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STRENGTHENING OF CONCRETE ELEMENTS Part-4

Dr. Fixit Institute
of Structural Protection & Rehabilitation

A Not-for-Profit Knowledge Centre

From the Editor's Desk

CONCRETE REPAIR, ITS SUCCESS RATE AND THE ULTIMATE SUSTAINABILITY

Concrete's versatility, durability and economy have made it the world's most used construction material. Lately, concrete has been recognized for its green character, which apparently comes from the following features :

- The production of concrete is resource-efficient as the processing requirements are minimal.
- Most materials for concrete are acquired and manufactured locally which minimizes the transportation energy.
- Concrete building systems combine insulation with high thermal mass and low air infiltration to make homes and buildings more energy efficient.
- Concrete has a long service life for building and transportation infrastructure.
- Concrete can incorporate recycled materials from its own demolition as well as other industrial by-products.

Notwithstanding the above merits, concrete deteriorates in service and often fails in use, essentially due to faulty design, incorrect construction practices, wrong specification of materials, etc. That is why the global investments for maintenance, repair and restoration are continuously on an increasing trend. As all buildings are generally unique with own histories, individual solutions become necessary for their maintenance and repair. This, in turn, has led to the development of different strategies and solutions including material development.

Many of my readers are certainly aware of the European research programme, known as ConRepNet, which was conducted from 2002 to 2006 as a consequence of the general impression that the current practices and results of concrete repairs are below the level of expectation to a very large extent. Based on a total population of 230 repair cases, the research results indicated, inter alia, that 20 percent of the repairs had failed within 5 years after application, while 55 percent failed within 10 years and 90 percent within 25 years. A similar kind of survey of the repair performance was conducted in the Netherlands in the year 2010 on a population of 102 cases. In the Dutch survey, the failure within 5 years was 12 percent compared to 20 percent in the European study. However, the failure within 6 to 10 years was about 60 percent and within 11 to 15 years more than 80 percent.

Interestingly in Europe in general 54 percent of the failures were attributed to the incorrect designs of the repairs coupled with wrong diagnosis of the causes of the damages observed.

However, in the Netherlands' limited survey, approximately half of the failures were attributed to incorrect execution of the repair jobs and one-fourth of the failures were on account of selecting unsuitable repair materials. Wrong diagnosis or design cases were less than 10 percent.

From the above two illustrations of the repair failure surveys it is obvious that the patterns were different, when the survey was broad-based in Europe or localised in one country. One may make a fair guess that if one were to cover different geographical and climatic regions, the repair failure patterns would be mind-boggling. In fact, the US Army Corps Engineers state in REMR CS2: "A little more than 50 percent of the repairs performed on the Corps structures are only performing satisfactorily, which is an unacceptable rate. Failures of repairs are attributable to design or evaluation errors, material performance, and installation or construction errors.

In September 2012 in the International Conference on Concrete Repair, Rehabilitation and Retrofitting III at Cape Town in South Africa, Vaysburd and his co-authors tried to define the concrete repair task as "an open-end approximate solution to an exact problem." According to them, the approximate solution to an exact problem is more meaningful than the exact solution to an approximate problem. They went on to say that unfortunately the repair solutions are often "approximate solutions to approximate problems". Hence they emphasized on durability planning measures for repair projects. Three basic questions need to be considered before the appropriateness of remedial actions can be finalized. The questions are:

- What is the cause of deterioration?
- Can steps be taken to slow or stop the processes?
- What are the structural consequences of the existing and projected damage?

The durability planning has to take into account the constraints of lack of control of ambient conditions, accessibility to the repair location, downtime for the completion of the work, the need to keep the facility open while repairs are being carried out, etc. Needless to emphasize that in durability planning it is essential to understand the importance of materials to be used to repair or replace the deteriorated concrete. Regardless of the type of repair, ensuring that the repair material is compatible with the substrate is crucial, as the repaired member must behave monolithically and carry all stresses in the region of repair without distress and deterioration. Cusson in his chapter on "Durability of repaired concrete structures" in the book edited by Norbert Delatte on "Failure, distress and repair of concrete structures" (CRC Press, UK, 2009) has very cogently summarised the repair materials (R) performance requirements with respect to those of the substrate concrete (C) as follows:

- Shrinkage strain: $R < C$
- Creep coefficient: $R < C$ or $R > C$
- Thermal expansion coefficient: $R = C$
- Modulus of elasticity: $R = C$
- Tensile strength: $R > C$
- Fatigue performance: $R > C$
- Adhesion: $R > C$
- Porosity and electrical resistivity: $R = C$
- Chemical reactivity: $R < C$

Numerous laboratory studies for evaluation of the performance of repair systems for concrete structures have been published from time to time but discrepancies between the laboratory test results and actual field performance have also been frequently observed. No doubt that satisfactory field performance can only be the most reliable basis for the selection of concrete repair systems. Therefore, field investigations of repaired concrete structures are absolutely necessary to develop guidelines for material selection, repair procedures and the improved durability of repaired structures. One approach that has proven successful to some extent in concrete durability studies is to complement field research with laboratory testing and computer simulation. While the field research offers the ultimate test for the acceptance of a new technology, the laboratory research in a controlled environment coupled with computer simulations would turn out to be the most cost-effective approach and would generate the data that complement the field studies. It appears, therefore, that a combined approach would lead to a more comprehensive and reliable assessment of repair materials and systems. This new direction of repair durability assessment needs to be made more popular amongst the concerned professionals.

The above discourse is to highlight that prolonging the life of concrete structures in the appropriate manner is essential for achieving the ultimate sustainability. A lot of focus on concrete sustainability is based on its use as a new construction material with high durability. Many different calculations and models are used for the estimation of embodied energy, environmental impact and release of emissions. But no consensus has yet been reached on the best methodology to quantify sustainability. But still it is widely accepted that, after the concrete is placed, the benefits of the material's durability, relatively low maintenance (if properly designed and constructed), thermal mass, fire resistance, resistance to different forms of decay and the low impact mode of disposal result in decreased ongoing environmental impact compared to alternative materials of construction. Therefore it is obvious that the greater the durability of concrete, the larger is the total reduction in the environmental impact over the life cycle of the structure. Another benefit of concrete structures is being recognized these days. Carbonation of concrete has always been considered detrimental to the passivation of reinforcing steel, although carbonated concrete is less permeable, stronger and more compatible with the environment due to lower pH. Crushing of concrete for recycling as a base material for roadways or on aggregate greatly increases the carbon dioxide absorption potential on use.

Concrete repairs can have a larger contribution to the environmental impact of a structure than a new construction on a unit volume basis. The common practice so far has been to discard the concrete from repairs and in those circumstances there is a premature loss of embodied energy. It is reported that the embodied energy of a plain 1:3 cement – sand mortar has about 1.5 times as much embodied energy as the conventional concrete but a 1:10 polymer- sand mortar has more than 250 times greater embodied energy per unit weight. Hence the selection of repair materials of lower embodied energy can add to desired sustainability of repaired concrete structures.

