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Evaluating Cracking in Concrete

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WHY CRACKS FORM IN CONCRETE STRUCTURES

Concrete provides structures with strength, rigidity, and resilience from deformation. These characteristics, however, result in concrete structures lacking the flexibility to move in response to environmental or volume changes.

Cracking is usually the first sign of distress in concrete. It is, however, possible for deterioration to exist before cracks appear. Cracking can occur in both hardened and fresh, or plastic, concrete as a result of volume changes and repeated loading. This involves tensile stresses being loaded onto the concrete, the cracks occurring when the force exceeds its maximum tensile strength.

We at Bluey Technologies maintain that it is important to understand the reasons why cracking occurs, the type of crack formed, and cracks' effects on structural stability. Once you understand these points you can take the appropriate action. This may mean leaving the crack alone, injecting the crack with an appropriate material, or applying other suitable repair methods.

EVALUATING CRACKS' CAUSES AND STATUS

It is important to identify the primary concern in regard to any cracking. The main concerns are whether the cracks are affecting structural integrity, caused by inappropriate design, aesthetically unacceptable, or reducing durability. You can only identify the primary concern after evaluating a crack thoroughly.

IMPORTANT POINTS TO EVALUATE

The type of cracking provides useful information to help understand a crack's effects on structural stability. Figure 1 presents a summary of the different types of concrete cracks and their possible causes.

A crack's status is critically important. Active cracks may require more complex repair procedures that may include eliminating the actual cause of the cracking in order to ensure a successful long-term repair. Failure to address the underlying cause may result in the crack's repair being short-term, making it necessary to go through the same process again. Dormant cracks are those not threatening a structure's stability, but those responsible for the structure must address durability issues and take appropriate action if aesthetics are a priority.

A crack's environmental conditions influence the extent to which it affects its structure's integrity. Greater exposure to aggressive conditions increases the possibility of structural instability.

Cracks' sizes range from micro-cracks that expose the concrete to efflorescence to larger cracks caused by external loading conditions. Noting cracks' sizes, shapes, and locations can aid in determining their initial causes. Figure 2 illustrates the types of cracks and their primary causes in relation to their location.

Figure 1: Types of cracks and their causes

CRACKING IN PLASTIC CONCRETE

Cracks that form in plastic concrete can be categorised as either plastic shrinkage cracking or plastic settlement cracking. Both of these types result from the bleeding and segregation process that occurs when fresh concrete is placed. Such cracks usually appear from one to six hours after concrete placement.

