v. Reinforcement Corrosion-Causes & Prevention

The corrosion of steel reinforcement is complex, but basically it is an electro-chemical reaction similar to that of a simple battery. The composition of mild

steel varies along its length and potential anodic (more negatively charged) and cathodic (positively charged) sites can be set up at various points.

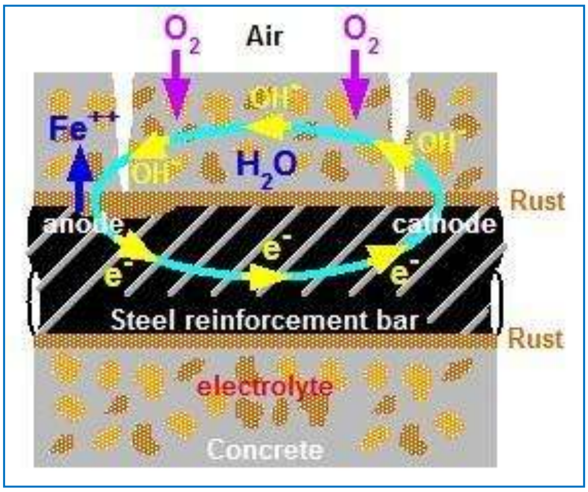

Figure (60): Reinforcement Corrosion progression

Concrete is capable of conducting and electric current and acts as the electrolyte with the circuit being completed by the bar through which the electrons can flow. However the highly alkaline environment (pH about 12.8) provided by good quality concrete produces a protective layer around the steel preventing the flow of current. This is known as Passivation.

The corrosion reaction can only occur when the following conditions prevail.

1. There is a breakdown of the passivating layer (de-passivation) brought about by

a) A lowering of the alkalinity of the concrete below a critical pH of about 10.5, caused normally by the ingress of carbon dioxide (carbonation).

b) The ingress of chlorides

2. Oxygen and water are present.

With the above conditions prevailing the ferrous ions (Fe++) released from the anode combine with the hydroxyl ions (OH-) from the cathode, in the presence of water and oxygen to produce rust (ferric hydroxide). This is an expansive reaction leading to eventual spalling of concrete cover and reduction in the area of the steel at the anodic site.

vi. The Mechanism Of Reinforcement Corrosion:

- Carbonation:

Acidic gases like carbon dioxide react with any free alkali that may be present, which can lead to a drop in the alkalinity of the concrete. This process, which starts at the surface of the concrete, slowly penetrates deeper and deeper. The penetration is nearly proportional to square root of time.

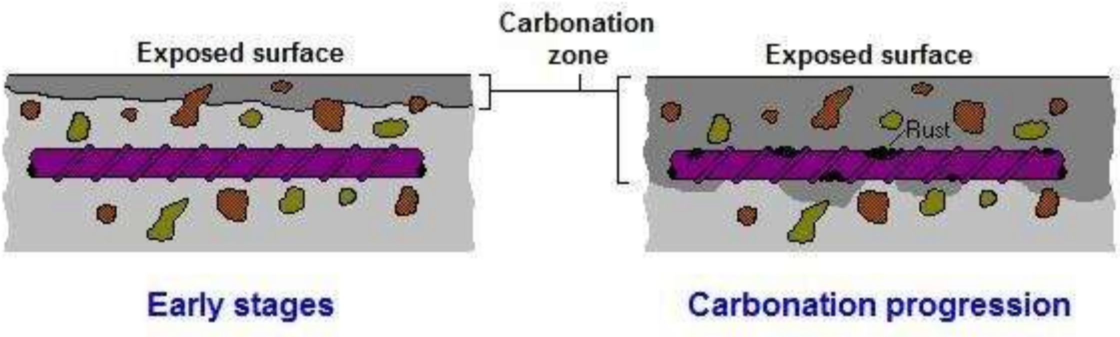

Figure (61): Carbonation progression

Pic. (30). Carbonation leads to the general corrosion along the full length of the bar.

Pic. (30):Effect of Carbonation started in concrete

The above figure shows the first outward signs of general corrosion taking place is surface cracking of the concrete along the line of the steel.

