INFORMATION BULLETIN: IB 73

Cracking

INTRODUCTION

Concrete cracks may occur in concrete construction for a variety of reasons. Cracking in concrete construction is almost inevitable because concrete, like most other building materials, moves with changes in its moisture content. Specifically, it shrinks as it loses moisture. Being a brittle material it is liable to crack as it shrinks unless appropriate measures are taken to prevent this, e.g. by the provision of control joints.

Shrinkage cracking, although common, is not the only form of cracking. Cracks may occur also 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 thermal movement.

Appropriate measures will at least minimise, if not prevent entirely, these forms of cracking. In all cases, joints at appropriate intervals will control cracking and ensure that it does not occur in a random fashion to the detriment of the appearance and long-term durability of the structure.

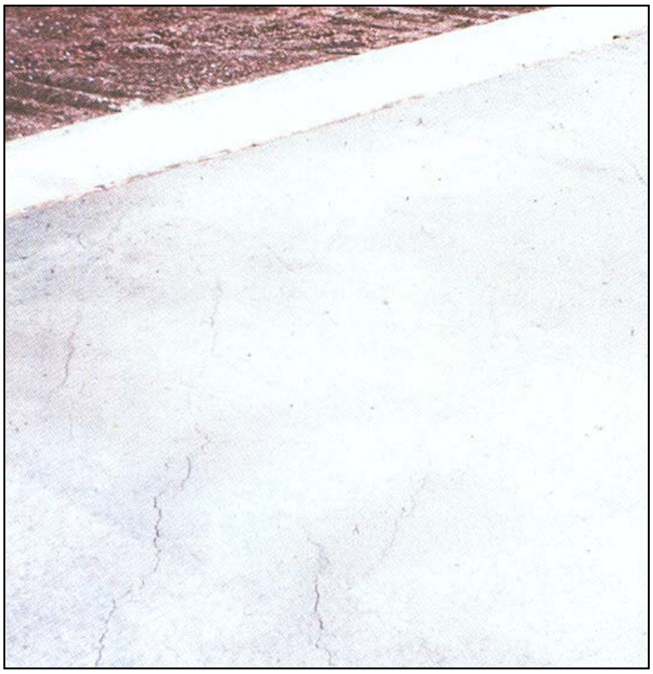
PREHARDENING CRACKS

Cracks that form before concrete has fully hardened (e.g. less than eight hours) are known as prehardening 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 faulty formwork design may lead to its movement and/or failure. Prehardening cracks are usually preventable by the adoption of good construction procedures.

Plastic Shrinkage Cracks



Plastic cracks are formed in the surface of the concrete whilst it is still plastic, that is before it has set and begun to harden, although they may not become visible until some time later. They are due to the too rapid loss of moisture from the surface of the concrete, e.g. during hot, dry and windy conditions (they are a form of drying shrinkage crack). Usually they form without any regular pattern, and may range from as little as 25 mm to as much as 2 m in length. They are fairly straight and vary from a hairline to perhaps 3 mm in width.

Prevention of Plastic Shrinkage Cracks

The best protection is to understand when the risks of plastic cracking are greatest so that appropriate actions can be taken. The main variables that control the evaporation rate are:

- wind speed;
- relative humidity;
- concrete temperature;

- air temperature.

The greatest risk of plastic cracking occurs on hot, dry, windy days. *Figure 1* (below) provides a method of estimating the evaporation rate given the above information. When the estimated evaporation rate exceeds 1 litre/m^2 per hour, precautions need to be taken to prevent plastic cracking. New Zealand experience suggests this limit is adequate. It is recommended that a conservative approach be adopted when deciding to take precautions, as in countries such as the United Kingdom it is advised that plastic cracking protection should be instigated at half this evaporation rate.

Typically one of the more significant variables is the wind speed. This is why in Britain it is often called 'wind cracking' as a reminder that it is primarily caused by air movements causing drying of the surface. In New Zealand's warmer, drier environment, temperature and humidity are equally important. Some protection can be obtained by preventing air movement over the slab with the use of a windbreak. The use of polythene will prevent both evaporation and air movement. It should be used with caution though when trying to obtain a consistent colour to the slab. Generally the use of polythene produces shade differences due to differing moisture conditions associated with wrinkling of the polythene. Polythene can be laid on the surface with sufficient rolled back in sections to allow finishing to be completed.