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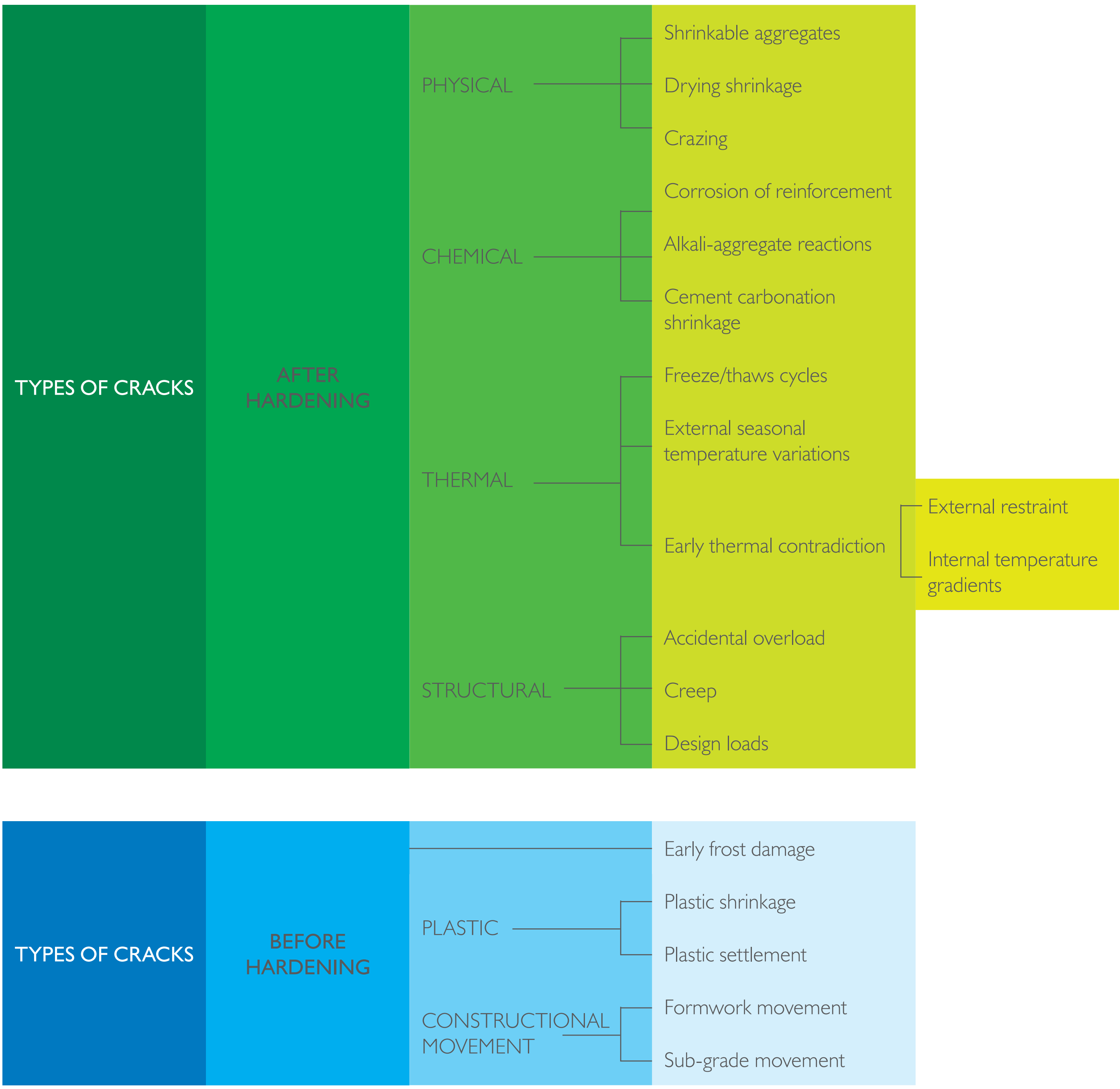

Figure 1: Types of cracks and their causes

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PLASTIC SHRINKAGE CRACKING

As the concrete's heavier particles settle due to gravity, they push the water and lighter particles toward the surface. This is called bleeding. If you fail to monitor the temperature, wind, and humidity conditions properly the evaporation rate of the surface water may exceed the bleed rate, drying out the concrete's superficial layer and therefore shrinking it due to dehydration. The concrete beneath the surface layer is still well hydrated, however, and maintains its volume. This applies opposing tensile forces to the lower part of the drying concrete on the surface, causing a cracked concrete profile.

These plastic shrinkage cracks are usually shallow and only from 1 to 2 mm in width, which means you cannot repair them with the injection method. They may, however, self-heal through continual cement hydration or by the precipitation of calcium carbonate from the concrete.

If the cracks are wider than 2 mm and do not self-heal, it is important that you repair them with a suitable coating or flood-grouting product to stop them from penetrating the full depth of the concrete slab. If they do become active their reaction to stresses may result in further cracking that weakens the structure either directly or by exposing its reinforcement steel to contaminants that will in time corrode it.

PLASTIC SETTLEMENT CRACKING

The settlement process is a major factor in concrete's strength at different levels as it forms. Plastic settlement cracking can occur as a result of such restraints to the consolidation of the fresh concrete as the use of steel reinforcing bars or formwork.