Pic. (31):Effect of Carbonation concrete spall way

The above fig. shows that as the corrosion proceeds, the concrete will spall away completely to expose the steel.

- Chlorides:

Chlorides are generally acidic in nature and can come from a number of different sources, the most common being, de-icing salts, use of unwashed marine aggregates, sea water spray, and certain accelerating admixtures (their use is now prohibited).

In the presence of chlorides localized pitting corrosion occurs which does not always have associated with it the early warning signs of surface cracking.

Chlorides induced corrosion is potentially more dangerous than that resulting from carbonation. Like most of the aspects of concrete durability, deterioration due to corrosion of the reinforcement can take place years (5 to 20) to manifest itselt.

- Minimizing the risk of corrosion:

The quality and depth of concrete in the cover zone are all important in minimizing the risk of corrosion as shown in figure (62) below.

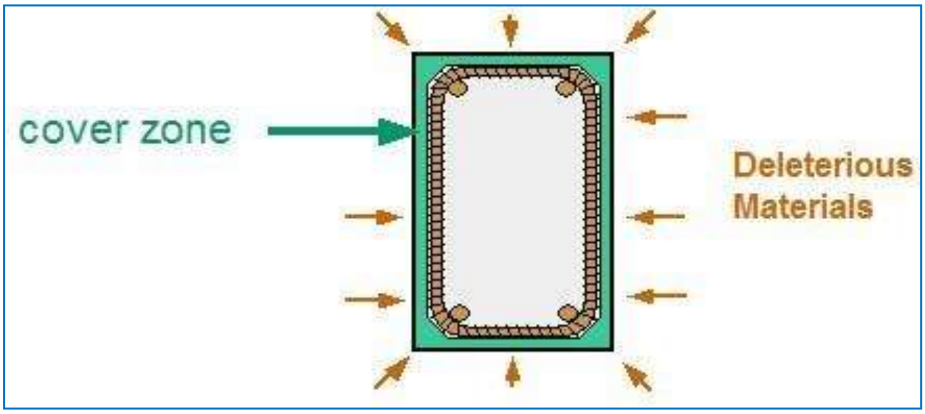

Figure (62): Effective the concrete cover on corrosion

- Quality:

Quality is controlled largely by minimizing permeability.

- Depth:

Recommendations for minimum depths of cover are given in the codes of practice and are based on exposure conditions and minimum cement contents. Higher cement contents infer lower water cement rations leading to permitted reductions in cover.

At no time should the normal cover be less than the maximum size of aggregates+5mm.

- Materials:

Blended cements made from combinations of PC/PFA and PC/GGBS can lead to significant reduction in chloride penetration. However, in situations where these materials are not cured properly there is a risk of increased carbonation.

Care must be taken that all aggregates and admixtures contain limited amount of chlorides.

vii. Steps For Concrete Damage Repairs In Structures

Repair of concrete is needed time to time as the structure gets old due to several reasons. We will discuss the steps involved in the process of repair of concrete structures.

Following are the steps involved in the repair of damaged concrete:

1. Determination of cause of Concrete defects:

The first and important step for repairing a damaged concrete structure is to identify the causes responsible for the damage. Because, if the cause of the damage to concrete structure is not identified or misidentified, then the same damage can repeat even if the repairing work have been done. Based on the causes of concrete damage, the nature of the cause can be identified. If the cause of damage is repetitive in nature then the structural repair will have to consider the effect of the cause, but if the cause is one time event, then that can be neglected.

2. Evaluation of extent of concrete damage:

Evaluation of the extent of damage to concrete helps to understand severity of damage and its effect on the life and serviceability of the structure. This activity includes prediction of how quickly the damage is occurring and what progression of the damage is likely. Knowing the extent of the damage to concrete, decision can be made weather the damage can be repaired or the structural members have to be replaced. It also helps to take precautionary measures to stop the damage in future for the known cause of the damage. The main difference in severity lies in the fact that proper maintenance can reduce or eliminate damage caused to the structural members.

