While reinforcement will resist these tensile stresses and help prevent the formation of large cracks, it does not completely prevent cracking. It merely ensures that the cracks, if they occur, are more closely spaced and of smaller width. In properly designed reinforced concrete these cracks will not be obvious or of concern when seen from normal viewing distances.

Unreinforced concrete on the other hand, will tend to develop somewhat larger cracks at more irregular intervals, wherever the tensile strength of the concrete is exceeded by the shrinkage stresses. To prevent such cracks, contraction joints must be installed at appropriate intervals. It may also be advisable to install contraction joints in reinforced concrete rather than relying solely on reinforcement to control shrinkage stresses.

Contraction joints may also be required in mass concrete or very large members to allow for the shrinkage or reduction in volume which occurs as concrete cools or loses temperature after it has been placed.

Location of Contraction Joints

The location of contraction joints is a matter for the designer or supervising engineer to decide. For example – their location will often be defined on the drawings for pavements, industrial floors and similar applications. In other cases, they will be in a regular pattern or be an integral part of the architectural features.

Generally, they will be situated where the greatest concentration of tensile stresses resulting from shrinkage are to be expected, namely:

- At abrupt changes of cross-section;
- In long walls, slabs.

Contraction joints are most common in large areas of concrete pavement where they are used to divide the concrete into bays. Ideally, these should be approximately square. They may also be necessary in long walls, particularly where an unplanned crack would be undesirable.

Contraction joints form a convenient point at which to stop concrete work at the end of the day. This is an optimal practice to avoid having construction joints in the middle of a bay, which may compromise its load-carrying capacity and durability.

Construction of Contraction Joints

Contraction joints are formed by creating a vertical plane of weakness in the slab or wall. Movement is allowed at this point to accommodate changes due to shrinkage. On the other hand, it is usually necessary to prevent movement in other directions, i.e. in directions parallel to the plane of the joint (**Figure 17.7**). These twin requirements have the following consequences:

- The bond between abutting concrete surfaces in the joint must be broken;
- Reinforcement is terminated on both sides of the joint;
- Dowel bars, if used, must be un-bonded on one side of the joint.

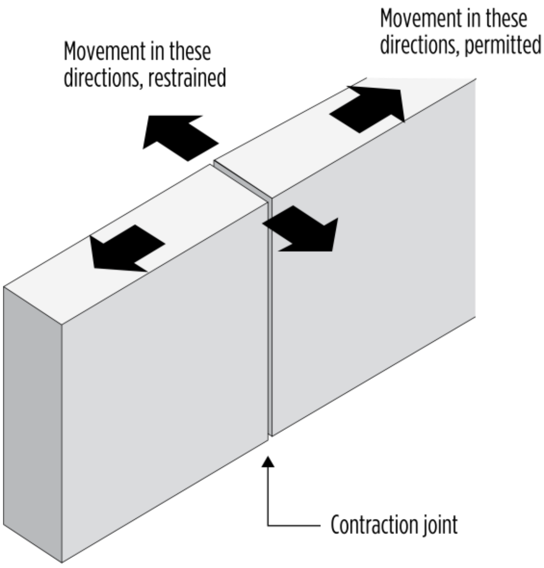


Figure 17.7 – Vertical Contraction Joint

Control Joints

A control joint is a form of contraction joint which is formed by building a plane of weakness into either a vertical or horizontal member. As the concrete shrinks, tensile stress is concentrated on this plane causing the concrete to crack there rather than elsewhere.

Normally, mechanical interlock across the two faces of the joint is expected to prevent other movement in the joint.

Control joints are a relatively simple alternative to a fully formed contraction joint. They are placed wherever a formed joint would have been placed and are most widely used in unreinforced slabs and pavements. Joint spacing in unreinforced slabs ranges from 1 m for thin pedestrian pathways, to approximately 6 m for road pavements.

