ReBuild

Vol. 10 No. 3 (Jul - Sep 2016)

A Quarterly Newsletter

STRENGTHENING OF CONCRETE ELEMENTS
Part-3

Dr. Fixit Institute
of Structural Protection & Rehabilitation

A Not-for-Profit Knowledge Centre

From the Editor's Desk

As part of the series of publication on concrete strengthening, we earlier published on the guidance on concrete repair, materials for structural and non-structural repair, methods of concrete breaking, surface preparation and rebar corrosion crack repair in the last two issues of ReBuild. In this issue, we shall discuss more on structural crack repair, crack repair of concrete in water retaining structures, different methods of structural strengthening, quality assurance during repair work and safety, health & environment issues of concrete repair.

While considering restoration work, it is important to realize that even fine cracks in concrete members that are unreinforced reduce their resistance in a very large way. Therefore all cracks must be located and marked carefully and the critical ones fully repaired either by injecting strong cementitious or chemical grout or by providing external bandage. The cracks in wet retaining structures need to be repaired with specialized materials based on specific requirement and performance of the materials to match with the environment.

The strengthening of existing reinforced concrete (RC) structures is a common requirement. Strengthening may be required because of a change of use resulting in an increased loading due to additional floor or equipment, changes in seismic zones/codal provision, design or construction error and damage to the structure due to ageing. The most popular means of strengthening RC beams, slabs, and columns is namely the addition of new concrete and/or steel reinforcement ("jacketing" and "overlays"), by using fibre reinforced plastic (FRP) plates, structural steel or external prestressing steel. In addition, the strengthening of columns by jacketing with new concrete or wrapping with FRP is most widely used. The structural assessment is very important before doing any repair and strengthening of the structure. The strengthening of concrete structures with various techniques is available. However based on the durability, cost economy and ease of application, the strengthening technique needs to be considered. In the last couple of decades, the attempts to strengthen the RCC structures have been mainly concentrated around the following methods:

i. sectional enlargement by using micro-concrete.

ii. external post tensioning of steel bars.

iii. strengthening by steel plate bonding.

All the above methods have been well experimented and widely used and are found to be very effective for strengthening purposes. However, the main obstacle or rather limitations faced in these methods are:

i. destructive in nature, as a lot of drilling to fix anchor bars is required.
ii. bulky methods, i.e. increasing self-load on the structural members.
iii. labour intensive, i.e. requires more labour for execution.
iv. time consuming, i.e. takes more time to complete execution.

v. increased member size, i.e. reduces commercial space.
vi. complex arrangement, i.e. bulky set-up requiring complex formwork arrangement.

The disadvantages in strengthening by jacketing with micro concrete are high risk of corrosion of embedded reinforcing steel and concrete deterioration thereafter. These problems are associated with relative dimensional incompatibility between existing and new concrete. Hence the micro concrete material to be used should have high tensile strain capacity with low shrinkage properties to avoid any volume changes resulting in formation of cracks. Similarly the disadvantage in post tensioning method is vulnerability to corrosion in strands and tendons. The problem associated with steel plate bonding is the heavy weight of the plates to be bonded, durability of bonding and corrosion of steel at interface of adhesive.

An alternative to the above methods of strengthening is to use epoxy-bonded fiber reinforcement polymer composite system for strengthening applications. Although the technology was originally developed for the aerospace industry, its use for the purpose of strengthening RCC structures has been increasingly pursued and popular in the recent past due to its light weight, ease of handling and rapid implementation. A number of structures like bridges, building, jetties, silos, etc., have been strengthened for various load requirements that were not incorporated during the original design. Strengthening of concrete members with externally bonded fiber reinforced polymer (FRP) system received remarkable attention. Typically used to compensate for steel in structures, available as glass, carbon or aramid fibre, it has to be fixed properly to the underlying surface. On the application side, FRP materials have been used in various projects worldwide for strengthening bridges, parking garages, multi-purpose convention centers, office buildings, silos, etc. The drivers for this technology are several, but perhaps the most relevant ones are the ease and speed of installation. ACI standard ACI440.2R-02, "Guide for the design and construction of externally bonded FRP systems for strengthening concrete structures" provides the detailed procedure for FRP strengthening system.

In the repair/upgrade arena, one of the most important unresolved questions remains that of durability of repair system. Addressing this issue as a part of quality control and quality assurance programme would increase the degree of confidence in any repair technique and allow for its full exploitation.

Structural Crack Repair

[Excerpts from Dr. Fixit Guide to Healthy Construction – 1, Cracks & Crack Repair (Unpublished)]

1.0 Methods of Structural Crack Repair

1.1 Epoxy Injection

When hardened concrete is cracked in depth or when hollow plane delaminations or open joints exist in hardened concrete and when structural integrity or watertightness must be restored for the structure to be serviceable, resin injection shall be used for repair, as directed. However, since not all cracked, delaminated, or jointed concrete can be restored to serviceable condition by resin injection, resin injection repairs shall be made only as directed by the structural consultant. Epoxy resins are used to rebond cracked concrete and to restore structural soundness. Epoxy resins may also be used to eliminate water leakage from concrete cracks or joints, provided that cracks to be injected with epoxy resin are stationary. Cracks that are actively leaking water and that cannot be protected from uncontrolled water inflow shall not be injected with epoxy resin. Cracks to be injected with epoxy resin shall be between 0.1 mm and 6 mm in width.

Epoxy resins are injected for repair of hair line cracks and fissures as narrow as 0.05 mm due to their unique property of super low viscosity. The appropriate viscosity of the epoxy will depend on the crack size, thickness of the concrete section, and injection access. For crack width of 0.3 mm or smaller a low viscosity epoxy injection can be used. For wider cracks, or where injection access is limited to one side, a medium to gel viscosity material may be suitable.

Injection can be made of low pressure or high pressure system depending on the nature of cracks. It is advisable to use two-component pumps with a static mix head to prevent premature reaction.

Epoxy grouts are widely used because:

- They adhere strongly to both fresh and hardened concrete
- Formulations are available which will adhere to most surfaces and harden even under wet conditions
- They have good mechanical strength and low shrinkage
- They are resistant to a wide range of chemicals, including alkalis
- They are almost totally UV resistant

Generally epoxy resins will have either good chemical resistance or good heat resistance, but not both. Another characteristic of this type of product in its cured state is the lack of flexibility, and the system might be prone to failure if movement occurs due to seismic activity, and or expansion/contraction. The two-component epoxy resins have good expansive properties.