Demolition of concrete structures is especially energy intensive. It has been indicated by certain agencies that demolition of a concrete structure takes 5 times as much energy as a wooden frame structure and 16 times as much as a steel frame structure. Thus, prevention of arriving at a condition, when there are no alternatives to demolishing a concrete structure, is always desirable. The cost-effective strategy is, therefore, is to extend the service life of a building through proper and timely maintenance and repair than to wait for extensive deterioration or obsolescence of the structure compelling its demolition and replacement. In an article on "ACI survey of concrete structure errors" the author J. Fraczek showed that 52 percent of concrete defects or failures are detected during construction. Hence the aphorism "do it right the first time" is critically applicable to the concrete construction. No doubt if the construction defects are not immediately attended to, they get magnified through wear and tear of use, environmental stress and damage from settlement, impact force, fire, seismicity, etc. The most effective strategy to sustainability in concrete repair is to avoid having to perform repairs in the first place. This is more easily said or written than done. But still prevention through proper construction methods, periodic monitoring, inspection and maintenance can result in enhancing the life cycle of concrete structures.

All in all, concrete that lasts longer conserves the embodied energy inherent in the material. Further, it requires fewer repairs over its life cycle. Preventive maintenance tends to be more effective in extending the life cycle of concrete structures than to attend to severe deterioration and to avoid repetitions of repair. Each cycle of repair contributes to generation of waste streams and causes more consumption of resources. Bigger and greater opportunities exist as touched upon in this editorial for the concrete repair industry to bring in sustainability of great significance to the construction sector at large.

I fervently hope that our readers and practising engineers will use this article to apprise the bigger world about their contribution to enhancing the sustainability of the concrete repairs.

Dr. Anjan K. Chatterjee

Concrete repair materials: polymers and green chemistry – How far synergistic are they?

[Extracted from the article by Dr. A. K. Chatterjee, International Journal of 3R's Vol. 4, No. 1, 2013, 534-538]

1.0 Introduction

Repair, restoration and renewal are unavoidable measures in extending the service life of concrete structures. The materials used, to start with, were based on Portland Cement in the form of mortars, concrete, shotcrete, etc. Because of their intrinsic deficiencies in many instances of actual repairs, there has been a preferred shift towards total or partial substitution of Portland Cement with polymeric or monomeric binders. In the process a significant departure is observed from the demands of green chemistry and associated sustainability requirements. This article is an attempt to highlight this issue along with the emerging corrective strategies to synergize the repairs systems with green chemistry.

Concrete, however prudently designed, prepared, placed consolidated and cured, deteriorates with time, particularly in reinforced construction. This happens primary on account of the dynamic nature of the microstructure of concrete and its continuous exposure to the environment. The worldwide inventory of concrete structures thus provides many opportunities for repair to prolong their service life. Consequently, in recent years repair of concrete including protection and retrofitting has become an economically important and scientifically interesting field. Globally investments for maintenance, repair and restoration of superstructure and infrastructure are continuously on the increase. As all buildings are generally unique with own histories, individual solutions become necessary for maintenance and repair. This, in turn has led to the developments of different strategies and solutions including material development. Towards this objective the use of polymers has turned out to be almost imperative and mostly unavoidable. But at the same time it has been seen that the embodied energy of a plain 1:3 cement-sand mortar has about 1.5 times as much as that of conventional concrete and that a 1:10 polymer-sand mortar has more than 250 times greater embodied energy per unit of weight. This is the context in which one needs to revisit the world of repair materials including the polymers in use from the perspective of synergy with green chemistry concepts. This paper is a desultory endeavor to peep into this issue.

2.0 Concrete Repair Materials

The basic property requirements of concrete repair materials can be briefly summarized as follows:

- Dimensional stability with respect to the substrate concrete
- Bonding ability with the substrate
- Compatibility of compressive, tensile, flexural and shear strength parameters with those of the substrate.
- Retaining the passivation of the embedded steel.
- Impermeability of aggressive ions to the extent practicable.
- Durability against chemical attack and weathering.
- Enhanced resistance to cracking
- Easy applicability.

Going by such property demand and concrete repair requirements, the first generation repair materials as illustrated in Table 1 was developed on the basis of hydraulic cement alone.

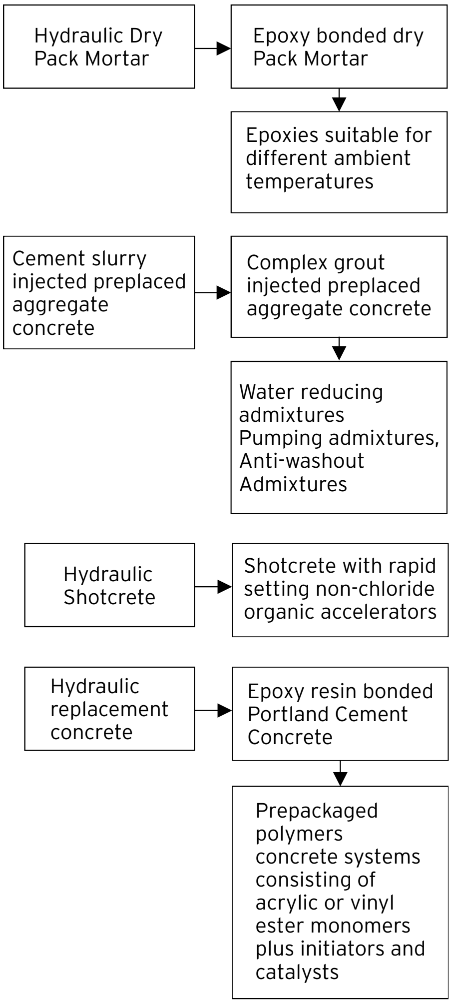
Although these materials have been or are still being used with suitable quality control measures, they suffer from shortcomings of delayed setting and hardening,

Table 1: Hydraulic cement-based repair materials

Type	Broad constitution	General applications
Normal Portland Cement mortar	Cement/ sand ratio 1:2 to 1:4. Cement type comparable to the concrete in repair. Placement with adequate water only.	Essentially for surface defects not prominently exposed, not too wide, not deeper than the far side of the reinforcement
Dry pack mortar	A mixture of 1 part of cement to 2.5 parts of a duly sieved sand fraction with just enough water to hydrate cement.	For filling holes having a depth equal to, or greater than, the least surface dimension of the repair area
Preplaced aggregate concrete	Injection of Portland cement grout with or without sand into the voids of formed, compacted mass of clean, graded coarse aggregate.	For placing in certain situations where placement of conventional concrete is difficult, such as, underwater repair.
Shotcrete	Mortar or concrete pneumatically projected at high speed on to a surface.	Variety of concrete repair applications.
Replacement concrete	Concrete for repair having the same w/c ratio as used for similar new structures but not exceeding 0.47 by weight. Aggregate of as large as maximum size and slump as low as is consistent with proper placing and vibration.	Most common repair material entirely through concrete sections.

low tensile strength, low elongation, unsuitability for thin sections repair, injectability difficulties, relatively poor bonding with the substrate etc, These shortcomings led to the extensive introduction of polymeric binders in partial or full replacement of hydraulic binders as summarised in.