Figure 2 illustrates how plastic settlement cracks form. As the concrete bleeds, the water works its way to the surface. Sedimentation then occurs as the aggregate and cement move downwards under the force of gravity. This separation forms a weaker layer of concrete near the surface. If such restraints as steel reinforcing bars are close to the surface and insufficiently covered with concrete the concrete bends back around the restraint and cracks at the apex. Deeper sections of concrete lead to greater separation between the sediment and the water, so it is important to ensure that you cover all superficial restraints adequately to reduce the amount of cracking.

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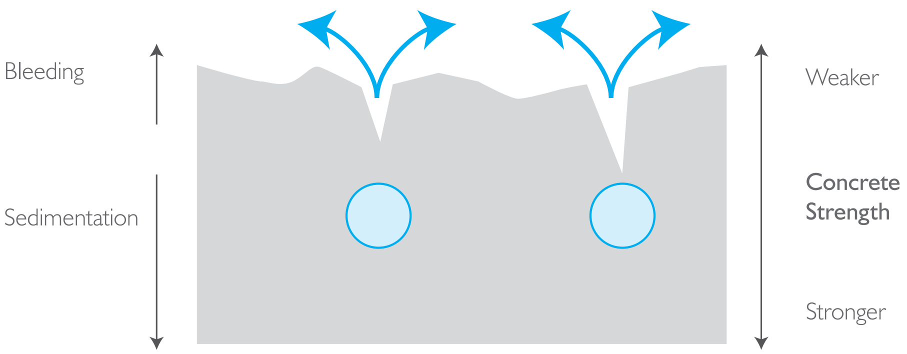
Figure 2: Schematic representation of plastic settlement crack formation

Plastic settlement cracks may also occur in forms involving a sudden change in the concrete's depth, as it settles more in the deep sections than the shallow ones, forcing cracking at the point of change. A good example of this is waffle troughs, in which the depth changes constantly across the length of the form.

DEFORMATION CAUSE BY TENSILE STRESSES OVER A RESTRAINT



CRACKING IN HARDENED CONCRETE

Cracking in hardened concrete can result from any one of many causes. These causes include (a) drying shrinkage, which is the main cause, (b) thermal stresses, (c) chemical reactions, (d) weathering, which involves heating and cooling and is linked to thermal stresses, (e) the corrosion of steel reinforcing, (f) poor construction practices, (g) construction and structural overloads, (h) errors in design and detailing, (i) externally applied loads, and (j) poor loading and storage practices.

It is important to understand the factors that influence the above causes of cracking in order to eliminate the cause and select the correct repair method. The following sections explore the causes of cracking in hardened concrete in more depth.

DRYING SHRINKAGE

This is the main cause of cracking in hardened concrete. This cracking takes place near the restraints due to volume changes in the concrete. When concrete is exposed to moisture it swells and when it is exposed to air with relatively low humidity it shrinks, such air drawing water out of its cement paste, which is cement and water. If the shrinkage could occur without restraint no cracking would result, but in most cases the requirements of structural support makes this impossible.

This cracking is the result of a combination of factors that influence the magnitude of the tensile stresses that cause it. These factors include the amount and rate of shrinkage, the degree of restraint, the modulus of elasticity, and the amount of creep. Additional

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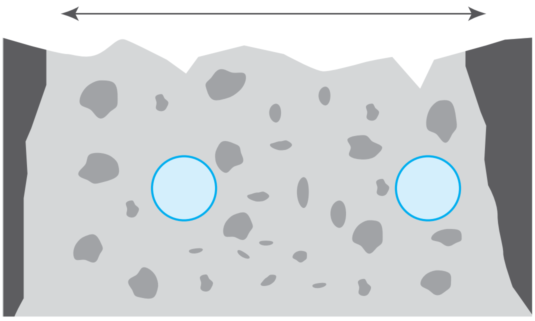
factors to be aware of include the type of aggregate, water content, binder type, and the concrete's mix proportions and mechanical properties.

