



Causes Evaluation and Repair of Cracks in Concrete Structures

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Cracks in concrete have many causes. They may affect appearance only, or they may indicate significant structural distress or a lack of durability. Cracks may represent the total extent of the damage, or they may point to problems of greater magnitude. Their significance depends on the type of structure, as well as the nature of the cracking. For example, cracks that are acceptable for buildings may not be acceptable in water-retaining structures. The proper repair of cracks depends on knowing the causes and selecting the repair procedures that take these causes into account; otherwise, the repair may only be temporary. Successful long-term repair procedures must attack the causes of the cracks as well as the cracks themselves. Concrete inherits certain type of cracks in pre-hardening stage and also develops some other types of cracks in post hardening stage in due course

of time due to various reasons, despite our utmost care in prevention of cracks. While concrete becomes older, these cracks become sources, of leakages and seepages and give easy access to the moisture, oxygen, chloride, carbon dioxide, and other aggressive chemicals and gases into the concrete leading to serious degradation of the structure and causing corrosion of steel and damage in the concrete in the form of spalling etc. and subsequently causing structural failure of the member. Cracking is the initial sign of distress of the structure baring other forms of distress and deterioration like deformation, surface deposits and construction defects etc. causing damage to structural strength, durability and serviceability.

The Phenomena of Cracking

(A) Cracking of plastic concrete

- Plastic shrinkage cracking-"Plastic shrinkage cracking occurs when subjected to a very rapid loss of moisture caused by a combination of factors which include air and concrete temperatures, relative humidity, and wind velocity at the surface of the concrete. These factors can combine to cause high rates of surface evaporation in either hot or cold weather." Refer Figure 1.

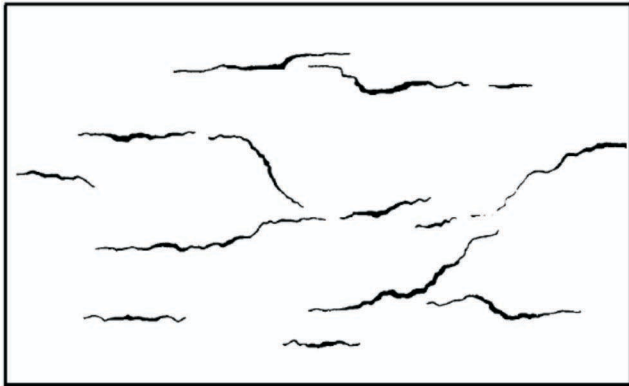


Figure 1: Typical plastic shrinkage cracking

- Settlement cracking - After initial placement, vibration, and finishing, concrete has a tendency to continue to consolidate. During this period, the plastic concrete may be locally restrained by reinforcing steel, a prior concrete placement, or formwork. This local restraint may result in voids and/or cracks adjacent to the restraining element. When associated with reinforcing steel, settlement cracking increases with increasing bar size, increasing slump, and decreasing cover. The degree of settlement cracking may be intensified by insufficient vibration or by the use of leaking or highly flexible forms. Refer Figure 2 and Figure 3.

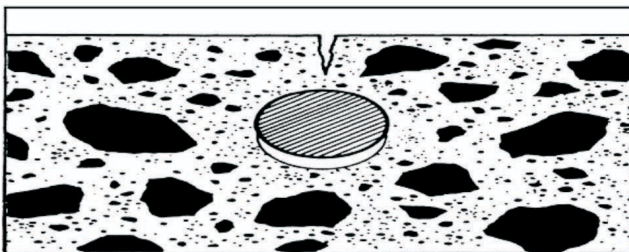


Figure 2: Crack formed due to obstructed settlement

(B) Cracking of hardened concrete

- Drying shrinkage-A common cause of cracking in concrete is restrained drying shrinkage. Drying shrinking is caused by the loss of moisture from the cement paste constituent, which can shrink by as much as 1 percent. Fortunately, aggregate provides internal restraint that reduces the magnitude of this volume change to about 0.06 percent. On wetting, concrete tends to expand.