Table 2: Transformation of hydraulic repair materials to organo-hydraulic or organic products



3.0 Polymeric Materials for Hydrophobic Treatment

Concrete surface treatments, which are able to make concrete hydrophobic, are usually found useful in the rehabilitation of damaged structure. It was earlier thought that the best protection against external aggressive agents can be achieved through impermeable coatings which are able to block gaseous and liquid penetration, even under a certain pressure. However, in this case the water retained in the structure cannot escape into the atmosphere without exerting certain pressure against the coating from inside. This water can generate many problems such as detachment of coating, decrease of thermal resistance, ice formation, efflorescence, biological attack etc.

Hydrophobic treatments only cover the pore walls by leaving pores practically empty. They hinder the penetration of water in the structure but they allow water vapour penetration.

The molecular size of the hydrophobic agents influences their performances (Fig. 1). Capillary pore in concrete varies from 100 A to 10,000 A. Acrylic and epoxy resins, due to their big molecular size, can only provide a surface fitness over it. On the contrary silanes and siloxanes can penetrate concrete since their molecular size varies from 10 A to 20 A and 25 A to 75 A respectively.

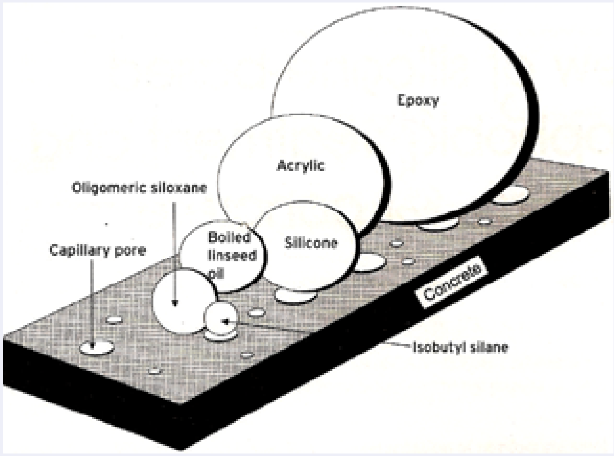


Fig. 1: Diagrammatic representation of molecular size of different hydrophobic agents in comparison with the capillary pores in concrete

The behaviour of silicone-based water repellents significantly depends on their chemical structure. The products mostly used for concrete surface treatment can be based either on monomers (alkyl – alkoxy silane) or polymers (siloxane) and they can be further classified on the basis of the molecule attached to the silicon atom in Rn(Si)X4-n, where R is the organic alkyl group. The alkyl group size influences the decrease of surface tension and thus the treatment effectiveness. Needless to mention that this kind of design flexibility for hydrophobic treatment of concrete surface is hardly available in the hydraulic cement coatings.

4.0 Resins Injection Technique for Crack Repair

When hardened concrete is cracked in depth or hollow plane delaminations or open joints exist in hardened concrete or when structural integrity or water-tightness requires to be ensured for the structure to be restored, the resin injection technique is taken resource to. Two types of resin injection are common: (a) epoxy resins and (b) polyurethane resins. While epoxy resins are used to rebond cracked concrete and to restore structural soundness, cracks with uncontrolled water is not injected with this material. Hydrophilic polyurethane resin is the right choice to eliminate or reduce water leakage from concrete cracks and joints. In addition, cracks with some movements can be injected with polyurethane resin. Polyurethane resins are available with substantial variation in their physical properties. Some polyurethane cures into flexible foams. Other polyurethane systems cure to semi flexible high-density solids that can be used to rebond concrete cracks subject to movement.

5.0 Increasing usage of organic substances in repair and their use related problems

From the information and data furnished in the previous section and from the field practices, one may observe that the following organic materials have turned out to be almost indispensable components in repair systems:

Epoxy resins for bond coat, epoxy mortar and epoxy concrete are generally supplied in 100% solids state with no unreactive diluents, setting agents or volatile solvents. However, the preparation of the resin for bond coat involves the addition of the curing component in certain recommended proportions. Skin contact with uncured epoxy has to be avoided. Adequate ventilation has to be provided at all times during use for epoxy and epoxy solvents. All epoxy-contaminated materials have to be disposed off in containers. High temperature curing and protection are necessary in the application of mortar and concrete.

Methacrylate monomer systems for polymer concrete as well as for crack repair systems can either be methyl methacrylate monomer or high molecular weight methacrylate monomer. The monomer system should consist of 100-percent reactive components without any nonreactive diluents or solvents. Use of the monomer material involves an initiator, which is an organic peroxide and a promoter which can either be a cobalt salt or an organic amine compound. Materials are used in the proportions recommended by the manufacturer for the temperature conditions at the job site to meet the pot life and curing time requirements.

Vinyl ester resin for polymer concrete is generally an elastomer-modified dimetha-cylate diglycidyl ether or bisphenol A. Styrene monomer, which is a component of vinyl ester resin is flammable and may form explosive mixture in air. The initiator is an organic peroxide and the promoter is either cobalt napthenate or cobalt octoate. In addition, there are requirements of a coupling agent such as an organosilane compound and a primer which is often the same monomer or resin used in the polymer concrete as mentioned above. Apart from the usual care of storage and handling, the disposal of liquid components and excess materials demands special care such as combining the materials in the same manner or procedure used for mixing polymer concrete, allowing the material to harden in an open container before disposing off as a solid non-hazardous waste.

One should also bear in mind that the initiator and the promoter in the preparation of polymer concrete have to be batched and packaged separately from each other in a manner that the two components cannot be combined until the time of the concrete mixing operation. The direct combination of these two components results in an extremely violent and explosive reaction.

Polyurethane injection resin systems contain either toluene diisocyanate or methylene dephenyl diisocynates. Both isocynates can create risks if safe handling procedures are not followed. Monomeric urethane resins react with water to produce polyurethane and carbon dioxide gas. If the reaction.

