xi. Replacing Damaged Structural Members

Replacing damaged beam, columns, braces and walls by supplemental members

Pic. (37): damaged reinforced concrete column

Supplemental members are new columns, beams, braces, or infilled walls that are installed to support damaged structural members. The location of these members is usually below the damaged or deflected areas to stabilize the structural framing. New members are installed to support seriously cracked and deflected flexural members and the technique is generally economical. The use of cross bracing, infilled walls, or other means of providing resistance to lateral forces are required if the original structure has lost the necessary resistance.

This repair method can be used if none of the other strengthening techniques is adequate. Supplemental members are quickly installed and, therefore, are suitable temporary emergency repair solutions. A new column obstructs passage and new beams reduce head room. Further, the new beam or new column is noticeable and architecturally unpleasant. Cross bracing and infilled walls seriously disturb the interior space utilization. Loads and stresses in the existing structure may not be relieved unless special procedures are used. The supplemental members may cause a redistribution of loads and forces that overstress an existing nearby member, foundations, or both. A simply supported beam propped by a column at midspan does not behave like a 2-span continuous beam. The expected cracking at the top of this central support must be investigated.

The new members are made up of timber, steel, concrete, or masonry and are tightly shimmed, wedged, or anchored in position so that loads are transferred to the new members. The packing force must not be so large that lifting of repaired and adjoining members occurs beyond their original position and no stress reversal should take place. The single span becomes continuous and negative and positive moment regions may be reversed. It must be decided whether the expected cracking in negative moment region will be acceptable or not. If shear cracks are present in a beam supported on columns, a post may be added adjoining an existing column to improve the shear resistance and reduce the effective span of the existing beam, which may provide economical solutions than collars. The eccentric positioning of the post over an existing footing is to be analyzed to determine if its size or strength is sufficient or its strengthening is also required. In placing the post, a permanent jack, props with shims, or both, may be required.

The jacking carried out before installing the props must effectively redistribute the dead loads to the new posts. In some cases a full new frame may be fitted within the already present frame. Two columns are erected adjoining the existing columns towards the inside and a new beam is constructed below the existing beam. The space between the new beam and existing structure is shimmed or dry packed. To provide lateral stability to the supplemental member, it may be necessary to mechanically anchor it to the existing slab, columns, or both. To strengthen an existing slab, extra beams may be provided resting on the already present beams.

xii. Repair Of Reinforcement In Concrete

The reinforcement repair techniques are different for mild steel and prestressing steel.

1. Mild reinforcing steel

The damaged bars may either be replaced or supplemented by additional reinforcement based on engineering judgment, the purpose of the reinforcement and the required structural strength of the member.

a) Replacement: In case it is decided to replace the bars, splicing of reinforcement with the remaining steel must be done. The lap length must be according to the provision of ACI 318 and the welding (if used) must satisfy ACI 318 and American Welding Society (AWS) D1.4 (or the codal provisions of the respective country). Butt welding is usually avoided due to the high degree of skill required to perform a full penetration weld because the back side of a bar is not usually accessible. Welding of bars larger than 25 mm may cause problems because the embedded bars may get hot enough to expand and crack the surrounding concrete. Mechanical connectors may also be used according to the code requirements.

b) Supplemental reinforcement: This alternative is selected when the reinforcement has lost cross section, the original reinforcement was inadequate, or the existing member needs to be strengthened. The allowable loss of cross-sectional area of the existing reinforcing steel and the decision to add supplemental reinforcement must be evaluated on a case-by-case basis and is the responsibility of the engineer. The damaged reinforcing bar must be cleaned and extra space is to be created by removing concrete to allow placement of the supplemental bar beside the old bar. The length of the supplemental bar must be equal to the length of the deteriorated segment of the existing bar plus a lap-splice length for smaller diameter bar on each end. Reinforcing bars, having corrosion of their original deformations, give less bond and this factor must be considered while designing the repair of the reinforcement.

c) Coating of reinforcement: New and existing bars that have been cleaned may be coated with epoxy, polymer cement slurry, or a zinc-rich coating for protection against corrosion. The coating must have a thickness less than 0.3 mm to minimize loss of bond development at the deformations.