The step by step approach of epoxy injection (Fig. 1 and Fig. 2 a to e) are shown to restore structural soundness of buildings, bridges, and dams where cracks are dormant or can be prevented from moving further. Except for certain specialized epoxies, the method cannot be used if the cracks are actively leaking. The detailed description is given as follows:

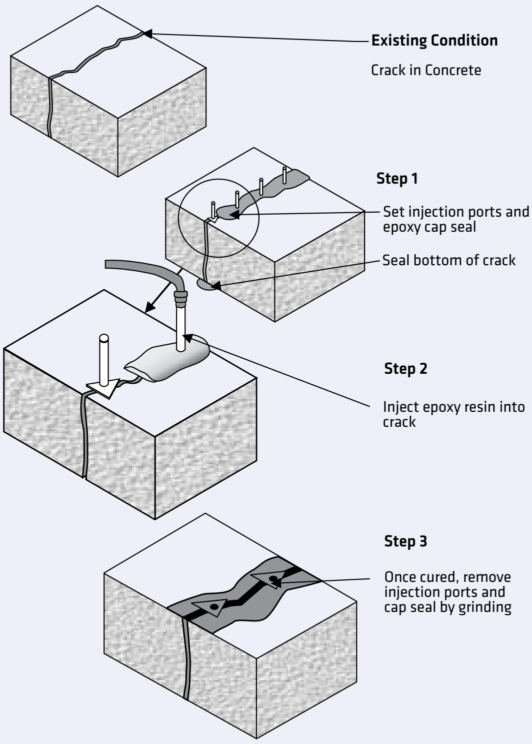

Fig. 1: Schematic diagram of epoxy Injection

- Clean the cracks : Cut and open the cracks. Remove any contamination by flushing with water or some especially effective solvent. Then blow out the solvent with compressed air, or allow adequate time for air drying.
- Seal the surfaces : This keeps the epoxy from leaking out before it gelled. A surface can be sealed by brushing an epoxy over the surface of the crack and allowing it to harden. If extremely high injection pressures are needed, cut out the crack in a V-shape, fill with an epoxy, and strike off flush with the surface.

Install the entry ports : There are three ways to do this:

- Fitting of nozzles inserted in drilled holes Drill a hole into the crack for 8 mm dia injection packers @ 200 to 300 mm c/c, (Fig 2 a) penetrating below the bottom of the V-grooved section. Insert a fitting such as a pipe nipple or tire valve stem into the hole and bond with an epoxy adhesive. A vacuum chuck and bit will help keep the cracks from being plugged with drilling dust.
- Bonded flush fitting when the cracks are not V-grooved, a common method of providing an entry port is to bond a fitting flush with the concrete face over the crack.

Fig. 2 a: Packer and Injection hand pump

Fig. 2 b: High pressure Injection pump

Fig. 2 c: Fixing the hose into the packer and start pumping

Fig. 2 d: Injection in progress

Fig. 2 e: Injection in underside

- Interruption in sealing is another way to allow entry is to omit the seal from part of the crack. This method uses special gasket devices that cover the unsealed portion of the crack and allow injection of the adhesive directly into the crack.
- Mixing: Mix the two components epoxy injection grout of base and hardener in a suitable container with heavy duty slow speed drilling machine with paddle attachment.
- Mix it for 2 to 3 minutes to obtain a uniform colour.
- Inject the epoxy: Hydraulic pumps (Fig 2 b), paint pressure pots, or air-actuated caulking guns can be used. Select the pressure carefully, because too much pressure can extend the existing cracks and cause more damage.
- If cracks are clearly visible, injection ports can be installed at appropriate interval by drilling directly into the crack surface. The surface of the crack between ports is allowed to cure. For vertical cracks, start by pumping epoxy into the entry port at the lowest elevation until the epoxy level reaches the entry port above. Then the lower injection port is caped and the process is repeated at successively higher ports until the crack has been completely filled in. For horizontal cracks, injection starts from one end of the crack to the other in the same way (Fig 2 c). When the pressure is maintained, the crack is filled completely (Fig 2 d). For injection from underside of ceiling of flat roof a lot of pressure is being exerted (Fig 2 e). Hence care should be taken while injecting from underside (Fig 2 e).
- Removal of the surface seal : After the injected epoxy has cured, the surface seal is being removed by grinding or some other appropriate means. Fittings and holes at entry ports should be covered with epoxy fairing putty prior to repainting.

1.2 Stitching

This method involves drilling holes on both sides of the crack and grouting in stitching dogs (U-shaped metal units with short legs) that span the crack. Stitching may be used when tensile strength must be reestablished across major cracks. Stitching a crack tends to stiffen the structure, and the stiffening may accentuate the overall structural restraint, causing the concrete to crack elsewhere. Therefore, it may be necessary to strengthen the adjacent section with external reinforcement embedded in a suitable overlay.

The stitching (Fig. 3) procedure consists of drilling holes on both sides of the crack, cleaning the holes, and anchoring the legs of the dogs in the holes, with either a nonshrink grout or an epoxy-resin-based bonding system. The stitching dogs should be variable in length and 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.

Spacing of the stitching dogs should be reduced at the end of cracks. In addition, consideration should be given to drilling a hole at each end of the crack to blunt it and relieve the concentration of stress. Where possible, both sides of the concrete section should be stitched so that further movement of the structure will not pry or bend the dogs. In bending members, it is possible to stitch one side of the crack only. Stitching should be done on the tension face, where movement is occurring. If the member is in a state of axial tension, then the dogs must be placed symmetrically, even if excavation or demolition is required to gain access to opposite sides of the section.

Stitching will not close a crack but can prevent it from propagating further. Where there is a water problem, the crack should be made watertight as well as stitched to protect the dogs from corrosion. This repair should be completed before stitching begins. In the case of active cracks, the flexible sealing method may be used in conjunction with the stitching techniques.

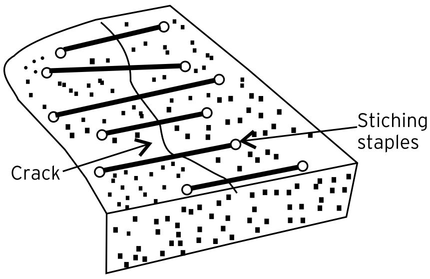

Fig. 3 : Stiching of cracks

2.0 Materials for Crack Repair of Water Retaining Structures

2.1 Polyurethane grouts

Polyurethane grouts are usually used to repair cracks that are 0.12 mm and greater in width, both wet and active, and leaking a significant amount of water through joints or cracks. These grouts are semi flexible; thus, they may tolerate some change in crack width. The reaction time to form the foam may be controlled from 30 to 45 seconds up to several minutes using different catalyst additives.

Polyurethane grouts generally are not suitable for structural repairs. Additionally, a highly skilled work crew is required along with special injection equipment. Finally, these materials typically are not stable when exposed to UV light. This is usually not a major concern because the material is injected into a narrow crack where exposure to UV light is minimal.

Because of the immediate crack arresting nature they are well suited for tanks for the storage of liquids, dams, tunnels, sewers, and other water-containment structures.