6.0 Concepts of Green Chemistry

Green and sustainable chemistry, a new concept that arose in the early 1990s gained wider interest and

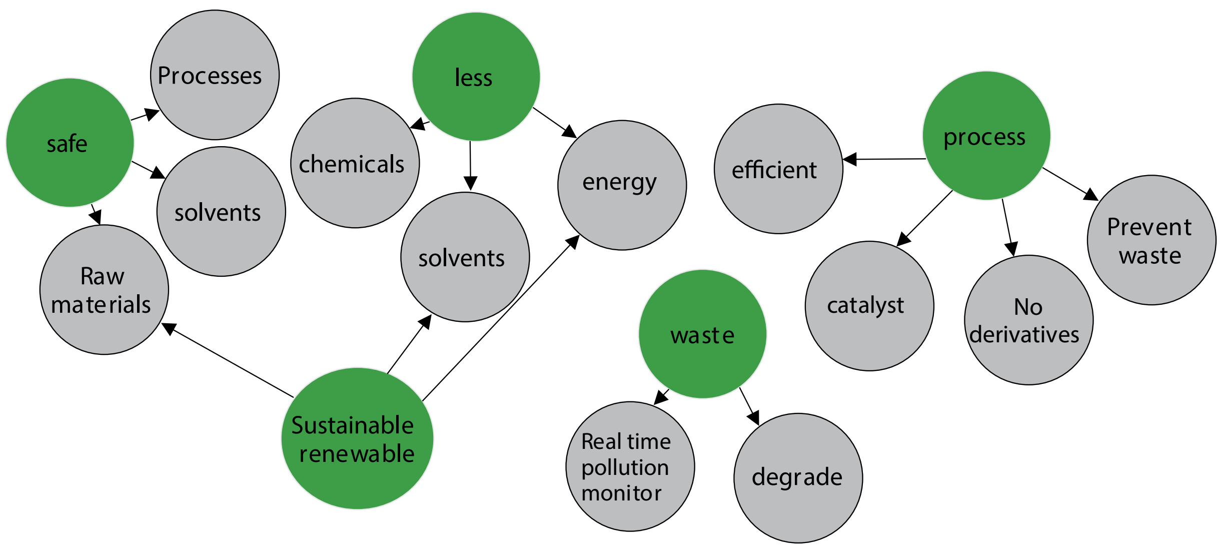


Fig. 2: Twelve principles of green chemistry

support only at the turn of the millenium. The green concept concerns the development of processes and technologies that result in more efficient chemical reactions that generate little waste and fewer environment emissions than the traditional cases. It is said that there are 12 principles of green chemistry as depicted in Fig. 2, which can be grouped in five key statements:

- Use of fewer chemicals, solvents and energy
- Safe raw materials, process and solvents
- Efficient catalytic process without waste and without derivatization
- Real time monitoring of waste which should be degradable
- Sustainability or renewability of raw materials, solvents and energy.

These green chemistry concepts are to be realized from both the perspectives of product manufacturing and product application.

7.0 Need for Benign Chemical Reactions for Materials used in the Repair Systems

The green chemistry requirements demand that more benign chemical synthesis of monomers and polymers be adopted for the sustainability of repair systems. In reducing the amount of waste, the energy usage, and the use of volatile, toxic, and flammable solvents, one should look for newer approaches, including the avoidance of organic solvents for the reaction media (Fig. 3).

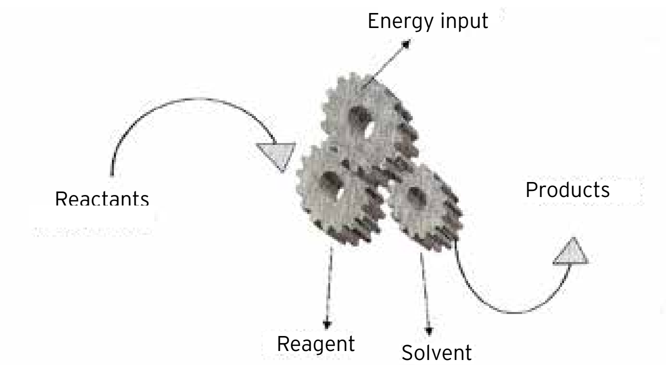


Fig. 3. Basic components of a reaction

The use of petrochemical solvents has been the key to the majority of chemical processes but not without severe implications on the environment. Most of these solvents are now described as VOCs, i.e., Volatile Organic Compounds. They are environmentally undesirable and may cause health problems. Green solvents have been developed as a more environment friendly alternative to petrochemical solvents. Ethyl lactate, for example is a green solvent derived from processing corn. Ethyl lactate is the ester of lactic acid and lactate ester solvents are commonly used solvents in the coatings industry. In addition, ethyl lactate has a high solvency power, which means it is able to dissolve a wide range of polyurethane resins.

In the paint industry the water-based varieties are being preferred in view of their much lower VOCs. PVA emulsion paints with less than 0.3 percent VOC are being produced.

Apart from the non-petrochemical solvents, a benign manufacturing technology for polymers needs to be examined as a green alternative. An illustration is given below for polyurethane.

Generally, these are manufactured through the use of phosgene, which is an extremely toxic and lethal gas, by the following reaction:

$RNH_2 + CO_2 \longrightarrow RNCO + 2HCl \longrightarrow RNHCO_2R'$------(Eq.1)

(Amine) (Isocyanate) R'OH (Urethane)

(Phosgene)

Monsanto has developed an alternate method of manufacture of polyurethanes and their precursors without the use of phosgene. Since the new process uses CO_2 gas, it not only helps to decrease the greenhouse gas but also eliminates the use of dangerous and toxic chemical as illustrated below:

$RNH_2 + CO_2 \longrightarrow RNCO + H_2O \longrightarrow RNHCO_2R'$-------(Eq.2)

R'OH

Needless to mention that polyurethanes manufactured by the more environment friendly approach will obviously be desirable as the component of repair systems. A similar strategy is necessary for the selection of other monomers and polymers to the extent practicable.

8.0 Preferred Indulgence in Polymer Modified Hydraulic Cement Systems

In addition to the option of choosing polymeric materials synthesized through benign processes, the other step towards green chemistry synergy is to use more extensively organo-hydraulic composites rather than pure polymer mortars and concretes.

Polymer modification of cement paste changes the properties of mortar and concrete. The extent and nature of changes depend on the polymer content expressed as polymer-cement ratio, the type of polymer and also the design of the mortar or concrete. Typical effects are given in Table 3.

Polymer modifications of mortars or concrete increases the toughness and, to some extent, the tensile and flexural strengths of these materials. By using a higher level of polymer modification with a low Tg polymer, a high flexibility in such composites can be achieved. The main use of these materials is in thin section application, in manufacturing and protection of concrete structures. The high flexibility allows the spanning of substrate cracks and provides waterproofing and protection that cannot be achieved by using conventional mortars or high Tg polymer mortars.

Table 3: Polymer modification effects on the performance of an concrete cement mortars

Type	Broad constitution
Compressive Strength	Decreased or increased
Tensile Strength	Increased
Fracture toughness	Increased
Adhesion	Increased
Modulus of Elasticity	Decreased or increased
Drying shrinkage	Decreased or increased
Water vapour permeability	Decreased
Hydraulic permeability	Decreased
Creep	Decreased or increased
CO_2 permeability	Decreased
Chloride penetration resistance	Decreased
Chemical resistance	Increased for selective chemicals

9.0 Development and Application of Novel Repair Systems

Needless to mention that often the durability of repair materials is in the range of about 10 years especially in the aggressive environment or under traffic. On the other hand the desired lifetime of a building is usually 50 years. Consequently the need for development of more durable but sustainable green material is quite high.