Pic. (38): Damaged reinforcing bars

2. Prestressing steel

Deterioration or damage to the strands or bars can result from impact, design error, overload, corrosion, or fire. Fire may anneal cold-worked, high-strength prestressing steel. The unbonded high-strength strands may need to be detensioned before repair and retensioned after repair to restore the initial structural integrity of the member.

a) Bonded strands: Because the prestressed strand is bonded, only the exposed and damaged section is restressed following repairs. The repair procedure requires replacing the damaged section with the new section of strand connected to the existing ends of the undamaged strands. The new strand section and the exposed lengths of the existing strand must be post-tensioned to match the stress level of the bonded strand.

b) Unbonded tendons: The strands are protected against corrosion by the sheathing, corrosion-inhibiting material (commonly grease), or both. Corrosion of the end connections and the strand has been the primary cause of failure of unbonded tendons. A deteriorated portion of a strand can be exposed by excavating the concrete and cutting the sheathing. Unbonded tendons can be tested to verify their ability to carry the design load. This can be done by attaching a chuck and coupler to the exposed end of the strand and performing a lift-off test. This usually requires at least 20 mm of free strand beyond the bulkhead. If there is excessive corrosion in the strand, failure occurs and the strand must be replaced or spliced. Shoring of the span being repaired and adjacent spans up to several bays away may be required before removing or retensioning unbonded prestressed strands.

The strand is cut on both sides of the deterioration and the removed portion of the strand is replaced with a new section. The new strand is spliced to the existing strand at the location of the cuts. The repaired strand is then prestressed. Carbon fiber or equivalent systems are available to supplement the reinforcement in prestressed, post-tensioned, and mild steel reinforced structures. This system is normally glued onto the exterior surface. Unless the component being reinforced is unloaded, the strengthening system only provides reinforcement for future loadings. Fiber wrapping is commonly used for reinforcing columns, especially in earthquake zones. There are systems available that recover the dried and damaged protective barrier within the sheathing.

xiii. Structural Defects Of Foundations At Construction Stage

Structural defects occur in foundations at construction stage. There can be many causes for these defects. The problem areas, effects in foundation and defects in structure due to those causes are presented here.

Table (138): Causes of structural defects occur in foundations at construction stage

Problem Areas	Effect on foundation	Defects in structure
Insufficient depth of foundation (mostly in soft clayey soil)	Movement of foundation due to changes in water table seasonally, and movement due to trees and vegetation.	Cracks in walls at natural lines of structural weakness, i.e. windows, doors, junctions with extension and bays.
Insufficient width of foundation	Settlement of foundation occurs due to insufficient distribution of load.	Cracking of walls above ground level.

Soft-spots in sub-soil	Foundation settles due to insufficient support from sub-soil.	Cracking in walls above affected section of foundation.
Insufficient steps in strip foundation on sloping ground.	Building may slide or creep in case there is soil erosion.	Displacement movement of building or section of building. Cracking in walls.
Trees and large shrubs close to building (mostly in case of soft shrinkable clayey soil)	Water-content of soil changes with season, i.e. desiccation occurs in absence of moisture and heave occurs with excess moisture.	Cracking in walls in line of weakness in structure.
Clayey soil with high sulphate content.	Sulphate attack in concrete foundation and cement mortar below ground level.	Movement in walls above ground level and expansion and deterioration of cement mortar and concrete below ground level.
Inadequate support to foundation from land-fill.	Excessive settlement of foundation which continues for a long time.	Cracking in walls, complete collapse of buildings.
Foundation near to	Foundation is	Cracking in walls occur

drains where drains are running below foundation and / or drains lacking concrete cover.	inadequately supported.	above ground level and walls move out of plumb due to lateral movement of foundation.

xiv. Repairing of Plaster In Walls

Repairing of plaster is needed from time to time as the building ages. The plaster repair work includes cutting the patch and preparing the wall surface.

Procedures involved in repair of plaster are:

1. Setting up Scaffolding:

Scaffolding if required for the proper execution of the repair work should be erected. Ladder can also be used in case of scaffolding if the work can be done safely.

2. Cutting of Old Plaster:

The mortar of the patch, where the existing plaster has cracked, crumbled or sounds hollow when gently tapped on the surface, is first removed. The patch is be cut out to a square or rectangular shape at position where repairing is needed. The edges of cut plaster is made under cut to provide a neat joint.