Polyurethane chemical grouts are usually injected under pressure as a liquid resin into or in the vicinity of the leak. Once the resin contacts water, a chemical reaction occurs. Depending on the material formulation, the grout/water combination forms either expansive closed cell foam or a gel (Fig. 4). The foam created can be flexible and resilient (hydrophilic) or ridged, meaning the cell structure of the foam crushes when compressed (hydrophobic).

Fig. 4: Injected material

2.2 Cementitious Crystalline

It is a cementitious chemically-reactive system which forms millions needle like crystals (Fig. 5) in presence of water and fill the pores, spaces and cracks between the concrete particles. Crystalline chemicals are adsorbed into the concrete by capillary action and diffusion. Once the cracks are filled in, they lie in a dormant stage until the new cracks develop through which water enters and reactivate the chemicals which form and grow to new crystals and fill the pores and arrest the cracks. This becomes a self-sealing process which permanently repairs the cracks and stops leaking.

Fig. 5: Growth of crystals

3.0 Methods for Crack Repair of Water Retaining Structures

3.1 Polyurethane (PU) injection

These materials are injected at high pressures. The grout prepolymer is usually mixed with water at ratios of 6:1, 8:1, and up to 12:1 (water to polymer ratio) to obtain a gel ranging from firm to weak. Hydrophilic expansive foam grouts are typically single component products requiring small delivery systems for the injection process. Pumping systems for hydrophilic foam grouts tend to be high pressure and low volume, while the gels utilize high volume and lower pressure systems.

The initial cure is the time it takes for the polyurethane grout to foam up, and the final cure is the time it takes for the grout to fully expand. This final cure time, which may take up to 12 hours, is critical to the success of the grouting process. The expansion rate of hydrophilic foam grouts can be up to 5 to 8 times its original volume and hydrophilic gels typically do not gain volume upon curing rather they shrink after cure in the absence of water.

These types of grouts are used in below grade structures, basements, and other areas that are often wet, such as subways and interior portions of a concrete dam as they will shrink in a dry environment.

Hydrophilic expansive foam grouts stick to concrete and stretch in a moving crack. Hydrophilic gel grouts will not stick to concrete and are not recommended for moving cracks. They are used for sealing sewer joints and manholes, and other underground applications. Due to their relatively short gel times and high viscosities compared to the acrylics, they are usually not used in sealing lateral sewers with remote lateral packers. They are generally much faster reacting systems and can reach up to 25 times expansion in as little as 7 to 10 seconds. With the high expansion rates and extremely fast reaction times, they can have the potential to move structures and require extreme care when using.

Hydrophobic foams can also be used to fill voids or abandoned underground pipes, vaults, tanks, etc. A major advantage to sealing active leaking cracks/joints is that material is water activated as opposed to most materials that require the water intrusion to be eliminated before the repairs can be done. The cured resin is designed to accept movement, allowing the materials to be successful in applications subject to movement due to seismic activity, contraction/expansion or movement designed into the structure where a rigid material like epoxy is prone to failure. Typical applications of hydrophobic PU include sealing cracks/joints, creating a water impenetrable barrier between the backside of a structure and the soil matrix from the negative side.

Most polyurethane grouts are considered to be "non toxic" although safe handling procedures should be closely followed with these and all other chemicals. Some hydrophilic foam grouts are certified to be used with potable drinking water systems.

3.2 Integral Crystalline System

The cracks are chiseled out along the length of the crack. Then they are cleaned and surface is pre-wetted. A cementitious highly concentrated crystalline dry pack is prepared and packed thoroughly through the cracks.

A cementitious coating is applied on the surfaces. This is a permanent self-sealing crack repair system mostly applied on positive side (Fig. 6) and also can be applied even on negative sides. It is suitable for basement, foundations, walls, tunnels, bridges, and dams, water retaining structures, sewage treatment tanks and pools. For using in water tanks the safety of the product has to be checked from the manufacturer.

3.3 Strip-and-seal System

Strip-and-seal systems may be used to treat cracks of any width, but are most commonly used to treat cracks that are 6 mm or greater in width. Strip-and-seal systems consist of a flexible sheet, such as synthetic rubber, that spans over a crack and is adhered to the structure on each side of the crack using a suitable adhesive.

These systems are designed to span over the crack and prevent leakage of liquids; the crack itself is not actually filled or repaired. Some systems have a high resistance to aggressive chemicals. These systems have virtually no limitation to the crack width. Moisture-insensitive epoxies may be used as an adhesive on damp surfaces. The elongation properties of these systems are excellent,

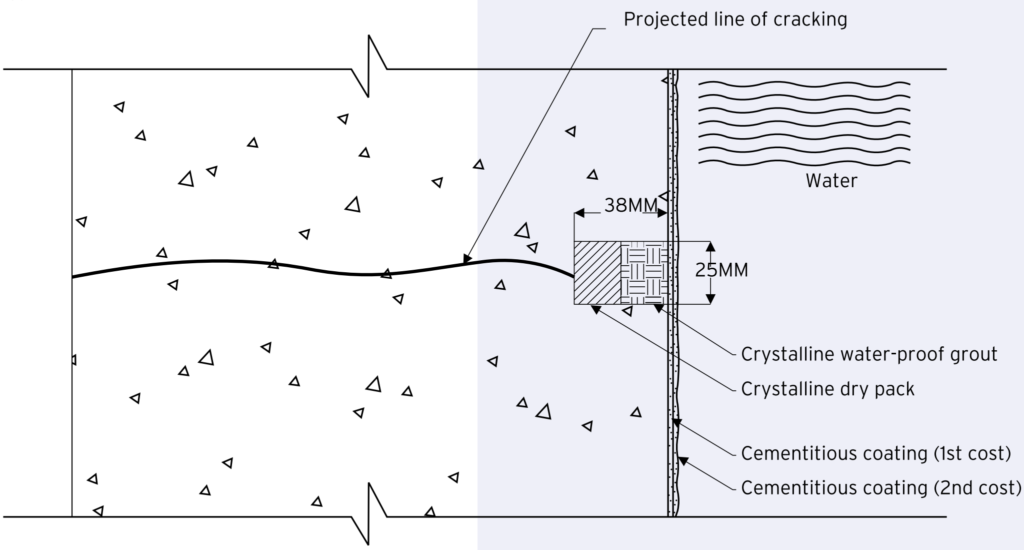

Fig. 6: Crystalline coating system

making them appropriate for use on active joints. Some strip-and-seal systems are highly resistant to UV light; thus, they do not chalk or weather. Generally, these systems do not require any special worker skills or equipment to install.