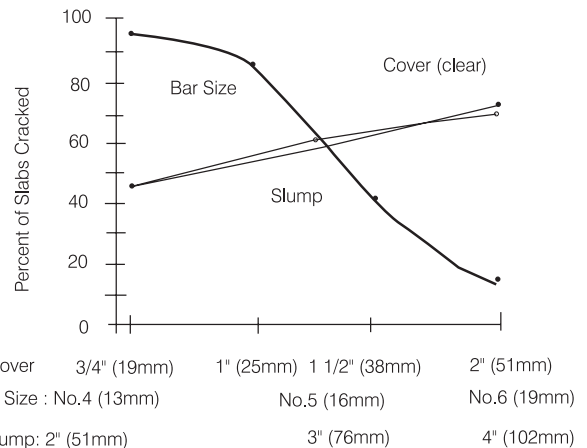


Figure 3: Settlement cracking as a function of bar size, slump and cover.

These moisture-induced volume changes are a characteristic of concrete. If the shrinkage of concrete could take place without restraint, the concrete would not crack. It is the combination of shrinkage and restraint (usually provided by another part of the structure or by the subgrade) that causes tensile stresses to develop. When the tensile strength of concrete is exceeded, it will crack. Cracks may propagate at much lower stresses than are required to cause crack initiation.

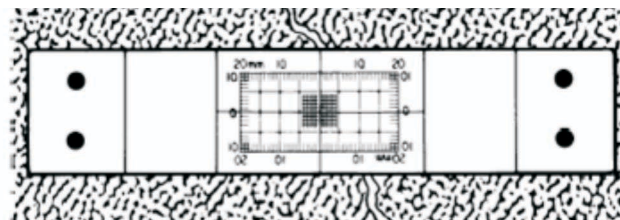
- Thermal stresses-Temperature differences within a concrete structure may be caused by portions of the structure losing heat of hydration at different rates or by the weather conditions cooling or heating one portion of the structure to a different degree or at a different rate than another portion of the structure. These temperature differences result in differential volume changes. When the tensile stresses due to the differential volume changes exceed the tensile stress capacity, concrete will crack. The effects of temperature differentials due to different rates of heat dissipation of the heat of hydration of cement are normally associated with mass concrete (which can include large columns, piers, beams, and footings, as well as dams), while temperature differentials due to changes in the ambient temperature can affect any structure. Cracking in mass concrete can result from a greater temperature on the interior than on the exterior. The temperature gradient may be caused by either the center of the concrete heating up more than the outside due to the liberation of heat during cement hydration or more rapid cooling of the exterior relative to the interior.
- Chemical reaction-Deleterious chemical reactions may cause cracking of concrete. These reactions may be due to materials used to make the concrete or materials that come into contact with the concrete after it has hardened.

- **Weathering**-The weathering processes that can cause cracking include freezing and thawing, wetting and drying, and heating and cooling. Cracking of concrete due to natural weathering is usually conspicuous, and it may give the impression that the concrete is on the verge of disintegration, even though the deterioration may not have progressed much below the surface.
- **Corrosion of reinforcement**-Corrosion of a metal is an electrochemical process that requires an oxidizing agent, moisture, and electron flow within the metal; a series of chemical reactions takes place on and adjacent to the surface of the metal
- **Poor construction practices**-A wide variety of poor construction practices can result in cracking in concrete structures. Foremost among these is the common practice of adding water to concrete to improve workability. Added water has the effect of reducing strength, increasing settlement, and increasing drying shrinkage. Lack of curing also increases the degree of cracking within a concrete structure. The early termination of curing will allow for increased shrinkage at a time when the concrete has low strength.
- **Construction overloads**-Loads induced during construction can often be far more severe than those experienced in service. Unfortunately, these conditions may occur at early ages when the concrete is most susceptible to damage and they often result in permanent cracks. Precast members, such as beams and panels, are most frequently subject to this abuse, but cast-in-place concrete can also be affected. A common error occurs when precast members are not properly supported during transport and erection. The use of arbitrary or convenient lifting points may cause severe damage.

