Repair and Strengthening of Reinforced Concrete Structures

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ABSTRACT

Repair and strengthening of damaged or vulnerable reinforced concrete structures is important in order to guarantee the safety of residents or users. Beams are important structural elements for withstanding loads, so finding the efficient repair and strengthening methods are necessary in terms of maintaining the safety of the structures.

This research study investigated various repair, retrofit, and strengthening techniques for reinforced concrete beams. The comparison and summary of each repair and strengthening method are provided in this thesis.

The thesis involves the literature review of current experimental test of repair and strengthening techniques for reinforced concrete beams. The experimental studies were summarized by describing the specimens and loading details. All the methods in the research were categorized into five chapters: section enlargement and concrete jacketing, external reinforcement, steel plates, unbonded-type strengthening, and concrete repairs. The installation procedures were summarized and the advantages, shortcomings, and considerations of each method were also discussed in the thesis.
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Chapter (1)

Introduction to Repair and Strengthening of Reinforced Concrete Structures

1.1 Introduction and Definitions :-

In design process we must take two important points in Considerations:-

1- Safety (the structure is safe under applied stresses).

2- Serviceability (the structure in a good appearance such as "no Deformations – no Cracks").

1.1.1 Terminology of Repair & Strengthening

Repair :-

It is the process of increasing the performance of structure from minimum performance to initial performance.

This process are depending on available cost for the repair process.

High cost means high performance.

Strengthening :-

It is the process of increasing the performance of structures more than the initial performance that the structure was designed on it.

We need this process when the loads that on structures were increased.

It is the process of adding capacity to a member of structure.

Maintenance :-

It is the simple repair process to increase the performance of structure.

This process was applied at periodic time.
The next graph shows the main difference between
( repair – strengthening – maintenance ).

Fig 1.1 The main difference between
( Repair – Strengthening – Maintenance )
1.1.2 Basic Philosophy

In strengthening

The resistance of structure element increased and subsequently the capacity of element increased for an additional load coming to the element.

1.1.3 Repair & Strengthening Techniques

A)-Increasing Resistance :-

- increasing cross section .

- add R.F.T .

- add Bonded material ( steel plates - F.R.P ).

B)-Without Increase Resistance :-

- Reduce Dead Load . ( change using of the structure ).

- Change structure system.( add support for the beam ).
1.1.4 General Steps for Evaluate any Structure :-

A- Visual inspection :-

(discover any problem in the structure such as cracking – spalling – disintegration, revision for statically system).

B- Non destructive tests :-

(Ultra sonic test – Core test – Loading test).

C- Selection of repair and strengthening materials :

(effective materials with optimum cost and suitable properties).

D- Design process

E- Economic condition for owner
1.2 Repair and Rehabilitation of Structures

This research deals with the latest techniques in repair and rehabilitation of structures. The various causes of structural failure and the principles of rehabilitation of structures are discussed. Major repair that are to be carried out in Brick walls, Plaster walls and RCC members are explained in detail and an in-depth analysis into Reinforced Cement Concrete repair options like

- Shotcrete method (Guniting)
- Form and Pump Method

The research also deals with the comparatively new Form and Pump technique developed for the past 20 years are discussed. Finally a case study of rehabilitation of the Freedom Towers (Florida, USA) was conducted where the latest techniques such as hydrodemolition, Abrasive blast cleaning, Form and Pump placement and Checkerboard pattern of construction are extensively applied.

1.2.1 Introduction To Rehabilitation and Repairs :-

A large stock of existing structures and infrastructure are deteriorated with use and time and might have passed their design life and require retrofitting and rehabilitation. The cost of retrofitting various infrastructures is estimated in the lakhs of rupees. To Overcome the ill effects caused by these deteriorated buildings Repair and Rehabilitation works are carried out from time to time. Many of the existing structures were designed to codes that have since been modified and upgraded. Change in use or higher loads and performance demands require modifications and strengthening of structural elements.

1.2.3 Why do some structures fall down ?

Site Selection and Site Development Errors :-

Failures often result from unwise land use or site selection decisions. Certain sites are more vulnerable to failure. The most obvious examples are sites located in regions of significant seismic activity, in coastal regions, or in flood plains. Other sites pose problems related to specific soil conditions such as expansive soils or permafrost in cold regions.
DESIGN ERRORS:
These failures include errors in concept; lack of structural redundancy; failure to consider a load or combination of loads; deficient connection details; calculation errors; misuse of computer software; detailing problems including selection of incompatible materials, failure to consider maintenance requirements and durability; inadequate or inconsistent specifications for materials or expected quality of work and unclear communication of design intent.

CONSTRUCTION ERRORS:
Such errors may involve excavation and equipment accidents; improper sequencing; inadequate temporary support; excessive construction loads; premature removal of shoring or formwork; and non-conformance to design intent.

MATERIAL DEFICIENCIES:
While it is true that most problems with materials are the result of human errors involving a lack of understanding about materials, there are failures that can be attributed to unforeseeable inconsistencies in materials.

OPERATIONAL ERRORS
Failures can occur after occupancy of a facility as the result of owner/operator errors. These may include alterations made to the structure, change in use, negligent overloading and inadequate maintenance.

1.2.4 PRINCIPLES OF REHABILITATION

ELIMINATION
Remove the materials that cause damage to buildings. This is no easy matter, because everything from the floor to the roofing may contain various undesirable materials in the form of additives and admixtures.

SEPARATION
Some things just can't be eliminated, but can still be protected. Use sealants or foil backed drywall to separate structures
from damage causing sources.

VENTILATION

Controlled, filtered ventilation may be the only way to insure that the air we bring indoors is ideal. High humidity air or extremely low humidity air can cause significant damage to concrete, plaster and brick walls.

1.2.5 GENERAL AREAS OF REPAIR/REHABILITATION WORK

- Repair, removal, replacement and maintenance of mechanical supports, sanitary treatment plant and pipelines.
- Repair and modifications to diffuser ports, aeration systems, and discharge pipelines.
- Installation and maintenance of dewatering structures.
- Pile restoration and wood pile concrete encapsulation.
- Anode installation for cathodic protection.
- Repair and replacement of trash-rack and debris screen.

1.2.6 MAJOR TYPES OF REPAIR

- Brick Wall Repairs
- Plaster Wall Repairs
- RCC Repairs

A) BRICK WALLS

Basically, brick is durable and long-lived as long as the mortar joints are sound. Brick houses are susceptible to moisture - more so than wooden framed houses - but require very little maintenance.

PROBLEMS WITH BRICK (STRUCTURAL PROBLEMS)

- Deteriorated Pointing affects many old houses. Mortar starts to disintegrate between the bricks, which can cause the entire wall to collapse, or single bricks to crumble.
- Dirty or stained brickwork can be caused by moisture, time, dirt along with rain or sprinklers.
- Efflorescence results from bricks getting wet, which leaves deposits of salts that are drawn out of the masonry as the moisture evaporates the brickwork and find the source of the moisture.
- Spalled brickwork is also common. Once bricks have been wet, the expansion of freezing water breaks off the top
surface of the brick, leaving the inner surface exposed. After a time, most of these bricks will crumble completely.

A couple of Don'ts for brick

- Don't assume that old mortar needs to be replaced. Old mortar is usually of a higher lime content than the newer replacement mortar we are likely to find to repoint, and the high portland cement content of new mortar can damage old walls beyond repair.

- Don't seal bricks with a water repellent (i.e., water seal) - it can mean that any moisture that is already in the brick stays in the brick, and interior moisture may not be able to escape.

- Don't use hydrochloric acid to clean brick, it can cause discoloration or mottling that is permanent.

- Never sandblast old brick! Sandblasting can damage the hard surface of fired brick and open the bricks up to water damage.

- Never use expansion joints in historic masonry - they can pulverize brick and ruin mortar joints.

REPAIR WORK

Cleaning Brickwork

- For normal dirt and grime, simply use plain water, rinsing with a hose and scrubbing with a stiff bristled brush.
- For stubborn stains add 1/2c ammonia to a bucket of water.
- Don't use a powerwasher except as a last resort - if we have a crumbling brick problem, this will make it worse (old windows don't stand up to high pressure water very well).

Removal of Organic Growth

A moist brick will often lead to growth a variety of molds and mosses.

- First, scrape the moss or mold off the surface with a non-metallic spatula (the same kind used on Teflon).
Second, apply a wash of 1 part bleach to 4 parts water to kill the spores.
After a couple of days, scrape again and rewash. It will probably take a few applications to kill everything off.

B) PLASTER WALLS

Should you repair or replace?
It is usually better to go in favour of repairing plaster walls, regardless of what they look like. But honestly, this is not always possible.

Basically, if:
- there is more than 1 large hole per 4 x 8 area, or
- there are more than 3-4 cracks in 100ft², or
- the cracks are more than 1/4" wide.

Then replace the section of wall. It will take more time and failed attempts to repair this wall than it is worth. Old plaster should be cherished - it is stronger and more soundproof than current walls made of gypsum board or sheetrock. Even cracking or crumbling plaster walls should be repaired, not replaced.

• PLASTER DAMAGE (NON-STRUCTURAL PROBLEMS)
Plaster is pretty tough stuff, but like any wall, it's going to get banged or gouged, and age will take its toll.

- Impact Damage can be serious problem in an old house. Over the years, the walls are going to get banged and dented. Generally we have to replace the plaster 6-12" from the visible hole to reach plaster that is still keyed to the lath tightly.

- Nearly every wall has a few nail holes. These can usually be fixed with a tiny bit of spackle applied with the finger. Not perfect, but they will be unnoticeable when the wall is painted.

- Water is the enemy of plaster. Brownish stains on the walls or ceilings are evidence for bowing out of plaster. Water-damaged plaster can be very friable.

- Old walls and old houses often have cracks. Stress cracks
are a sign of possible structural shifting, extreme temperature changes, incorrect plaster mix, improper curing or leaks. Diagonal cracks over doorways signal settlement, or a nearby source of vibration, such as a highway or railroad.