4.0 Quality Assurance

4.1 Causes of Repair Failures

There are many causes of failure of repair system. The various causes are

- Wrong diagnosis of crack formation.
- Material: Incorrect specifications, bad quality, properties like incompatibility.
  - Contraction of repair materials may cause cracking.
  - If tensile strength of repair material is too high compared to the bond strength on the substrate, a ring shape crack may occur at the boundary of crack repair.
  - If bond strength is higher than tensile strength, cracks may develop on surface of repair.

Method of application: In correct surface preparation, wrong way of application, unskilled workmanship.

For any repair failure the blame goes to the quality of the material. But material failure accounts for 1% of total failure. Hardly any material fails but it is the wrong diagnosis and incorrect surface preparation which cause maximum failure of the repair.

4.2 Tests for Effectiveness of Crack Repair

Performance of a concrete repair needs to be measured in physical terms and quantification of physical parameters for comparison is also necessary. Other parameters such as environmental effects, safety and whole-life costs should be taken into consideration. Hence, after the repair of crack it is essential to test the effectiveness of the repair system. The most of polymeric repair materials fail due to improper surface preparation, wrong application methods, incompatibility of the repair material with the original concrete etc.

To check the effectiveness of crack repair by injection method, core samples of 50 mm dia should be extracted from the locations (Fig. 7) where there is no reinforcement. Cores should be taken after the final setting of injected materials. Extracted cores can be visually inspected and further tested for compressive as well as split tensile strength. The cores should be filled in with an expansive cementitious or epoxy grout with proper surface preparation.

The following NDT (Non destructive tests) such as Ultrasonic pulse velocity, pull-off test, impact echo, can be performed to find out the effectiveness of the concrete repair system.

Ultrasonic pulse Velocity test : To determine the cracks and honeycombs.

Impact Echo : To detect flaw and evaluate thickness and integrity

Slab Impulse Response : To detect voids, delamination and structural integrity

Pull off Test : To determine Adhesive force of repair material (Fig. 8).

Fig. 7: Core sample taken from crack area

Fig. 8: Pull off test on concrete repaired surface

Half-cell potential surveys: To highlight areas of ongoing corrosion, before, immediately after and sometime after electrochemical treatment.

Acid soluble chloride profile analysis: To determine total chloride content at depths before and after treatment.

Pore water analysis: To determine the chloride ion (free chloride) and hydroxide ion concentrations before and after treatment.

Petrographic analysis: To examine the structure and quality of the concrete and to examine for alkali-silica reaction (post treatment).

The most of the failure takes place at the interface of the bonding for which bond strength is very important. Bond strength increases between 28 days to 1 year after which failure may occur. Hence bond strength should satisfy after 1 year of repair. A more stiff material than parent concrete is suitable for crack repair. All corrosion related cracks should be tested by corrosion analyzer etc. All water retaining structures should be tested for water tightness of the structures. Structural crack repairs should be tested for an in-situ non destructive load testing to demonstrate satisfactory performance under an overload above the design working value after 28 days.

4.3 Performance requirements of repair materials and systems

New repair materials and methods are developing day by day which is not followed with enough experience on their performance. The selection of the best repair option should be based on technical and economical (apart from social) considerations and, therefore, it seems that a life cycle cost analysis, (LCCA) is the most suitable methodology for making an inter comparison between them. This can be calculated by repair index method (RIM) which is based on defining a set of requirements: safety, serviceability, environmental impact, durability and economy that are quantified through certain weightage given to them based on level of importance for determining repair performance indicators (RPI). All indicators can be ranged in four categories such as slight (4), moderate (3), severe (2) and very severe (1).The performance requirements for calculating repair index is given below.

- Safety

It is related to the structural safety during and after repair.

  - Structural consequences of the failure
  - Failure type
  - The quality control of the repair execution
  - The feasibility of post repair monitoring
  - Safety of workers
  - Safety of users

- Serviceability, functionality, aesthetics

They are related to the limit state on serviceability during and after the repair.

  - Fitness for use
  - The disturbance of the aesthetical appearance of the structure due to the repair or to its dimensions or function.

- Environmental impact

  - Emission of pollutants to the environment during and after application
  - The sustainability of the materials and techniques used in the repair.

- Durability
  - The expected service life

The repair itself has been identified as one of the RPI of this requirement. The four categories have been classified based on repair duration of 15, 30, 50 or more than 50 years.

  - Number of attack types
  - The aggressivity of exposure

- Economy
  - Direct cost by m^2 of structure,
  - Extension of the damage (m^2)
  - Period of disturbance or stopping of the functional use of the structure
  - Maintenance cost of the structure after being repaired
  - Need of preparation of the substrate.

The repair index is calculated by assigning some percentage to all those five factors and taking their weighted arithmetic mean. The economy is given as 50%, Durability is given as 20%, and other 30% equally divided among safety, serviceability and environment. Sometimes safety is given more importance. Higher the repair index value of the system more suitable for a cost economy durable repair and considering all other factors. Lesser the repair index value may not have a cost economy and durable repair system. This analysis will help to find out an economy and a durable repair system.

5.0 Safety, Health & Environment

5.1 Material safety

Some of the Crack repair materials are hazardous and some are non-hazardous. However Material Safety Data Sheets (MSDS) should be read and understood before the application. Many of the materials are corrosive or flammable for which care should be taken for transportation, storage, application and disposal of such material. The chemicals can change or decompose under storage conditions. Generally all such polymeric materials should be kept in cool areas. Proper label has to be given during storage.

Education of Personnel: All the people should be informed of the characteristics and hazardous of those materials that they are going to handle.

5.2 Personal Safety

- Wearing protective clothing and protective eyewear where required
- Wearing rubber gloves or barrier creams for hand protection
- Having eye wash facilities available
- Wearing respirators where needed
- Providing ventilation of closed spaces
- Secured storage of hazardous materials
- Having necessary cleaning materials on hand
- Notifying occupants of pending repair procedures

5.3 Health issues

Typical health problems which may be encountered when carelessly handled are:

- Skin irritation such as burns, rashes and itches old skin sensitization due to allergic reactions. This can occur if the materials come in direct contact with the body then shower immediately with soap and water of the materials come in contact with the eyes then flush out with large amounts of water for at least 15 minutes followed by immediate medical check-up.

- Most solvents have some degree of volatility and the vapors can be toxic when inhaled.

5.4 Environmental issues

- Emission of pollutants to the environment during and after application : The materials used should be of low VOC or no VOC contents.
- The sustainability of the materials and techniques used in the repair. It should be considered in terms of materials and energy consumed. Systems which consume higher amount of energy are not eco-friendly. Materials which release chemical contaminants should be avoided.
- Disposal of solvents: Disposal of excess materials, disposable protective gear and empty containers should be taken care. Some materials can be incinerated.

6.0 Bill of Quantities (BOQ) of Structural Repair

A standard bill of quantities of concrete structural repair and strengthening is given in table below for a reference.