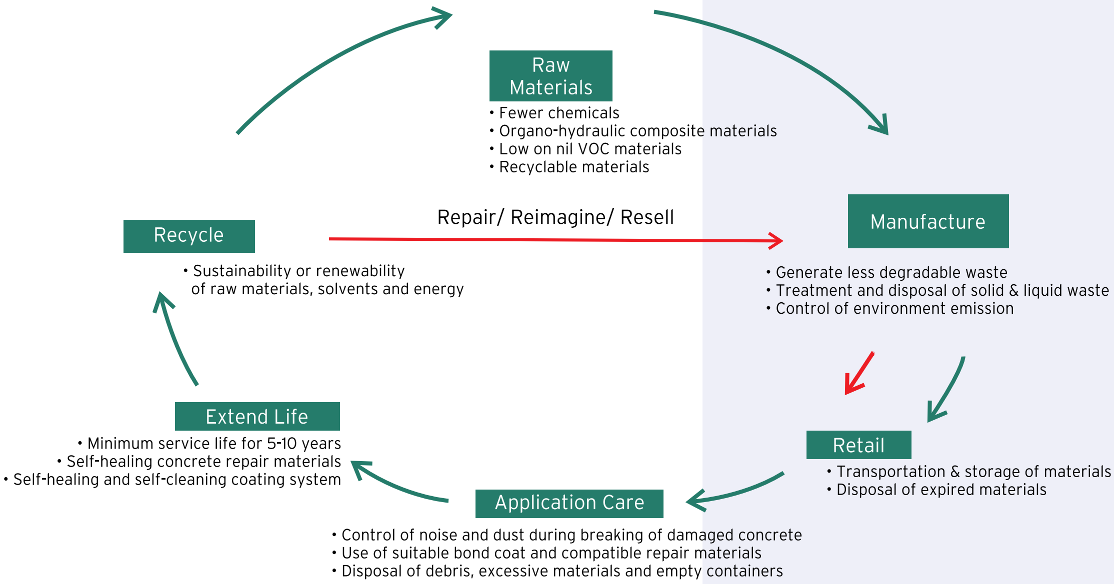
It may be relevant to mention in this context the development of glass systems for the use in sewage plants or wastewater pipes with high risk to biogenous sulphuric acid corrosion. Special glasses are available which are resistant against such acid attacks and highly durable, which can be mounted on concrete surfaces with special glues.

Another potentially new area is the application of nanotechnology to the development of durable and green repair materials. The development is a shift from the simple use of nanoparticles in coatings to 3D nanosystems with heterogeneous nano components and molecular nano systems with heterogeneous molecules.

Researches are on to create super hydrophobic self-cleaning surfaces, self-healing coating systems with nanotubes filled with shape memory polymers, photocatalytic reductions of atmospheric organo-biogenic pollution with nano titania, anti-bacterial protection with nano-silver particles, creating high-strength concrete surfaces with carbon nanotubes, etc. A concept green and sustainable repair material system for concrete repair is given in Fig. 4.

10.0 Conclusion

Concrete repair can have a larger contribution to the environmental impact of a structure than new construction on a unit volume basis. The premature loss of embodied energy in the concrete is compounded by the removal and disposal of deteriorated concrete. Use of polymeric repair materials with larger environmental impacts further adds to the problem of green chemistry and sustainability. As a first step a shift from pure polymer mortar and concrete to polymer modified. Portland Cement products may reduce the departures from green chemistry. Then comes the selection of polymers made with more benign methods of synthesis. The future of adopting green chemistry and sustainability in concrete repairs lies in the successful application of newer protective systems including special glasses and nano-particulate compositions. Demolition of concrete structure is specially energy intensive. Prevention of the need to repair concrete is much more beneficial to the environment and more cost-effective through service life extension strategy.



Arresting Leakages on the Inside Walls of Inspection Gallery (Muran Dam) of Upper Indravati Hydro Electric Project, Odisha - A Case Study

[Excerpts from International Journal of 3R's,Vol.1, No.2, pp. 126 - 134]

1.0 Introduction

The Muran Dam is located on Muran river, a major left bank tributary of river Indravati of Upper Indravati Hydro Electric Project (UIHEP), Khatiguda, Orissa, India. This dam is a masonry gravity and concrete structure with a maximum height of 65 m and a crest length of 494 m (Fig. 1). It is provided with five spillways with a combined capacity of 8060m^3 /s. It has four depletion sluices with a total capacity of 588 m^3 /s.

Fig. 1: A panoramic view of Muran Dam.

2.0 NEED OF THE JOB

The dam safety deficiencies were heavy leakages in the drainage gallery of the dam (Fig. 2). As per the measurement taken (October 2007), the rate of leakage of water was 44.19 litres per second. Thus, due to delay in execution of the work from January 2005 to December 2008, there was loss of water of 5.58 MCM (Million Cubic Metres) which would have generated 4.82 MU (Million Units) of electricity valued at ₹ 2.4 million.

Fig. 2 : Water leakages in the drainage gallery.

The Inspection gallery walls were in a situation where the leakages were just like fountains as the water behind the wall was in upstream side and the water head would be around 60 m.

Water spurting out under pressure was obviously dangerous to the health of the dam and it could have spoiled the strength of the inspection gallery walls. In order to overcome this danger the walls needed to be sealed properly to avoid further degradation and the wall structure from water ingress and associated durability problems.

The Dam Safety and Review Panel suggested in December 2004 to arrest the leakage of water through drilling and grouting. The job was assigned to Pidilite Industries Ltd. and it was executed departmentally in 2009.

3.0 Arresting the Leakages

The inspection gallery was then tracked for the water spilling areas for the sealing activity. The walls were made of concrete and were of old construction pattern. Keeping in view the age, the thickness, the strength and other physical conditions, a Polyurethane (PU) Injection system was considered for arresting the leakages which is being narrated below.

3.1 Step-1

A random jet spurt place was detected and then it was marked properly with yellow paint.

3.2 Step-2

The perforations were evaluated and sealing activity with a branded instant leak plug was adopted for small leakages which is ideal for instantaneous sealing of leaks and plugging wet cracks in concrete and masonry surfaces. It can stop running cracks temporarily until the final repairs are carried out and hardens instantly under continuous wet conditions.

3.3 Step-3

Proper positioning of the drill holes were made as per standard practices with drill machine (Fig. 3). The Packers for injection were assembled and then put in to the holes screw tightened properly to get a grip to the active cavities (Fig 4 and 5).

3.4 Step-4

Three packers were installed and all the small holes were sealed with the branded instant leak plug to channelize the water jet to those three packers so that the injection of Polyurethane (PU) could be initiated.

3.5 Step-5

The Pump was made ready along with a two-part Polyurethane injection material (Fig. 6). It was ensured that mixed material was used immediately as the high air humidity might cause a skin formation over the material surface.

The workability of the mix was approximately 2–3 hours. The injection was started at a pressure of approximately 20 bar depending upon the nature of the building structure, hydrodynamic and hydrostatic conditions, and the desired depth of penetration needed in the walls of the inspection gallery.