1.2.7 REPAIRS

- For repair of minor cracks, use fiberglass mesh tape then go over with a wide trowel and joint compound. There are also plaster patch compounds available that are excellent.
- For larger cracks and holes, we need to remove all the debris and enlarge the crack until we reach solid plaster and fill the crack with joint compound or plaster patch.
- If we choose to put wallboard over the plaster, use the following tips:
  - Apply wallboard horizontally
  - Use the largest boards available.
  - Use screws, not nails, 12” apart in ceilings, 16” on walls
  - Use a floating joint - the wall holds up the ceiling sheets
  - Use corner clips at all corners
  - Use fiberglass mesh tape, not paper, and special compound that is available for plaster walls.
  - Caulk interior corners with acrylic latex caulk its not historically correct, but the effect is smooth and unnoticeable.
1.2.8 RCC STRUCTURES

PROBLEMS IN RCC STRUCTURES (STRUCTURAL PROBLEMS)

- Flexure, Shear, Torsion, Shrinkage And Tension cracks
- Splitting, Diagonal, Horizontal cracks in Columns
- Rusting, Buckling, Bending, Twisting Distress in Steel structures

1.2.9 METHOD OF REPAIR FOR RCC STRUCTURES

A) WETMIX SHOTCRETE

Fig 1.3 – (Describe wet mix shotcrete)

Wet mix shotcrete is a method that involves premixing of all ingredients including binder, water, aggregates and admixtures. The
premixed repair materials are deposited into a pump which transports the materials to an exit nozzle where compressed air is introduced. The repair material is propelled onto the substrate with compressed air. Admixtures can be used to enhance durability. Air entrainment is required for freeze-thaw resistance. Fig(1.3).

B) DRYMIX SHOTCRETE

![Diagram of Drymix Shotcrete]

Fig 1.4 – describe dry mix shotcrete

- Problems associated with Drymix Shotcrete:
  - Presence of voids due to encapsulated rebound
  - Shrinkage cracking caused by high cement content, improper curing or excessive water control.

Dry mixing involves premixing of binders and aggregates which are fed into special mechanical feeder metering the premixed materials into a hose. The mix is jetted out along with compressed air from a nozzle connected to the hose having a water ring outfitted to it. This mix is injected to the repair spot. The resultant hardened properties include increased flexural, compressive strengths and more durability.

C) FORM AND PUMP TECHNIQUE
The form and pump repair method is a two step process of constructing formwork and pumping repair material into the cavity confined by formwork and existing concrete.

The form and pump technique allows use of different materials. Repair materials are mixed and pumped into the cavity. When the cavity is full, pump pressure is exerted into the form causing the repair material to consolidate and make contact with existing concrete surfaces.

1.2.10 SURFACE REPAIR OF VERTICAL LOCATION (COLUMN)

One of the most common methods of surface repair of vertical and overhead location is placement of formwork and casting of repair material into the prepared cavity. The repair material must be of low shrinkage and necessary flow ability. Rodding or internal vibration is necessary to remove air and provide intimate contact for placing concrete substrate. In some applications complete filling of the cavity may be difficult. In those cases a final step of dry packing the remaining cavity works well.

1.2.11 SURFACE REPAIR OF OVERHEAD LOCATION (BEAM)

There are many techniques available to restore damaged or deteriorated concrete structures. Each surface repair techniques offer advantages and limitations depending upon the conditions of the repair project. Form a pump technique is relatively new method which has been developed as a viable alternative to Shotcrete (gunite), hand placement and grouted preplaced aggregate techniques.
1.2.12. ADVANTAGES OF FORM AND PUMP TECHNIQUE:

- The use of almost any type of repair material - from fine grained mortar to course grained cement concrete.
- Placement is not limited by depth of repair, or by size or density of reinforcements.
- The pressurization process provides full encapsulation of exposed reinforcing steel.
- The formwork protects the repair material during curing process.

Fig 1.6 – Pump and Form Technique
1.2.13 PLACEMENT OF THE MATERIALS

The sequence of material placement into the formed cavity depends upon the geometrics involved. Vertical surfaces start at the lowest point, filling in a manner that prevents air entrapment. Arrangements for ports for pump line attachments are usually in grid form. When the flow is without the intrusion of air, the pump is shut off temporarily, the port closed off and pump line connected to the adjacent port which has seen flow. The sequence is carried out until the cavity is filled. Once the cavity is filled, the full line pressure is available to pressurize the formed cavity.

1.2.14 Selection of Materials

Constructability requirements for materials used in form and pump method are limited only by their ability to be pumped and flow characteristics. The materials in-place properties like low drying shrinkage, compatibility, thermal and elastic properties. Drying shrinkage can cause cracking, delamination, inability to carry loads and low durability. Pumpability and
flowability can be brought into the materials by additives and admixtures. Prepacked repair materials which are designed for pumping and incorporating shrinkage compensating additives are appropriate for many applications.

1.2.15 Compatibility of Repair and Substrate:-

The term "compatibility" has become very popular in the field of concrete repairs. It is always associated with the durability of repairs in general and with the load-carrying capacity of structural repairs. It had been suggested that failed repairs are the consequent of imperfect choices (the selection of repair materials incompatible with the substrate in a given environment).

Compatibility as shown in Figure 1.7 is the balance of physical, chemical, and electrochemical properties and dimensions between a repair material and the substrate that will ensure that the repair can withstand all the stresses induced by volume changes and chemical and electrochemical effects without distress and deterioration over a design period of time.

Recently, the selection of a repair material has been shifted from compressive strength, and low permeability to the combination of properties collectively called compatibility with existing substrate.
Fig. 1.7 Factors affecting compatibility of repair materials
1.3 Evaluation and Rehabilitation of Reinforced Concrete Structures:-

The extent of deterioration to concrete structures globally is occurring at an alarming rate, which challenges engineers on this continent and throughout the world on a daily basis. This includes damage to bridges, buildings, parking structures, environmental facilities, as well as other structures. Unfortunately, repair costs can be staggering. Delaying repairs usually results in much more costly repairs later. Furthermore, if concrete deterioration or damage is not addressed, some of these structures eventually may cease to be serviceable and worse yet, failures could occur.

There are a multitude of methods and materials available to repair concrete. Additionally, there is an abundance of references which deal with this problem. The International Committee of Concrete Repair (ICRI) and some committees within the American Concrete Institute (ACI) as well as other organizations throughout the world are devoted to developing methods for repair and to disseminate information to professionals regarding the repair of concrete.

Two excellent resources that cover this topic in great depth are:

1. ACI 546R-96, Concrete Repair Guide
2. Concrete Repair Manual, published jointly by ICRI and the ACI. This is a compilation of various repair documents currently available in North America, and will soon be expanded to include documents from Europe

Concrete repair, strengthening and renovation is an immense subject. The intent of this paper is to present an overview of the topic. This will include a discussion of how to approach a concrete repair program, as well as introducing some of the commonly used repair techniques and materials.

1.3.1 Typical Concrete Problems:

- Poor Quality Concrete
- Corrosion-related
deterioration Carbonation
- Freeze-thaw damage
- Earthquake damage
- Design-related
  - Substandard “Halo of Anodic” Ring effect
**Poor quality concrete:** The quality of concrete in a structure will impact the long-term performance. Good durable properly-consolidated concrete, placed with the minimum of honeycombing and internal shrinkage, will provide an environment that should protect the embedded reinforcing for years before repairs are required, if ever.

**Corrosion-related deterioration:** Corrosion of embedded reinforcing steel is the most common cause of concrete deterioration. When the iron in steel is exposed to water, oxygen, and chlorides, it oxidizes and produces corrosion (rust). The oxidized metal can expand up to 10 times its original volume, resulting in intense bursting forces in the surrounding concrete. This will eventually lead to cracking and delamination.

**Carbonation:** In normal concrete, the reinforcing is protected by the naturally high alkalinity of the concrete with a pH of about 12. A passivating layer of stable mineral scale is formed on the reinforcing which protects it from corrosion. Carbonation is the reduction of the protective alkalinity of the concrete. It is caused by the absorption of carbon dioxide and moisture which lowers the pH to 10 or less and renders the reinforcing vulnerable to corrosion. Reinforcing steel embedded in carbonated concrete will corrode in the presence of water and oxygen.

**Freeze-thaw damage:** Freeze-thaw damage is more likely to occur in poor quality concrete, especially if it is not air-entrained. This is a problem in the colder climates with a wide variation of temperature on a daily basis.

**Earthquake damage:** This is a problem here in Mexico City as well as at various other locations throughout the world. There are methods to modify and/or strengthen existing structures to meet current earthquake standards. Earthquake issues are not addressed by ACI 546 but are instead the responsibility of ACI Committees 341 and 369.

**Design-related problems:** Improper design or detailing can occasionally result in damage or deterioration to that structure. The lack of proper expansion joints in large concrete tanks, for example, will often result in significant cracking.

**Substandard workmanship:** Misplaced reinforcing, for example, is a common problem in concrete structures. This often results in severe cracking, and eventually leads to delamination because of corrosion.

**Environmentally-related problems:** Structures located along seacoasts, or in northern climates where deicing salts are used, for example, often have serious problems with corrosion of the underlying reinforcing steel because of its contact with chlorides.
“Halo of Anodic” Ring effect: It is common for the same reinforcing bars to extend from a repaired area to an adjacent un-repaired, contaminated concrete. Because the same bar extends into two distinctly different environments, conditions result in an electrochemical process, which fosters corrosion where the new repair and parent concrete meet (bond line). The build-up of rust at the surface of the reinforcing, usually in the original concrete, results in spalling, typically around the perimeter of repair patches.

1.3.2 Repair Methodology:
There must be a basic understanding of the underlying causes for the concrete deficiencies prior to selecting repair techniques or materials. Quite often it is not possible to eliminate the reasons that caused the deterioration. An example of this is inadequate concrete cover over reinforcing bars on the façade of a building. The best option is to use repair techniques which take into account the inadequate cover and to provide an appropriate protection system.