The amount and type of aggregate and the cement paste are the main influences on the amount of drying shrinkage. To minimise the amount of shrinkage it is best to use a stiff aggregate in high volumes relative to the cement paste. The rate of shrinkage increases with the volume of cement paste. The aggregate provides internal restraints to shrinkage. Similarly, increases in the ratio of water to cement in the cement paste increase the level of shrinkage by increasing the potential for volume loss through water evaporation.

The optimum condition for preventing drying shrinkage is a relative humidity of 100%. This is rarely possible, so sealing the concrete surface to prevent moisture loss can control the amount of shrinkage, and the use of suitably spaced contraction joints and proper steel detailing allows shrinkage to occur in a controlled manner.

Bluey Technologies' BluCem range contains shrinkage-compensating cements that you can also use to control the degree of concrete shrinkage.

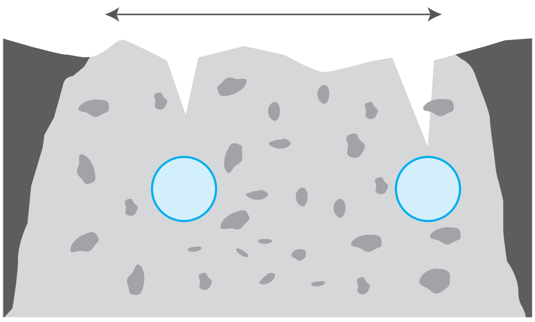
Drying Shrinkage



Original Concrete Volume

A greater volume of stiff aggregate reduces concrete shrinkage, as the aggregate provides restraints. This reduces the tensile stresses and thereby minimises concrete cracking.

Drying Shrinkage



Original Concrete Volume

Reducing the volume of aggregate increases the movement in the concrete during shrinking, as the aggregate provides less restraint. This increases drying shrinkage and consequently the tensile stresses causing concrete cracking.

Figure 3: The effects of aggregate volume on concrete shrinkage

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As the outside of the concrete cools more quickly than the inside it shrinks, and the pressure caused by the inner section's lack of shrinkage produces tensile stresses that, when exceeding the concrete's tensile strength, cause the concrete to crack to relieve the pressure

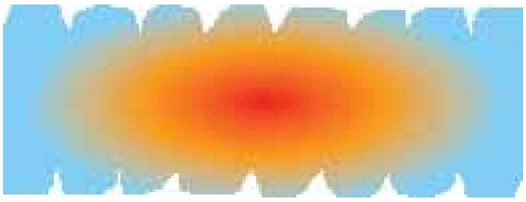

Figure 4: The effects of thermal stresses on cracking in hardened concrete structures

THERMAL STRESSES

Volume differentials are likely to develop in the concrete when different temperatures occur across a concrete section. The concrete then cracks when the tensile stresses imposed by a change in volume differential exceed that of its tensile strength.

Thermal stresses usually cause cracking in mass concrete structures, the main cause of the temperature differentials being the influence of the heat of hydration on volume change. The heat of hydration is the amount of heat released during the cement's hydration, causing a temperature differential to occur between the concrete structure's centre and exterior as a result of either greater exterior cooling or greater heat hydration in the centre (see Figure 4). Either situation puts increased pressure on the exterior as the heat tries to escape from the core.

CHEMICAL REACTIONS

Chemical reactions in concrete can be due to the materials used to make it or materials that may have come into contact with it after it has hardened. The cause of the cracking is the expansive reactions between the aggregate and the alkalis in the cement paste. The chemical reaction occurs between active silica and alkalis, producing an alkali-silica gel as a by-product. The alkali-silica gel forms around the surface of the aggregate, increasing its volume and putting pressure on the surrounding concrete. This increase in pressure can cause the tensile stresses to increase beyond the concrete's tensile strength. When this occurs the concrete cracks to relieve the pressure.