Fig. 3. Drilling holes with drill machine

Fig 4. Instalation of packers in the holes.

Fig. 5: Screwing of packers tightly.

The PU injection was carried out at intervals so that it could be understood intermittently from the reaction of the material with moisture inside whether to continue or stop the injection process (Fig. 7).

The material was injected at temperatures of more than 25°C, although it was known that the best results were expected between 15°C to 25°C. The higher initial temperatures accelerate the reaction. For a durable and effective crack sealing, a secondary injection is often necessary depending on the object. The secondary crack injection was carried out in this case through the same holes (Fig. 8). Had there been some delay for the secondary injection, it would have necessitated the installation of new packers at different positions.

3.6 Curing after injection

After the curing process of the injection resin (approximately 24 hours after the injection), the packers were removed and the drill holes were closed with suitable mineral binding materials (rigid quick-binding cement, swelling mortar etc.) The closure of drill holes in this case is shown in Fig. 9.

Fig. 6: Pumping being ready after mixing of materials

Fig. 7: PU Injection in process

Fig. 8: Continuing with secondary PU Injection

Fig. 9: Filling the drill holes with polymeric grout.

4.0 CONCLUSIONS

The PU Injection was carried out successfully for arresting the water leakages in Muran Dam's inspection gallery. It was ascertained from the engineer concerned that the system was totally successful as the affected area was intact even after the rise of water level in the upstream side.

Repair of Distressed Bridges and Culverts on a National Highway – A Case Study

[Excerpts from International Journal of 3R's,Vol.1,No.4,pp. 179-182]

1.0 Background

The old distressed bridges and culverts between Chikkaballapura to Bagepalli in the State of Karnataka in India on the National Highway No. 7 were repaired and rehabilitated by using polymeric repair materials in the year 2009 – 2010. The repair work consisted of corrosion treatment as well as the repair of spalled and extensively damaged concrete. The structures were strengthened by injection grouting in cracks and honeycombs. The deck slab and piers were additionally protected with anti-carbonation coatings for long term durability. The present case study narrates the step by step approach taken during this repair and rehabilitation project.

A wellknown Indian Construction Company had undertaken the project of upgrading a segment of the National Highway No. 7 to 4/6 lane divided carriageway configuration. This project was a part of the construction of North-South corridor in the State of Karnataka (Andhra/ Karnataka Border to Avathi Village 463.00 km. to 524.00 km.) under National Highway Authority of India (NHAI). The project also included construction of some new bridges and repair and rehabilitation of old bridges between Chikkaballapura to Bagepalli. Additionally, existing small bridges had to be widened and additional structures had to be provided by the side of these old bridges. The clients were also concerned about the economic implications of the total project. These bridges had to be strengthened as per the required loading standards of National Highway Authority of India. Pidilite Industries Ltd, Mumbai was the prime supplier of repair materials to this project.

2.0 CONDITION SURVEY

A condition survey was carried out by visual inspection after which some bridges and culverts were identified for repair and rehabilitation. The following signs of distresses were observed:

- Spalling of concrete on the end beams (Fig. 1)
- Exposed reinforcement and corrosion (Fig. 2)
- Spalled concrete on the piers (Fig. 3)
- Small to large honeycombs (Fig. 4)
- Cracks at different locations (Fig. 5)

The deterioration was essentially due to the combined environmental diffusive effects of oxygen, moisture and carbon dioxide.

The various components of the bridges that needed to be strengthened were deck slab area, deck slab and pier together, deck slab and side piers, either side of the pier, construction joints, beams, slabs and pier.

Fig. 1: Spalled concrete at the edges

Fig. 2: Spalled concrete and reinforcement corrosion

Fig. 3: Spalled concrete in the piers

Fig. 4: Honeycombs

3.0 REPAIR MATERIALS & METHODOLOGY

3.1 Treatment of corroded reinforcement and repair of spalled concrete

The repair area was earmarked and the entire area was chipped off at least 5 mm beyond the reinforcement and the edge profile was maintained like saw-cut edges for the entire repair area.

The existing corroded steel was cleaned properly to remove the corrosion products completely by emery paper and also by applying a rust remover. Rust remover is based on chloride free chemical additive solution in water. It was used for effectively cleaning rust from steel surfaces, before application of repair mortar.

At some places where the cross section of the corroded bars was reduced by 1/5th of its original diameter, additional steel was welded to the existing reinforcement bars to make up for the loss of metal.

The entire steel surfaces were coated with an anti-corrosive epoxy zinc primer (Fig. 6) in two coats. It was a two-component system based on metallic zinc and epoxy resin, hardener and additives. Active zinc-rich system combated corrosion by electro-chemical means. It actively resisted corrosion within the confines of the repair location and avoided the generation of incipient anodes in immediately adjacent locations. It bonded strongly to cement concrete and mortars.

For extensively distressed members proper leak proof shuttering was provided to the repair area. A free flow high strength non-shrink micro concrete was mixed and poured into the repair area. It was a ready to use dry powder which required only addition of clean water at site to produce a free flowing mix. It was composed of good quality cement, properly selected aggregates and additives. It had excellent flowability, workability & proper particle size to reach small and congested reinforcement.

Fig. 6: Anticorrosive treatment to corroded reinforcement after rust removal

At some places where only spalling had occurred up to 80 mm thick, shuttering was not required. A cement-based ready-to-use structural grade mortar (Fig. 7) was applied at those places.

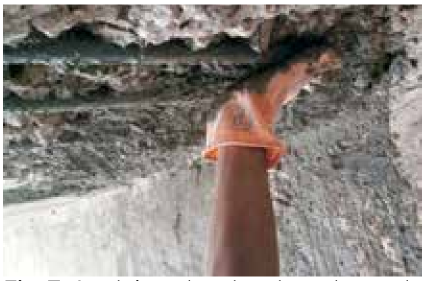


Fig. 7: Applying structural grade mortar

Repair mortar was applied tightly by hand (Fig. 8) on the repaired surfaces and finishing was done (Fig. 9).

Fig. 8: Repair work carried out by structural grade mortar

Fig. 9: Finishing of spalled repair

After removing the shuttering the surfaces were coated with a wax-based curing compound, which took care of curing for 28 days.

3.2 Repair of Cracks and Honeycombs by Epoxy Injection

At places of honeycombs and small cracks, injection points were selected (Fig. 10) and holes were drilled by a drilling machine. The drilled holes were cleaned and pressure washed. The non-return valve nozzles were driven through those holes and sealed with epoxy putties for facilitating injections (Fig. 11).

Fig. 10: Injection location point

Fig. 11: Fixing non-return valve nozzle for injection

A 2-part epoxy injection grout was injected (Fig. 12) with pressure grout equipment having capacity of 40 psi (0.275 MPa), through non-return valve nozzles.

After completion of the injection, the pumping equipment was shifted to a different nozzle location and again injection was made at new location (Fig. 13) and thus entire area was injected for strengthening.