1.3.3 Concrete Repair Program:
The basic steps for a repair program include:
- Current condition evaluation
- Selection of repair methods and repair materials
- Preparation of Repair Documents
- Bidding/Negotiation process
- Execution of work

1.3.3.1 Current condition evaluation:
The objective of the condition evaluation is to find the cause for the deterioration or distress and to determine the extent of corrective work that is required. The tasks for a condition evaluation ideally/should include:
- Review of all available drawings, reports, maintenance records or any other pertinent documents.
- Perform structural analysis for the deteriorated condition if warranted, to determine if there are any safety issues.
- Visually inspect the entire structure. As much of it as possible should be sounded to determine the extent of deterioration. Record all results.
- Implement appropriate testing program. The purpose of the testing program is to evaluate the extent of corrosion activity, the properties of the concrete and reinforcing, the condition of concrete and to collect any other data that might be useful to determine the cause for the deterioration and to help establish an appropriate repair program.
Carefully evaluate all laboratory results and other findings from the testing program.

Analyze findings to determine the cause for the distress. Prepare an evaluation report including findings, conclusions, and recommended repair program along with an opinion of cost to implement the repairs.

The concrete testing program should be designed to yield the necessary information to properly assess the structure. The testing program may include:

- Determination of the locations of delaminating by sounding with a hammer or chain drag or any other device. Note that good concrete, when tapped, has a pinging sound whereas delaminated has a dull sound.

- Determination of chloride levels of the concrete. Reinforcing steel in concrete with high chloride levels is more likely to corrode.

- Determination of corrosion activity within the concrete. This is accomplished by such methods as copper-copper sulfate half cell.

- Taking cores from existing concrete to perform compression tests to determine its strength. This can be supplemented by Windsor Probe or non-destructive tests, such as a Swiss Hammer.

- Determination of internal tensile strength of concrete or at bond line of repairs by performing bond or pull-out tests.

- Determination of physical properties of concrete, such as internal cracking, freeze-thaw damage, estimate of air void system and other pertinent data, with a Petrographic Analysis (microscopic evaluation).

  - Determination of levels of carbonation.
  - Testing to determine if there is any internal cracking or voids with impact-echo tests.
  - Testing with radar to locate reinforcing steel.
  - Testing with pachometer to locate reinforcing steel.
1.3.3.2 Selection of repair methods and repair materials:

A. Considerations prior to implementing repair program
Sometimes it makes more sense to repair the ongoing problems than to eliminate the cause. This might be the case for a parking garage scheduled to be replaced in a few years. Spot repairs would be appropriate, as opposed to a more aggressive repair program. The objective would be to keep the structure safe and operational.

When selecting repair methods and materials, outside constraints must be considered such as:

- Limited access to work areas
- Operating schedule (when owner will allow work to take place)
- Budget limitations
- Required useful life of structure (The repair program should be consistent with objective of owner. For example, the minimum repairs should be done if the structure is to be demolished in a few years.)
- Weather implications
- There may be constraints imposed by governmental agencies which have to be considered. This could include regulations regarding:
  - Airborne vapor and/or particles
  - Noise
  - Hazardous waste
  - Other governmental restrictions

Structural safety issues must be considered prior to implementing repairs, as well as throughout the duration of the repair program. If, for example, during an initial evaluation there is a concern regarding the structural integrity of a parking deck, it would be prudent to provide temporary shoring immediately.

Before selecting repair materials, consult with manufacturers to get a sense of what materials are available, the methods of installation, cost effectiveness and technical feasibility to use certain products. Be aware that manufacturers or vendors may not inform you of the limitation of their materials. It is important that the specifier carefully researches the repair materials that might be appropriate for the project before making a final selection.
The following factors should be considered when selecting a repair material:

- Coefficient of thermal expansion
- Shrinkage Permeability.
- Modulus of elasticity
- Chemical properties (pH close to 12 is desirable)
- Electrical properties
- Color and texture properties

The following references are now available regarding repair materials:
ICRI Guideline No. 03733 *Guide for Selecting and Specifying Materials for Repair of Concrete Surfaces*.
- ACI 546R-96 *Concrete Repair Guide*, Chapter 3.
1.3.4 Concrete Protection

Concrete protection systems may be incorporated into a repair program to extend the life of repairs and minimize future deterioration. In some cases, they will improve the appearance of the repaired structures.

1) Surface applied Protection systems include:

- Penetrating sealers -- materials which, after application, are generally within the substrate of the concrete. Such products include boiled linseed oil, silanes, siloxanes and high molecular weight methacrylates.
- Surface sealers -- products of 10 mils (0.25 mm) or less in thickness that generally lay on the surface of the concrete. Such products include varieties of epoxies, polyurethanes, methyl methacrylates, moisture-cured urethanes and acrylic resins.
- High-build coatings -- materials with a dry thickness greater than 10 mils (0.25 mm) and less than 30 mils (0.75 mm) applied to the surface of the concrete. Such products include acrylics, styrene-butadienes, polyvinyl acetates, chlorinated rubbers, urethanes, polyesters, and epoxies.
- Membranes -- systems with a thickness of greater than 30 mils (0.7mm) and less than 250 mils (6 mm). Such products include urethanes, acrylics, epoxies, neoprenes, cement, polymer concrete, and asphaltic products.
- Overlays -- products over 250 mils (6 mm) in thickness that are, in general, bonded to the surface of the concrete. Such products include concrete, polymer concrete, and polymer-modified concrete.

The selection factors when comparing the various systems and products include:

- Track record Cost
- Appearance.
- VOC (volatile organic compounds) compliance with governmental regulatory agencies.
- Compatibility with substrate.
- Durability and performance.
1) Cathodic Protection
The corrosion process is an electrochemical process where anodic and cathodic areas are formed on the steel. When the anodic and cathodic areas are electrically continuous and in the same electrolyte, corrosion at the anodic areas will occur. The corrosion is created as an electrical current flow occurs through the corrosion cell, anodes cathode and electrolyte. For reinforcing bars embedded in concrete, unless mitigated, the corrosion will continue, ultimately resulting in cracking, delamination and spalling of the concrete adjacent to the reinforcing. (From ACI 546R-96, Section 4.3).

An effective method to control the corrosion of steel in contaminated concrete is cathodic protection. The basic principle is to make the embedded reinforcing steel cathodic, thereby preventing further corrosion of steel. This can be accomplished by electrically connecting the reinforcing steel to another metal that becomes the anode, with or without the application of an external power supply.

Cathodic protection systems without an external power source are referred to as sacrificial systems. The metal used to protect the steel is “less noble” or more prone to corrosion than the steel. Zinc is commonly used for this purpose.

Cathodic protection systems using an external power source are referred to as impressed current systems. This method incorporates an external power supply to force a small amount of external current through the reinforcing steel. The purpose of this current is to counteract the flow of current caused by the corrosion process. A metal that corrodes at a very slow rate, such as platinum, is typically provided to serve as an anode.

1.3.5 Surface Preparation
Probably the most important task to achieve successful concrete repairs is the surface preparation. Good surface preparation requires that minimal damage be done to the remaining concrete at the bond line. Any loose concrete as a result of micro-cracking must be removed. This can be achieved by abrasive blasting or high pressure water jetting. The surface also needs to be clean, free of contaminants, and roughened to an appropriate amplitude for the selected material. The edges of concrete patches should have shoulders to avoid feathering. This is usually accomplished by saw cutting. Repair patches should be made as regular as possible and re-entrant corners should be avoided. See attached Drawing RS1-1 reproduced from ICRI Surface Preparation Guideline 03730.
It is difficult to determine the extent of concrete removal until the work is implemented. The actual quantity of required concrete repairs may vary from the work as shown and specified in the repair documents. Initially the extent of the area to be repaired is sounded with a hammer, chain, or other device to determine the approximate area of removal. All delaminated, unsound, or otherwise unsuitable concrete must be removed. The concrete removal must extend around the existing reinforcing with approximately ¾ Inch (19mm) clearance. At mats of reinforcing, if the lower layer is not corroded and tight, the removal need not extend below the lower layer. If the lower layer of reinforcing is also corroded, the removal must extend below the lower layer. Refer to Drawings RS1-1, RS1-2A and RS1-2B, which are based on ICRI Surface Preparation Guideline 03730.

Impact methods for concrete removal, such as jackhammers, can result in micro-cracking of the substrate. The lightest hammers possible should be used to minimize this impact. Care must be taken to remove all loose concrete prior to installing any overlays or repair materials. For larger projects, hydrodemolition might be an option. This method removes concrete with high pressure water jets which is efficient and leaves a rough profile. After the surface is thoroughly cleaned, it usually is very satisfactory for bonding new concrete. Although, micro-cracking is minimized, containment and subsequent disposal of the water can be a problem.

Note: A typical “Concrete Repair Procedure” is attached to this paper as an example of the steps required to attain proper concrete repairs. It is intended to be used only as a guide and must be modified appropriately for each project. The author cannot assume any liability for its use on any project and does not warranty its accuracy.

References for methods of removal and preparation include:

- ACI 546R-96, *Concrete Repair Guide*, Chapter 2
- ICRI Guideline No. 03730, *Guide for Surface Preparation for the Repair of Deteriorated Concrete Resulting from Reinforcing Steel Corrosion*
1.3.6 Repair Concept:

The method of repair should be designed and detailed to mitigate the damage or deterioration as much as possible. Sometimes it is necessary to rebuild portions of the structure as part of the repair program. There are times when strengthening is required, in addition to repairs. Each project must be carefully evaluated, as previously discussed, prior to selecting a repair method appropriate for that job.

Deterioration adjacent to concrete repair patches commonly occur because of the “Halo of Anodic” Ring effect. When the same bar extends into two distinctly different environments, conditions result in an electrochemical process which may result in corrosion where the new and parent concrete meet (bond line). The build-up of rust at the surface of the reinforcing, usually in the original concrete, leads to spalling, typically around the perimeter of repair patches. This problem must be addressed in repair programs to delay the onset of future corrosion and the need for repairs. The methods to mitigate this problem include:

- Protective coatings
- Migrating corrosion
- Inhibitors
  - Cathodic Protection-impressed current
  - Cathodic Protection-passive

The most common repair methods include:

1) Cast-in-place concrete — Repair by conventional concrete is generally the replacement of defective concrete with new concrete.