3. Preparation of Surface:

The masonry joints which become exposed after removal of old plaster is raked out to a minimum depth of 10 mm in the case of brick work and 20 mm in the case of stone work. The raking is carried out uniformly with a raking tool, and loose mortar is dusted off. The surface is then thoroughly washed with water, and kept wet till plastering is commenced.

In case of concrete surfaces, the old plaster is thoroughly scrubbed with wire brushes after the plaster had been cut out and pock marked the surface is roughened by wire brushing and all the resulting dust and loose particles cleaned off. The surface is washed and cleaned and kept wet till plastering is commenced.

Pic. (39): damaged plastering in wall

4. Application of Plaster:

Mortar of specific mix such as CM 1:4 or CM 1:6 with the good quality plaster sand is used. After the plaster has been applied to the surface, finishing of plaster is done to match with the old surrounding plaster. All dismantled mortar & rubbish etc.

5. Protective Measure:

Doors, windows, floors, articles of furniture etc. and such other parts of the building should be protected from being splashed by mortar.

6. Curing of plaster:

Curing of plaster is necessary to prevent cracking. It should be done for at least 3 days at regular interval.

7. Finishing of plaster:

After the plaster is thoroughly cured and dried the surface is then painted with the colour of the surrounding area.

xv. Epoxy Coating Of Steel Reinforcement

It is important to use epoxy coated rebar to protect steel from corrosion. Using certain types of epoxies yielded positive results, especially in steel exposed to seawater while evaluating the use of epoxy to coat steel reinforcements exposed to chloride attack.

Pic.(40): steel reinforcing protected with epoxy

Epoxies have been used in painting reinforced steel for bridges and offshore structures since 1970. Some shortcomings have been found using this method. Precautions must be taken during the manufacturing and operation of painting the steel, such as avoiding the absence of any friction between the bars, which would affect the result of the erosion of the coating layer due to friction. Also, it is difficult to use methods for measuring the corrosion rate such as polarization or half-cell, so it is not easy to predict the steel corrosion performance or measure the corrosion rate. Painting steel-reinforced bars has been used extensively in the United States and Canada for 25 years. The coated steel bar must follow ASTM A 775M/77M-93, which sets allowable limits as the following:

- Coating thickness should be in the range of 130–300 mm.
- Bending of the coated bar around a standard mandrel should not lead to formation of cracks in the epoxy coating.
- The number of pinhole defects should not be more than six per meter.
- The damage area on the bar should not exceed 2%.

These deficiencies cited by the code are the result of operation, transportation, and storage. There are some precautions that must be taken in these phases to avoid cracks in the paint.

Painting steel reinforcement bars will reduce the bond between the concrete and steel; therefore, it is necessary to increase the development length of steel bars to overcome this reduction in bond strength. According to American Concrete Institute (ACI) code (ACI Committee 318 -1988), the increase of the development length is from about 20–50%. The American code stipulates that, in the case of painting, the development length of steel bars must be increased by 50% when the concrete cover is less than three times the steel bar diameter or the distance between the steel bars is less than six times the bar diameter; in other circumstances, the development length should be increased by 20%.

Painting the mild, low tensile steel at full bond strength is prohibited due to friction; when it is painted with coating, all the bond strength will be lost, so it is important to avoid coating the smooth bars. Care must also be taken not to increase the thickness of the paint coating to more than 300 ?m(micrometer). Some researchers have stated that when painting with a thickness of 350 mm was used for the main steel reinforcement in concrete slab, testing found too many cracks, which led to separation between steel bars and concrete.

xvi. Repairing of Off-Centre Footings (Fixes for Misplaced Footings)

It is sometime hard to position footings in the trench, so contractors often see walls that are not in the center of the footing (Pic. 41). The foundation wall has to be located correctly to support the house, of course, so it has been placed off-center on the footing.

Pic.(41): This incorrectly placed footing caused the foundation wall to be off-center.

If the soil is very strong, this may not lead to problems. If the footing is on a weaker soil it is recommended that it is fixed.