Fig. 12: Epoxy injection through nozzle

Fig. 13: Epoxy injection in progress at different location

Injection grout was a solvent less material composed of very low viscous liquid epoxy resin and amine hardener system. It provided shrink free solid mass, strong bonding inside the cracks and honey combs. Low viscosity epoxy helped in deep penetration into the cracks. It was resistant to aggressive chemicals, corrosion, abrasion & dust formation.

Epoxy injection met the specification requirements of BS 6319 & ASTM C 881 standards.

3.3 Application of Anti-Carbonation Coatings

Entire area of the bridge deck and piers were cleaned properly and coated with anti-carbonation coating. It was basically solvent based composition of acrylic solution polymer, properly selected & graded inert fillers, light fast pigments & additives. It was specially formulated to protect reinforced concrete and other masonry cementitious substrate exposed to atmospheric conditions like UV radiation, high humidity, heavy rain, industrial pollution, & carbonation. It penetrated into the porous concrete substrate, producing an exterior impermeable coating.

4.0 CONCLUSION

For structural strengthening epoxy injection grout was the best material and micro concrete could help for rapid gain strength and facilitated for early reinstatement of the structures. In this case an economical repair system was provided and required strength could be achieved. Anti-carbonation coating would also prevent carbonation and moisture ingress. The repair and rehabilitation work of this project was carried out successfully and bridges were opened to traffic.

Structural Repairs and Rehabilitation of A Commercial Office Building at Masjid Bandar, Mumbai – A Case Study

[Excerpts from International Journal of 3R's,Vol.1,No.4,pp. 337-345]

1.0 Background

The building structure was G+5 floors and consisted of 249 galas, most of which were being used as small manufacturing units and a few that were being used as offices. The building is 37 years old and has one staircase and one lift. It is located at the corner of two very busy road junction at Masjid Bandar in South Mumbai. A structural audit of the building was carried out to assess its present condition. The building got damaged due to extensive corrosion of its structural members. The existing brick bat koba treatment of the terrace was damaged badly and needed to be replaced with modern waterproofing system. The present case study discusses a step-by-step approach that was adopted for repair and rehabilitation of the building and for effective repair management that systematically had numerous constraints.

2.0 REPAIR AND STRENGTHEING

2.1 Re-casting of RCC Sunshade

It was suggested that a continuous sunshade Fig. 1 be constructed for protection against rainwater, instead of the old sunshades just over the window openings. This helps prevent water running over empty spaces along the walls that results in the growing of moss and fungus, which causes the appearance of black spots and spoils the paint. All new re-bars were anchored to the beam with the help of FISCHER epoxy resin capsules and 100 mm thick reinforced concrete was cast uniformly with the help of waterproof ply shuttering.

Fig. 1: Continuous sunshade being provided

2.2 Plastering

Old and new plaster was joined using a bonding adhesive for proper bonding. PP (Polypropylene) Fibres were used as transverse reinforcement to join the first and second coats of plaster consecutively, in 1 : 4 and 1 : 3 cement mortar ratio. Liquid waterproofing compound was added as an admixture in the mortar. The gaps between the RCC and masonry were filled by a polymer modified mortar, embedded with metal aggregates. Fresh pointing was done in loose brickwork wherever bedding and jointing mortar had disintegrated. Dash coat plaster was provided wherever loss of brick/ block work required the application of a mortar thickness of more than 25 mm.

2.3 RCC Coping

To prevent leakage on top of the parapet, RCC coping was laid over at a height of a 1.04 m parapet wall with 25 mm projecting outside, 75 mm projecting inside and a top finish of a 25 mm inward slope. Making shuttering on three sides has no complication because of the scaffolding support. The fourth side was also cast with additional safety measures. RCC coping before and after are shown in Fig. 2 and Fig. 3 respectively.

Fig. 2: RCC coping before

Fig. 3: RCC coping after

3.0 STRUCTURAL STRENGTHENING

The external columns, beams and slabs on the ground floor and the columns and beams on the top most floors deteriorated very badly and were repaired with a polymer modified mortar and micro concrete. Fibre wrapping on a few columns was done to enhance the strength of these weak columns.

All the old bars were cleaned with rust remover. 24 hours after application, the surface was cleaned with water jets so that all rust and loose concrete was cleaned thoroughly. Wherever reinforcement bars lost more than 25% of their original diameter volume, additional rebars were provided as replacement/ replenishment. Old and new bars were coated with a rust preventer, as a passivator coat. One or more coats were applied using a ready-to-use powder that was mixed with water and modified with powder polymers. The new reinforcement was connected to the original concrete by fixing Shear Connectors, using polyester resin anchor fix grouts. These connectors were fixed using a chemical based grout that has high pullout bond strength by drilling a hole into the concrete of a minimum of 100 – 150 mm in length. It was ensured that the pullout strength of that anchor was more than the tensile strength of the bar. After 24 hours, the entire surface was coated with a long pot life epoxy bond followed by a watertight shuttering, prepared to pour micro concrete.

The beams and slabs in the basement were damaged Fig. 4 due to leakage from the common WC block on the ground floor. A complete beam was jacketed in micro concrete by drilling a hole from the top floor. A portion of the slab bottom sagged and de-bonded. By providing watertight shuttering, slab casting was done using micro concrete with 6 mm down pea gravels poured from the top floor by making a few core cuttings for maximum flow up to 2 metres Fig. 5. Similarly the damaged columns were strengthened were micro concreting. Fig. 6 and Figure 7 show the column before micro concreting and column after micro concreting respectively.

Fig. 4: Roof slab before micro concreting

Fig. 5: Roof slab after micro concreting

Fig. 6: Column before micro concreting

Fig. 7: Column after micro concreting

5.0 External Protection Treatment

The external surface of the building was protected again with good quality coating that had elastomeric properties. A hand roller was used for application instead of a brush. Three coats were applied with the hand roller as per manufacturer recommendations. Acrylic coating was used having crack bridging properties. This is very important for old buildings. A five year warranty against leakage was received and given to the client stating that the manufacturer will give free material during the tenure of the contract and the contractor will apply the material at no extra cost to the Society during the defect liability period. Such work will start within a week after a written intimation of complaint is submitted. The work will be done under supervision of the consultant till the defects are rectified. Fig. 8 and Fig. 9 show the view of building before and after repair.