2) Form and pour — Formed and poured concrete is a method of replacing damaged or deteriorated concrete by placing a repair mortar in a formed cavity.

3) Troweling — This method is used for shallow and/or limited areas of repair. These repairs are generally made with Portland cement mortars, proprietary cementitious materials or polymer-modified grouts or polymer grouts and mortars.

4) Dry packing — Dry packing is the hand placement of a very dry Portland cement mortar, which is tamped or rammed into place.

5) Preplaced aggregate — In this method the aggregate is placed in the forms first and the voids are filled by pumping in a cementitious or resinous grout. A benefit of this method is a significant reduction of dry shrinkage.

6) Shotcrete — This method involves pneumatically conveying concrete or mortar through a hose at a high velocity onto a surface.
7) Injection grouting — This is a common method for filling cracks or open joints. The materials used for this method can be either cementitious or chemical.

8) External Reinforcing — This method incorporates steel elements, Fiber Reinforced Polymers (FRP), Post-tensioning cables or other materials placed outside or on the surface of structural members to strengthen them.

**1.3.7 Repair Documents**

On many, if not most repair projects, it is difficult to establish the exact scope of work. The documents must be structured to allow for a fair and competitive bid process and to protect the owner for negotiated projects. This can be accomplished by providing the contractors bidding the projects with specified quantities. This requires that the specifier perform a reasonable evaluation of the existing conditions to establish the scope of work. Based on the findings, the specifier must establish quantities for each type of repair or task to be performed by the contractor. The contractors will be asked to provide unit prices for each type of repair so that adjustments can be made for the actual quantities of work performed.

The repair details provided on the documents should be for the known conditions that need repair. It is usually necessary to modify details during construction for actual field conditions, which may vary from the assumed conditions. Re-engineering during construction is not uncommon.

When deterioration is particularly severe or when extensive concrete removal is anticipated, the project documents should caution the contractor that temporary structural support should be anticipated. Special attention should be given to the structural components under repair as well as to adjacent framing. Redistribution of loading during the work should be anticipated and considered during the preparation of the construction drawings. Contingency provisions should be included in the drawings and specifications for addressing potential increases in the scope of work.

The parameters for concrete removal should be defined and, if possible, boundaries of concrete removal and replacement shown on the documents. The specifications and drawings need to establish the criteria for preparation and provide adequate information to provide a standard for acceptance.
1.3.7.1-Bidding/Negotiation process

The selection of a qualified concrete repair contractor is an important aspect of the repair process. Not all repair contractors are proficient in all phases of repair work. If possible, select contractors who have demonstrated competency on projects with work similar to the project being bid.

A Pre-Bid conference should be held with all of the bidders, the engineer and the owner present. This will provide an opportunity for the bidders to ask questions and to increase their awareness of the project objectives and the scope and nature of work. It is best that the meeting be held at the repair site.

Prior to the start of work, a Pre-Construction Meeting should be held which would include the owner, engineer, contractor and their project manager, superintendent, and material suppliers. The contractor should present their schedule for the project at this meeting. The frequency of meeting, field reports, submittals and other items pertaining to the delivery of the project should be discussed at this meeting.

1.3.7.2-Execution of work

The repair work should be executed in accordance with the project documents. Typically the documents will be based on specified quantities. It is thus important that the actual quantity of each type of work be carefully determined and documented. The owner should be informed immediately of any overruns in the specified quantities.

The repair process, especially concrete removal and reinforcing repair, may alter the load distribution of the structure and of the members being repaired. Proper shoring and bracing needs to be provided throughout the construction.

All of the required tasks, including concrete removal and surface preparation, need to be done in accordance with the specifications and drawings and to good industry practice. The installation of materials should be done in strict compliance with the manufacturer’s instructions and the specifications.

Quality control throughout the repair process is essential to any successful project. Appropriate inspections by the engineer and/or testing/inspection agency and contractor needs to be performed on a regular basis. This should be supplemented with field testing as deemed appropriate by the engineer and testing agency.
1.4. Summary and Conclusion

Concrete repair projects are very challenging, as is true with most repair and renovation projects. It is imperative that the engineer understands the reasons which led to the damage and/or deterioration prior to developing a repair program. The underlying causes should be corrected, although this is not always possible. As a minimum, all unsafe conditions must be corrected, and if necessary, temporary shoring or bracing provided, as soon as they are identified.

The owner must be included when formulating a repair program, especially determining the project objectives. Because budget constraints often control the approach to a repair program, it is important that the owner has a clear understanding of what is being done. Furthermore, the owner should be apprised of the anticipated life of the repairs and the long-term costs to maintain that structure, after the repairs are implemented.

Periodic maintenance of structures is essential. Each and every problem should be properly analysed and then the appropriate repair methods undertaken. Primary design of the building reflects its performance in long run. Each repair technique is suitable only for the particular application for which it is meant for. Form and Pump technique which has become the alternative for grouting, gunneting nowadays is also cost effective in large scale operations. Cost should not be significant planning factor in rehabilitation though it is a deciding factor.
Chapter (2)

Repair and Strengthening

Materials and Techniques

2.1- Repair and Strengthening Materials

2.1.1- Introduction

This Chapter contains descriptions of the Various categories of materials that are available for repair and strengthening of concrete structures. Typical properties, advantages, disadvantages or limitations and typical applications will be discussed for each material.

2.1.2- Cementitious Materials

In order to match the properties of the concrete being repaired and strengthened as closely as possible, Portland cement concrete and mortar or other cementitious compositions are frequently the best choices for repair materials.

2.1.2.1-Conventional Concrete

Conventional concrete is composed of Portland cement, aggregates, and water. Admixtures are frequently used to entrain air, accelerate or retard hydration, improve workability, reduce mixing water requirements, increase strength, or alter other properties of the concrete. Pozzolanic materials, such as fly ash or silica fume, may be used in conjunction with Portland cement for economy, or to provide specific properties such as reduced early heat of hydration, improved Later-age strength development, or increased resistance to alkali-aggregate reaction and sulfate attack.
Concrete proportion must be selected to provide workability, density, strength, and durability necessary for the particular application. To minimize shrinkage cracking, the repair and strengthening concrete should have a water-cement ratio as low as possible and a coarse aggregate content as high as possible.

Conventional concrete is readily available, well understood, economical, and relatively easy to produce, place, finish, and cure. Generally, concrete mixtures can be proportioned to match the properties of the underlying concrete; therefore conventional concrete is applicable to a wide range of repairs.

Conventional concrete without admixtures should not be used in repairs and strengthening where the aggressive environment that caused the original concrete to deteriorate has not been eliminated unless a reduced service life is acceptable. When used as a bonded overlay, the shrinkage properties of the repair and strengthening material are critical since the new material is being placed on a material that has exhibited essentially all of the shrinkage that it will experience. Full consideration of the shrinkage properties and the curing procedure should be addressed in the specification for the repair strengthening procedure.

Conventional concrete is often used in repair and strengthening involving relatively thick sections and large volumes of repair and strengthening material. Typically, conventional concrete is appropriate for partial-and full-depth repairs and resurfacing overlays where the minimum thickness is greater than about 100 mm on walls piers, and hydraulic structures conventional concrete is particularly suitable for repair and strengthening in marine environments because the typically
high humidity in such environments minimizes the potential for shrinkage.\textsuperscript{[1]}

\textbf{2.1.2.2--Conventional Mortar}

Conventional mortar is a mixture of Portland cement, fine aggregate, and water. Water - reducing admixtures, expansive agents, and other modifiers are often used with conventional mortar to minimize shrinkage.

The advantages of conventional mortar are similar to those of conventional concrete. In addition, mortar can be placed in thinner sections. A wide variety of prepackaged mortars is available. They are particularly appropriate for small repair and strengthening.

Mortars generally exhibit increased drying shrinkage compared to concrete because of their higher water volume, higher unit cement content, and higher paste-aggregate ratio.

Conventional mortar can be used in the same situations as conventional concrete wherever thin repair sections are required.

\textbf{2.1.2.3--Dry Pack Mortar}

Dry pack mortar may consist of one part cement, two and one-half to three parts sand, or prepackaged proprietary materials, and only enough water so the mortar will stick together when molded into a ball by slight pressure of the hands and will not exude water but will leave the hands damp. Curing is critical because of the low initial water content of dry pack mortar.
Because of its low water-cement ratio, dry pack exhibits very little shrinkage. Therefore, the patch remains tight and is of good quality with respect to durability, strength, and water tightness. If the patch must match the color of the surrounding concrete, a blend of gray and white Portland cement may be used. Normally, about one-third white cement is adequate, but the precise proportions can only be determined by trial.

Dry pack is not well suited for patching shallow depressions or for patching areas requiring filling behind exposed reinforcement, or for patching holes extending entirely through concrete sections. Without adequate curing, dry pack repairs are subject to failure.

Dry pack can be used for filling large or small cavities form tie holes, or any cavity that allows for adequate compaction. Such repairs can be accomplished on vertical and overhead surfaces without forms. Dry pack can also be used for filling narrow slots cut for the repair of dormant cracks, however, it is not recommended for filling or repairing active cracks.

2.1.2.4-Ferrocement

Ferrocement is a term used to describe a form of reinforced concrete that differs from conventional reinforced or prestressed concrete primarily by the manner in which the reinforcing elements are dispersed and arranged. Ferrocement is commonly constructed of hydraulic cement mortar reinforced with closely spaced layers of continuous and relatively small diameter wire mesh. The mesh may be made of steel or other suitable materials. [2]
Ferrocement has a very high tensile strength – to – weight ratio and superior cracking behavior in comparison to reinforced concrete.

Since no formwork is required, ferrocement is especially suitable for repair and strengthening of structures with curved surfaces such as shells, and free-form shapes.