In good bearing soil, it is not the matter of much concern about this foundation for the loads involved in a simple wood frame house. The full width of the footing is not needed to support the loads; wall can be constructed right on the edge of the footing and still have enough support. However, if it goes over the edge and have the wall sticking out past the footing on the side or on the end, then rotational force is generated which the footing is not designed to handle. In that case, an engineer has to get involved. If soils are relatively soft, the risk is even greater.

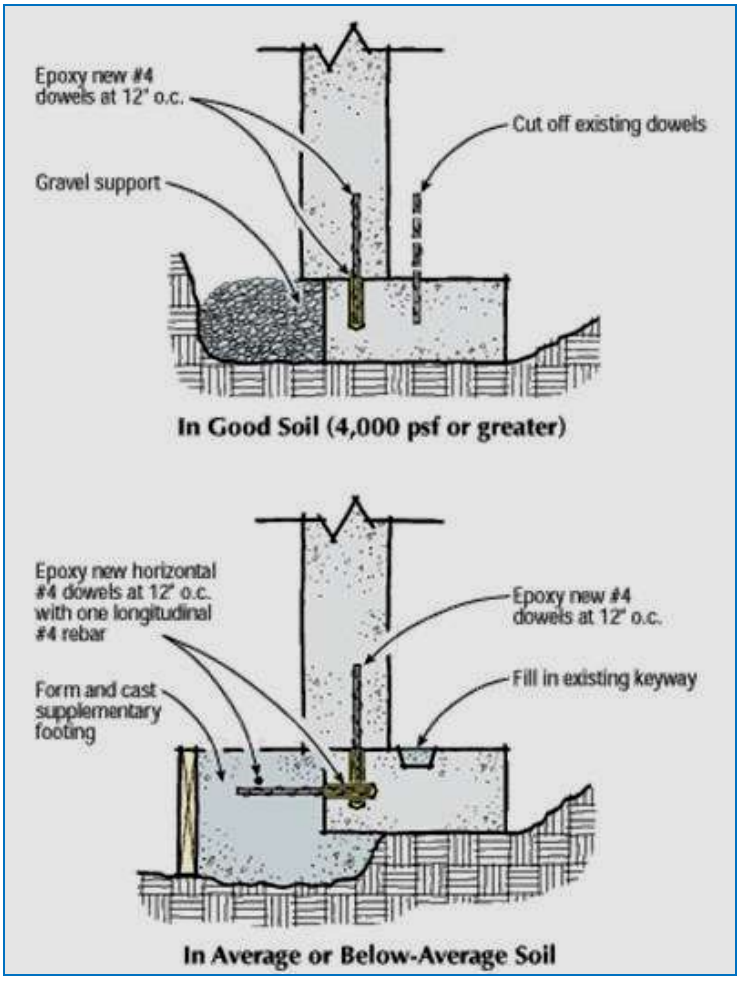

Figure (65): In strong soils, a mistake in footing layout can be corrected by placing gravel to support the wall (top). In weaker soils, casting an augmented footing alongside the existing footing is recommended (above), connected by dowels epoxied into the side of the existing footing. Be sure to fill any notches in the footing, and cut off any existing steel dowels that will miss the wall.

- In soils with high bearing capacity greater than about 4,000 psf, excavating next to the footing and under it and placing compacted large gravel into the space is suggested. That should be adequate to support the wall.
- In weaker soils, the footing itself has to be augmented with steel and concrete. Excavation has to be done as before, but instead of filling it with gravel, drilling into the side of the footing has to be done and epoxy steel dowels into it, and then concrete is placed to extend the footing out to the proper width.

xvii. Surface Treatments For Roof & Walls

Surface treatments include any material applied to either horizontal or vertical surfaces of concrete to provide protection. The objective is to limit corrosion by reducing the existing moisture level in the concrete and preventing further ingress of moisture and chlorides. All the materials in contact with each other must be compatible to avoid bond failures of the surface treatment materials with the underlying substrate. Appropriate surface preparation is a must for success of surface treatments.'The surface treatments must be applied to a clean, dry, and sound substrate at moderate temperature and humidity conditions in a well-ventilated space. A relatively smooth surface is needed for liquid-applied membranes. All concrete repairs are completed and allowed to cure before applying most of the surface treatments. The curing time is usually 28 days but varies with the repair material.

Details of expansion and control joints, door and window openings, drains, and curbs must be reviewed and installed properly.