Evaluation concrete cracking

Before repair of any type of crack the causes and nature of the crack should be diagnosed properly. The visual observation can be made for surface appearance of the crack which indicates the basic cause of the cracking. Location and pattern of cracking like diagonal, longitudinal, transverse, vertical and horizontal are also to be noted. Some non-destructive tests should also to be carried out to find out the root cause of cracks in the concrete. Ultrasonic pulse velocity is being used to find out the voids, identifying the cracks and measuring the crack depth. Crack microscope can be used to locate and find out the width of the crack and a digital crack measuring gauge can also be used for the same purpose. For active crack a crack monitor should be used which is used to monitor the changes in the crack by taking observation for a longer period. Concrete endoscope and fiberscope are also being

used to find out the cracks inside the concrete. Cracks due to fire damage can be evaluated by petrography. To detect the leakages, voids inside the concrete thermal imaging camera can be used. Refer Figure 4 and 5 for Crack meter and Rebar locator. The Table 1 shows how to identify the pattern of cracks, their possible causes and further tests required.



Newly Mounted Monitor

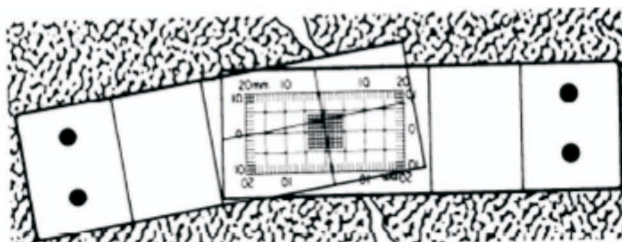


Figure 4: Crack Meter

Repair of Cracks

The aim of crack repair has to be established a prior and achieved by proper selection of repair material and methodology. As described in ACI 224.1R the goal of all crack repairs is to achieve one or more objectives such as: restore and increase the strength of cracked components; restore and increase the stiffness of cracked components; improve functional performance of the structural members; prevent liquid penetration; improve the appearance of the concrete surface; improve durability; and prevent development of a corrosive environment at the reinforcement. Materials for nonstructural crack repair of dormant nature should be a rigid material. The crack should be three to four times wider than the largest aggregate particle. Cementitious, polymer modified cementitious grouts of acrylic, styrene-acrylic and styrene-butadiene should be used for wider cracks. However polyester and epoxy resins should be used for injection of dormant cracks. For live cracks flexible material of polysulphide or polyurethane should be used. Before repair of any non structural cracks the factors have to be considered are: whether the crack is dormant or live; 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 and whether or not appearance is a factor.



Figure 5: Rebar locator

Selection of repair procedures- Based on the careful evaluation of the extent and cause of cracking, procedures can be selected to accomplish one or more of the following objectives:

- Restore and increase strength;
- Restore and increase stiffness;
- Improve functional performance;

- Provide watertightness;
- Improve appearance of the concrete surface;
- Improve durability; and/or
- Prevent development of corrosive environment at reinforcement.

Methods of Crack Repair

(A) Epoxy injection- Cracks as narrow as 0.002 in. (0.05 mm) can be bonded by the injection of epoxy. The technique generally consists of establishing entry and venting ports at close intervals along the cracks, sealing the crack on exposed surfaces, and injecting the epoxy under pressure. Epoxy injection has been successfully used in the repair of cracks in buildings, bridges, dams, and other types of concrete structures (ACI 503R). However, unless the cause of the cracking has been corrected, it will probably recur near the original crack. If the cause of the cracks cannot be removed, then two options are available. One is to rout and seal the crack, thus treating it as a joint, or, establish a joint that will accommodate the movement and then inject the crack with epoxy or other suitable material. Epoxy materials used for structural repairs should conform to ASTM C 881 (Type IV). ACI 504R describes practices for sealing joints, including joint design, available materials, and methods of application. Epoxy injection requires a high degree of skill for satisfactory execution, and application of the technique may be limited by the ambient temperature. The general procedures involved in epoxy injection are as follows