The use of ferrocement in a repair situation will simply be limited by the nature of the repair and strengthening.

2.1.2.5- Fiber – reinforced Concrete

Fiber-reinforced concrete is conventional concrete with either metallic or polymeric fibers added to achieve greater resistance to plastic shrinkage and service-related cracking. In most applications, fiber reinforcing is not intended as primary reinforcement. Fiber reinforced concrete has been used for repair and strengthening using conventional and shotcrete placement methods. [3]

The fibers are added during concrete production and are in the concrete when it is placed. These fibers can be used to provide reinforcing in thin overlays that are not thick enough to include reinforcing bars.

Fiber reinforced concrete has been used for overlays of concrete pavements, slope stabilization, and reinforcement of structures such as arches or domes. Reinforced concrete structures have been repaired with fiber-reinforced shotcrete. Areas subject to shock or vibration loading, where plastic shrinkage cracking is a problem, or where blast resistance is required, could benefit from the addition of fiber reinforcement.
The addition of fibers reduces the slump and can cause workability problems for inexperienced workers. Rust stains may occur at the surface of steel fiber-reinforced concrete due to corrosion of fibers at the surface. In patching applications, the electrical conductivity of the patch material, when using metallic fibers, could influence corrosion activity when patches are installed around previously damaged reinforcement. For other applications, a wicking effect suggests that permeability may be higher than for conventional concrete systems of equivalent thickness. Curing and protection of fiber-reinforced concrete should be similar to that for equivalent conventionally reinforced concrete.

2.1.2.6- Grouts

The grouts described herein are categorized as either hydraulic cement or chemical.

a) Cement Grouts

Cement grouts are mixtures of hydraulic cement, aggregate, and admixtures that when mixed with water produces a trowellabl, flowable, or pumpable consistency without segregation of the constituents. Admixtures are frequently included in the grout to accelerate, or retard time of setting, minimize shrinkage, improve pumpability or workability, or to improve the durability of the grout. Mineral fillers may be used for reasons of economy when substantial quantities of grout are required.

Cement grouts are economical, readily available, easy to install, and compatible with concrete. Admixtures can be used to modify cement grouts to meet specific job requirements at relatively low cost. Admixtures to minimize shrinkage are available on the market.
Cement grouts may be used for repairs by injection only where the width of the opening is sufficient to accept the solid particles suspended in the grout. Normally, the minimum crack width at the point of introduction should be about 3 mm.

Typical applications of hydraulic cement grout may vary from grout slurries for bonding old concrete to new concrete to filling of large dormant cracks or to filling of voids around or under a concrete structure. No shrink cement grouts may be used to repair spalled or honeycombed concrete or to install anchor bolts in hardened concrete.

b) Chemical Grouts

Chemical grouts consist of solutions of chemicals that react to form either a gel or a solid precipitate as opposed to cement grouts that consist of suspensions of solid particles in a fluid. The reaction in the solution may involve only the constituents of the solution, or it may include the interaction of the solution with other substances, such as water, encountered in the use of the grout. The reaction causes a decrease in fluidity and a tendency to solidify and fill voids in the material into which the grout has been injected.

The advantages of chemical grouts include their applicability in moist environments, their wide ranges of gel setting time, and their low viscosities. Cracks in concrete as narrow as 0.05 mm have been filled with chemical grout. Rigid chemical grouts, such as epoxies, exhibit excellent bond to clean, dry substrates, and some will bond to wet concrete. These grouts can restore the full strength of a cracked concrete member. Gel-type or foam chemical grouts, such as acryl amides and
polyurethanes, are particularly suited for use in control of water flow through cracks and joints. Some gel grouts can be formulated at viscosities near that of water so they can be injected into almost any opening that water will flow through.

Chemical grout are more expensive than cement grout. Also, a high degree of skill is needed for satisfactory use of chemical grouts. Chemical bonding agents, such as epoxies, have relatively short pot life and working times at high ambient temperatures. Gel grouts should not be used to restore strength to a structural member. Most gel or foam grouts are water solutions and will exhibit shrinkage if allowed to dry in service.

Repair of fine cracks, either to prevent moisture migration along the crack or to restore the integrity of a structural member, is one of the most frequent applications of chemical grout. Some grouts, such as epoxies, are frequently used as bonding agents.

**2.1.2.7- Low Slump Dense Concrete**

Low slump dense concrete (LSDC) is a special form of conventional concrete. It generally has a moderate to high cement factor, a water- cement ratio less than 0.40, and exhibits working slumps of 50 mm or less. LSDC generally gains strength rapidly and is distinctive because of its high density and reduced permeability.

Overlays of LSDC with a minimum thickness of only 38 mm have provided up to 20 years of service when properly installed. The cost of LSDC is relatively low, and it can be placed using conventional equipment with slight modifications. Compared to structural grade concrete, LSDC provides reduced chloride permeability.
LSDC’s require maximum consolidation effort to achieve optimum density, or the use of a high-range water-reducing admixture (HRWRA) to improve workability of the concrete and reduce the compaction effort needed to provide bond to the reinforcing steel and to the underlying concrete. These low water-cement ratio concretes generally require at least 7 days of continuous moist curing obtaining adequate hydration. LSDC permits galvanic corrosion even with a 0.32 water cement ratio and 25 mm cover. Drying shrinkage cracks, depending on crack width and depth, can increase chloride ion intrusion resulting in corrosion of the reinforcing steel in bridge deck overlays.

LSDC is frequently used as an overlay or final wearing course in a composite repair and strengthening to obtain a high (acceptable) quality, abrasion resistant, and durable concrete surface.

**2.1.2.8- Magnesium Phosphate Concretes and Mortars**

Magnesium phosphate concretes and mortars (MPC) are based on a hydraulic cement system that is different from Portland cement. Unlike Portland and some modified Portland cement concretes which require moist curing for optimum property development, these systems produce their best properties upon air curing—similar to epoxy concretes. Rapid strength development and heat are produced although retarded versions are available that produce less heat.

Setting times of 10 to 20 minutes are typically encountered at room temperatures, and early strength development of 14 MPa within 2 hours is regularly obtained. Retarded versions with extended setting times of 45 to 60 minutes at room temperature are also available. Salt-scale resistance is similar to Portland cement based concrete materials. When extended with aggregates, abrasion resistance of MPC is similar to
PCC. Neat magnesium phosphate cement will naturally have lower abrasion resistance, similar to Portland cement mortars.

Patching applications are the most common use of MPC. It is frequently cost effective for rapid repairs where a short down time is important. The common uses are in highway, bridge deck, airport, tunnel, and industrial repairs. Repairs in a cold-weather environment are important applications. Due to the exothermic nature of the reaction, heating of the materials and the substrates is not usually necessary unless the temperature is below freezing. MPC is useful for cold weather embedments and anchoring because of its high bond strength and low shrinkage rate.

2.1.2.9- Preplaced- aggregate Concrete

Preplaced- aggregate concrete is produced by placing coarse aggregate in a form and later injecting a Portland cement-stand grout (usually with admixtures), or a resinous material to fill the voids. Preplaced- aggregate concrete differs from conventional concrete in that it contains a higher percentage of coarse aggregate.

Because of the point – to – point contact of the coarse aggregate, drying shrinkage of preplaced- aggregate concrete is about one-half that of conventional concrete. Because the aggregate is preplaced and the grout pumped under pressure, segregation is not a problem and virtually all substrate voids will be filled with mortar.

Typically, preplaced- aggregate concrete is used on large repair projects, particularly where underwater concrete placement is required or when conventional placing of concrete would be difficult. Typical applications have included underwater repair of stilling basins, dams,
Preplaced-aggregate concrete has also been used to repair and strengthening beams and columns in industrial plants, water tanks and other similar facilities, as well as caissons for underpinning existing structures.

**2.1.2.10- Rapid - Setting Cement**

Rapid-setting cementitious materials are characterized by short setting times. Some may exhibit very rapid strength development with compressive strengths in excess of 6.9 MPa within 3 hours. Type III Portland cement with accelerators has been used for the patching of concrete for a long time and has been more widely used than most other materials in full depth sections. [7]

Rapid-settings cements provide accelerated strength development that allows the repair to be placed into service more quickly than conventional repair materials. This advantage is of importance in repair of highways and bridges because of the reduced protection times, lower traffic control costs, and improved safety.

Rapid-settings cements are especially useful in repair and strengthening situations where an early return to traffic is required, such as repair of pavements, bridge decks, and airport runways.

**2.1.2.11- Shotcrete**

Shotcrete is a mixture of Portland cement, sand, and water “shot” into place by compressed air. In addition to these materials, shotcrete can also contain coarse aggregate, fibers, and admixtures. Properly applied shotcrete is a structurally adequate and durable repair material which is
capable of excellent bond with existing concrete or other construction materials.

The successful application of shotcrete is dependent on the training, skill, and experience of the nozzlemans. The nozzlemans should be required to demonstrate his skill by placing a test panel that reflects the site conditions. His performance should be evaluated and approved before he is allowed on the job. Dust and rebound require special attention in indoor application.

2.1.2.12- Shrinkage-compensating Concrete

Shrinkage-compensating concrete is an expansive-cement concrete which is used to minimize cracking caused by drying shrinkage the basic materials and methods are similar to produce high-quality Portland cement concrete. Consequently, the characteristics of shrinkage-compensating concrete are, in most respects, similar to those of Portland-cement concrete.

When properly restrained by reinforcement, shrinkage-compensating concrete will expand an amount equal to or slightly greater than the anticipated drying shrinkage. Subsequent drying shrinkage will reduce these expansive strains but, a residual expansion will remain in the concrete, thereby eliminating shrinkage cracking.

