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GUIDE TO IMPLEMENTATION OF CONCRETE REPAIR

KUWAIT CHAPTER

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GUIDE TO IMPLEMENTATION OF CONCRETE REPAIR

This guide provides informations about implementation of concrete repair to owners, professionals working in the field of repair under the specific conditions applicable to Kuwait

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CONTENTS

Introduction

This guide to implementation of concrete repair ACI/KC - 03 should be read in conjunction with Guide to assessment of concrete repair ACI/KC - 01 year 1998. This guide gives an overall scope of services that should be known to the parties involved in the concrete repair process, namely: the owner, the consultant, contractors and end-users. Based on the method statements outlined in this guide, the owner should be able to:

1. Prevent safety hazards
2. Increase the return on investment by extending the lifespan of the project/ building
3. Decide the course of action either to repair or demolish and rebuild
4. Obtain the necessary special guarantees from the rehabilitation contractor.

This approach differs from the traditional way of lump sum contracts. Literature is intended for the use of all professionals working in the field of repair including concrete works consultants and contractors.

The guide contains four major sections:

Repair Material

This section defines for the consultants the criteria for selecting repair materials. Following that, a list summarizes the various repair materials, application requirements.

To link repair method and selected repair material, another list of repair method, corresponding repair materials and available market material is included.

Repair Methods

This section is for consultants and contractors to reveal and select the appropriate method of repair.

This document reviews the repair methods used in the gulf region and in Kuwait. For the sake of completion, the guide contains some other repair methods used worldwide such as: form and pump. In addition, we present the latest advancements in the field of electrochemical, concrete repair and protection in severely chloride- contaminated environment.

The repair methods are discussed in detail starting with the logical sequence of execution, the substrate preparation, protection of steel reinforcement, followed by a detailed discussion of methods of repair.

Repair methods are classified into two main categories:

1. Repair without section enlargement i.e. sections having residual safe and service load carrying capacity
   and
2. Repair with section enlargement. These are sections, which have no sufficient carrying capacity and need to be strengthened by section enlargement

Quality Assurance

This section deals with quality assurance process, before starting repair works. Professionals are pre-qualified and selected from those working in the field of repair. For quality control, apply testing standard of the selected repair material during the course of executing repair works. For proper documentation apply administrative procedures to ensure the

quality control on submittals and workmanship are as specified.

For proper and controlled workmanship approve mockups to ensure that the selected repair materials and methods conform to the specified end product prior to execution on a project scale and finally evaluate the performance of repair material after execution.

Tender Documents

This section deals with the recommended form of contracts based on Kuwait experience in various repair projects to avoid all future claims and have a fair, balanced contract between the owners and contractors.

We added some legal and contractual items and guarantees to reserve the owner rights. The method of measurement of the completed repair work differs totally from the traditional type of lump sum contracts.

Based on the estimated cost of repair prepared by the consultants the owner will decide to either repair or demolish and rebuild.

Chapter 1 Repair Materials

1.1 Objective

Selecting materials that meet all necessary properties and requirements after the condition survey and strength evaluation of the old-aged/damaged structural member is difficult. Some require load carrying capacity and others durability or resistance to ingress of chemicals or any combination of each. It is important to understand the repair material response to loads, exposure and surface conditions to which the selected material will be subjected.

1.2 Types of repair materials

- Portland cement mortar with admixture
- Portland cement concrete with admixture
- Micro-silica modified Portland cement concrete
- Latex modified Portland cement
- Polymer modified Portland cement mortar & concrete with non sag fillers
- Steel plates or steel sections
- Fiber glass reinforced plastics (FRP)
- Carbon Strips (CFRP Laminates)
- Epoxy Mortar
- Shotcrete

1.3 Criteria for selection of Repair materials

- The repair material should be compatible with properties of the host/ old concrete
- Both the host material and repair material will work as a composite section under the service loads
- If the repair material and host material are not compatible the risk of delaminating is eminent and the repair is nullified and worsens the state of the damaged member by increasing extra load of repair material.