Pic.(32): Shows the extent of concrete damage

The most common technique used to determine the extent of damage is sounding the damaged and surrounding undamaged concrete with a hammer. If performed by experienced personnel, this simple technique, when combined with a close visual inspection, will provide the needed information in many instances of concrete damage. In sounding suspected delaminated or disbonded concrete, it should be remembered that deep delaminations or delaminations that contain only minute separation may not always sound drummy or hollow. The presence of such delaminations can be detected by placing a hand close to the location of hammer blows or by closely observing sand particles on the surface close to the hammer blows. If the hand feels vibration in the concrete, or if the sand particles are seen to bounce however slightly due to the hammer blows, the concrete is delaminated.

Strength of concrete can also be determined while evaluation of the extend of damage by hammer blows. High strength of concrete gives distinct ring from a hammer blow and hammer rebounds smartly. Low strength of concrete rebounds with dull thud and little rebound of the hammer.

Non-Destructive Testing of concrete can also be done to evaluate the extent of damage of concrete structures and also to get its strength. More details about **NDT tests** on concrete.

3. Evaluate the Need for Concrete Repair:

Repair of concrete structural members required cost and time. So, it should be evaluated whether the structure needs the repair or can serve its intended purpose. Not all damaged concrete requires immediate repair. Repairs should be carried out immediately on concrete if the damage affects the safety and serviceability of structure. Also, if the damage has reached to the stage or progressing at a rate that soon the structure will become unserviceable, then repair should be carried out. Most concrete damage, however, progresses slowly, and several options are usually available if the deterioration is detected early. With early detection, it may be possible to arrest the rate of deterioration using maintenance procedures. Even if repair is required, early detection of damage will allow orderly budgeting of funds to pay the costs of repair.

4. Select the Concrete Repair Method:

There is a tendency to attempt selection of repair methods/materials too early in the repair process. This should be guarded against. With insufficient information, it is very difficult to make proper, economical, and successful selections. Once the above three steps of the repair process have been completed, or upon completion of a detailed condition survey, the selection of proper repair methods and materials usually becomes very easy. These steps define the types of conditions the repair must resist, the available repair construction time period, and when repairs must be accomplished. This information, in combination with data on the volume and area of concrete to be repaired, will usually determine which standard repair materials should be used. Also, this information will determine when the standard repair materials cannot be expected to perform well and when nonstandard materials should be considered.

5. Prepare the Old Concrete for Repair:

Preparation of the old concrete for application of the repair material is of primary importance in the accomplishment of durable repairs. The very best of repair materials will give unsatisfactory performance if applied to weakened or deteriorated old concrete. The repair material must able to bond to sound concrete. It is essential that all of the unsound or deteriorated concrete be removed before new repair materials are applied. Saw cutting of perimeter, removal of concrete, preparation of reinforcement, maintenance of prepared damaged area should be carried out before application of concrete repair.

Pic.(33): Dameged of old concrete

6. Apply the Suitable Repair Method:

There are many different standard concrete repair methods and materials available based on type of damage. More details about these will be discussed in future post. Suitable methods and materials should be used based on types of concrete damage.

Pic.(34): Suitable Repair of concrete

7. Cure the Concrete Repair Properly:

Concrete damage when applied with repair materials, it requires proper curing to gain the required strength and durability. Curing is usually the final step of the repair process, followed only by cleanup and demobilization. It should be noted that if the proper curing has not been done to the concrete repair works, then the concrete will not gain required strength and all the cost and time invested to the repair work goes waste. So, special attention is required for the curing the concrete repair.

viii. Replacement Concrete: Materials And Applications

Replacement concrete is a method of repair for defective concrete when the defects or cracks in concrete have large area. In this method of concrete repair, defective concrete is removed from the structural member and area is prepared for repairs and then replacement concrete is used. Concrete repair using this method is used when the area exceeds 1 square foot and has a depth greater than 6 inches (150 mm) and when the repair is of appreciable continuous area.

Replacement concrete repairs are also used for:

- Holes extending entirely through concrete sections.
- Holes in which no reinforcement is encountered, or in which the depth extends 1 inch (25 mm) below or behind the backside of the reinforcing steel and which are greater in area than 1 square foot and deeper than 4 inches (100 mm), except where epoxy- bonded concrete replacement is required or permitted as an alternative to concrete replacement.
- Holes in reinforced concrete greater than one-half square foot and extending beyond reinforcement Replacement concrete is the most

common concrete repair material and will meet the needs of a majority of all concrete repairs.

