CAUSES, EVALUATION AND REPAIR OF CRACKS IN CONCRETE

4.0 Methods of Crack Repair:
Crack repair could be done to accomplish one or more of the following objectives:
- Restore and Increase strength.
- Restore and Increase stiffness
- Improve functional performance.
- Provide water tightness.
- Improve appearance of the concrete surface.
- Improve durability.
- Prevent development of corrosion in steel.

Depending on the nature of damage, one or more repair methods may be selected, for example, tensile strength may be restored across a crack by injecting it with epoxy or other high strength bonding agent. However, it may be necessary to provide additional strength by adding reinforcement or using post-tensioning. Epoxy injection alone can be used to restore flexural stiffness if further cracking is not anticipated. To minimize future deterioration due to the corrosion of reinforcement, cracks exposed to a moist or corrosive environment should be sealed.

Key methods of crack repair to accomplish above objectives are outlined in following sub-paras:

4.1 Repair of Dormant Cracks:

4.1.1 Sealing of Cracks:
Sealing of cracks as stand alone repair should be used in conditions where structural repair is not necessary. Isolated cracks whether extending through the concrete section or partially into it, should be sealed at the concrete surfaces. For this a slot of approx. 25mm wide should be saw cut upto 10mm deep along the crack keeping crack at the center of the slot. The concrete should be chiseled out from between the two saw cut edges and concrete should be further undercut beyond the 10mm depth up to say 20mm depth so that the base width is slightly greater than the surface width. After the slot is thoroughly cleaned, soaked with water for 10 hrs. and surface dried, a bond coat/ primer coat, of an approximate latex bonding compound should be applied. Once the primer becomes tacky, high strength polymer modified cementitious mortar with specification mentioned in Para 10.1 should be filled in the slot, properly tamped and surface finished. Curing compound should be applied as soon as surface becomes touch dry. 7 days wet curing should be done by covering with wet Hessian and polythene sheet.

4.1.2 Routing and Sealing of Cracks:
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Alternatively a V-groove should be prepared along the crack at the surface ranging in depth from 6 to 25mm and minimum opening at surface of 6mm (Fig. 11)

![Diagram of V-groove]

Fig. 11, Repair of Crack by routing and Sealing

A concrete saw, hand tools or pneumatic tools may be used. The groove is then cleaned by air blasting, sand blasting or water blasting and dried. A sealant is placed into the dry groove and allowed to cure.

The sealant may be any of several materials, including epoxies, urethanes, silicones, polysulphides, asphaltic materials or polymer mortars. A bond breaker may be provided at the bottom of the groove to allow the sealant to change shape, without a concentration of stress on the bottom. The bond breaker may be polyethylene strip or tape which will not bond to the sealant.

4.1.3 Bond Breaking:

In some cases over bonding (strip coating) is used independently of or in conjunction with sealing. For this an area approx. 25 to 75mm on each side of the crack is sand blasted or cleaned by other means, and a coating (such as urethane) 1 to 2mm thick in a band is applied over the crack. A bond breaker may be used over the crack or over a crack previously sealed (Fig. 12). Cracks subject to minimal movement may be over banded, but if significant movement can take place, sealing must be used in conjunction with over banding to ensure a water proof repair.

![Diagram of bond breaking]

Fig. 12, Effect of Bond Breaker
4.1.4 Epoxy Injection:
Cracks as narrow as 0.3mm can be bonded by the injection of epoxy successfully in buildings, bridges and other concrete structures. However, unless the cause of the cracking has been corrected, it will probably recur near the original crack. If the cause of the crack cannot be removed and it is not causing reduction in strength of the structure, then either the crack could be sealed with flexible sealant thus treating it as a joint or establish a joint that will accommodate the movement and then the crack should be grouted with epoxy. With the exception of certain moisture tolerant epoxies, this technique is not applicable if the cracks are actively leaking and cannot be dried out. Epoxy injection requires a high degree of skill for satisfactory execution, and the ambient temperature may limit application of the technique. The procedure is explained in para 10.3.6.

4.2 Repair to Active Cracks:

4.2.1 Drilling and Plugging through Crack:
One of the approximate methods would be to drill holes normal to cracks, fill them with a suitable epoxy or epoxy-mortar formulation and then place reinforcement bars (of predetermined sizes and lengths) in them to stitch across the cracks. The bars may be placed in the clean holes prior to filling the epoxy (so as to save loss of epoxy) but then great care is needed not to entrap any air.

4.2.2 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 Figure.
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Stitching should be used when tensile strength has to be restored back across major cracks. Stitching a crack tends to stiffen the structure and the stiffening may increase the overall structural restrain, causing the concrete to crack elsewhere. Therefore, it is necessary that proper investigation is done and if required, adjacent section or sections are strengthened using technically designed reinforcing methods. Because stresses are often concentrated, using this method in conjunction with other methods may be necessary.