  The major aspects of the overall compatibility of repair material are:

- **Performance Compatibility**

  Elastic modulus of the repair material (stress strain relationship) must match the host concrete. Compressive strength, tensile strength, bond strength of the repair material must have higher values than the host concrete (recommended minimum compressive strength of repair material is 27.6 Mpa - 4000 psi at 28 days).

- **Environment Compatibility**

  The repair material must exhibit low permeability to the ingress of sulphate ions, chloride ions, carbon dioxide and moisture.

- **Dimensional Compatibility**

  This item deals with long term integrity/ durability of the repair material. The thermal coefficient of expansion of the repair material shall match the substrate or host material while the drying shrinkage of the repair shall be equal or less than 500 micro-strain after 28 days.

- **Electrochemical Compatibility**

  The objective is to ensure that the patch repair of highly contaminated substrate concrete with chloride content environment, will not act as an

Incipient Anode (Preliminary or Start up anode) which will nullify the repair process and creates an environment that chemically passivates the reinforcement.

- **List of Various Repair Materials, Application Requirements and Properties**

The following two tables include lists of different repair materials. The first includes the properties and application requirements for some different repair materials, while the second includes the materials corresponding to each repair method along with the available market materials.

Table # 1
List of Various Repair Materials

Materials	Ingredients		Material Properties									
	Binder	Admixture	Drying Shrinkage	Coeff. Of Thermal Expansion	Compressive Strength pssi/MPa				Elastic Modulus psi/MPa	Permeability (Concrete = 10)	Non-Sag Quality	Comments
					1 Hr.	1 Day	3 Days	28 Days				
Portland Cement Mortar	Portland cement	Water reducer. Air-entr.	U	Equal to substrate	0	650 / 4.5	2500 / 17.2	5000 / 34.5	3.4×10^6 / 2.3×10^4	9	Moderate	
Portland Cement Concrete	Portland cement	Water reducer. Air-entr.	U	Equal to substrate	0	650 / 4.5	2500 / 17.2	5000 / 34.5	3.8×10^6 / 2.6×10^4	9	N/A	
Microsilica Modified Portland Cement Concrete	Portland cement	Super plistizer	U	Equal to substrate	0	3000 / 20.7	4000 / 27.6	7000 / 51.7	4×106 / 2.8×104	6	Good	
Latex Modified Portland Cement Concrete	Portland cement	Latex SBR	U	Compat. w/substrate				6000 / 41.4	2.5×10^6 / 1.7×10^4	5	N/A	
Polymer Modified Portland Cement Mortar with Non-sag Filler	Portland cement	Acrylic latex	L	Compat. w/substrate		1500 / 10.3		5000 / 34.5	2.5×10^6 / 1.7×10^4	5	Excellent	
Magnesium Phosphate Cement Concrete	Magnesium phosphate cement		L	Equal to substrate	2000 / 13.8	6400 / 44.1	7000 / 48.3	8400 / 57.9	3.2×10^6 / 2.2×10^4	9	Low	ACI 304 R-23
Preplaced-Aggregate Concrete	Portland cement	Fluidifier	L	Equal to substrate	0	500 / 3.4	2250 / 15.5	4500 / 31	3.8×10^6 / 2.6×10^4	10	N/A	ACI 503.4
Epoxy Mortar	Epoxy resin		L	(1.5 - 5) x concrete				12000 / 82.7	$2.2\text{x}10^6$ / $1.5\text{x}10^4$	1	Moderate	Vapor may cause problems in confined areas
Methylmethacrylate (MMA) Concrete	Acrylic resin		L	(1.5 - 5) x concrete	4000 / 27.6	12000 / 82.7		12000 / 82.7	3×10^6 / 2×10^4	1	N/A	
Shotcrete	Portland cement	Water reducer. Acceler. Latex	L	Equal to Substrate	0	800 / 5.5	3500 / 24.1	5000 / 34.5	3.8×10^6 / 2.6×10^4	6	N/A	ACI 506 R-90

HRWR:

Drying Shrinkage: (U) Upper limit 300 micro strain - 7 days
(L) Lower limit 500 microstrain - 28 days

Table # 2
LIST OF REPAIR METHODS AND CORRESPONDING REPAIR MATERIALS

Repair Method Preparation	Repair Material	Available Market Material or Equal Approved
Substrate	Bonding Agents • Cement Based Slurries (for Portland cement based repairs)	• KUT SBR # 1 • KUT Poly fix (Site mixed mortar) • Nitobond SBR
	• Epoxies (ASTM C881)	• Nitobond EP • KUT Epoxy mortar GB or HB
	• Latex Emulsion (ASTM 1059) (For Latex modified or micro silica modified repair)	• Nitobond AR (Acrylic Base) • Nitobond SBR • KUT SBR # 1
Reinforced Steel Bars Protection	• Alkaline Slurry coating • Zinc applied to bar surface	• KUT Flexi • Nitroprime Zincrich
Galvanic Protection	• Zinc scarified anode	• Glavashield XP
REPAIR WITHOUT SECTION ENLARGEMENT		
FORM AND CAST Fluid Micro-silica Surface Repair for vertical location and partial depth repairs	• Fine grained Mortars • Coarse aggregate concrete including Micro-silica	• KUT Flow Grout • KUT Flow Crete • KUT Fast Crete • Randroc LA
Hand Applied/Dry Packing (Mortar Types) For all locations Overhead, vertical or flat small cavities (tie holes) honeycombs or gabs.	Portland cement mortar or concrete, low (W/C) Nearly zero slump	• KUT GP Grout • KUT Flow Grout • KUT Flowcrete • KUT "Dualex" Additive • Randroc TGx • Randroc Sx
SHOTCRETE Premixed binder and aggregates sprayed under pressure the mix is jetted through a nozzle at a high-speed used for any thickness vertical, overhead for slabs, beams, walls and columns. Repair damage due to fire attack or severe corrosion	Portland Cement and aggregates with admixtures-silica fume for: • Increased thickness • Increased density • Increased chemical resistance • Increased adhesion • Increased Flexural and compressive strength	• KUT Polyganite • Rendroc SPX
FULL DEPTH REPAIR		
Extensive surface damaged slabs	Portland cement concrete with very low shrinkage	• KUT Flowcrete • Rendroc LAx

Repair Method Preparation	Repair Material	Available Market Material or Equal Approved
HAND APPLIED		
For vertical and overhead location-application by layers Surface repair for all concrete spalled cover	NON Sag material special blend of cement, only graded aggregates, non sag fillers shrinkage compensating systems and water	• KUT Super coat # 1 • KUT Super coat # 2 • KUT overhead mortar • Rendroc TG Xtra • High strength non-sag RendrocHSX
FILL IN CRACKS		
Structural Cracks (Non Moving Cracks) Repair to restore load transfer for (> 3mm crack width)	Epoxy	• KUT Epoxy grout EPLV • KUT Inject Pox • NITOFILL EPLV
Non Structural Cracks (Moving Cracks) Thermal Expansion for (< 3mm crack width)	Polyurethane (Low viscosity)	• NITO fill UR63
PROTECTION		
• Chloride Induced Corrosion • Carbonation induced corrosion. Agressive surface damage	Surface Applied Penetration sealers & membrane high density, low vapor transmission	• KUT Aqua Flow Stop • KUT tar Epoxy coating HS • KUT Epoxy Coating SF • NITOCOTE Dekguard
	ELECTROCHEMICAL CONCRETE REPAIR	
CORROSION INHIBITORS • Added to concrete during mixing • Surface applied coating to concrete • In service by Brush or Roller	• Admixtures as calcium nitrate • Surface applied	Conplast CN
Cathodic Protection • Sacrificed Anode System • Impressed Current System	• Zinc or Magnesium anodes • Mesh of inter metal and conductive material • Conductive coatings • (paints heavily loaded by carbon) • Mesh Anodes in the form of chicken wire from titanium with an activating coats	• Galva shield XP • Galva shield LJ
Chloride Extraction Apply Electrical field between reinforcement and externally mounted anode mesh	The system have been developed to remove chloride ions from the contaminated concrete and re-instate the passivity of steel bars	Norcure
Realkanization The system involves passing an electric current through the concrete to the reinforcement using an applied anode to concrete surface	System Reinstates high PH values in carbonated concrete	Norcure