Fig. 8: View before repair

Fig. 9: View after repair

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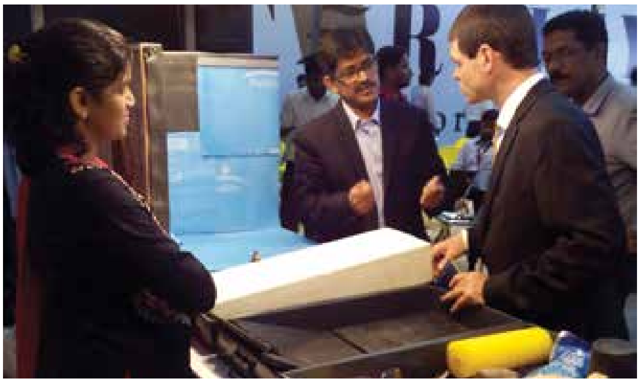

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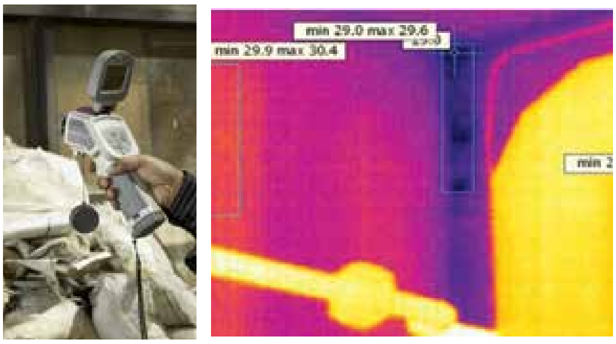

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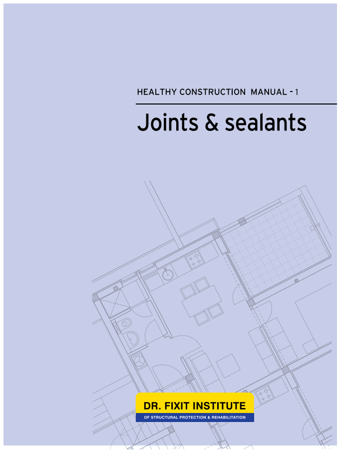
Publications

HEALTHY CONSTRUCTION MANUAL - 1

Joints & Sealants



ISBN 978-81-909802-0-3,

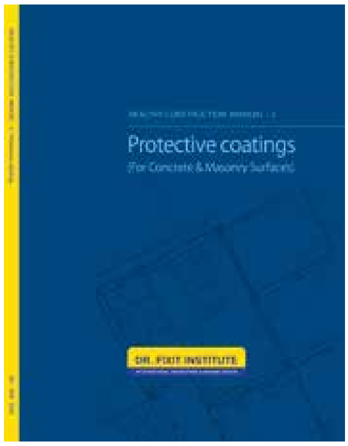
Price : ₹ 300
Postage : ₹ 25 for Mumbai and ₹ 50 for outside
Pages : 53

The Manual on "Joints and Sealants" covers different types of joints and their need in concrete structures. It explains the movement of joints and how to design such joints at different locations consisting of different materials both for cast-in-situ as well as precast constructions. It also provides solutions to seal those joints with different types of sealants. The manual provides guidelines for selection of materials for structures with fluid pressure and industrial floor joints and how to install those sealants including use of water stops / waterbar. The environment, health and safety aspects are also covered.

HEALTHY CONSTRUCTION MANUAL - 2

Protective Coatings

(For Concrete & Masonry Surfaces)



ISBN 978-81-909802-1-0,

Price : ₹ 400
Postage : ₹ 25 for Mumbai and ₹ 50 for outside
Pages : 104

The Manual on "Protective Coatings for Concrete and Masonry Surfaces" is aimed to guide the practising and maintenance engineers in selecting suitable protective coating for durability of concrete and masonry structures. It also provides details on method of application, standards and specifications for executing the jobs at site. The various topics covered: Introduction, Properties and Test Methods, Characteristics Performances of different Coatings, Application, Quality Assurance, Safety, Health & Environment and Preparation of Tender documents including Appendixes, List of Relevant standards, equipment and their function.

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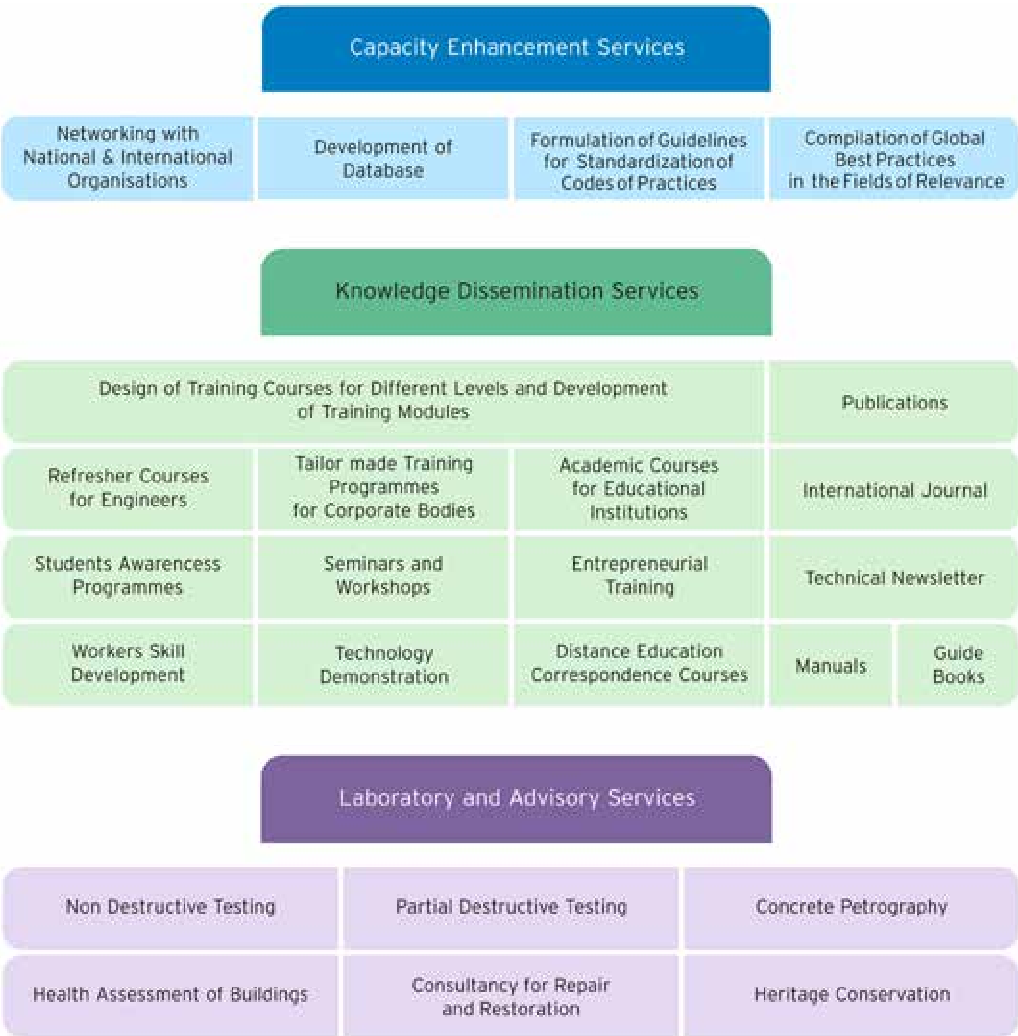

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