Shrinkage-compensating concrete has been used to minimize cracking caused by drying shrinkage in replacement concrete slabs, pavements, bridge decks, and structures. Also, shrinkage-compensating concrete has been used to reduce warping tendencies where concrete is exposed to single face drying and carbonation shrinkage.
2.1.2.13- Silica- Fume Concrete

Silica fume, a by-product in the manufacture of silicon and ferrosilicon alloys, is an efficient pozzolanic material. Adding silica fume and a high range water-reducing admixture to a concrete mixture will significantly increase compressive strength, decrease permeability, and thus improve durability. Silica fume is added to concrete in either liquid or powder form in quantities of 5 to 15 percent by weight or cement. Compressive strengths of 33 to 103 MPa can be attained with silica-fume concrete. [9]

The first major applications of silica–fume concrete in the United States were for repair and strengthening of hydraulic structures subjected to abrasion-erosion damage (Holland and Gutschow, 1987). The high strength of silica-fume concrete and the resulting abrasion-erosion resistance appear to offer an economical solution to abrasion-erosion problems, particularly in those areas where locally available aggregate otherwise might not make acceptable concrete. Silica-fume concrete has been used extensively in overlays on parking structures and bridge decks to reduce the intrusion of chloride ions into the concrete.

2.1.2.14- Bonding Materials

Bonding materials can be used to bond new repair materials to an existing prepared concrete substrate. Bonding materials are of three types: epoxy based, latex based, and cement based.

a) Epoxy: Care should be taken when using these materials in hot weather. High temperatures may cause premature curing and the creation of a bond break. Most epoxy resin bonding materials create a moisture barrier between the existing substrate and the repair material.
b) **Latex:** Latex bonding agents are classified as Type I – Redispersible and Type II – Non – redispersible. Type I bonding agents can be applied to the bonding surface several days prior to placing the repair materials; however, the bond strength is less than that provided by Type II bonding agents. Type I bonding agents should not be used in areas subject to water, high humidity, or structural applications. Type II systems act as bond breakers once they have skinned over or cured.

c) **Cement:** Cement based systems have been used for many years. Cement bonding systems use neat Portland cement or a blend of Portland cement and fine aggregate filler generally proportioned one to one by weight. Water is added to provide a uniformly creamy consistency.

### 2.1.3- Polymer Materials

The improvement of properties of hardened concrete by the addition of polymers is well documented. This guide presents information on various types of polymer materials and on their storage, handling, and use, as well as on concrete formulations, equipment to be used, construction procedures, and applications.\[11\]

Three basic types of concrete materials use polymers to form composites, each type of material will be discussed in the following sections.

#### 2.1.3.1- Polymer-impregnated Concrete

PIC is a hydrated Portland-cement concrete that has been impregnated with a monomer that is subsequently polymerized. Impregnation is usually done using monomers which contain a polymerization initiator that can be activated by heat. The most widely
used monomer is methyl methacrylate, although other monomers have been used. With polymer loadings of 1.5 to 2.5 percent by weight, and depths of impregnation of at least 6 mm and up to 38 mm, significant improvements in durability can be achieved. It is important to achieve a complete shell of impregnated concrete at the exposed surfaces.

Almost all existing types of concrete, whether they were cast with impregnation in mind or not, can be impregnated provided the proper procedures are followed. The impregnation of concrete surfaces with a suitable polymer has been shown to improve several important properties, including abrasion resistance; resistance to penetration by, and damage from water, acids, salts, and other deleterious media; and resistance to cycles of freezing and thawing.

Polymer impregnation reduces the permeability of concrete and thereby increases its durability in exposure to aggressive agents. However, impregnation does not render the concrete completely impermeable, and since concrete is still exposed, aggressive agents, such as sulfuric acid, will attack the concrete slowly. Cracks that are not sealed could serve as channels for ingress of aggressive agents into the concrete thereby defeating the purpose of the surface impregnation treatment. Cracks are also likely to occur during drying of the concrete prior to application of the monomer, and all of these cracks may not be filled during the impregnation process. All cracks must be filled with the polymer to achieve a reduction in permeability and corresponding increase in durability.

Polymer impregnation has been applied to existing concrete structures to improve durability, reduce maintenance requirements, and restore deteriorated concrete. The process has been used in a variety of
applications including bridge decks, spillways, stilling basins, curbstones, concrete pipes and mortar-lined steel pipes, and deteriorated buildings.

2.1.3.2- Polymer-modified Concrete:

Polymer-modified concrete (PMC) has at times been called polymer-portland-cement concrete (PPCC) and latex-modified concrete (LMC). It is identified as Portland cement and aggregate combined at the time of mixing with organic polymers that are dispersed or redispersed in water. This dispersion is called a latex, and the organic polymer is a substance composed of thousands of simple molecules combined into large molecules. The simple molecules are known as monomers and the reaction that combines them is called polymerization. The polymer may be a homopolymer if it is made by the polymerization of one monomer or a copolymer if two or more monomers are polymerized.

Polymer dispersions are added to the concrete to improve the properties of the final product. These properties include improved bond strength to concrete substrates, increased flexibility and impact resistance, improved resistance to penetration by water and by dissolved salts, and improved resistance to frost action.

Of the wide variety of polymers investigated for use in PMC, polymers made by emulsion polymerization have been the most widely used and accepted. Styrene butadiene and acrylic latexes have been the most effective and predictable for concrete restoration. Other latexes commonly used include polymers and copolymers of vinyl acetate. \cite{12}

When emulsified and mixed with concrete, epoxies provide excellent freeze-thaw resistance, significantly reduced permeability, and improved chemical resistance. Bond is excellent and flexural,
compressive, and tensile strengths are high. However, epoxy emulsions have had limited use in concrete.

Latex-modified concrete (LMC) overlays have exhibited excellent long-term performance. Properly installed overlays are highly resistant to freeze-thaw damage, and they exhibit minimal bond failure after many years of service. LMC overlays installed on severely deteriorated bridge decks, after proper surface preparation, continue to perform many years after installation.

Mixing and handling of PMC is similar to conventional Portland cement concrete and mortar. Curing, however, is different. Whereas conventional concrete requires extended periods of moist curing, PMC generally requires one day to two days of moist curing followed by air curing. The PMC is placed in service when it has developed sufficient strength, which is dependent upon the hydration of the cement.

An advantage of latex-modified concrete is its good workability and ease of application when compared to similar systems. The bonding characteristics of latex-modified concrete are excellent and latex-modified concrete usually exhibits low permeability. Styrene-butadiene LMC has excellent durability for exterior exposures or environment where moisture is present. Surface discoloration will occur when the concrete is exposed to UV light. Where such discoloration is not acceptable, acrylic polymers should be used.

Like conventional concrete, latex modified concrete should be placed and cured at 7 to 30 °C with special precautions taken when either extreme is reached. It is recommended that mobile, continuous mixers, fitted with an additional storage tank for the latex, be used for large applications of LMC.
Like many mixtures with a low water-cementitious materials ratio, LMC has a tendency for plastic shrinkage cracking during field placement. Special precautions are necessary when the evaporation rate exceeds 0.5 kg/m$^2$/hr. Latex modified concrete, similar to other Portland cement based materials, is susceptible to shrinkage cracking, which may allow ingress of chloride ions in some applications. The modulus of elasticity is generally lower compared to conventional concrete; therefore its use in vertical or axially loaded members should be carefully evaluated. Polyvinyl acetate should not be used in applications that may be exposed to moisture. Epoxy emulsions are more expensive than most latexes, and some are susceptible to color change and deterioration from exposure to sunlight.

PMC applications include overlays of bridge decks, parking structures and floors, and patching of any concrete surfaces. Styrene butadiene latex has been commonly used for repair and or strengthening of bridges, parking decks and floors. Acrylic latexes have been used for floor repair and patching and are particularly suitable in exterior white cement applications where color retention is important.

Latex concrete is most commonly used for overlays. It is normally applied in sections ranging from 19 to 50 mm thick. These systems restore lost sections and provide a new, high-strength wearing surface that is very durable against weathering. Although used as overlay materials, polymer-modified concretes are effective patching materials. Since most patches and repairs in which PMC is used are relatively shallow, mixture proportions similar to those shown in ACI 548.3R should be considered.
2.1.3.3- Polymer Concrete:

PC is a composite material in which the aggregate is bound together in a dense matrix with a polymer binder. The composites do not contain a hydrated cement phase, although Portland cement can be used as an aggregate or filler. The term PC should never suggest a single product, but rather a family of products. Use of the term PC in this section also includes mortar.

PC has been made with a variety of resins and monomers including polyester, epoxy, furan, vinylester, methyl methacrylate (MMA), and styrene. Polyester resins are attractive because of moderate cost, availability of a great variety of formulations, and moderately good PC properties. Furan resins are low cost, and highly resistant to chemical attack. Epoxy resins are generally higher in cost, but may offer advantages such as adhesion to wet surfaces. Detailed information on the use of epoxy compounds with concrete is available. [15]

The properties of PC are largely dependent upon the properties and the amount of the polymer used, modified somewhat by the effects of the aggregate and the filler materials. Typically, PC mixtures exhibit a) rapid curing, b) high tensile, flexural, and compressive strengths, c) good adhesion to most surfaces, d) good freeze-thaw durability, e) low permeability to water and aggressive solutions, and f) good chemical resistance.

PC can provide a fast-curing, high-strength patching material that is suitable for repair of Portland cement concrete structures. PC is mixed, placed, and consolidated in a manner that is similar to conventional concrete. With some harsh mixtures, external vibration is required.
A wide variety of prepackaged polymer mortars is available which can be used as mortars or added to selected blends of aggregates. Depending upon the specific use, mortars may contain variable aggregate gradations intended to impart unique surface properties or aesthetic effects to the structure being repaired. Also, polymer mortars are available that are trowellable and specifically intended for overhead or vertical applications.

Epoxy mortars generally shrink less than polyester or acrylic mortars. Shrinkage of polyester and acrylic mortars can be reduced by using an optimum aggregate loading. The aggregate grading and the mixture proportions should be available from the polymer formulator.

Organic solvents may be needed to clean equipment when using polyesters and epoxies. Volatile systems such as MMA evaporate quickly and present no cleaning problems. However, such systems are potentially explosive and require nonsparking and explosion-proof equipment. It should be recognized that rapid curing generally means less time for placing and finishing operations. Working times for these materials are variable and, depending on ambient temperatures, may range from less than 15 minutes to more than one hour. Also, high or low ambient and concrete temperatures may significantly affect polymer cure time or performance.