Other precautions that can be adopted include:

- The use of proprietary anti-evaporant alcohols. These are simply sprayed onto the surface, to provide a thin layer of alcohol that reduces water evaporation rates at the concrete surface. These products are inexpensive and can be applied with a weed sprayer. It is important to note that these products are not curing agents, and will need to be re-applied if the surface is disturbed.

- Water misting – this can be difficult to achieve in windy conditions.

- Polypropylene fibres – these are typically added at the batching plant and therefore their use requires planning.

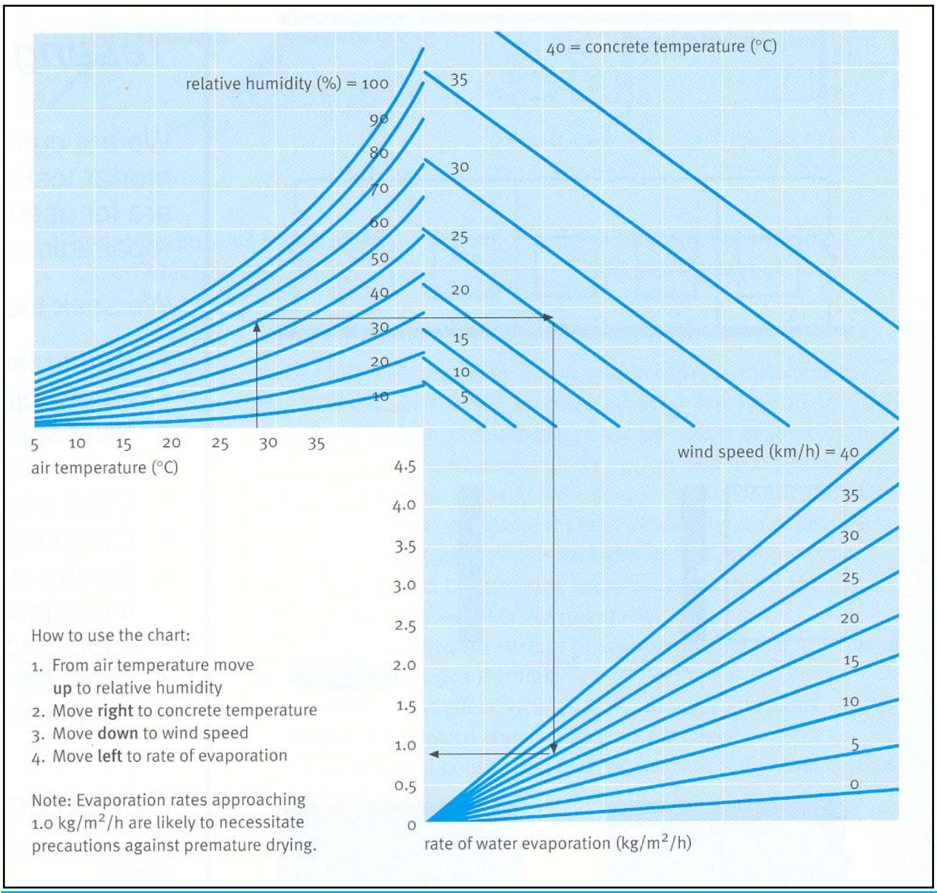


Figure 1:

The effect of concrete and air temperatures, relative humidity, and wind velocity on the rate of evaporation of surface moisture from concrete.