Replacement concrete repairs are made by bonding new concrete to the repair areas without the use of a bonding agent or Portland cement grout. Because the defective concrete is being replaced with high quality concrete very similar to the surrounding concrete, the repair is compatible in thermal expansion and in other physical and chemical properties with the old concrete. For this reason, in many cases, the best repair method is the use of replacement concrete.

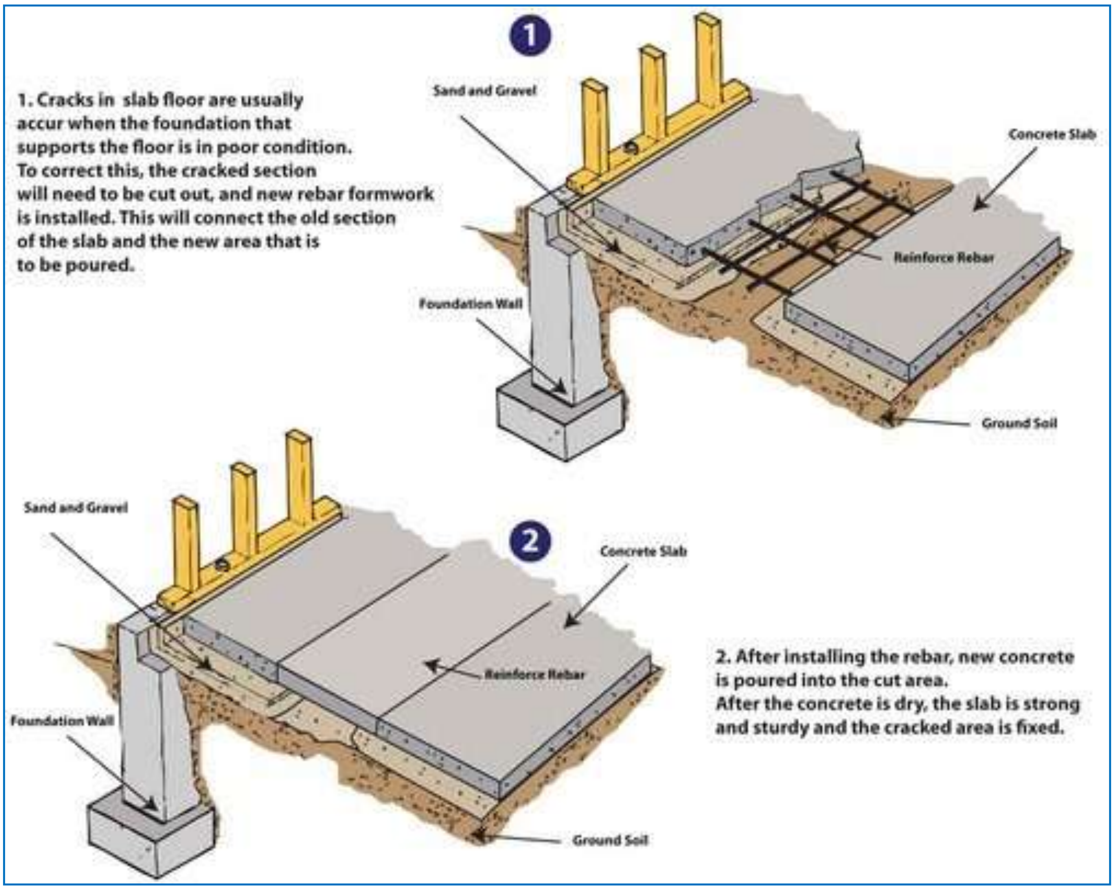

Figure (63): Steps of concrete replacement

1- Preparation of Surface for Replacement Concrete:

Pic. (35): Preparation of surface for replacement concrete

To obtain satisfactory results with the replacement concrete method, preparation should be as follows:

- The reinforcement in the reinforced concrete should be exposed for a minimum of 25mm around the it to use replacement concrete.
- The minimum depth of concrete removal for replacement concrete should be around 25mm and should extend till all the defective concrete has been removed. In case of a vertical member, the top of the hole should be cut in a 1:3 upward slope from the back toward the face from which the concrete will be placed. This is essential to permit vibration of the concrete without leaving air pockets at the top of the repair. In case where concrete from removed from one side to other side of the structural member, the replacement concrete should be filled completely in the hole.