Repair Method Preparation	Repair Material	Available Market Material or Equal Approved
REPAIR WITH SECTION ENLARGEMENT		
Concrete placement: of additional concrete and steel reinforcing bars for beams, slabs, columns and walls	• Low Shrinkage • Compressive strength, bond and modulus of elasticity to match or more than host concrete	
Steel Plates And Steel Sections Mechanically bonded to concrete	• Standard Steel Sections or Pre-Engineered Sections as required by Structural Analysis and Design	
Carbon Fiber Reinforced Plastic Strips (CFRP) Cross wise applied strips installed with epoxy adhesive	• CFRP - strips Carbon Fiber Reinforced Plastics	
Fiber Reinforced Plastic (FRP) plates may be used as steel plates to improve carrying capacity of beams and arrest propagation of crack - Fixed by epoxy adhesive or mechanically bonded or both	• FRP - Fiber Reinforced Plastic Plates or Reinforcing bars versatile and can be used in any shape used where high risk of corrosion is anticipated	
Shotcrete premixed binder and aggregates sprayed under pressure	• Portland Cement and aggregates with admixtures (silica fume)	• KUT polyganite • Rendroc SPX

Chapter 2 Repair Methods

2.1 Preparation

The success of any concrete repair method is attributed to the proper Implementation of the safety precautions and following the right procedures as stated hereunder.

2.1.1 Steel Propping

Prior to any concrete removal, the contractor shall design and install a Steel temporary supporting system, which has two folds:

- Prevent Safety hazards
- Redistribute the load allowing stress relief during the repair - The steel propping operation shall be kept in place until the repair material application gains the required design strength.

2.1.2 General Surface Preparation Procedures

The following steps are the general requirements for surface repairs.

Step 1: Prepare necessary Equipments

Step 2: Mark out the area to be repaired

Step 3: Cut back around the area to be repaired to a minimum depth of 10 mm.

Step 4: Remove contaminated concrete and expose rear face of steel

Step 5: Expose fully the steel bars

Step 6: Clean steel bars by sand blasting

Step 7: Clean the substrate

Step 8: Apply prime coat to steel bars

Step 9: Soak with clean water under pressure

Step 10: Prime the substrate and leave to become tacked

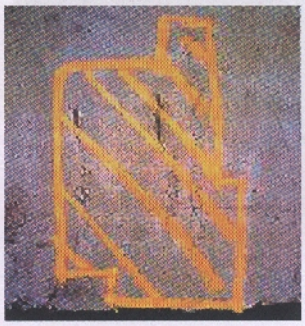
STEEL PROPPING

Steel Proping For Beams and Slab

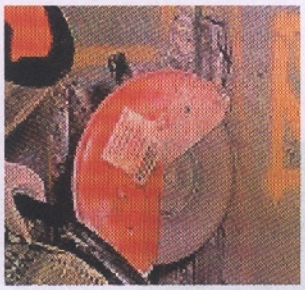
Steel Proping For Column Repair

Appendix # 1
General Surface Preparation

1. Equipment

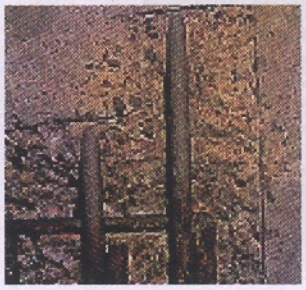


2. Marking Out



3. Cutting Back

4. Breaking Out



5. Fully Expose Steel

6. Clean Reinforcement

7. Clean The Substrate

8. Prime Reinforcement

9. Soak the Substrate

10. Priming The Substrate

2.2 Repair without section enlargement

2.2.1 Shotcrete

General

Shotcrete is successfully used for partial depth repair for vertical surfaces. Beams walls and columns or for overhead sofits of slabs or beams. It is recommended for Fire attack repairs having large concrete spalls and where the steel reinforced bars are exposed. Also can be applied for concrete having severe corrosion of steel in columns beams or slabs. There is no limit for the repair section and no or little formwork are used as guides to control the thickness.