Beaufort Scale

F	Wind Speed (kph)	General Description	Sea State	Land Description
0	0 – 1.5	Calm.	Sea like mirror.	Smoke rises vertically.
1	1.5 – 5	Light.	Small ripples, no foam crests.	Smoke drifts, leaves rustle.
2	6 – 11	Light breeze.	Small wavelets, short but more pronounced, crests glassy and do not break.	Wind felt on face.
3	12 – 19	Gentle breeze.	Large wavelets, crests start to break, occasional whitecaps.	Flags extended, leaves move constantly.
4	20 – 29	Moderate breeze.	Small waves becoming longer, frequent whitecaps.	Dust moves, small branches move.
5	30 – 38	Fresh breeze.	Moderate waves, long form, many whitecaps, some spray.	Small trees begin to sway.
6	39 – 50	Strong breeze.	Large waves begin to form, whitecaps all around, moderate spray.	Large branches move, wires whistle.
7	51 – 60	Near gale.	Sea heaps up, foam from breaking waves begins to blow in streaks in direction of wind.	Trees in motion, resistance is felt when walking.
8	61 – 75	Gale.	Moderately high waves, edges of crests break into spindrift, foam is blown in well-marked streaks in direction of wind.	Walking impeded.
9	76 – 86	Strong gale.	High waves, dense streaks, spray may affect visibility.	Some structural damage begins.

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 and there is a loss of total volume – the concrete has 'settled'.

If there is no restraint, the net result is simply a very slight lowering of the surface level. However if there is something 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. See *Figure 2* (page 4).

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. See *Figure 3* (page 4).

Settlement cracks tend to follow a regular pattern coinciding with a 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;
- the depth of reinforcement relative to total thickness;
- the total time of settlement;
- the depth of reinforcement/size of bar ratio;
- the constituents of the mix; and
- the slump

Prevention of Plastic Settlement Cracking

Plastic settlement cracks may be prevented or closed, by revibrating the concrete after settlement is virtually complete, and it has begun to set e.g. after half an hour to one hour. Revibration closes the cracks and enhances the surface finish and other properties of the concrete. Careful timing is essential to ensure that the concrete reliquefies under the action of the vibrator and that the cracks close fully. Applying vibration before the concrete has begun to stiffen may allow the cracks to reopen. Applying it too late, i.e. after the concrete has begun to harden, may damage the bond with reinforcement or reduce its ultimate strength.

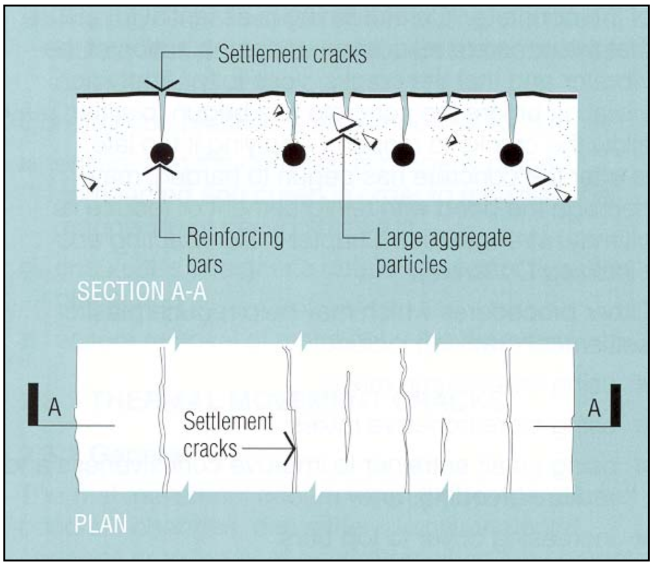


Figure 2: Settlement Cracking

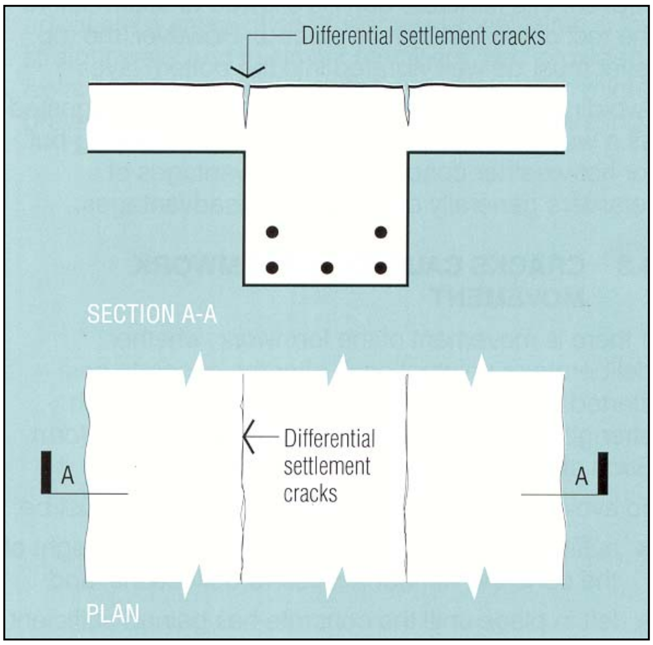


Figure 3: Differential Settlement Cracking

Other procedures which may help reduce plastic settlement cracking include:

- using lower slump mixes;
- using more cohesive mixes;
- using an air entrainer to improve cohesiveness and reduce bleeding; and
- increasing cover to top 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 reducing plastic settlement cracking, but for hot-weather concreting, the advantages of retarders generally outweigh the disadvantages.

Cracks Caused By Formwork Movement

If there is deliberate or unintentional 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. 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, may take longer to gain strength and allowance should be made for this.

CRACKS IN HARDENED CONCRETE

Cracks occur in hardened concrete for two principal reasons:

- volume changes in the concrete; and
- chemical reactions within the body of the concrete which cause expansion and subsequent cracking of the concrete.

Volumetric movement in concrete cannot be prevented. It occurs whenever concrete gains or loses moisture (drying shrinkage) or whenever it's 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 sulphate attack, and alkali-aggregate reaction. 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

'Crazing' describes the very fine 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 the former, particularly when wet. It occurs as 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 use of cement-rich mixes on the surface of the concrete, 'driers', exacerbates the problem, as does overworking (bringing excess mortar 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.

It is generally accepted that crazing is a cosmetic problem. There is much anecdotal evidence of industrial floor slabs that exhibit crazed surface cracking which have been in service for many years without deterioration. Autogeneous healing of fine cracks can occur, and although 'healed' the cracks will still be visible.

Prevention of Crazing

To avoid crazing on trowelled surfaces:

- avoid very wet mixes;
- do not use 'driers';
- do not overwork the concrete;
- do not attempt finishing whilst bleed water is present;
- do not steel trowel until the water sheen has gone;
- commence continuous curing promptly; and
- 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.

Drying Shrinkage Cracks

Hardened concrete shrinks, i.e. it reduces in volume as it loses moisture due to:

- the hydration of the cement; and
- evaporation.

The shrinkage caused by moisture loss is not a problem if the concrete is completely free to move. However, if it is restrained in any way, then a 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 shrinkage of concrete, in particular the total water content. Others include:

- the content, size and physical properties of the aggregate;

- the relative humidity;
- admixtures, especially those containing calcium chloride; and
- the curing conditions.

The cement content of concrete influences shrinkage drying almost only to the extent that it influences the amount of water used in a mix.

In order to reduce the total shrinkage of concrete:

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

Simply reducing the shrinkage of a concrete will not necessarily reduce cracking since this 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 is essential. Specifically, attention must be given to the following:

- The provision and location of adequate reinforcement to distribute the tensile stress caused by drying shrinkage. 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 must:

- ensure that the concrete is properly placed, compacted and cured in order to minimise the magnitude of drying shrinkage;
- ensure the designer's details are correctly put in place; and
- ensure removal of restraint by the formwork.

THERMAL MOVEMENT CRACKS

Thermal cracking is attributable to the heat generated during the cement hydration process. The subject is complex, and therefore with the space limitations of this information bulletin we will look only at:

- Developing some initial understanding of the issues.
- Determining when designers and builders should think carefully about this subject.
- The types of cracks that can form.
- Design and construction strategies to remove, or reduce the incidence of this type of cracking.

For those wanting a more detailed discussion on this subject, use CIRIA Report 91 "Early-age thermal crack control in concrete".

Heat of Hydration

The mixing of cement with water starts a chemical reaction that gives of heat. The amount of heat generated is influenced by several factors, including:

- The amount of cement used.
- Whether supplementary cementitious materials are used.
- The type of cement, for example, High, Early or General Purpose cement.
- The properties of aggregates.
- The placing temperature of the concrete.
- The ambient temperature.

- The type of formwork, and when it is stripped.

Table 1 (page 7) provides an indication of the temperature rises above mean ambient for various cement contents, section thickness and formwork types.