Sr.	Description	Unit
1.	**Injection Grouting**	
1.1	**Nozzle Fixing:** Drilling 12-16 mm dia holes at honeycomb portions / voids / construction joints cracks etc spaced at specified spacing and placing 8-12 mm dia. Nozzle of length 75 mm suitable for grounting into a 150 mm deep hole using polymer mortar including cutting of nozzle after the grounting and finishing with polymer mortar etc. complete	Nos
1.2	Drilling 16 mm dia holes at honeycomb portions / voids / construction joints etc. at spacing specified and placing 12 mm PVC flexible tubes for grouting and sealing the gaps with quick setting repair mortor (spacing as per detailed specifications).	Nos
1.3	Drilling 13 mm dia holes and providing & fixing special injection nozzles in cracks and joints in columns, Beams, silo shells and other concrete members where major honeycombing is found by drilling 12 mm dia. Holes at a grid specified for Epoxy grouting and sealing. (spacing as per detailed specifications).	Nos
1.4	Providing and applying injection grouting through the nozzles provided into the cracks / homeycombed areas by suitable grouting pump under pressure till the refusal including all labour, supervision, tools and tackles and transportation etc., complete as per specification and as directed.	Nos
a.	Cement slurry mixed with non-shrink polymer grouts	Kg
b.	a. Using low viscous two components epoxy resin based grouts of Dr.Fixit Epoxy Injection Grouts to meet the requirement of ASTM C-881 as per direction of Engineer-in-charge.	Kg
c.	Super low viscous (100-150 CPS) epoxy resin injection grouts.	Kg
d	Using cementitious injection grouts mixed with OPC cement, dry sand upto 2mm admixed with Dr. Fixit Pidicrete AM to meet the requirement of ASTM C 109: 99 and ASTM C 307 as per direction of Engineer-in-charge.	Kg
e	Using low viscous two components epoxy resin based grouts of Dr.Fixit Epoxy Injection Grouts to meet the requirement of ASTM C-881 as per direction of Engineer-in-charge	Kg
2.0 Structural strengthening by Fibre warpping		
	Fibre Wrapping : Strengthening structural elements with specified Fibre wrapping and compatible saturate, by dry/wet layup system including the following and as per direction of Engineer-in-charge:-	
	Surface preparation: Grinding / moulding concrete substrate, cleaning it with wire brush removing oil, laitance if present, rounding sharp edges to min 25mm radius etc. complete. Profilling: Applying compatible primer of approved make and brand on prepared substrate, filling the holes and uneven surface with thixotropic putty etc.complete.	
	Wrapping: Wrapping the fibre sheet with approved / recommended overlapping to structural element at desired orientation using tamping roller to avoid any air voids etc. repet the same procedure for multiple layer with the interval of 8 hrs.	
	Sand Pasting: Applying second coat of saturate after min 12 hrs. rectify air voids if any, paste the coarse sand on it to make surface rough to take any further finishes. (Mode of measurment: Per Sqm surface area of application per layer).	Sqm
2.1	Glass Fibre:With non metallic composite fibre sheet (900 GSM).	Sqm
2.2	Carbon Fibre:With non metallic composite fibre wrapping system comprise of uni-directional high strength carbon fibre sheet (200 GSM).	Sqm
3.0 Structural strengthening by Steel plate bonding.		
	Providing & strengthening of structural steel members at their locations by providing splice plates, additional plates to the flanges or web of the members providing stiffeners etc as per the requirment and as directed including cutting fixing in position by bolting and welding.	Kg

7.0 Conclusion

The concrete repair requires breaking by mechanical means where the dust, noise and vibration are generated. Personal safety needs to be ensured by PPE, and standard safety procedures need to be strictly adhered during the repair work.

The demolition work creates large pieces of concrete and aggregate, which can be cleaned, graded and used as recycled aggregates in new concrete.

The environmental issues in concrete repair and strengthening system should be considered such as use of green material, VOC content, recyclability, energy efficiency, embodied energy, life cycle cost analysis and sustainability.

Structural Strengthening

[Excerpts from the article "Keys to Success: Structural Repair and Strengthening Techniques for Concrete Facilities" May 2004 by Tarek Alkhrdaji]

1.0 Introduction

Concrete experts commonly use the terms structural repair and strengthening to describe building renovation activities. Although the two terms sound similar, they refer to slightly different concepts. Structural repair describes the process of reconstruction and renewal of a facility or its structural elements. This involves determining the origin of distress, removing damaged materials and causes of distress, as well as selecting and applying appropriate repair materials that extend a structure's life.

Structural strengthening, on the other hand, describes the process of upgrading the structural system of an existing building to improve performance under existing loads or to increase the strength of structural components to carry additional loads. For upgrade projects, design engineers must deal with structures in which every element carries a share of the existing load. The effects of strengthening or removing part or all of a structural element – such as penetrations or deteriorated materials – must be analyzed carefully to determine their influence on the global behavior of the structure. Failure to do so may overstress the structural elements surrounding the affected area, which can lead to a bigger problem and even localized failure.

2.0 Strengthening Methods

Many buildings that originally were constructed for a specific use now are being renovated or upgraded for a different application that may require higher load-carrying capacity. As a result of these higher load demands, existing structures need to be reassessed and may require strengthening to meet heavier load requirements.

In general, structural strengthening may become necessary because of code changes, seismic upgrade, deficiencies that develop because of environmental effects (such as corrosion), changes in use that increase service loads, or deficiencies within the structure caused by errors in design or construction. The structural upgrade of concrete structures can be achieved using one of many different upgrading methods such as span shortening, external composites, externally bonded steel, external or internal post-tensioning systems, section enlargement, or a combination of these techniques. Similar to concrete repair, strengthening systems must perform in a composite manner with an existing structure to be effective and to share the applied loads. The following gives a brief description of these methods and their applications.

2.1 Span shortening

Span shortening (Fig. 1) is accomplished by installing additional supports underneath existing members. Appropriate materials for span shortening include structural steel members and cast-in-place reinforced concrete members, which are simple to install. Connections can be designed easily using bolts and adhesive anchors. The structural steel system shown in Fig.1 was installed on a parking deck to shorten the span and carry part of the load, transferring it to the existing supporting system. On the down side, such applications may result in loss of space and reduced headroom.

Fig. 1: View of span shortening by providing structural steel members in a parking deck

2.2 Composites

Fiber reinforced polymer (FRP) systemsare high-strength, lightweight reinforcement in the form of paperthin fabric sheets(Fig. 2), thin laminates (Fig. 3), or bars that are bonded to concrete members with epoxy adhesive to increase their loadcarrying capacity. Important characteristics of FRPs for structural repair and strengthening applications include their non-corrosive properties, speed and ease of installation, lower cost, and aesthetic appeal.