Control joints can be made at any one of three stages during construction:

- A pre-moulded strip may be inserted into the concrete as it is being placed, to create a plane of weakness. Metal strips inserted into terrazzo or preformed plastic strips inserted into concrete pavements to form the centre line of the pavement are examples;
- A joint can be formed in the surface of the concrete with a suitable jointing or grooving tool. Upon hardening, the concrete cracks at this point, creating a joint.
  *(**NOTE**: The resultant joint <u>must</u> be at least 25% of the depth of the slab to be effective.);*
- After the concrete has hardened sufficiently to prevent ravelling of the edges, a sawn joint may be formed. The joint should be made as early as possible and prior to drying shrinkage starting to occur. Delay can result in unplanned cracking of the pavement. The sawn joint is then filled with a joint sealant to prevent dirt and other debris entering it (**Figure 17.8**) as unsealed joints tend to fill with dirt and become ineffective.

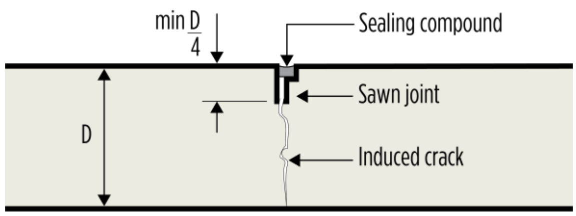


Figure 17.8 – Sawn Joint in Concrete Pavement

4.4 EXPANSION JOINTS

Expansion joints are formed to permit concrete elements to expand as the temperature of the concrete increases. Although the thermal expansion of concrete is relatively low, it is sufficient to cause distress under Australian climatic conditions where the surface temperature of a concrete pavement might increase by as much as 40-50°C during a hot summer's day.

There is considerable divergence of opinion on the necessity for expansion joints in concrete structures. Most often, such structures have contraction or control joints, which, if properly protected from becoming filled with dirt or other debris, will accommodate the thermal expansion of concrete under most conditions. On the other hand, expansion joints are normally too widely spaced to function as contraction joints.

In the final analysis, it is the designer who must give careful consideration to the need for expansion joints in a particular building or structure. Considerations which might influence that decision are:

- Whether the structure will contain contraction or control joints. (Some reinforced concrete structures incorporate reinforcement to control shrinkage cracking and omit contraction or control joints);
- Whether the structure is likely to be subjected to a considerable range of temperature;
- Whether there are fixed restraints which are likely to cause damage (or be damaged) should thermal expansion take place. A pavement abutting a bridge deck is a good example;
- Whether the structure is likely to be subjected to a significant temperature rise before it has dried out and drying shrinkage has occurred.

Construction of Expansion Joints

Since expansion joints are designed to permit movement in only one plane, i.e. at right angles to the plane of the joint, some provision must be made to prevent movement in the plane of the joint. This may take the form of a dowel or dowels (**Figure 17.9**).

Keyed joints are not usually satisfactory because of the difficulty of sealing and maintaining them. Those which become packed with dirt or other debris cease to function and may result in damage to the building or structure.

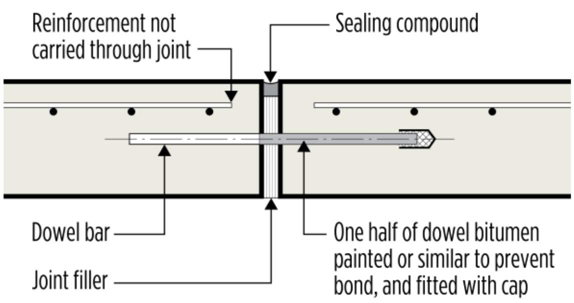


Figure 17.9 – Dowelled Expansion Joint

4.5 ISOLATION JOINTS

An isolation joint is one that allows complete freedom of movement on either side of the joint – as they have to accommodate both vertical and horizontal movements.

A common example of this is where a slab on ground abuts another structure which it is not connected to and must allow for expansion and shrinkage of the slab without damaging either the slab or the structure it buts up to.

Location of Isolation Joints

Isolation joints are located in buildings and other structures at points where differential movement is likely to occur. Where such movements include both vertical and horizontal components, an isolation joint is indicated. They are used to isolate:

- Machinery footings from the rest of the building;
- One part of a building from another, e.g. basement slabs from columns by boxing out the column support (**Figure 17.10**), or a floor from a wall (**Figure 17.11**);
- Delicate equipment from moving or vibrating floors.

4.6 WATERTIGHT JOINTS

In structures like reservoirs, water tanks, sludge tanks and other liquid-retaining structures, watertightness is a very important consideration. In consequence, both vertical joints and horizontal joints require special attention to ensure that they remain watertight in service.