Material and Applications Wet Method

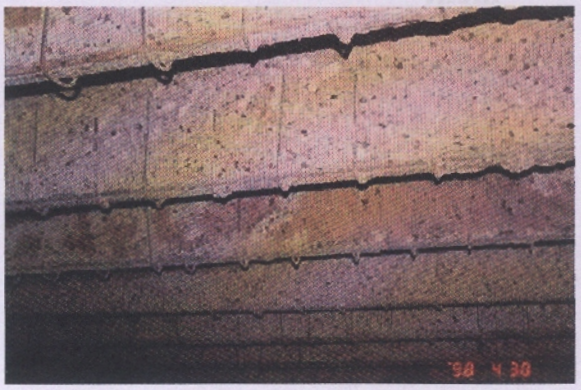
Shotcrete is a method that involves premixing of sand, cement, (8mm to 10mm) aggregates, admixtures and water. The premixed repair material is deposited into a pump or pressure vessel, which transports the material to an exit nozzle. The nozzle man directs the jet into the substrate where it adheres and simultaneously compacted by the impact force. The application will be in layers. In order to produce a low porosity concrete, reduced permeability and increase resistance to chemical penetration, admixtures are used to enhance concrete properties. Silica fumes, fibers and micro-silica are generally used.

Procedure

1. Arrange adequate scaffolding before surface preparation.
2. Cut all defected concrete by small jackhammer (light weight)
3. Sandblast all cut areas.
4. Add any required substitute steel bars. With the necessary overlaps with the in defected bars.
5. Fix wood or metal strip guides to establish the required thickness.
6. Damp well all surfaces before shotcrete application.
7. Replace the defected concrete by shotcrete.
8. Leave the shotcrete material undisturbed, trowel to the required finish within an hour of application. Cure for an adequate period.

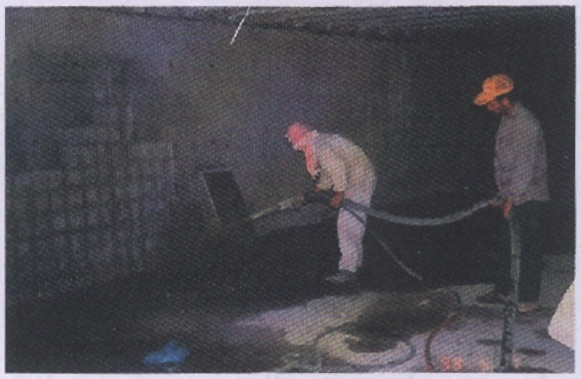
Shotcrete

Delamination of concrete cover after fire damage



Removal of all deteriorated concrete and sand blast all exposed surfaces

Cutting back to expose the surface area of walls



Shotcrete application

Ribbed Beams after repair

Shear walls after repair

2.2.2 Hand Applied / Dry Packing

Hand Applied

Hand applied method is used to place non-sag layers of repair materials such as polymer modified Portland cement mortar with non-sag fillers on vertical or overhead locations. The mixed material is applied to the prepared surface by hand or trowel. Each layer is roughened to ensure bond with subsequent layers. The repair is used for cosmetic or surface repair. It does not involve steel bars.