Fig. 2: A column being strengthened with FRP sheets

A wide range of uni-directional, bi-directional and quadri-directional carbon fiber, glass and aramid fiber fabrics, available in different weights, are in the form of dry, flexible fabrics that should then be impregnated (saturated) with epoxy resins immediately before placement (wet layup) or during placement (dry layup). As the epoxy cures, a rigid composite is formed andshapes itself to the original structure in a monolithic bond. These fabrics are used for confinement of structural elements, such as columns, beams and slabsfor improved ductility and for load-bearing capacity, especially in seismic areas.

As with any other externally bonded system, the bond between the FRP system and the existing concrete is critical, and surface preparation is very important. Typically, installation is achieved by applying an epoxy adhesive to the prepared surface, installing the FRP reinforcement into the epoxy and, when required, applying a second layer of the epoxy adhesive. After curing, the FRP composite will add capacity to the element because it has a tensile strength up to 10 times that of steel.

Fig. 3: A roof slab being strengthened with FRP strips

In addition to FRP, steel reinforced polymer composites (SRP) (Fig. 4) may be used as externally bonded reinforcement. This steel-based, innovative strengthening system (known as Hardwire)is a low-cost, reinforcement system consisting of ultra-high-strength steel wires that are twisted together to form reinforcing steel cords approximately 1 mm in diameter(Fig. 5). This strengthening system can be applied using epoxy or cementitious materials and can be used to increase the shear and flexural capacity of structural elements.

Fig. 4: Roof strengthened with combined FRP and steel plates

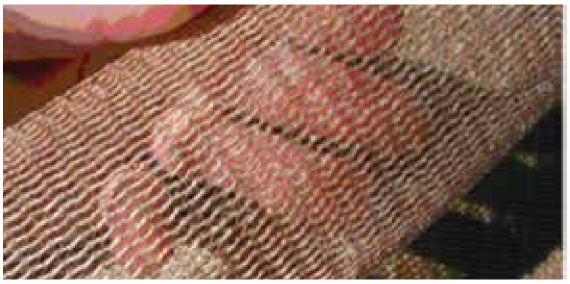

Fig. 5: 12WPI tape with cords held together by a polyester scrim for SRP composite bonding

2.3 Bonded steel elements

By using bonded steel plates method (Fig.6), steel elements are glued to the concrete surface by a two-component epoxy adhesive to create a composite system and improve shear or flexural strength. The steel elements can be steel plates, channels, angles, or built-up members.

In addition to epoxy adhesive, mechanical anchors typically are used to ensure that the steel element will share external loads in case of adhesive failure. The exposed steel elements must be protected with a suitable system immediately following installation. And regardless of the specified corrosion protection system, its long-term durability properties and maintenance requirements must be considered fully.

Fig. 6: A column being strengthened with steel plate bonding

2.4 External post-tensioning

The external post-tensioning (Fig. 7) technique has been used effectively to increase the flexural and shear capacity of both reinforced and prestressed concrete members since the 1950s. With this type of upgrading, active external forces are applied to the structural member using post-tensioned (stressed) cables to resist new loads. Because of the minimal, additional weight of the repair system, this technique is effective and economical, and has been employed with great success to correct excessive deflections and cracking in beams and slabs, parking structures, and cantilevered members.

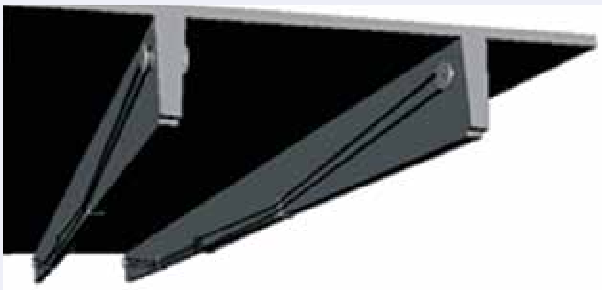

Fig. 7: View of external post-tensioning of beams

The post-tensioning forces are delivered by means of standard prestressing tendons or high-strength steel rods, usually located outside the original section. The tendons are connected to the structure at anchor points, typically located at the ends of the member. End-anchors can be made of steel fixtures bolted to the structural member, or reinforced concrete blocks that are cast into place. The desired uplift force is provided by deviation blocks, fastened at the high or low points of the structural element. Prior to external prestressing, all existing cracks are epoxy-injected and spalls are patched to ensure that prestressing forces are distributed uniformly across the section of the member.

2.5 Section Enlargement

This method of strengthening involves placing additional "bonded" reinforced concrete to an existing structural member in the form of an overlay or a jacket. With section enlargement (Fig. 8), columns, beams, slabs, and walls can be enlarged to increase their load-carrying capacity or stiffness. A typical enlargement is approximately 50 to 75 mm for slabs and 75 to 125 mm for beams and columns. This is popularly known as jacketing with micro concreting.

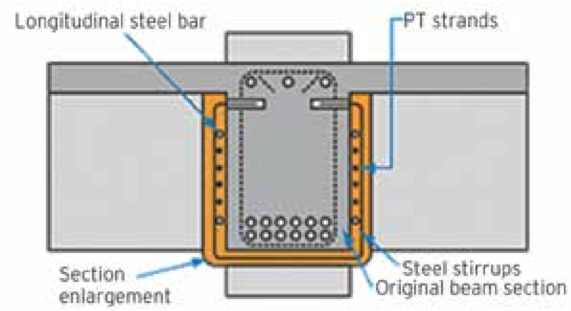

Fig. 8: Sketch showing strengthening of beam by section enlargement

2.6 Ferrocement Strengthening

Ferrocement, a thin structural composite material, exhibits better crack resistance, higher tensile strength-to-weight ratio, ductility and impact resistance than conventional reinforced concrete. These properties have been exploited through the use of ferrocement for structural upgrading and the rehabilitation of concrete structures. A number of successful commercial precast applications of ferrocement for use in the upgrading of building fixtures and services have resulted in repair industry.

Ferrocement repairs and rehabilitation can be done in RCC structures to increase the strength of columns, beams and slabs upto 30% as well as contribute towards prevention of crack formation. Ferrocement which can be made from non-formwork construction processes is an advantage over other types of repair and strengthening techniques; enhanced crack resistance combined with high toughness, its rapid constructions with no heavy machinery involved, small additional weight it imposes, and considering an economical aspect of rehabilitation, this material proves to be a cost effective solution for rehabilitation and general applications. It can totally replace deteriorated/damaged RCC chajjas with reduction in dead load.