Vertical construction joints require sealing as they tend to open up as the concrete shrinks.

Similarly, contraction joints and expansion joints, which are designed to move, require special treatment.

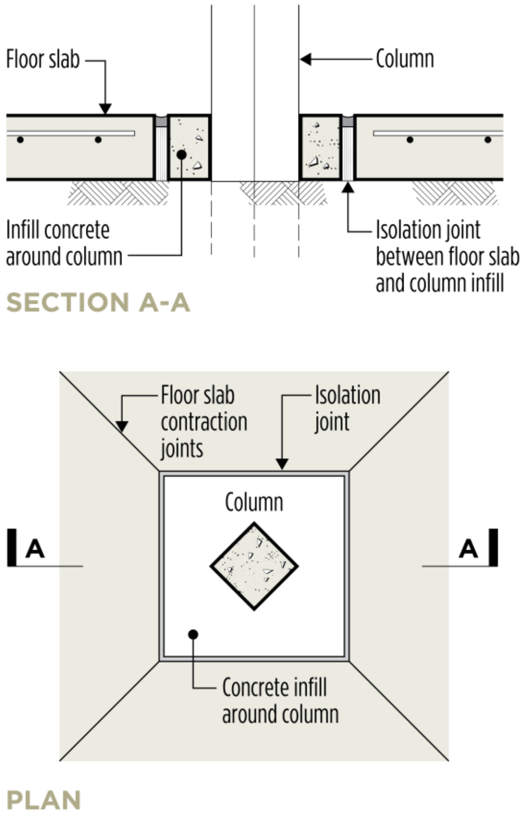


Figure 17.10 – Isolation Joints around Column

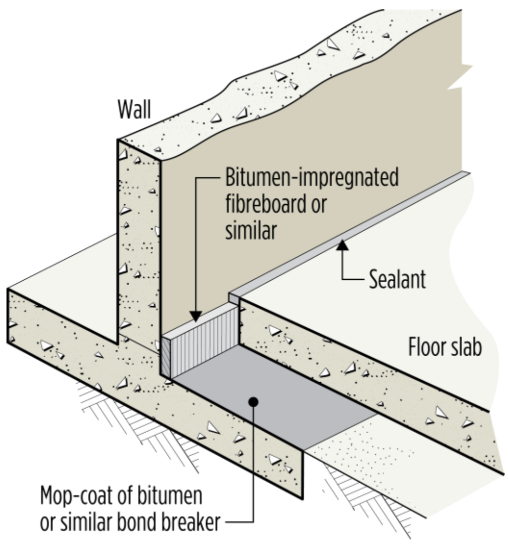


Figure 17.11 – Isolation Joint between Slab and Wall

The most common solution in all three cases is the insertion of a water-stop in the joint. This may be one of two types:

- A metal water-stop – normally a strip of copper sheeting placed in the joint so that it extends equal distances on either side;
- A flexible water-stop – normally a rubber or PVC moulded shape. It may have the shape of a dumb-bell or have a central bulb (**Figure 17.12**).

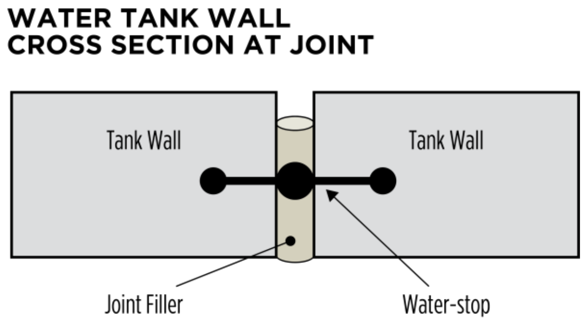


Figure 17.12 – Typical Rubber Water Stop with Central Bulb

Where specific sealing of an expansion joint is required, the water-stop must be capable of movement itself. Copper strips with a central crimp or flexible stops with a central bulb meet this requirement. Isolation joints may need similar treatment. Horizontal joints, in walls for example, will not normally require a water-stop since, if properly prepared, there is less tendency for them to open up.