- The cutting of damaged concrete should be such that there is no damage to the existing concrete and there is no spalling of concrete.
- For repairs on the surfaces subject to destructive water action and for other repairs on exposed surfaces, the outlines of areas to be repaired should be saw cut as directed to a depth of 1-1/2 inches before the defective concrete is excavated.

Surfaces of old concrete to which new concrete is to be bonded must be clean, rough, and in a saturated surface dry condition. Extraneous material on the joint resulting from form construction must be removed prior to placement.

2- Materials for Replacement Concrete:

- Concrete for repair should have the same water-cement ratio as used for similar new structures or the existing structure but should not exceed 0.47, by weight.
- Aggregate of as large a maximum size and slump as low as is consistent with proper placing and thorough vibration should be used to minimize water content and consequent shrinkage.

The concrete should contain 3 to 5 percent entrained air.

- To minimize shrinkage, the concrete should be as cool as practicable when placed, preferably at about 20C° or lower. Materials should, therefore, be kept in shaded areas during warm weather. Use of ice in mixing water may sometimes be necessary.
- Batching of materials should be by weight; but batch boxes, if of the exact size needed, may be used. Since batches for this class of

work will be small, the uniformity of the materials is important and should receive proper attention.

- The slump of concrete shall be as minimum as possible for replacement concrete and should be around than 75mm.
- Structural concrete placements should be started with an over-sanded mix containing about a 20mm-maximum size aggregate; a maximum water-cement ratio of 0.47, by weight; 6 percent total air, by volume of concrete; and having a maximum slump of 100 mm. This special mix should be placed several inches deep on the joint at the bottom of the placement. A mortar layer should not be used on the construction joints.

3- Application of Replacement Concrete:

The quality of a repair depends not only on use of low-slump concrete, but also on the thoroughness of the vibration during and after depositing the concrete. There is little danger of over-vibration. Immersion-type vibrators should be used if accessibility permits.

Immediately after the hole has been completely filled, pressure should be applied to the fill and the form vibrated. This operation should be repeated at 30-minute intervals until the concrete hardens and no longer responds to vibration. Pressure is applied by wedging or by tightening the bolts extending through the pressure cap.

Concrete replacement in open-top forms, as used for reconstruction of the tops of walls, piers, parapets, and curbs, is a comparatively simple operation. Only such materials as will make concrete of proved durability should be used. Top surfaces should be sloped to provide rapid drainage.

Forms for concrete replacement repairs usually may be removed the day after casting unless form removal would damage the green concrete, in which event stripping should be postponed another day or two.

Some replacement concrete does not require forms. Replacement of damaged or deteriorated paving or canal lining slabs, wherein the full depth of the slab is replaced, involves procedures no different from those required for best results in original construction.

4- Curing and Protection of Replacement Concrete:

It is very important for the replacement concrete to be cured after the forms have been removed or the concrete has hardened. If the proper curing is not done to the replacement concrete, there are chances of complete failure of the repaired concrete. Because of the relatively small volume of most repairs and the tendency of old concrete to absorb moisture from new material, water curing is a highly desirable, at least during the first 24 hours. One of the best methods of water curing is a soil- soaker hose laid beneath a plastic membrane covering the repair area. When curing compound is used, the best curing combination is an initial water-curing period of 7 days (never less than 24 hours) followed, while the surface is still damp, by a uniform coat of the compound.

ix. Grouting Procedure For Cracks In Concrete

Procedure for cement grouting of cracks in concrete structures:

- 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 covering adequately the area proposed to be grouted. Holes spacing can be altered as per site conditions.

- 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 for14 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.