Ferrocement confinement (Fig. 9) is done around defective circular or square/rectangular RCC columns in order to enhance the strength, ductility and energy absorption capacity of existing concrete columns. A jacketing layer of 30 mm is created all around the RCC columns and ferrocement is done in order to increase its load carrying capacity. This confinement work also protects the existing reinforcement, provides water tightness and prevents ingress of the aggressive species to the surface of original concrete or steel surface. Ferrocement not only increases the performance/function of structures but also enhances the appearance of the existing RCC structure. The repair in the structural elements using ferrocement can withstand for long years without cracking provided the mortar used is of proper proportion using good quality materials, and the wire mesh is of anti-corrosive coating type.

Fig. 9: View of ferrocement repair of concrete with welded wire mesh reinforcement

2.7 Shotcrete

Shotcrete (Fig. 10) is a process in which compressed air forces mortar through a nozzle to be sprayed on a surface of a structural member at a high velocity and also called as spray concrete. The materials used in shotcrete are generally same as those used for conventional mortar. The reinforcement provided is generally welded wire fabric and deformed bars tacked onto the surface. Sprayed concrete repairs are particularly appropriate for larger repair volumes, such as large surface areas of repair or multiple repair sites situated close together. It can be noted that the spray-applied repair materials with a higher elastic modulus than the substrate attracts load from the parent concrete.

Shotcrete is applied using either wet or dry process. Shotcrete by dry process is known as guniting. The wet mix consists of cement and aggregate premixed with water and the pump pushes the mixture through the hose and nozzle. Compressed air is introduced at the nozzle to increase the velocity of application. In the dry mix process, compressed air propels premixed mortar and damp aggregate and at the nozzle end water is added through a separate hose. The dry mix and water through the second hose are projected on to a prepared surface. Generally shotcrete gun nozzle is held at 0.6 to 1.8 m from the surface. In most cases shotcrete can be applied in a single application for the required thickness. It is versatile as it can also be applied on curved or irregular surface. Its strength after application and its good physical characteristics make it ideal for strengthening weak members.

There are many strengthening methods that can be considered for RCC structures. Based on the requirement the structural consultant can select a suitable repair methodology considering the performance requirement, availability of the materials, cost, and ease of application and durability of the repair system. Table 1 gives guidelines for strengthening of different structural members for improvement of different properties.

Fig. 10: View of concrete repair by shortcrete method

Table 1. Strengthening of Structural members

RCC Members	Performance improvement	Recommended strengthening methods
Column	Enhancing load carrying capacity	Section enlargement, Fibre wrapping
	Improving ductility	Section enlargement, steel plate bonding, fibre wrapping
	Retrofitting joints	Section enlargement, providing steel collars, fibre wrapping
Beam	Flexural strengthening	Section enlargement, additional reinforcement in tension, MS plate bonding, high strength fibre wrapping, external post tensioning
	Shear strengthening	Section enlargement, shear ties anchored in compression zone, post tension strap around section, diagonally anchored bolts, MS plat bonding, fibre wrapping
	Retrofitting joints	Fibre wrapping
Slab	Control of deflection (negative moment deficiency)	Concrete overlays
	Control of deflection (positive moment deficiency)	Concrete underlays ,span shortening by structural steel members or cast-in-situ RCC members, fibre wrapping
Chajja & sunshade	Repair due to corrosion related damages	Ferrocement strengthening, jacketing with microconcreting
Foundation	Control of settlement	Shoring and underpinning
	Seismic retrofitting	Base isolation

3.0 Conclusion

It is crucial that structural engineers recognize that strengthening assessment and design is infinitely more complex than new construction. Typically, challenges arise because of unknown factors associated with the structural state – such as continuity, load path, and material properties – as well as the size and locations of existing reinforcement or prestressing. The degree to which the upgrade system and the existing structural elements share the loads also must be evaluated and addressed properly in the upgrade design, detailing, and implementation procedure. The importance of detailing and its direct effects on the effectiveness and durability of structural upgrades cannot be overemphasized. In fact, inadequate detailing is one factor that can lead to the total failure of a structural repair system.

In addition, engineers should consider the procurement process for specialty repair and strengthening projects to be different from new construction services. Engaging contracting firms that are familiar with all of the critical aspects highlighted here will ensure the most cost-effective and long-lasting results. Although it may appear that there is an up-front financial benefit to obtaining these specialty services from firms with experience in new construction, the real risk is that the repairs will cause an endless "repair of repairs" cycle, resulting in additional disruption and expenditure to owners. When it comes to structural repair and strengthening, the mantra "do it right the first time" pays dividends.

Factors affecting the durability of concrete repair: the contractor's viewpoint

[Excerpts from the article by P. H. Emmons and A. M. Vaysburd "Construction and Building Materials" 1994 Vol.8 No.1.pp.15-20]

1.0 Introduction

Despite the large and expanding repair and rehabilitation market, little has been done to establish the methodology of design for repair durability and to establish performance criteria for selecting and specifying repair materials. The object of any repair project should be to produce adurable repair, which means to produce a repair at relatively low cost with a limited and predictable degree of changeover time and without deterioration and/or distress throughout its intended life and purpose. Lack of durability of repaired structures is manifest inthe form of spalling, cracking, scaling, loss of strength.

2.0 Factors affecting the durability of concrete repair

The factors relevant to the durability of concrete repairs are given in Fig.1:

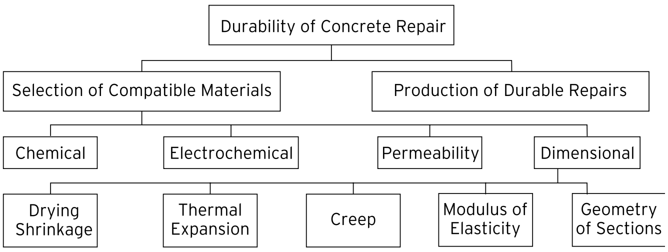

Fig. 1: Factors affecting durability of concrete repairs

2.1 Compatibility of repair materials with existing concrete

It is mostly due to overemphasis on strength rather than on long-term durability that a majority of repairs suffer from cracking due to drying shrinkage, creep, excessive heat of hydration, and other causes. Compatibility of the repair materials with the existing substrate and durability under various conditions in service are of much greater importance. In practical applications of repair materials, the emphasis in many cases has to be shifted from compressive strength and/or low permeability to other properties or combinations of properties of the repair material collectively called compatibility with the existing substrate.

Compatibility is the balance of physical,chemical and electrochemical properties and dimensionsbetween repair materials and existing substrates that ensures that a repair withstands all stresses induced by volume changes, chemical and electrochemical effects without distress and deterioration in a specified environment over a designed period of time.

2.1.1 Dimensional compatibility

Dimensional compatibility is the phenomenon of volume changes and the major problem of concrete repairs. It adversely affects the durability of repair and/or load-carrying capacity of structural repairs. It may lead to the inability to carry the expected portion of the load and to overstressing in the existing structure, but would not necessarily affect durability.