The procedure consists of drilling holes on both sides of the crack, cleaning the holes and anchoring the legs of the staples in the holes, with either a non-shrink cement grout or any epoxy resin-based bonding system. The staples should be variable in length, orientation, or both and they should be located so that the tension transmitted across the crack is not applied to a single plane within the section but is spread over an area.

4.2.3 External Prestressing:
The flexural cracks in reinforced concrete can be arrested and even corrected by the ‘Post –tensioning’ method. It closes the cracks by providing compression force to compensate for tensions and adds a residual compression force. This method requires anchorage of the tie-rods (or wires) to the anchoring device (the guide – bracket- angles) attached to the beam (Fig. 14).

The rods or wires are then tensioned by tightening the end-nuts or by turning of turnbuckles in the rods against the anchoring devices. However, it may become necessary in certain critical case to run at least an approximate stress-check to guard against any possible adverse effects.

4.2.4 Drilling and Plugging:
When cracks run in reasonable straight lines and are accessible at one end, drilling down the length of the crack and grouting it to form a key as shown in Fig. 15 could repair them.
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A hole of 50 to 75mm dia depending on width of crack should be drilled, centered on and following the crack. The hole must be large enough to intersect the crack along its full length and provide enough repair material to structurally take the loads exerted on the key. The drilled hole should then be cleaned, made tight and filled with grout. The grout key prevents transverse movements of the sections of concrete adjacent to the crack. The key will also reduce heavy leakage through the crack and loss of soil from behind a leaking wall. If water tightness is essential and structural load transfer is not, the drilled hole should be filled with a resilient material of low modulus in lieu of grout. If the key effect is essential, the resilient material can be placed in a second hole, the first being grouted.

4.3 Gravity Filling:
Low viscosity monomers and resins can be used to seal cracks with width of 0.03mm to 0.3mm by gravity filling. High molecular-weight methacrylates, urethanes and some low viscosity epoxies could be used successfully. Lower the viscosity, finer the cracks that can be filled. First the surface should be cleaned by air blasting and/or water blasting. Wet surfaces should be permitted to dry several days to obtain the best crack filling. The monomer or resin can be poured on the surface and spread with brooms or rollers,

4.4 Cement Grouting:
Wide cracks, particularly in mass concrete abutments/piers and masonry substructures may be repaired by filling with portland cement grout. This method is effective in sealing the crack in concrete, but it will not structurally bond cracked sections. Para 209.1 of IRBM briefly describes the cement pressure grouting as following:
4.4.1 Places for Application:

i) When cracks are dormant

ii) Cracks are active but cause of cracking has been determined and remedial action has been taken.

iii) When honeycombing is present in concrete structures.

iv) When masonry is hollow.

v) When deep leached mortar joints are present.

4.4.2 Materials proportion and pressure:

Ordinary Portland cement to IS:269, sand and water conforming to IRS Concrete Bridge Code, are required. With the approval of the Divisional Engineer, admixtures to impart non-shrinkable properties and to improve flowability of grout may be added. The method of using admixture may be as per the manufacturer’s recommendations. The water-cement ratio (by weight) for the grout should be 0.4 to 0.5, the lower ratio being used when crack width exceeds 0.5mm. In a typical mix proportion for grout, 20 litres of water to be mixed with 50 kg of cement along with 225 gms of non-shrink admixture, such as conbex 100 (of M/s Fosroc), should be used. The grouting pressure should be 2 to 4 kg/cm$^2$.

4.4.3 Equipment used:

The equipment required for cement pressure grouting are:

i) Air compressor with a capacity of 3 to 4 cum/ per minute and with a pressure of 2 to 4 kg per sq.cm.

ii) Grout injecting machine or grouting pump with inlet and outlet valves and pressure gauges. It should be capable of injecting cement grout up to 4 kg/cm$^2$ (Now up to 20 kg/cm$^2$ pumps are available).

iii) An air tight, pressure mixer chamber, with stirrer for proper mixing of the grout and keeping it in proper colloidal suspension during grouting.

iv) Flexible pressure hose pipes for transmitting grout from pressure chamber to ports embedded in the masonry.

v) Drilling equipment, pneumatic or electric, for drilling of holes upto 25mm dia.

vi) 12-20mm dia G.I. pipes with couplers, or lockable type PVC nozzles.