- Clean the Cracks

Crack Pattern (Symptom)	Possible Cause (Diagnosis)	Further work-up (Tests)
Rust Stain on surface	Ferrous compounds present in concrete / mortar, binding wire, nails etc. left, corrosion of rebars.	Chemical analysis of sample, cover check and carbonation test.
Crack in cover concrete, Rebars exposed, concrete spalls.	Corrosion of rebars (main and secondary) caused by chlorides.	Cover check, loss of rebars, carbonation and chlorides test.
Vertical and horizontal cracks at interval.	Corrosion of secondary Rebars.	Cover to secondary rebars check.
Cracks at definite interval.	Rebars too near the surface, corrosion of rebars.	Cover check.
Map pattern	Alkali-Silicate Reaction, early drying out condition, high cement content, excess compaction, poor curing.	Chemical analysis of constituents.
Diagonal cracks in beams near the support.	Overload inadequate section of beam, inadequate stirrups.	Reverse calculation of shear strength of beam section
Vertical cracks in beams near mid span.	Overload, inadequate section of beam, inadequate longitudinal rebars.	-
Vertical tapering cracks in masonry near vertical joint.	Foundation / substrate / supporting member movement.	-
Horizontal cracks	Corrosion of embedded Rebars	Check the rebar near the crack for corrosion.
Cracks between RCC and masonry.	Thermal expansion and contraction.	Check the bond between RCC and masonry.
Water routed through cracks in concrete.	Movement of joint, through crack in RCC member.	Check the Rebar detail.

Table 1

- Seal the Surfaces
- Install the entry and venting ports- three methods are in general use
 - a. Fittings inserted into drilled holes
 - b. Bonded flush fitting
 - c. Interruption in seal
- Mix the Epoxy
- Inject the Epoxy
- Remove the Surface Seal

Figure 6 and 7 gives a view of the epoxy injection pump and injection procedure.



Figure 6: High Pressure Epoxy Injection pump.



Figure 7: Epoxy Injection in progress.

(B) Routing and sealing- Routing and sealing of cracks can be used in conditions requiring remedial repair and where structural repair is not necessary. This method involves enlarging the crack along its exposed face and filling and sealing it with a suitable joint sealant (Fig. 3.1). This is a common technique for crack treatment and is relatively simple in comparison to the procedures and the training required for epoxy injection. The procedure is most applicable to approximately flat horizontal surfaces such as floors and pavements. However, routing and sealing can be accomplished on vertical surfaces (with a non-sag sealant) as well as on curved surfaces (pipes, piles and pole).

(C) Stitching- Stitching involves drilling holes on both sides of the crack and grouting in U-shaped metal units with short legs (staples or stitching dogs) that span the crack as shown in Fig 3.3 (Johnson 1965). Stitching may be used when tensile strength must be reestablished across major cracks (Hoskins 1991). Stitching a crack tends to stiffen the structure, and the stiffening may increase the overall structural restraint, causing the concrete to crack elsewhere. Therefore, it may be necessary to strengthen the adjacent section or sections using technically corrected reinforcing methods. Because stresses are often concentrated, using this method in conjunction with other methods may be necessary. Refer Figure 8.

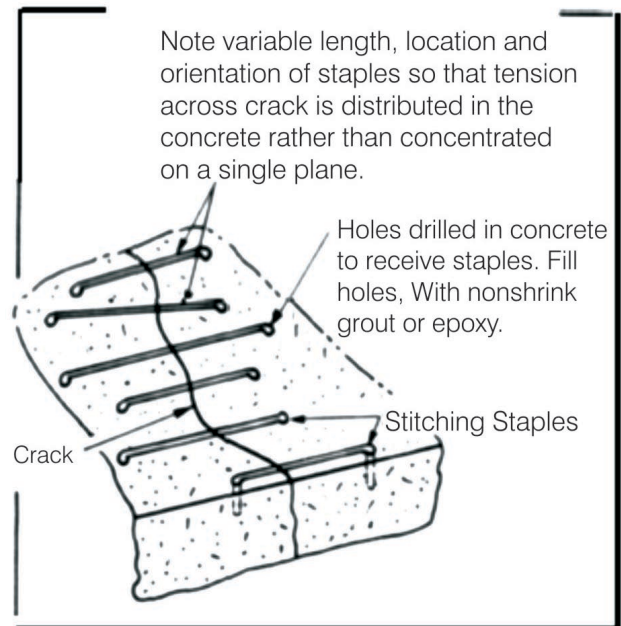


Figure8: Concrete Stitching

(D) Additional reinforcement

- Conventional reinforcement-Cracked reinforced concrete bridge girders have been successfully repaired by inserting reinforcing bars and bonding them in place with epoxy.
- Prestressing steel-Post-tensioning is often the desirable solution when a major portion of a member must be strengthened or when the cracks that have formed must be closed. This technique uses prestressing strands or bars to apply a compressive force. Adequate anchorage must be provided for the prestressing steel, and care is needed so that the problem will not merely migrate to another part of the structure. Refer Figure 9.