Application

The following steps are the general requirements for repair:

Step 1: Mix full bag and add required water content, mix steadily using slow speed drill for 5 minutes

Step 2: Thoroughly compact by a trowel onto the substrate

Step 3: Finish with steel trowel

Step 4: Cure as soon as surface is dry using a curing agent or Water

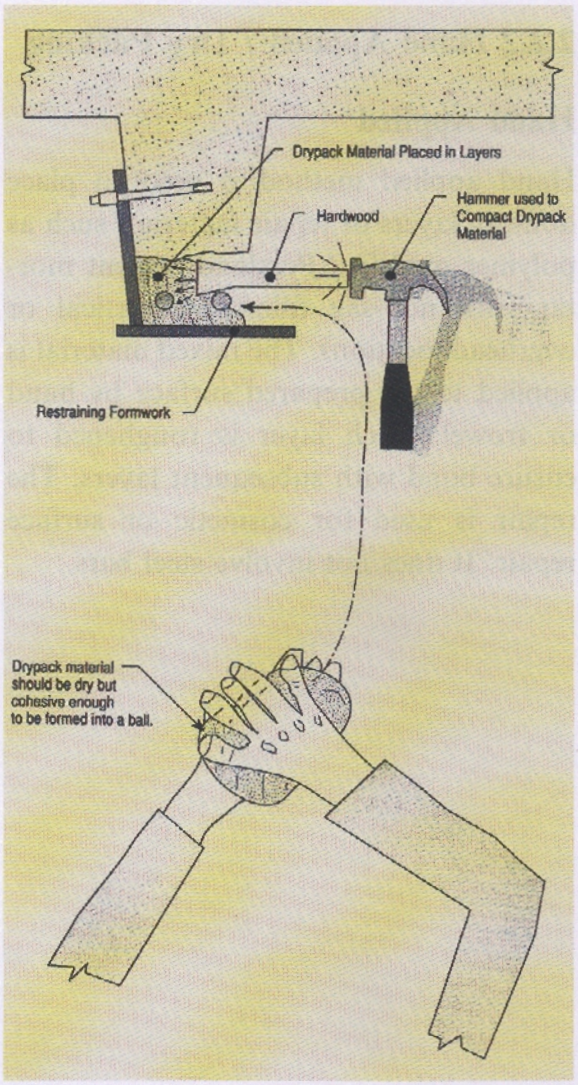
Dry Packing

Dry packing is a method of placing zero-slump, or near zero-slump, mortar or concrete, by ramming into surface cavities. The Consistency of dry pack mortar must be such that it can be molded into a ball without excessive bleeding. Compaction densities the mortar and provides the necessary intimate contact with the existing concrete for achieving bond. Dry packing techniques can be used in all locations. Overhead, vertical and flat. Best applications are generally small cavities such as tie holes, small areas of surface honeycomb, or rib bottoms (shown in illustrations)

Each dry pack mortar repair is placed in layers. Compaction is achieved with a hardwood stick to prevent polishing of the surface. Curing is accomplished with a continuous 7-day moist cure.

Ref: *Concrete Repair and Maintenance Illustrated*

Peter H. Emmons



Measure Out Water

Mixing

Application

Build-up

Finishing

Striking off

Curing

2.2.3 Form and Pump

General

Form and pump is an alternative to shotcrete, hand placement and grouted preplaced aggregate methods. It is used for vertical and overhead application and has no limits for placement for depth or size of repair (bulk repair). In cases of difficult accessibility i.e. offshore marine repairs.

Material

Use of almost any repair material.

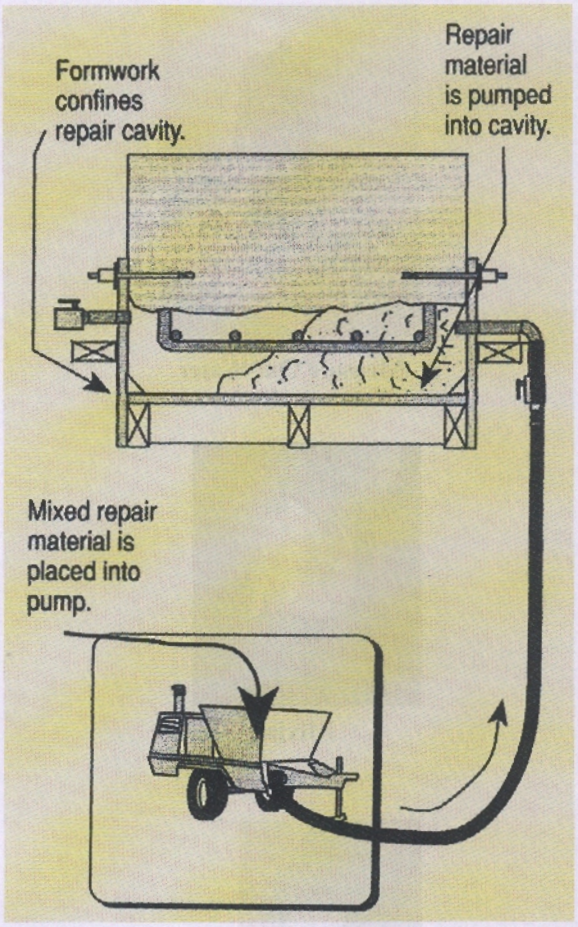
Fine grained mortars, coarse aggregates concrete and polymers. Pumpility and Flow-ability is necessary for the selected repair material.