Pic.(42): Surface treatments to limit corrosion by reducing the existing moisture level in the concrete.

Surface treatment classification: The surface treatment can be by using penetrating sealers, surface applied corrosion inhibitors, surface sealers, high-build coating, membranes, overlays, and joint sealants.

1. Penetrating sealers

Penetrating sealers are materials that are generally absorbed within the repaired concrete and the depth of penetration varies by the product, the size of the sealer molecule and the size of the pore structure in the concrete. Deep penetration of sealers is usually not an important factor although it may be desirable for abrasion resistance of surfaces. These sealers are effective for protection in two ways; as water repellents and as surface hardeners. Penetrants do not have crack-bridging capabilities, but the hydrophobic properties imparted by some of these products may reduce the intrusion of moisture into narrow cracks. The appearance of concrete surface is usually not affected by applying these sealers, only slight change in color may take place. Such sealers include boiled linseed oil, silanes, siloxanes, certain epoxies, magnesium and zinc fluorosilicates, and high molecular-weight methacrylates. The sealants do not usually hide the surface flaws.

These products may be applied by roller, squeegee, or spray to the concrete substrate and proper surface preparation is important for successful application. UV, wear, and abrasion resistance are generally good when compared with coatings or membrane systems. Penetrating sealers do not bridge new or existing cracks. Some of these products are solvent-based (that can cause air-pollution) and others are water-based.

2. Surface-applied corrosion inhibitors

Surface-applied corrosion inhibitors are designed to reduce the rate of corrosion. The effectiveness and life expectancy of these materials varies with the properties of the concrete, site conditions and type of inhibitor material.

3. Surface sealers

Sealers and paints are applied on the surface of concrete where it adheres. The finished thickness may be 0.03 to 0.25 mm. Pigmented or naturally colored paints are used according to the requirements, while transparent paints result in a wet or glossy appearance. Surface sealers do not have significant crack-bridging capabilities. The hydrophobic nature of some of these products may reduce the movement of moisture into narrow cracks and some of these products may fill dormant cracks, reducing the penetration of moisture through those cracks.

Epoxies, polyurethanes, HMWM (high molecular weight methacrylate), siloxanes, silanes, moisture-cured urethanes, and acrylic resins are included in this category. Certain paints, whether oil-based or latex-based (such as styrenebutadiene, polyvinyl acetate, acrylic or blends of these with other polymers dispersed in water), can also be included if the resulting thickness of layer is less than 0.25 mm.

These materials have the capability to reduce the intrusion of water, chlorides, and mild chemicals. They also may or may not permit the transmission of water vapor. The materials may be applied with brush, roller, sponge, or spray. Surface sealers reduce skid resistance and they do not bridge moving cracks. However, these are effective in filling (not bridging) small, nonmoving cracks. These products are affected by UV exposure and wear under surface abrasion. Some of these products depend on solvents to work and may have problems with environmental quality.

4. High-build coatings

High-build coatings are materials with a dry thickness between 0.25 mm and 0.75 mm applied to the surface of the concrete. High-build coatings alter the appearance of the surface and may be pigmented. The base polymers of such products include acrylics, alkyds, styrene butadiene copolymers, vinyl esters, chlorinated rubbers, urethanes, silicones, polyesters, polyurethanes, polyurea, and epoxies. These products are generally used for decorative or protective barrier systems but some products may be suitable for use against rain, salts, and mild chemicals.

These products may be applied with brush, roller, sponge, or spray. For exterior environments, the coating must be resistant to oxidation and UV and infrared radiation exposure. On floors, resistance to abrasion and punctures and resistance to mild chemicals (salts, grease and oil, and detergents) are also important. The coating material must be durable and the bond between the coating and concrete substrate must be strong. Epoxy resins are commonly used repair materials that generally have good bonding and durability characteristics and can be mixed with fine aggregates to improve abrasion and skid resistance. Some high-build coatings result in a very slippery surface when wet and may not be suitable for pedestrian or vehicular traffic. Non-elastomeric high-build coatings generally do not bridge moving cracks, but are usually effective in filling small, nonmoving cracks. These products have better wear characteristics than thinner systems. A coating intended to reduce reinforcement corrosion in repair work may also be required to waterproof the structure, protect against chemical attack, or improve the appearance. Breathability is often an important factor when selecting a protection material on exterior walls and slabs-on-ground. Some of these products are solvent-based and can have pollution problems.

