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TECHNICAL NOTE

Cracks In Concrete

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INTRODUCTION

All concrete is susceptible to cracking, both in the plastic state and in the hardered state. This technical note provides basic information about the various types of cracks in concrete and their potential effect on the long-term performance of concrete structures. All concrete has a natural tendency to crack due to either internal or external factors, generally influenced by materials, design, construction, service loads and exposure conditions either individually or in combination. Suitable measures including good material selection, design detailing and proper construction practices, need to be undertaken to prevent or at least minimise the occurrence of cracking. When they occur, it is important to determine whether the cracks will adversely affect the durability, load bearing capacity and the serviceability of the structure.

The various types of cracks are essentially defined by the principal cause or mechanism associated with their function. Structural cracks are caused by applied loads, whereas non-structural cracks are mainly the result of the properties of concrete and its constituent materials, design practices and where in-service conditions cause deterioration[1,2,3,4,5].

STRUCTURAL CRACKS

(a) Flexural Cracks – Cracking in reinforced concrete flexural members subjected to bending starts in the tensile zone, e.g: at the soffit of beams. Generally beams and slabs may be subjected to significant loads and deflection under these loads, with the steel reinforcement and the surrounding concrete subject to tension and stretching. When the tension exceeds the tensile strength of the concrete, a transverse or flexural crack is formed (Fig. 1). Although in the short term the width of flexural cracks narrows from the surface to the steel, in the long-term under sustained loading, the crack width increases and becomes more uniform across the member.

(b) Shear Cracks – These are caused by structural loading or movement after the concrete has hardened. Shear cracks are better described as diagonal tension cracks due to the combined effects of bending and shearing action. Beams and columns are generally prone to such cracking.

(c) Internal Micro-Cracks – Micro cracking can occur in severe stress zones, due to large differential cooling rates, or due to compressive loading. These are discontinuous microscopic cracks which can become continuous and become a visible sign of impending structural problems.

NON-STRUCTURAL CRACKS

Non-structural cracks include pre-hardening cracks, cracks in hardened concrete, and cracking due to chemical effects. Non-structural cracks are influenced by the constituent materials of the concrete, and other factors such as ambient temperature, humidity, overall exposure conditions, construction practices and restraint effects of either internal or external nature. Due to their cumulative nature, the intrinsic effects of one type of crack can be further exacerbated by the effects of another type. Some crack types allow penetration of aggressive chemical agents to the steel reinforcement, leading to corrosion of the steel and possible cracking and spalling. Intrinsic effects of cracking can usually be minimised and controlled by careful attention to both design details such as distribution and positioning of reinforcement and construction techniques.

Pre-hardening (Plastic) Cracks

These cracks occur within a few hours after the placement and compaction of concrete, but before the concrete has fully hardened.

(a) Plastic Shrinkage Cracks - Caused by rapid drying of the concrete surface, within the first six hours (even within minutes) after placement, as a result of large moisture losses from the surface (Fig. 2). Strong winds, high air or concrete temperatures and low humidity, alone or in combination, can cause cracking because they promote evaporation of water which exceeds the rate of bleeding of water to the surface. Plastic shrinkage cracks can form large map patterns or they may appear as diagonal or parallel cracks of various depths. Any drying cracks which appear before or during finishing operations should be immediately closed with either a wooden or steel float and curing should commence immediately following the progressive completion of final finishing operations.

VicRoads Standard Specification Section 610 – Structural Concrete [6] (Section 610) has prescribed requirements for controlling temperature, moisture evaporation limits and concreting operations to minimise the potential for plastic shrinkage cracking. Precautionary measures may include the use of aliphatic alcohol-based evaporative retarders where the evaporation limits of mixing water are exceeded. The use of aliphatic alcohol is mandatory if curing compounds are used on concrete decks and slabs (Fig. 3). If not prevented or minimised initially, plastic shrinkage cracking can be further exacerbated by subsequent drying shrinkage and thermal contraction (movement).

(b) Plastic Settlement Cracks - Caused by concrete settling under its own weight, especially when there is excessive bleeding and the settlement is impeded by a local restraint. The cracks occur in the hardening mass over restraints such as steel reinforcement, deep sections and steps in formwork. The cracks can be further exacerbated by inadequate compaction and the presence of voids under reinforcing bars. Plastic settlement cracks can be enlarged by subsequent drying shrinkage and become more obvious. These cracks tend to form longitudinally over the steel reinforcement and can be a cause of serious corrosion. Plastic settlement cracks can be prevented by ensuring that the concrete is a well graded, well balanced mix at appropriate water content which enables good compaction, and the formwork is rigid and not subject to movement.