(E) Drilling and plugging- Drilling and plugging a crack consists of drilling down the length of the crack and grouting it to form a key. Refer Figure 10.

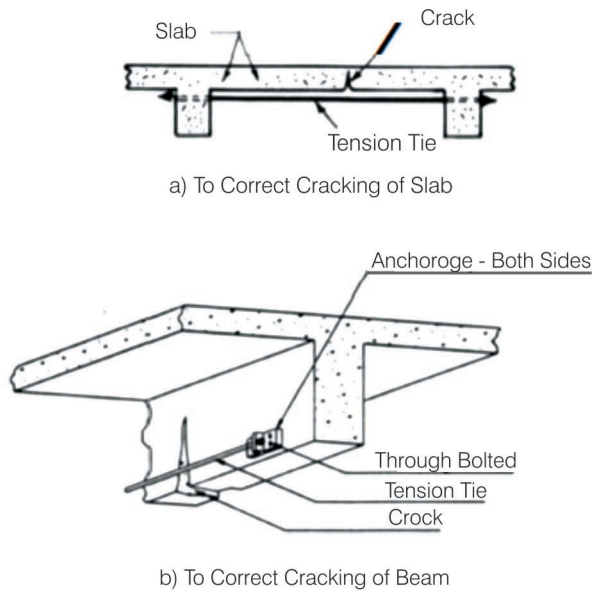


Figure 9: Process of External prestressing

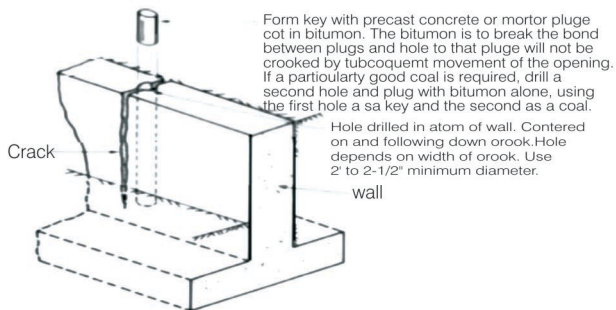


Figure 10: Process of drilling and plugging

(F) Gravity Filling- Low viscosity monomers and resins can be used to seal cracks with surface widths of 0.001 to 0.08 in. (0.03 to 2 mm) by gravity filling. High-molecular- weight methacrylates, urethanes, and some low viscosity epoxies have been used successfully. The lower the viscosity, the finer the cracks that can be filled.

(G) Grouting

- Portland cement grouting-Wide cracks, particularly in gravity dams and thick concrete walls, may be repaired by filling with portland cement grout. This method is effective in stopping water leaks, but it will not structurally bond cracked sections. The procedure consists of cleaning the concrete along the crack; installing built-up seats (grout nipples) at intervals astride the crack (to provide a pressure tight connection with the injection apparatus); sealing the crack between the seats with a cement paint, sealant, or grout; flushing the crack to clean it and test the seal; and then grouting the whole area. Grout mixtures may contain cement and water or

cement plus sand and water, depending on the width of the crack.

- Chemical grouting-Chemical grouts consist of solutions of two or more chemicals (such as urethanes, sodium silicates, and acrylomides) that combine to form a gel, a solid precipitate, or a foam, as opposed to cement grouts that consist of suspensions of solid particles in a fluid. Cracks in concrete as narrow as 0.002 in. (0.05 mm) have been filled with chemical grout.

(H) Drypacking- Drypacking is the hand placement of a low water content mortar followed by tamping or ramming of the mortar into place, producing intimate contact between the mortar and the existing concrete (U.S. Bureau of Reclamation 1978). Because of the low water-cement ratio of the material, there is little shrinkage, and the patch remains tight and can have good quality with respect to durability, strength, and watertightness.