5. Membranes

Membrane systems are treatments with thicknesses between 0.7 mm and 6 mm applied to the surface of the concrete, significantly changing the appearance of the concrete surface. They may be bonded, partially bonded, or unbonded to the concrete surface. Elastomeric membrane systems generally have sufficient thickness and flexibility to bridge narrow, nonmoving cracks of various widths.

Some systems require that cracks wider than 0.25 to 0.375 mm should be located and sealed before application of the membrane. Elastomeric membranes are usually gray or black, but some manufacturers offer several other colors.

Chemically these materials consist of urethanes, acrylics, epoxies, neoprenes, cement, polymer concrete, and asphaltic products. The membranes are generally used as protective, waterproofing, wearing course for traffic and damp-proofing systems.

Liquid forms of these products may be applied by brush, sponge, roller, trowel, or spray. Preformed sheets are sealed at the edges to form a continuous waterproofing membrane. Most of these membranes are resistant to water absorption. These bridge small (less than 0.25 mm) moving or nonmoving cracks. Membranes with a rigid urethane mortar or epoxy-mortar top coat offer reasonable skid and abrasion resistance under traffic. Standardized tests must be conducted for permeability, elongation, tensile strength, tear strength, adhesion, modulus of elasticity, abrasion resistance, low temperature flexibility, and water vapor transmission.

6. Overlays

Overlays are depositions of 6 mm or greater in thickness that can be bonded, partially bonded, or unbonded to the surface of the concrete. The details of the overlay materials and the placing methods are given earlier. The materials for the overlays may be Portland cement concrete, latex modified concrete, polymer concrete and silica-fume concrete, as described earlier.

7. Joint sealants

Protection systems of joints include the sealing of cracks, contraction (control) joints, expansion joints, and construction joints. Joint sealants in concrete minimize the intrusion of liquids, solids, or gases, and protect the concrete against damage. Sealing of various types of joints is discussed below:

a) Cracks: Cracks are produced in concrete due to shrinkage, thermal changes, structural-related stresses, and long-term strain shortening. Before selecting a sealant, the reason for the cracking must be determined and moving cracks must be identified. In some cases, structural bonding of a crack may be required, whereas in other situations, restraint across the crack is to be avoided.

b) Contraction (control) joints: Contraction joints are intentional gaps / discontinuities provided to control crack locations to accommodate the contraction of concrete. The necessary plane of weakness may be formed by reducing the concrete cross section by tooling or saw cutting a joint, usually within 24 h. It must be sealed in such a way that it must allow contraction to occur.

Pic. (43): Cracks in concrete due to thermal changes

c) Expansion (isolation) joints: Expansion joints are made by providing a space over the entire cross section between abutting structural units and are used to prevent crushing and distortion of abutting concrete structural units due to the transmission of compressive forces that may be developed by expansion, applied loads, or differential movements arising from the configuration of the structure or its settlement.

Pic. (44): joint treatement to prevent crushing and distortion of concrete

d) Construction joints: Construction joints are formed by interruptions in the placement of concrete or due to the positioning of precast units. Locations are usually predetermined so as to limit the work that can be done at one time to a convenient size. They may be required to function later as expansion or contraction joints, or they may be required to be firmly bonded together so as to maintain complete structural integrity. Construction joints may run horizontally or vertically depending on the placing sequence prescribed by the design of the structure.

Pic. (45): Injection of joints with flexible material

e) Sealing methods: Methods to seal joints include injection techniques, routing and caulking, bonding, installing pre-molded seals, or installing appropriate surface protection systems (such as elastomeric membranes).

xviii. Injection Grouting /Grouting From Surface

Injection grouting is usually carried out from the surface and is the common method for filling cracks, open joints, and interior voids with a material that cures in place to produce the desired results. Besides cement grout, polymer-cement slurry, epoxy, urethane, and high-molecular-weight methacrylate (HMWM) may be used as grouting material. Grouting can strengthen a structure and can prevent water movement. Proper grouting material is to be selected for a particular project to achieve the desired objectives, while cores are tested to ensure quality control.