5. CRACK REPAIR

5.1 GENERAL

When repairs to a crack are being considered, the following factors should be taken into account:

- Whether the crack is dormant (i.e. it is unlikely to extend or open further) or whether it is live (i.e. it is likely to be subject to further movement);
- The width and depth of the crack;
- Whether or not sealing against pressure is required, and, if so, from which side of the crack will the pressure be exerted;
- Whether or not appearance is a factor.

Above all, it is necessary to determine the cause of the cracking. While this may seem obvious, it is not always done. For example, the repair of cracks caused by corroding reinforcement without remedying the cause of the cracking will inevitably provide only a short-term solution.

Dormant cracks, i.e. those judged not likely to move further, have traditionally been filled by chasing them out and then sealing them with a cement grout or mortar. Whilst this is still an effective method in many cases, many other material types are now available which are more effective, albeit more expensive. They include epoxy resins, polyester resins and synthetic latex.

Live cracks, i.e. those judged to be still moving, require a sealant to be flexible if it is to be effective (e.g. polyurethane resins, acrylic gels and flexible epoxy resins). Since there are such a wide variety of these materials available, it is not possible to give detailed instructions on their usage. What follows is intended to provide general guidance only. More detailed information should be sought from the manufacturers of particular products.

Dormant Cracks

Dormant cracks may range in width from 0.05 mm or less (crazing) to 5 mm or more. Obviously, the width of the crack will have considerable influence on the materials and methods chosen for its repair.

Very fine cracks (e.g. crazing) are very difficult to repair effectively and in many cases the best option may be to do nothing. Autogenous healing of very fine cracks may occur with time.

If the problem is an aesthetic one, rubbing down the surface with a grinding stone followed by sealing with a water-repellent material (such as sodium silicate) may provide a solution. Dirt, collecting in very fine cracks, tends to accentuate them.

Fine cracks, those up to about 1 mm in width, may often be sealed against water penetration by simply rubbing in a cement grout or slurry. The grout may be modified with a styrene butadiene or styrene acetylate polymer to increase adhesion.

Fine cracks may also be sealed by injecting them with either a cement grout or an epoxy resin. Epoxy resins have been produced for this purpose and low viscosity formulations are available which will penetrate cracks as fine as 0.1 mm in width, or less.

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;
- They are resistant to a wide range of chemicals, including alkalis.

Epoxy grouts are normally injected under pressure. Nipples or injection points are fixed along the line of the crack and the surface is then sealed on both sides of the cracked element should this be necessary. The epoxy is then injected under pressure using specialised equipment. In some instances, a vacuum may first be applied to the crack to exhaust the air and assist the inflow of resin when the vacuum is released.

Wider cracks (over 1 mm in width), may also be sealed by injecting epoxy resin and particularly cracks on vertical surfaces. On horizontal surfaces it may be possible to simply pour the grout into the crack. For cracks wider than say 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. Polyvinyl acetate, for example, is water soluble.

Live Cracks

Live cracks must be sealed with a flexible material which can accommodate the movement in the crack. This is especially so when cyclic movements are anticipated.

Flexible epoxy resins are available which will accommodate a small amount of movement, but the more usual procedure is to choose a mastic, thermoplastic or elastomer.

Mastics are generally viscous liquids such as non-drying oils, butyl rubber or low melting asphalts. They are used in conjunction with a groove or chase cut into the surface of the crack which is then filled with the mastic. These are likely to be the lowest cost of the available sealants, but their use is restricted to vertical surfaces or horizontal surfaces which are not trafficked.

Movement in the crack, particularly in hot weather, may cause the sealant to extrude.

Thermoplastic materials are those which soften and become liquid or semi-liquid at higher temperatures, normally in excess of 100°C. Although less susceptible to temperature than mastics, they suffer from similar disadvantages.

Elastomers include a wide range of materials, such as polysulphides, polyurethanes, silicones and various acrylics. Some are one-part, and some are two-part materials. They have advantages in that they are less susceptible to temperature in the normal range experienced in buildings and other structures, adhere strongly to concrete and are able to accommodate significant movements without failure. Reference should always be made, however, to the information supplied by the manufacturer to ensure the correct application of particular products to particular situations.

6. REFERENCES

1) AS 3600 – *Concrete structures*
2) SA HB 84 – *Guide to concrete repair and protection*

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