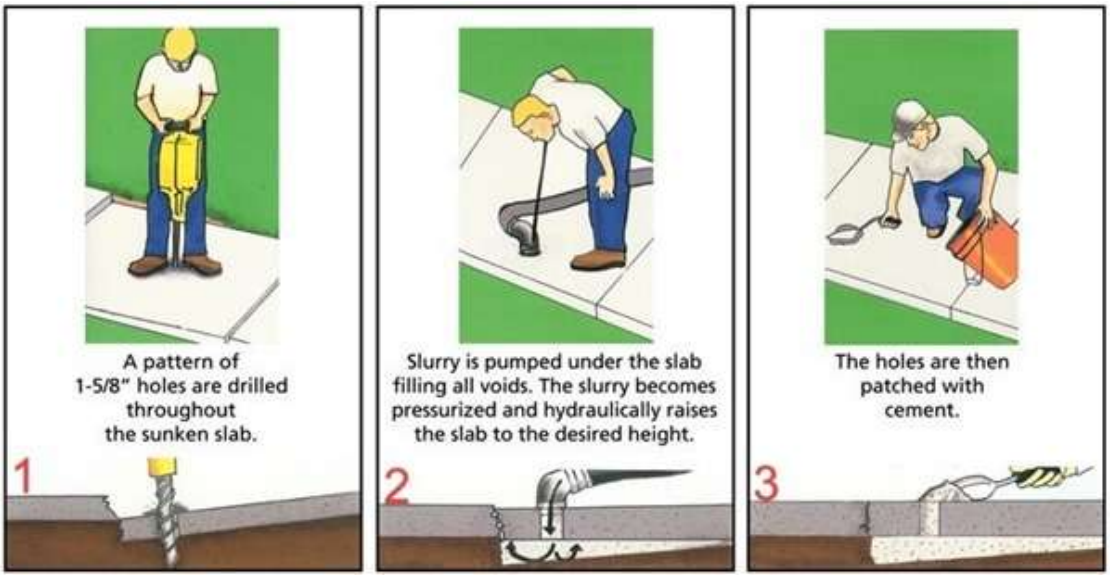

Figure (64): Grouting of concrete cracks procedure

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 appropriate speed restriction at each individual site should be considered.
- 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 and should be kept under observation for a period of 6 months to 12 months for its behavior 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.

x. Epoxy Injection For Concrete Crack Repair

Epoxy injection for Concrete Crack Repair in foundations, basements, beams, columns, slabs, walls and other concrete structures. Injection of epoxies under pressure may be used to bond the cracks having greater than or equal to 0.05mm opening. This method is not applicable if the crack is active, the cracks are large in number, or when the water leakage can not be controlled. If the cause of the cracking has not been corrected, it will reoccur near the original crack. Extreme caution must be exercised when injecting cracks that are not visible on all surfaces.

Pic. (36): Epoxy injection for Concrete Crack Repair in basement wall

Epoxy injection is commonly used to restore the pre-cracking condition of the member without increasing its strength. The epoxy tensile bond to the concrete substrate is stronger than the concrete's tensile strength. Future cracking may occur at the same load as that of the original uncracked member but at different locations. Strengthening is provided by installing additional reinforcement across the failure plane in combination with the resin injection. Frequently, internal or external reinforcement is installed in combination with the epoxy injection for strengthening and restoration. Crack injection can be successfully performed on cracks as narrow as 0.013 mm in width with general epoxy injection resins. Cracks with less width can be injected with epoxy or other polymer systems having a low viscosity of 200 cps.

Poured foundation cracks may be repaired by using low-pressure injection of an epoxy or polyurethane foam material. For the repair of concrete floor cracks, certain epoxies and polyurea materials exists, suitable for such slab repairs.

Epoxies and other resins lose strength when exposed to fire or sustained elevated temperatures and fireproofing protection is required for such structural repairs. Epoxies that are labeled water-insensitive during curing may develop milky white bond lines if injected into wet or damp cracks. Verification that the epoxy is completely water-insensitive should be made by injecting the test epoxy into pre-wetted cracks, then evaluating the cored sample of the cured epoxy injected into the crack. Slabs and walls restrained at their ends may develop full-depth slab cracks due to shrinkage as a result of volume changes during concrete curing or during extreme thermal fluctuations. The cause for the local overstress should be either eliminated or considered in the repair. Injecting the crack at the midrange temperature minimizes thermal stress fluctuations.