Pic.(46): Interior voids in concrete

Short entry holes (called ports) are drilled into the opening having a minimum diameter of 25 mm and a minimum depth of 50 mm. These holes are drilled from face of the concrete at spacing of 150 mm c/c for finer cracks to 300 mm c/c for others (to be used as entry and venting terminals). The spacing of ports is usually kept greater than the desired depth of grout penetration, but it may be adjusted based on judgment and requirements for a particular project. The crack / opening surfaces between ports are sealed by applying epoxy, polyester, strippable plastic surface sealer (for low injection pressures) or cementitious seals (if surface appearance is important) to the surface of the crack. Time required for hardening of seal depends upon the type of material used. To stiffen the surface seal, the cracks are usually routed 6 mm in width and 13 mm in depth.

Sometimes, the crack can be cut out to a depth of 13 mm and width of about 20 mm in a V-shape, which is then filled with an epoxy to get a flush surface. When the ports are drilled after sealing the openings and the grout pressure is up to 350 kPa, a hand-held, cone-shaped fitting on the grout hose is sufficient. If cracks pass through the structure (such as a wall) the surface seals and ports are applied on both sides. Openings may be sealed by plugging with cloth or fabric that allows passing of water or air but retaining of solids. Paper and other materials that remain plastic are not suitable for this purpose. For larger grout pressures, short pipe nipples are connected in to the holes to obtain grout hose connections. The method of installing entry and vent ports in case of V-grooving of the cracks is to drill holes 20 mm in diameter and 13 to 25 mm deep below the groove at the required spacing. A pipe nipple or tire valve stem is usually bonded with an epoxy adhesive. The method commonly used in case of rectangular grooves is to use a flush fitting has an opening at the top for the adhesive to enter and a flange at the bottom that is bonded to the concrete face. Third method is to use special gasket devices which can be directly fitted on to the discontinuities / openings in the surface seals. Before grouting, flushing is done with clean water to obtain the following objectives:

1. To wet the interior surfaces for better grout flow and penetration.

2. To check the effectiveness of the surface sealing and port system.

3. To gather information on grout flow patterns and details of interconnections of voids / discontinuities in the mass.

4. To familiarize the grouting crew with the situation.

Full crack cleaning may not be possible in practical situations and judgment must be used to decide the extent of this cleaning. Grouting is started at one end of a horizontal opening or at the bottom of a vertical opening. It is continued until grout appears at the next port or the surface seals of cracks bulge out, after which the grouting operation is shifted to the next port. The port valves from where the grout is coming out are plugged before moving to the next injection location.

Pic. (47): Injection Grouting in to concrete wall tunnels

Grouting is usually started with a relatively thin grout, thickened as quickly as possible to the heaviest consistency that can be pumped without blockage.

Extreme caution must be exercised when injecting cracks that are not visible on all surfaces. For injection of the epoxy, hydraulic pumps, paint pressure pots, or air-actuated caulking guns are generally used. The pressure used for injection must be selected carefully and it must not be excessive. For vertical or inclined cracks, the injection process must begin by pumping epoxy at the lowest level until the epoxy level reaches the entry port above. The lower injection port is then capped, and the process is repeated until the crack has been completely filled. An indication of full filling of the crack is that the pressure does not drop. Epoxy injection requires a high degree of skill for satisfactory application of the technique. The atmospheric temperature at the repair site is also an important consideration.

Only that quantity of epoxy is mixed which can be used before gelling of the material, otherwise pressure injection becomes considerably difficult. During the batch mixing process, the components of the epoxy are mixed in a fixed quantity using a mechanical stirrer, such as a paint mixing paddle. In the more advanced continuous mixing system, the two liquid adhesive components are passed through an automatic mixing head after the pumping just before leaving the gun.

This system allows the use of fast setting adhesives that have a short working life. After the injected epoxy has cured, the projected part of surface seal is removed by grinding or other appropriate means.

For massive structures, the procedure consists of drilling a series of holes, 20 to 100-mm diameter, at a spacing of 1.5 m along the crack. In a recently developed method, a bag is wrapped all along the member and the liquid adhesive is introduced at the bottom and is sucked by a vacuum pump at the top, or epoxy is injected in the cracks from one side and pulled from the other side.