The coefficients of thermal expansion of polymer materials are variable from one product to another, and are significantly higher than conventional concrete. Shrinkage characteristics of PC's must be closely evaluated so that unnecessary shrinkage cracking is avoided.

The modulus of elasticity of PC may be significantly lower than that of conventional concrete, especially at higher temperatures. Its use in
load carrying members must be carefully considered. Only a limited number of polymer systems are appropriate for repair of wet concrete surfaces. In general, the aggregates used in PC should be dry in order to obtain the highest strengths.

High temperatures can adversely affect the physical properties of certain PC's, causing softening. Service temperatures should be evaluated prior to selecting PC systems for such use. Epoxy systems may burn out in fires where temperatures exceed 450 °F (230 °C) and can significantly soften at lower temperatures. Users of PC must consider its lack of fire resistance. Conventional concrete generally will not bond to cured PC, and compatibility of the systems should be considered.

Many PC patching materials are primarily designed for the repair and / or strengthening of highway structures where traffic conditions allow closing of a repair area for only a few hours. However, PC's are not limited to that usage and can be formulated for a wide variety of applications. PC is used in several types of applications; 1) fast-curing, high-strength patching of structures, and 2) thin (5 to 19 mm thick) overlays for floors and bridge decks.

Polymer mortars have been used in a variety of repair and / or strengthening where only thin sections (patches and overlays) are required. Polymers with high elongation and low modulus of elasticity are particularly suited for bridge overlays. PC overlays are especially well suited for use in areas where concrete is subject to chemical attack. [16]
**2.1.4- Fiber Reinforcement Polymer Materials**

FRP materials consists of a large number of small, continuous, directionalized, non-metallic fibers with advanced characteristics, bundled in a resin matrix. Depending on the type of fiber they are referred to as AFRP (aramid fiber based), CFRP (carbon fiber based) or GFRP (glass fiber based). Typically, the volume fraction of fibers in FRPs equals about 50-70% for strips and about 25-35% for sheets. Hence fibers are the principal stress bearing constituents, while the resin transfers stresses among fibers and protects them.

**2.1.4.1- Adhesives**

The purpose of the adhesive is to provide a shear load path between the concrete surface and the composite material, so that full composite action may develop. The most common type of structural adhesives will be discussed here, namely epoxy adhesive, which is the result of mixing an epoxy resin (polymer) with a hardener. Depending on the application demands, the adhesive may contain fillers, softening inclusions, toughening additives and others. The successful application of an epoxy adhesive system requires the preparation of an adequate specification, which must include such provisions as adherent materials, mixing / application temperatures and techniques, curing temperatures, surface preparation techniques, thermal expansion, creep properties, abrasion and chemical resistance.

When using epoxy adhesives there are two different time concepts that need to be taken into consideration. The first is the pot life and the second is the open time. Pot life represents the time one can work with the adhesive after mixing the resin and the hardener before it starts to
harden before it starts to harden in the mixture vessel; for an epoxy adhesive, it may vary between a few seconds up to several years. Open time is the time that one can have at his/her disposal after the adhesive has been applied to the adherents and before they are joined together. Another important parameter to consider is the glass transition temperature, Tg. Most synthetic adhesives are based on polymeric materials, and as such they exhibit properties that are characteristic for polymers change from relatively hard, elastic, glass-like to relatively rubbery materials at a certain temperature. This temperature level is defined as glass transition temperature, and is different for different polymers.

Epoxy adhesives have several advantages over other polymers as adhesive agents for civil engineering use: [17]

a) High surface activity and good wetting properties for a variety of substrates.

b) May be formulated to have a long open time.

c) High cured cohesive strength; joint failure may be dictated by adherent strength.

d) May be toughened by the inclusion of dispersed rubbery phase.

e) Lack of by-products from curing reaction minimizes shrinkage and allows the bonding of large areas with only contact pressure.

f) Low shrinkage compared with polyesters, acrylics and vinyl types.

g) Low creep and superior strength retention under sustained load.

h) Can be made thixotropic for application to vertical surfaces.
i) Able to accommodate irregular or thick bond lines.

Typical properties for cold cured epoxy adhesives used in civil engineering applications are given in Table 3.1. for the sake of comparison, the same table provides information for concrete and mild steel too.\(^{[18]}\)

<table>
<thead>
<tr>
<th>Property (at 20 °C)</th>
<th>Cold-curing epoxy adhesive</th>
<th>Concrete</th>
<th>Mild steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (kg/m³)</td>
<td>1100-1700</td>
<td>2350</td>
<td>7800</td>
</tr>
<tr>
<td>Young's modulus (GPa)</td>
<td>0.5-20</td>
<td>20-50</td>
<td>205</td>
</tr>
<tr>
<td>Shear modulus (GPa)</td>
<td>0.2-8</td>
<td>8-21</td>
<td>80</td>
</tr>
<tr>
<td>&quot;Poisson's ratio</td>
<td>0.3-0.4</td>
<td>0.2</td>
<td>0.3</td>
</tr>
<tr>
<td>Tensile strength (MPa)</td>
<td>9-30</td>
<td>1-4</td>
<td>200-600</td>
</tr>
<tr>
<td>Shear strength (MPa)</td>
<td>10-30</td>
<td>2-5</td>
<td>200-600</td>
</tr>
<tr>
<td>Compressive strength (MPa)</td>
<td>55-110</td>
<td>25-150</td>
<td>200-600</td>
</tr>
<tr>
<td>Tensile strain at break (%)</td>
<td>0.5-5</td>
<td>0.015</td>
<td>25</td>
</tr>
<tr>
<td>Approximate fracture energy (Jm-2)</td>
<td>200-1000</td>
<td>100</td>
<td>105-106</td>
</tr>
<tr>
<td>Coefficient of thermal expansion (10⁻⁶/°C)</td>
<td>25-100</td>
<td>11-13</td>
<td>10-15</td>
</tr>
<tr>
<td>Water absorption: 7days – 25 °C (% w/w)</td>
<td>0.1-3</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Glass transition temperature (°C)</td>
<td>45-80</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

Table 2.1: Comparison of typical properties for epoxy adhesives, concrete and steel.

2.1.4.2- Matrices

The matrix for a structural composite material can either be of thermosetting type or of thermoplastic type, with the first being the most common one. The function of the matrix is to protect the fibers against abrasion or environmental corrosion, to bind the fibres together and to distribute the load. The matrix has a strong influence on several mechanical properties of the composite, such as the transverse modulus.
and strength, the shear properties and the properties in compression. Physical and chemical characteristics of the matrix such as melting or curing temperature, viscosity and reactivity with fibres influence the choice of the fabrication process. Hence, proper selection of the matrix material for a composite system requires that all these factors be taken into account. [19]

Epoxy resins, polyester and vinylester are the most common polymeric matrix materials used with high-performance reinforcing fibres. They are thermosetting polymers with good processibility and good chemical resistance. Epoxies have, in general, better mechanical properties than polyesters and vinylesters, and outstanding durability, whereas polyesters and vinylesters are cheaper.

2.1.4.3- Fibres

There are mainly three types of fibres that are used for strengthening of civil engineering structures, namely glass, aramid and carbon fibres. It should be recognized that the physical and mechanical properties can vary a great for a given type of fibre as well of course the different fibre types.

Glass fibres for continuous fibre reinforcement are classified into three types: E-glass fibres, S-glass and alkali resistant AR-glass fibres. E-glass fibres, Which contain high amount of boric acid and aluminate, are disadvantageous in having low alkali resistance. S-glass fibres are stronger and stiffer than E-glass, but still not resistant to alkali. To prevent glass fibre from being eroded by cement-alkali, a considerable amount of zircon is added to produce alkali resistance glass fibres; such
fibres have mechanical properties similar to E-glass. An important aspect of glass fibres is their low cost.

Aramid fibres were first introduced in 1971, and today are produced by several manufacturers under various brand names. The structure of aramid fibre is anisotropic and gives higher strength and modulus in the fibre longitudinal direction. The diameter of aramid fibre is approximately 12 um. Aramid fibres respond elastically in tension but they exhibit non-linear and ductile behavior under compression; they also exhibit good toughness, damage tolerance and fatigue characteristics.

Carbon fibres are normally either based on pitch or PAN, as raw material. Pitch fibres are fabricated by using refined petroleum or coal pitch that is passed through a thin nozzle and stabilized by heating. PAN fibres are made of polyacrylonitrile that is carbonised through burning. The diameter of pitch-type fibres measures approximately 9-18 um and that of the PAN-type measures 5-8 um. The structure of this carbon fibre varies according to the orientation of the crystals; the higher the carbonation degree, the higher the orientation degree and rigidity as a result of growing crystals. The pitch base carbon fibres offer general purpose and high strength / elasticity materials. The PAN-type carbon fibres yield high strength materials and high elasticity materials.

Typical properties of various types of fibre materials are provided in Table 3.2. Note that values in this table are only indicative of static strength of unexposed fibers. [20]
<table>
<thead>
<tr>
<th>Material</th>
<th>Elastic modulus (GPa)</th>
<th>Tensile strength (MPa)</th>
<th>Ultimate tensile strain (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High strength</td>
<td>215-235</td>
<td>3500-4800</td>
<td>1.4-2.0</td>
</tr>
<tr>
<td>Ultra high strength</td>
<td>215-235</td>
<td>3500-6000</td>
<td>1.5-2.3</td>
</tr>
<tr>
<td>High modulus</td>
<td>350-500</td>
<td>2500-3100</td>
<td>0.5-0.9</td>
</tr>
<tr>
<td>Ultra high modulus</td>
<td>500-700</td>
<td>2100-2400</td>
<td>0.2-0.4</td>
</tr>
<tr>
<td>Glass</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>70</td>
<td>1900-3000</td>
<td>3.0-4.5</td>
</tr>
<tr>
<td>S</td>
<td>85-90</td>
<td>3500-4800</td>
<td>4.5-5.5</td>
</tr>
<tr>
<td>Aramid</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low modulus</td>
<td>70-80</td>
<td>3500-4100</td>
<td>4.3-5.0</td>
</tr>
<tr>
<td>High modulus</td>
<td>115-130</td>
<td>3500-4000</td>
<td>2.5-3.5</td>
</tr>
</tbody>
</table>

Table 2.2: Typical properties of fibres
2.2 Techniques of Repairing of Reinforced Concrete Structures :-

2.2.1. Introduction:-

• 3 Basic symptoms of distress in a concrete structure.