CORROSION OF STEEL REINFORCING

Three conditions must be present for metals to corrode. These are an oxygen supply, moisture, and an electron flow within the metal. Eliminating or limiting any of these conditions eliminates or reduces corrosion of concrete's steel reinforcement, thereby reducing the risk of cracking.

Concrete usually provides passive protection to the steel as it forms a protective oxide coating around it in an alkaline environment. However, corrosion may occur if carbonation alters the concrete's levels of alkalinity.

Corroding reinforcement steel produces iron oxides and hydroxides as by-products. As these form on the steelworks surface its volume increases. This increase in volume increases the pressure on the concrete and causes radial cracking as the concrete fails under the tensile stresses. It is important to address these cracks because as they become larger oxygen and moisture have a greater chance of

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POOR CONSTRUCTION PRACTICES

Numerous poor construction practices can initiate cracking in concrete structures. The following table presents these poor practices.

POOR PRACTICE	EFFECT OF PRACTICE	FACTOR CAUSING CRACKING
Adding water to concrete to increase its workability	Reduces concrete strength Increases settlement	Increased drying shrinkage and plastic settlement cracking
Increasing cement content to offset a decrease in strength from adding water	Increases the temperature differential between interior and exterior sections of the structure Increases the cement paste's volume	Increased dry shrinkage Thermal stresses
Inadequate curing	Lack of concrete hydration Decreases strength	Increased shrinkage at a time when the concrete is at low strength
Lack of support forms, inadequate consolidation, and incorrect placement of construction joints	Increases settlement Insufficient support for the setting concrete Joints open at points of high stress	Concrete cracks from its load before it has developed enough strength to support itself

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CONSTRUCTION OVERLOADS

It is important to pay close attention to the way you load, transport, and unload pre-cast concrete, and how you secure it in place. At any one of these stages the pre-cast concrete modules can become subject to stresses that overload their structure. If these stresses occur in the concrete's early ages they may result in permanent cracks. You need to employ lifting procedures that disperse the load across the structure in order to reduce the risk of overload stresses.

Pre-tensioned beams may present cracking problems at the time of stress relief, especially in beams that are less than one day old.

You need to pay particular attention to the storage of materials and operational equipment during the construction phase, as these may generate loads that exceed those that the structure was designed to withstand.

ERRORS IN DESIGN AND DETAILING

Numerous problems can occur due to incorrect design and detailing, including increased concentrations of stress from poorly designed re-entrant corners, cracking due to inadequate reinforcement, and excessive differential movement from improper foundation design. It is therefore important to ensure that the design and detailing are specific to the particular structure and the loads to which it will be exposed. Overlooking these points may result in cracking, causing a major serviceability problem.

EXTERNALLY APPLIED LOADS

Most concrete structures are susceptible to external loads that induce tensile stresses through their concrete members. It is important to deal with these loads in the most effective way, so try to disperse the load evenly across the individual members to reduce the risk of uncontrolled cracking. Factors that can reduce cracks' widths are an increased amount of steel reinforcement and larger concrete sections to disperse the loads more evenly.

THE DESIRED OUTCOME OF CRACK REPAIRS

Once you understand the cause and significance of the cracking you need to apply the appropriate repair method or methods. You should select the repair method based on an evaluation of the crack and the repair's objective or objectives. Such objectives include (a) restoring or increasing strength, (b) restoring or increasing stiffness, (c) improving functional performance, (d) providing watertightness, (e) improving the concrete surface's appearance, (f) improving durability, and (g) preventing the development of a corrosive environment for the reinforcement.

For detailed guidelines for the preparation and application of crack-repair methods related to Bluey Technologies products please refer to the relevant documentation.

IMPORTANT NOTE

Bluey Technologies offers this document as a standard guide for evaluating cracking in concrete. It remains the responsibility of the engineer or client to determine the correct methods of evaluation.

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