A typical arrangement of pressure grouting equipment is shown in Annexure

4.4.4 Procedure for cement grouting:

- Holes are drilled in structure along cracks and in an around hollow spots. If there are several cracks, holes can be drilled in a staggered manner at 500 to 750mm spacing in both directions.
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covering adequately the area proposed to be grouted. Holes spacing can be altered as per site conditions with approval of the Engineer.

- G.I. pieces (12 to 20mm dia x 200mm) with one end threaded or PVC nozzles are fixed in the holes with rich cement mortar.
- All the cracks and annular space around G.I. pipes are sealed with rich cement mortar. All the cracks are cut open to a ‘V’ shaped groove, cleaned & sealed with rich cement mortar.
- All the grout holes should be sluiced with water using the same equipment a day before grouting as per following sequence; so as to saturate the masonry.

All holes are first plugged with proper wooden plugs or locked in the case of PVC nozzles. The bottom most plug and the two adjacent plugs are removed and water injected in the bottom most hole under pressure. When the clear water comes out through the adjacent holes the injection of water is stopped and the plugs in the bottom most hole and the one immediately above are restored. The process is repeated with other holes till all the holes are covered. On the day of grouting all the plugs are removed to drain out excess water and restored before commencing grouting.

- The same sequence as described above is adopted for injecting the cement grout also. The grout is kept fully stirred/ agitated under pressure throughout the grouting. The grouting is carried out till refusal and/ or till grout starts flowing from the adjacent hole. A proper record of the quantity of grout injected into every hole should be maintained.
- After grouting, curing should be done for 14 days.
- Tell tales are provided for checking the effectiveness of grouting.
- Only such quantities of material for preparing grout should be used, as can be used within 15 minutes of its mixing.
- Grouting equipment must be cleaned thoroughly after use.

4.4.5 Precautions to be taken during the work:

- During the grouting operation in track or close to it, speed restrictions of stop-dead and proceed at 10 kmph shall be imposed at the site of work and same should be continued for a period of 24 hours. The restriction may then be relaxed to non-stop 30 kmph to be continued for a period of another 2-3 days. However, speed restrictions indicated above are only guidelines and the Engineer at
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site shall use his own discretion for imposing appropriate speed restriction at each individual site.

- Immediately after grouting work, all the grouting equipment including the slurry and mixing drums, pipes, nozzles, etc. should be thoroughly washed so that set cement does not damage the equipment.

- After the work has been completed, it should be inspected thoroughly by the Engineer Incharge and should be kept under observation for a period of 6 months to 12 months for its behaviour after grouting. In case arch masonry of bridges is grouted to strengthen the structure, some load tests may be carried out in selected cases to satisfy that grouting has helped to reduce the deflection of crown and spread at the springing to within permissible limits.

4.4.6 Additional Preparations for Masonry Structures in Bridges:

- **Inspection:**
  Before undertaking grouting work, the portions of masonry, which need grouting, have to be carefully inspected and identified. As stated in para 1.3, grouting may be necessary to recondition old brickwork or stonework with disintegrated or perished mortar joints due to age and weathering or for repairing cracked masonry. Masonry in former cases loses its compressive strength and in extreme cases becomes shaky. However, condition of joints in masonry structures developing cracks is frequently sound and if the cracks can be satisfactorily repaired the structure should be sound. In the first case, pressure grouting has to be done on the entire body of the masonry while in the second case, grouting may be necessary only along the cracks. In some of the tunnels built with brick or stone masonry, the mortar in joints in the soffit disintegrates or gets washed off as a result of constant seepage through the joints. Again sometimes the masonry in the soffit of tunnels, tunnel walls and in abutments has a drummy sound, through the exterior appearance is sound. In such cases, the area omitting drumming sound has to be demarcated by careful tapping. Pressure grouting can be of help to fill the hollow, pockets above the soffit or behind the walls.

- **Preparation:**
  All masonry to be pressure grouted should be carefully inspected and cleaned of moss, soil, etc. All exposed joints of the masonry needing strengthening by cement grouting should be thoroughly
raked and repointed with mortar to correct specification. The repointed joints should be adequately cured for a period of 7 days so that the mortar used in pointing sets and develop full strength. Unless all the joints are thoroughly repointed, it is likely that the grouting slurry under pressure will escape through some of the open joints and cannot fill up the disintegrated joints in the masonry or any hollows behind soffit. In cracked masonry, the cracks shall be cut at the surface to form a groove about 3-5mm wide and of about 6mm depth. The v-notch shall be neatly pointed with cement mortar to seal the slurry inside the masonry and to prevent its escape.

4.5 Chemical Grouting:
It consists of solutions of two or more chemicals, such as urethanes, sodium silicates, and acrylomides that combine to form a gel, a solid precipitate, or foam. Cracks in concrete as narrow as .05mm could be filled with grout.