• Cracking, Spalling and Disintegration.

• Reasons for their development may be poor materials, poor design, poor construction practice, poor supervision or a combination.

• Repair of cracks usually does not involve strengthening.

• Repair of a structure showing spalling and disintegration, it is usual to find that there have been substantial losses of section and/or pronounced corrosion of the reinforcement.

2.2.2 Repairing Cracks:

• In order to determine whether the cracks are active or dormant, periodic observations are done utilizing various types of telltales.

  ▪ By placing a mark at the end of the crack.

  ▪ A pin or a toothpick is lightly wedged into the crack and it falls out if there is any extension of the defect.

  ▪ A strip of notched tape works similarly :

    Movement is indicated by tearing of the tape.

  ▪ The device using a typical vernier caliper is the most satisfactory of all.

    Both extension and compression are indicated.

  ▪ If more accurate readings are desired, extensometers can be used.
Where extreme accuracy is required resistance strain gauges can be glued across the crack.

2.2.3 Types of Cracks:

- Active cracks and dormant cracks.
- The proper differentiation between active and dormant cracks is one of magnitude of movement, and the telltales are a measure of the difference.
- If the magnitude of the movement, measured over a reasonable period of time (say 6 months or 1 year), is sufficient to displace or show significantly on the telltales, we can treat the crack as an active one.
- If the movements are smaller, the crack may be considered as dormant.
- Cracks can also be divided into solitary or isolated cracks and pattern cracks.
• Generally, a solitary crack is due to a positive overstressing of the concrete either due to load or shrinkage.

• Overload cracks are fairly easily identified because they follow the lines demonstrated in laboratory load tests.

• In a long retaining wall or long channel, the regular formation of cracks indicates faults in the design rather than the construction, but an irregular distribution of solitary cracks may indicate poor construction as well as poor design.

• Regular patterns of cracks may occur in the surfacing of concrete and in thin slabs. These are called pattern cracks.

2.2.4. Techniques of Repairing Cracks

2.2.4.1 Bonding with Epoxies:

• Cracks in concrete may be bonded by the injection of epoxy bonding compounds under pressure.

• Usual practice is to:
  ▪ Drill into the crack from the face of the concrete at several locations.
  ▪ Inject water or a solvent to flush out the defect.
  ▪ Allow the surface to dry.
  ▪ Surface-seal the cracks between the injection points.
  ▪ Inject the epoxy until it flows out of the adjacent sections of the crack or begins to bulge out the surface seals.
- Usually the epoxy is injected through holes of about ¾ inch in diameter and ¾ inch deep at 6 to 12 inches centers.

- Smaller spacing is used for finer cracks.

- The limitation of this method is that unless the crack is dormant or the cause of cracking is removed and thereby the crack is made dormant, it will probably recur, possibly somewhere else in the structure.

- Also, this technique is not applicable if the defects are actively leaking to the extent that they cannot be dried out, or where the cracks are numerous.

### 2.2.4.2 Routing and Sealing:

- This method involves enlarging the crack along its exposed face and filling and sealing it with a suitable material.

- The routing operation.

- Placing the sealant.

- This is a method where thorough water tightness of the joint is not required and where appearance is not important.
2.2.4.3. Stitching:

- Concrete can be stitched by iron or steel dogs.

- A series of stitches of different lengths should be used.

- Bend bars into the shape of a broad flat bottomed letter U between 1 foot and 3 feet long and with ends about 6 inches long.

- The stitching should be on the side, which is opening up first.
Fig. 2.3 Stitching

- If necessary, strengthen adjacent areas of the construction to take the additional stress.

- The stitching dogs should be of variable length and/or orientation and so located that the tension transmitted across the crack does not devolve on a single plane of the section, but is spread out over an area.

- In order to resist shear along the crack, it is necessary to use diagonal stitching.

- The lengths of dogs are random so that the anchor points do not form a plane of weakness.

**2.2.4.4. External Stressing:**

- Cracks can be closed by inducing a compressive force, sufficient to overcome the tension and to provide a residual compression.

- The principle is very similar to stitching, except that the stitches are tensioned; rather than plain bar dogs which apply no closing force to the crack.

- Some form of abutment is needed for providing an anchorage for the prestressing wires or rods.
2.2.4.5. Grouting:

- Same manner as the injection of an epoxy.
- Cleaning the concrete along the crack.
- Installing built-up seats at intervals along the crack.
- Sealing the crack between the seats with a cement paint or grout.
- Flushing the crack to clean it and test the seal; and then grouting the whole.
2.2.4.6. Blanketing:

- Similar to routing and sealing.
- Applicable for sealing active as well as dormant cracks.
- Preparing the chase is the first step.
- Usually the chase is cut square.
- The bottom should be chipped as smooth to facilitate breaking the bond between sealant and concrete.
- The sides of the chase should be prepared to provide a good bond with the sealant material.
- The first consideration in the selection of sealant materials is the amount of movement anticipated.
- And the extremes of temperature at which such movements will occur.
- Elastic sealants.
- Mastic sealants.
- Mortar-plugged joints.
Fig. 2.5 Type of chase

Fig. 2.6 Sealed chase
2.2.4.7 Use of Overlays:

- Sealing of an active crack by use of an overlay requires that the overlay be extensible and not flexible alone.

- Accordingly, an overlay which is flexible but not extensible, ie. Can be bent but cannot be stretched, will not seal a crack that is active.

- Gravel is typically used for roofs.

- Concrete or brick are used where fill is to be placed against the overlay.

- An asphalt block pavement also works well where the area is subjected to heavy traffic.
2.2.5. Repairing Spalling and Disintegration

- In the repair of a structure showing spalling and disintegration, it is usual to find that there have been substantial losses of section and/or pronounced corrosion of the reinforcement.

- Both are matters of concern from a structural viewpoint, and repair generally involves some urgency and some requirement for restoration of lost strength.

2.2.5.1. Jacketing:

- Primarily applicable to the repair of deteriorated columns, piers and piles.

- Jacketing consists of restoring or increasing the section of an existing member, principally a compression member, by encasement in new concrete.

- The form for the jacket should be provided with spacers to assure clearance between it and the existing concrete surface.

- The form may be temporary or permanent and may consist of timber, wrought iron, precast concrete or gauge metal, depending on the purpose and exposure.

- Timber, wrought iron Gauge metal and other temporary forms can be used under certain conditions.

- Filling up the forms can be done by pumping the grout, by using prepacked concrete, by using a tremie, or, for subaqueous works, by dewatering the form and placing the concrete in the dry.

- The use of a grout having a cement-sand ratio by volume, between 1:2 and 1:3, is recommended.
• The richer grout is preferred for thinner sections and the leaner mixture for heavier sections.

• The forms should be filled to overflowing, the grout allowed to settle for about 20 minutes, and the forms refilled to overflowing.

• The outside of the forms should be vibrated during placing of the grout.

2.2.5.2. Gunning:

- Gunter is also known as shotcrete or pneumatically applied mortar.

- It can be used on vertical and overhead, as well as on horizontal surfaces and is particularly useful for restoring surfaces spalled due to corrosion of reinforcement.

- Gunite is a mixture of Portland cement, sand and water, shot into the place by compressed air.

- Sand and cement are mixed dry in a mixing chamber, and the dry mixture is then transferred by air pressure along a pipe or hose to a nozzle, where it is forcibly projected on to the surface to be coated.

- Water is added to the mixture by passing it through a spray injected at the nozzle.

- The flow of water at the nozzle can be controlled to give a mix of desired stiffness, which will adhere to the surface against which it is projected.

2.2.5.3. Prepacked Concrete:

- This method is particularly useful for carrying out the repair under water and elsewhere where accessibility is a problem.
• Prepacked concrete is made by filling forms with coarse aggregate and then filling the voids of the aggregate by pumping in a sand-cement grout.

• Prepacked concrete is used for refacing of structures, jacketing, filling of cavities in and under structures, and underpinning and enlarging piers, abutments, retaining walls and footings.

• Pumping of mortar should commence at the lowest point and proceed upward.

• Placing of grout should be a smooth, uninterrupted operation.

2.2.5.4. Dry pack:

• Drypacking is the hand placement of a very dry mortar and the subsequent tamping of the mortar into place, producing an intimate contact between the new and existing works.

• Because of the low water-cement ratio of the material, there is little shrinkage, and the patch remains tight. The usual mortar mix is 1:2.5 to 1:3.

2.2.5.5. Replacement of Concrete:

• This method consists of replacing the defective concrete with new concrete of conventional proportions, placed in a conventional manner.

• This method is a satisfactory and economical solution where the repair occurs in depth (at least beyond the reinforcement), and where the area to be repaired is accessible.

• This method is particularly indicated where a water-tight construction is required and where the deterioration extends completely through the original concrete section.

• Overlays.
In addition to seal cracks, an overlay may also be used to restore a spalled or disintegrated surface.

- Overlays used include mortar, bituminous compounds, and epoxies.
- They should be bonded to the existing concrete surface.

### 2.3. Summary & Conclusions

- When repairing cracks, do not fill the crack with new concrete or mortar.
- A brittle overlay should not be used to seal an active crack.
- The restraints causing the cracks should be relieved, or otherwise the repair must be capable of accommodating future movements.
- Cracks should not be surface-sealed over corroded reinforcement, without encasing the bars.
- The methods adopted for repairing spalling and disintegration must be capable of restoring the lost strength.