(I) Crack arrest- During construction of massive concrete structures, cracks due to surface cooling or other causes may develop and propagate into new concrete as construction progresses. Such cracks may be arrested by blocking the crack and spreading the tensile stress over a larger area. Refer Figure 11.

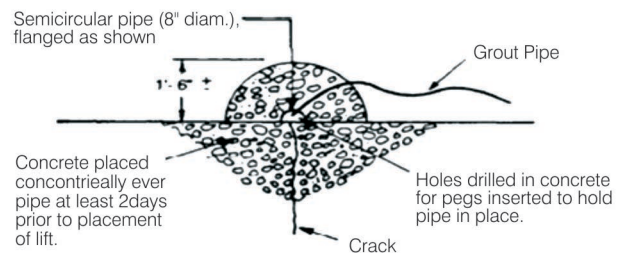


Figure 11: Crack Arrest Method of Crack Repair

(J) Polymer impregnation- Monomer systems can be used for effective repair of some cracks. A monomer system is a liquid consisting of monomers which will polymerize into a solid. Suitable monomers have varying degrees of volatility, toxicity and flammability, and they do not mix with water. They are very low in viscosity and will soak into dry concrete, filling the cracks, much as water does. The most common monomer used for this purpose is methyl methacrylate. Refer Figure 12.

(K) Overlay and surface treatments- Fine surface cracks in structural slabs and pavements may be repaired using either a bonded overlay or surface treatment if there will not be further significant movement across the cracks. Unbonded overlays may be used to cover, but not necessarily repair a slab. Overlays and surface treatments can be appropriate for cracks caused by one-time occurrences and which do not completely penetrate the slab. These techniques are

not appropriate for repair of progressive cracking, such as that induced by reactive aggregates, and D-cracking.



Figure 12: Process of polymer impregnation.

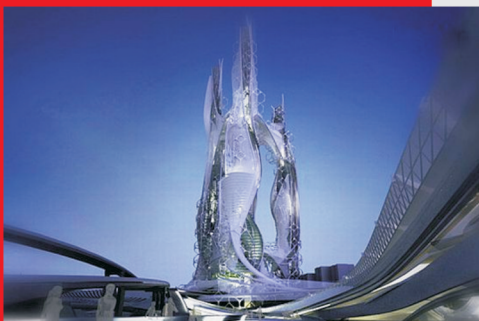
Conclusion

Cracks in the concrete structures are early signs of distress which have to be diagnosed properly otherwise the repair of same crack takes place again and again causing loss of time and money. The structural cracks need more attention than non structural cracks. The repair materials and methodology are different depending upon types of cracks, their locations such as joints, structural members etc. and conditions such as dry or moist. A thorough and logical evaluation of the current condition of a concrete structure is the first step in any repair project. Regular inspection and monitoring is essential to detect problems with concrete structures. The structures should be inspected a minimum

of once per year. It is important to keep written records of the dimensions and extent of deterioration as scaling, disintegration, efflorescence, honeycombing, erosion, spalling, popouts, and the length and width of cracks. Structural cracks should be monitored more frequently and repaired if they are a threat to the stability of the structure. Photographs provide invaluable records of changing conditions. All maintenance and inspection records should be kept.

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Fascinating Piercing Towers of Yerevan

Leading architect Vahan Misakyan has designed a fascinating skyscraper for the city of Yerevan in Armenia. The building consists of an assemblage of structural geodesics that form three piercing towers linked by habitable bridges at the top and bottom. There are offices, residences and hotel in each tower and the geodesics change in size and configuration accordingly. The bridges are used as commercial and recreational areas for the general public. One of the main concepts of the proposal is to create a soft transition between the vertical and horizontal planes by creating surfaces that peel off from the ground and transform into habitable areas. A transportation hub for the entire region emerges from one of these structures while a second one creates a bridge and a recreational park. The building is designed with the latest green technologies. An intelligent skin controls, through mechanical openings, the amount of light incidence and could also be used to reduce heat and provide natural ventilation. This skin is also equipped with rain water collection systems, photovoltaic cells, and wind turbines.