Application

- Prepare surface to receive repair material
- Install vent tubes prior to construction of formwork.
- Construct formwork; attach pump hose and pumping fittings (valves etc.)
- Pump repair material into the cavity confined by concrete substrate and formwork.
- Cure and strip formwork.
  (Follow concrete practice rules)

Ref: *Concrete Repair and Maintenance illustrated.*

Peter H. Emmons



2.2.4 Crack Injection

Areas of Application

Crack injection will be applied in two cases:

- If there is a potential threat to the durability of steel bar reinforcement.
- If it causes unacceptable leakage.

Crack Definition

- Structural Crack: (Non moving crack)
  Crack width is more than 3 mm due to accidental overload, creep and design loads or wrong detailing.
- Non-Structural Crack: (Moving crack) width is less than 3 mm due to thermal expansion and restrain from movement

Material

Most injection materials consist of two components thoroughly mixed together before injection: Polymers include:

- Epoxies: Are Used for structural crack repairs,
- Polyurethanes: Are used for moving cracks and sealing leakage cracks.

Methods of Application

General

Resin (Epoxy or Polyurethane) is injected under pressure (4-6 bars) through ports or holes drilled along the crack.

Application

Clean the surface of concrete alongside the crack by removing loose or contaminated material.

- Drill holes along the crack and insert ports through the previously drilled holes seal around the ports, the spacing between ports depend on the crack width and not to exceed 50 cm.
- With all ports open, resin is injected under pressure from bottom to top.
- Start with the ports at the bottom (in case of vertical cracks) until a continuous flow comes from the next; continue the process until the crack is filled.

Leaking Cracks

Follow the above-mentioned procedure (clean the surface, drill holes)

Inject Polyurethane resin foam to stop water leakage.

Once the leakage has been stopped, the crack is re-injected with a second material, which replaces the polyurethane foam and form a permanent seal.

Quality Control

Cut cores from the injected crack to visually check the degree of filling the crack.

Crack Injection

Foundation injection

Foundation and column neck injection

Preparation for ground beam injection

Injection of ground beam

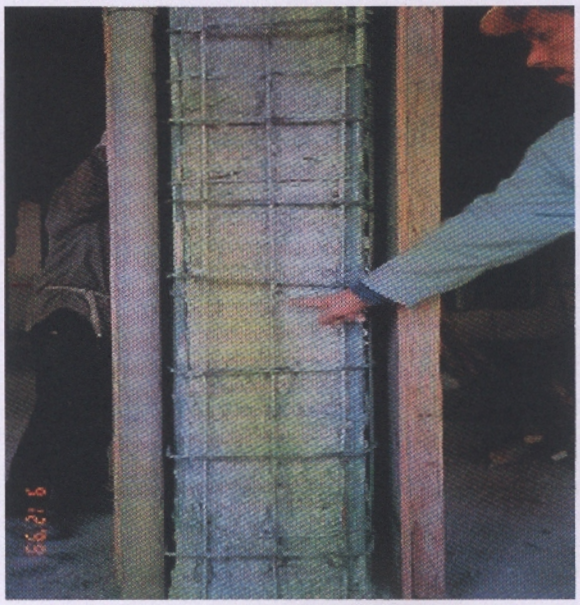
Injection of main frame

Injection of suspended beams

2.2.5 Form and cast in place, full or partial depth

One of the methods for partial or full depth repair. It is used for vertical and in some cases for overhead surfaces.