(c) Cracks Caused by Formwork Movement – Movement of formwork after the concrete has started to stiffen but before it has gained enough strength to support its own weight, can cause cracking. Formwork must be left in place until the concrete has gained sufficient strength to support itself. Formwork must also be sufficiently strong to avoid excessive deflections.

Cracks in Hardened Concrete

Cracking in hardened concrete can be attributed to drying shrinkage (loss of moisture), early thermal contraction (movement) and structural and chemical effects.

(a) Craze Cracking – Characterised by a series of very fine closely spaced map pattern cracks which are caused by the shrinkage of the cementitious material of the surface layer of concrete. The cracks are fairly shallow and affect the appearance more so than the structural integrity or durability. They are mainly caused by the use of wet concrete mixes, working the bleed water into the surface during finishing, and inadequate curing. Craze cracking can be prevented by ensuring that final finishing of concrete surfaces is only carried out after all bleed water has been removed, power trowels are not overused, driers such as dry sand, cement or stone dust are not used to absorb free water, by avoiding the use of wet concrete and by adopting good curing practices.

(b) Drying Shrinkage Cracks - Occur when concrete reduces in volume as a result of moisture losses into the atmosphere in its hardened state. If the concrete is unrestrained and free to move and undergo shortening without a build up of shrinkage stresses, no shrinkage cracking will occur. However, the combination of shrinkage and sufficient restraint (for example, by another part of the structure) produces tensile stresses. When these stresses exceed the tensile strength of concrete, cracks (Fig. 4) will occur that, over time, can penetrate the full depth of the concrete. A significant proportion of shrinkage generally occurs within the first few weeks, with the drying environment surrounding the concrete having a major effect. Shrinkage cracks generally appear after several weeks or even months after casting. Drying shrinkage can be reduced by increasing the amount of aggregate, particularly the larger coarse aggregate, and more importantly by reducing the total water content. Other factors which influence cracking in hardened concrete such as restraints, geometry and construction practices need to be addressed. Adequate and correctly positioned steel reinforcement can more evenly distribute shrinkage stresses within a reinforced concrete member and better control crack widths. Generally drying shrinkage can range from 450 to 750 microstrain for high quality special class concrete to about 1000 microstrain for normal class concrete.

(c) Early Thermal Contraction (Movement) Cracks – All immature concrete elements are subject to thermal contraction or movement for up to 14 days after placement, due to temperature rise from the heat of hydration of the cementitious material. This is more pronounced in the case of higher quality special class concrete which contains higher amounts of cementitious material. Thermal cracking may appear between one day and two weeks after construction. Larger and thicker members (i.e. columns, beams, footings, etc.) are more susceptible due to the greater heat and higher internal temperatures generated which can be as much as 45 °C to 65 °C. As the surface temperature falls to the ambient level, a concrete element (i.e. cooler concrete surface) is subjected to thermal contraction or movement due to the development of large temperature differentials (greater than 20°C) across the concrete element. If this contraction is restrained by either an internal restraint such as the inner core or adjacent previous pours, tensile stresses are induced which can cause cracking of the concrete once its low tensile strength capacity is exceeded. VicRoads Section 610 requires that temperature differentials are monitored and precautions are implemented where the temperature differential within a concrete element exceeds 20°C.

Cracks due to Chemical Effects

The expansive effects of chemical reaction products from corrosion of steel reinforcement on alkali-aggregate reaction can also cause cracking in hardered concrete.

(a) Corrosion of Steel Reinforcement - Some cracks are induced by the expansive forces associated with corrosion of the steel reinforcement which crack and subsequently spall the concrete (Fig. 5). These cracks are mainly longitudinal in nature and are located directly above or below the reinforcement, run parallel with it and are often associated with shallow or porous cover concrete. Such cracking and spalling is noticeable at corners of columns and beams and usually show signs of rust stains. Cracking associated with corroded reinforcement usually takes a long time to become evident.

(b) Alkali -Silica Reaction Cracks - The chemical reaction between the alkali hydroxide in the concrete and reactive aggregates produces an expansive gel, causing map cracking or directional cracking (pre-stressed members) in the structure. Other visible signs of damage may be aggregate pop out and discolouration.