The table specifically relates to an assumed concrete placing temperature of 20°C and a mean ambient temperature of 15°C. Higher placement and ambient temperatures will increase the rate of hydration, and higher temperature rises above ambient will occur. The table also assumes that the formwork remains in place until after the peak temperature has been reached. For a 500 mm thick section the peak temperature will typically be reached between 20-48 hours.

If it is considered desirable to reduce the temperature build-up in the concrete, there are several mix design related options that could be explored. It is worth discussing the options with your local ready mix company to assist in evaluating both the technical and economic implications of the options.

Options which may be considered include:

- Using supplementary cementitious materials such as granulated ground blast furnace slag, silica fume, or fly ash.
- Using larger aggregates.
- Using water reducing admixtures.
- Lowering the placement temperature.

Heat of Hydration Cracks

Cracking associated with hydration heat, can be roughly split into two categories:

- Cracks that are due to the development of a large thermal gradient through the member (internal restraint).
- Cracks that develop due to external restraint from free contraction as the member cools.

Internal Restraint

The usual rule of thumb used to prevent the first type of cracking, is to ensure that the temperature difference through the member is less than 20°C. Temperature differences larger than this can occur in large members such as raft foundations, or potentially when the formwork is removed early. It is suggested that this issue should be carefully considered when the member thickness is greater than 500 mm.

External Restraint

As concrete cools it contracts. If this contraction is prevented by external restraints it can crack.

The key to the prevention of this cracking lies in ensuring that the coefficient of expansion x temperature drop x restraint factor is less than the tensile strain capacity. Therefore reducing the thermal movement or the restraint, or increasing the tensile strain capacity reduces or prevents early age thermal cracking. If it is not possible to prevent early age thermal cracking, the crack widths can be controlled by reinforcement.

Table 2 (page 8) provides a summary of factors that help prevent or control early age thermal cracking.

Table 1: Range of temperature rises above mean ambient temperature (C) for concretes.

Section thickness (mm)	*Steel Formwork Cement content (kg/m³)*				*18-mm plywood formwork Cement content (kg/m³)*			
	220	*290*	*360*	*400*	*220*	*290*	*360*	*400*
<300	5–7	7–10	9–13	10–15	10–14	14–19	18–26	21–31
500	9–13	13–17	16–23	19–27	15–19	20–27	27–36	31–43
700	13–17	18–24	23–33	27–39	18–23	25–32	34–43	40–49
>1000	18–23	24–32	33–43	39–49	22–27	31–37	42–48	47–56

Table 2: Summary of strategies to prevent or control early-age thermal cracking.

Mix Design

Factor	*Most heat* → *Least heat*	*Comments*
Cementitious materials	HE · GP · GP/Pfa GP/Silica fume · GP/GGBFS	Cement type has a significant influence on the heat generated. Cement selection will depend upon economic risk and consequence consideration.
Admixtures	None · Water reducers Superplasticisers	Modest reduction in heat achieved as a cementitious material remover.
Aggregate Size	Small diameter · Large diameter	Consider implications of aggregate size on placing around reinforcing.

Construction Technique

Factor	*Greater risk of cracking* → *Lower risk*	*Comments*
Placing temperature	High · Low	Is cooling the concrete before placing feasible and economic?
Ambient temperature	High · Low	Little or no control over this.
Cooling of placed concrete (a) Cooling pipes (b) Surface cooling		Effective, but expensive. Should only be used in sections under about 500 mm thick.
Formwork material (a) Section thickness under about 500 mm (b) Large isolated sections	 (a) Insulated · plywood · GRP · steel (b) Steel · GRP · plywood · insulated	The aim is to minimise the thermal gradients across the section.
Formwork striking times (a) Section thickness under about 500 mm (b) Large isolated sections	 (a) Long period · Short period (b) Short period · Long period	Also keep the upper surface insulated.
Reducing restraint (a) Construction sequence (b) Movement joints	 (a) Alternate bay · Sequential construction or short infill bays Long period between suc-cesssive lifts · Short period between lifts · Slipforming (b) None · Partial movement joints · Full movement joints	Sequence of casting is not significant if the joints are full movement joints.
Control of crack widths with reinforcement	Large dia. bars at wide spacings · Small dia. bars at close spacings	

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