The most important of them with regard to dimensional compatibility isdrying shrinkage. At the same time, drying shrinkage is the most ignored property of repair materials. Thermal compatibility is another critical property to consider when specifying and selecting any repair material, regardless of its chemical composition.

2.1.2 Chemical compatibility

Chemical compatibility properties to consider may include alkali content, C_3A content, chloride content, etc. All aspects of chemical compatibility must be considered in the selection of repair materials. For instance,when concrete that is being repaired includes potentiallyreactive aggregates, a repair material with low alkalinity must be specified.

The reactivity of the repair material to reinforcing steeland other embedded metals or to specific protective coatings or sealers applied over the surface repair must also be considered. Repair materials with moderate to low pH may provide little protection to reinforcement. Moreover, certain repair materials are not compatible with waterproofing membranes required as protection following a repair. Therefore, the reactivity of the various repair materials with both the substrate and surface protection product should be considered.

2.1.3 Electrochemical compatibility

For each reinforced concrete repair case, electrochemical compatibility must be considered, and an evaluation of the electrochemical behaviour of local (substrate) and potential (repair material) macrocell must be carried out.

2.1.4 Permeability compatibility: a revised viewpoint

It is widely accepted that very low permeability is desirable for a repair material, which is actually not true in many cases. This concept may, in some cases, lead to a false sense of security, and unsuitable materials incapable of providing lasting performance can be specified.

The concept of using low-permeability repair materialsregardless of the situation is a fallacy. It is correct that permeability is the key to durability of concrete, a composite material. A number of major points, including one that a repaired structure is not a composite material but a composite system of materials, have been ignored, not because they do not matter, but largely because they do not conflict with the general concrete durability theory. Therefore, it appears advisable that this concept be abandoned because of altogether too much conflicting evidence. It iscompletely conceivable that in the cases discussed, repairmaterials with permeability compatible with the existing concrete should have been specified and used.

2.2 Properties of the environment

It can be noted that the repair failures manifested in cracking, delamination and spalling. Some force has imposed tensile stress on the repair beyond its capacity to resist that force. Cycles of wetting and drying due to sun and rain cause dimensional expansion and contraction and may generate stresses in excess of the tensile capacity of the repair and thus cause cracking. Temperature changes also cause expansion in hot weather and contraction in cold weather. That again may create tensile stresses beyond the resistance capability of the repair and thus cause cracking.

If the properties of the environment in which the repaired structure is to serve are known, the levels of the relevant properties that repair materials must have in that environment to yield the desired performance may be selected. When the specifications are properly prepared and complied with, the repair possesses such properties that as it interacts with the elements of the environment, it will not deteriorate.

2.3 Load conditions

Concrete repair problems are diverse in nature. Each deterioration condition requires a clear understanding ofwhat is expected of the repair.Three general performance requirements are protection, appearance and load carrying. The process of repairdesign and specification consists of determining the exactfunction of the repair so that the correct repair materialscan be specified. A concrete repair must replace damaged concrete around the damaged areas. To recreate the ori-ginal load distribution, full load relief must be provided during the surface repair process. Repair material must be installed and cured. After the material reaches the specified strength, loads would be allowed on the member. Load relief from members is typically provided with temporary shoring and jacking.

2.4 Condition of the interface (concrete-repair bond)

Concrete repair is a composite system consisting of repair material and concrete substrate. In composites the bond between the individual constituents (phases) is most critical for the properties of the composite. Assuming the properties of the constituents are good, any improvement of the bond will improve the properties of the composite system.

Achieving an adequate bond between repair materials and existing concrete is a critical requirement for durable surface repairs. The bond at the interface between the repair material and concrete substrate is likely to be subject to considerable stress from volume changes, force of gravity and, sometimes, impact andvibration.

2.5 Production of durable repair

The best methods and materials specified for the repair project will be entirely deprived of their merits if there is even the slightest neglect in construction practices. The placement technique must deliver the selected repair material to the prepared substrate with specified results. The repair material must achieve a satisfactory bond to the existingsubstrate, must fill the prepared cavity without segregation, and must fully encapsulate the exposed reinforcingsteel. Without achieving the above requirements, the surface repair may not perform its intended structural, protective and aesthetic duties. The bond of the repair to the substrate depends to a large degree on mechanical interlocking with the prepared concrete surface. For this to occur, an adequate force should be applied to the repair material to bring it into intimate contact with the prepared surface. The repair material must also have an adequate amount of binder to interact with the prepared surface.

All operations involved in concrete repair are equally important. An issue relevant to many current problems with concrete durability is corrosion of steel reinforcement, which can be attributed, in most cases, to faulty design, material specifications and selection, and work-manship. When considering the protection provided by acement-based material to embedded reinforcing steel, the condition of the interface between the steel and the cement-based material is of paramount importance.

Among the various technological factors affecting the production of concrete repairs, the curing process employed has the greatest influence on durability. It should also be recognized that the curing process is possibly the least controlled process in the production of concrete repair owing to a lack of understanding that only adequate curing will allow the achievement of suit-able hydration of a repair material and designed levels of durability.

3.0 Conclusions

The architect and engineer need to apply engineering principles in the design of repair projects with the same professionalism as they do in designing new structures. The presented methodology defines the most important factors to be considered when designing for repair durability. When details are properly designed and specifications are properly prepared and complied with, the repair will possess such properties that, when interactive with the environment, will have the serviceability and durability required for the intended use.

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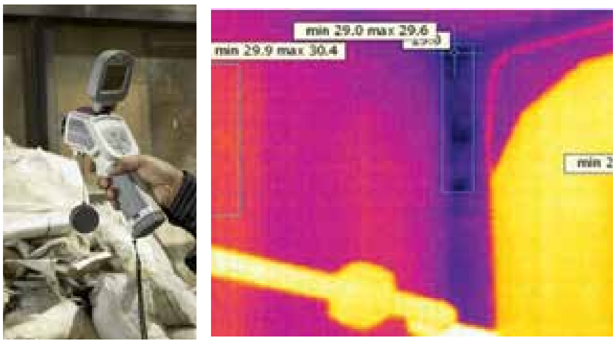

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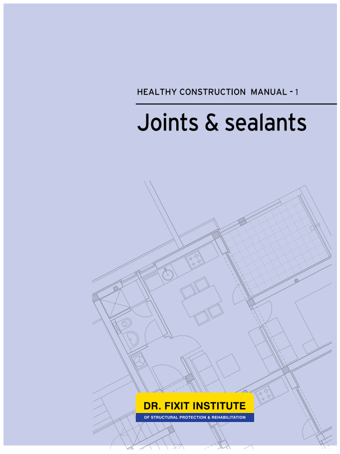

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Ramkrishna Mandir Road, Post Box No.17411, Andheri (E), Mumbai 400 059 INDIA. Tel +91-22-28357973

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