CRACK WIDTHS

Under normal exposure or favourable dry service conditions crack widths of less than 0.3 mm on the concrete surface do not pose any threat of corrosion of the steel reinforcement. In highly aggressive or corrosive environments however, the safe limit is considered to be 0.2 mm or less. In the most severe exposures (alternate wetting and drying) or in structures designed to retain or exclude liquids, the safe limit is considered to be 0.1 mm. In the case of bridge decks, cracks tend to grow in length and width due to the influence of the traffic and impact loading and therefore, even cracks of the order of 0.1 mm to 0.2 mm may become significant for long-term durability. Sometimes under favourable conditions, cracks which do not exceed 0.2 mm may seal by the process of autogenous healing (deposition of calcium carbonate). However, it is unlikely that cracks through which water has percolated for more than a few weeks will seal themselves later.

For structural concrete which is designed to provide a service life of 100 years, VicRoads Section 610 specifies maximum acceptable crack widths (Table 1). At any stage after construction, cracks measured at the concrete surface should not be greater than the acceptable limits. For pre-cast prestressed concrete elements, the acceptable crack width at the concrete surface should not exceed 0.1 mm. When these crack widths are exceeded, consideration should be given to carrying out appropriate remedial measures during construction in accordance with the requirements of VicRoads Section 610 and VicRoads Standard Specification Section 687 – Repair of Concrete Cracks [7].

Table 1 Maximum acceptable crack widths, as specified in Section 610

Exposure Classification	Maximum Acceptable Crack Widths (mm)
A	0.20
B1	0.20
B2	0.15
C, U	0.10

REPAIRING CRACKS

Repair of cracks should not be undertaken unless the cracked concrete structure has been assessed and the influence of cracks on load bearing capacity, serviceability and durability has been evaluated. The assessment of the cracked concrete structure should be undertaken by a technical specialist with experience in the diagnostic assessment and investigation of concrete structures. A crack repair method should be selected based on the assessment of the cause(s) of the crack, crack width, the moisture condition of the crack and whether a crack is active or inactive prior to any repair works taking place. The crack repair method should also include details of the crack-filling material properties, location, local environment, likely crack behaviour, effect on load capacity, serviceability and durability, surface preparation and method of application.

For the purposes of deciding upon the most appropriate and effective type of crack repair to be undertaken, cracks may be separated into two classes, namely, inactive (dead) cracks which are unlikely to open, close or extend further and active (live) cracks which may be subject to further movement (Fig. 6). The repair of concrete cracks should be undertaken in accordance with Section 687 and the following methods can be used as a guide:

Resin Injection - Crack filling under pressure using a selected polymer resin such as epoxy or polyurethane to restore structural soundness and penetrability of concrete where cracks are inactive or can be prevented from moving further (Fig. 7).

Routing and sealing - Enlarging the crack along its exposed face and filling with a suitable joint sealant to produce a repair method for cracks that are inactive and not structurally significant.

Gravity feed - Filling and sealing of horizontally positioned cracks using low viscosity resins by pouring and spreading onto surface or placing into purposely formed reservoirs.

Coating over cracks - Application of coatings with a crack bridging capability or silane impregnations for cracks of width of 0.3 mm or less subject to function and service conditions.

Flexible sealing - Use of suitable flexible sealants to seal active cracks in the same manner as flexible joints (Fig. 6).

Stitching of cracks - Anchoring of U-shaped metal legs in predrilled holes on both sides of cracks to restore the tensile strength of the crack affected concrete.

VERIFICATION OF DEPTH OF PENETRATION OF CRACK-FILLING MATERIAL

Concrete cores should be extracted from the crack repair works to verify the depth of penetration of the crack filling material (Fig. 8). The core samples should be extracted at predetermined locations to verify that the crack-filling material has penetrated to the full depth of the crack. A cover meter should be used to ensure that the core locations are remote from the existing steel reinforcement. The cored holes should be cleaned and repaired with a suitable shrinkage compensating cementitious repair material applied in accordance with the manufacturer's recommended method of use. The exposed surface of the repaired hole should be similar in texture and colour to the surrounding concrete. For larger areas, non-destructive methods such as Ultrasonic Pulse Velocity or Impact Echo may also be used to verify penetration of material.

CRACK CONTROL

In general, cracking can be minimised by taking various types of appropriate measures. Structural assessment and the selection of appropriate repair methods and products requires expert technical advice. This is available from VicRoads Technical Consulting, as well as other sources.

REFERENCES

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Fig 1 - Flexural cracks that self sealed through autogenous healing

Fig 2 - Plastic shrinkage cracks

Fig 3 - Application of evaporative retarder

Fig 4 - Drying shrinkage cracking

Fig 5 - Longitudinal crack at corners of crosshead associated with corrosion of steel reinforcement

Fig 6 - Active or live cracks sealed with an appropriate flexible sealant

Fig 7 - Injected cracks with epoxy resin through nipples

Fig 8 - Cores showing epoxy penetration