Place formwork and cast of repair material into the prepared cavity. The repair material must be of low shrinkage and provide flow-ability. The material used is micro-silica modified Portland cement with super plasticizer. Complete filling of the last portion in case of vertical surfaces is difficult. In those cases final step of filling by dry packing, the remaining cavity is needed or adjusts the formwork to be higher than the final casting the level (Letterbox shape).



Formwork for sides of columns

Removal of form work

Casting repair material

2.2.6 Electrochemical Concrete Repair, Non Destructive Repair

General

The objective is to ensure that the patch repair of highly Contaminated substrate concrete with chloride content Environment, will not act as an Incipient Anode, (preliminary anode). Nullify the repair process and to create an environment that chemically passivates the reinforcement.

Repair Method

Breaking out the affected areas in deteriorated concrete having a higher percentage of chloride content (more than 0.3% by weight of cement) will only be effective if all the contaminated concrete is removed. Leaving residual chloride contaminated and cover by patch repair will create an incipient anode, this will reverse the process by ensuring that the newly cleaned steel embedded in a free chloride zone is forced to become a cathode polarizing the adjacent steel and lead to corrosion.

Several electrochemical methods are developed to repair concrete and protect concrete suffering from deterioration due to severe corrosion environment. The following are some of the developed mitigating systems:

- Impressed Current Cathodic Protection (ICCP)
- Electrochemical Chloride Extraction (ECCE)
- Electrochemical Realkanisation (ERA)

Impressed Current Cathodic Protection (ICCP)

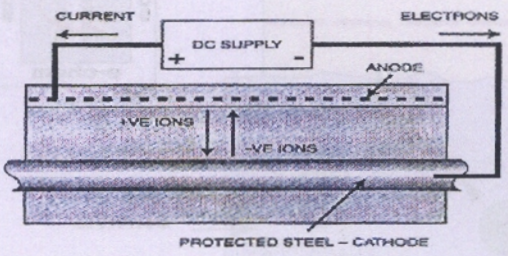
GENERAL

It is mainly used to reduce corrosion rates. Cathodic Protection (C.P.) is an electrochemical process resulting from formation of cathodes and anodes at different position of the metal surface. Oxidation of metal, corrosion occurs at the Anodic sides.

Cathodic protection works by connecting the metal to another material, which is Anodic.

TYPES

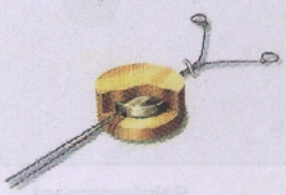
- **Sacrificial Anode System**
  Material of the anode is more reactive than the metal in the structure. Zinc or Magnesium anodes. The anode is consumed in preference to the structure which is protected.
- **Impressed Current System**
  The anode material it self may be inert but maintained in an anodic state by connecting to appropriate pole of a direct current supply.
  In order to provide adequate protection the anode has to be distributed over the surface.
- **Types of surface anodes**
  Meshes of inert material and conductive coating repair material, conductivity to be similar to that of the surrounding material. Clean surface of concrete to ensure adhesion and passage of current are not impaired.
- **Conductive coating**
  Paints heavily loaded with carbon material or (other conductive material). They are sprayed to the concrete surface or by rollers. Bare current feeder wires are stuck to the coating by using a tape.
- **Mesh anodes**
  In the form of chicken wire but are made from Titanium with an activated coating. They are fixed to the surface by using plastic fixing discs to space the disc off the surface. Electrical leads are welded to the mesh, which is covered by overlay of cementatious material.
- **Quality Control**
  Embed half-cells to check that the system is continuing to operate successfully.



Impressed current system

Placing of zinc anodes

Fixing of zinc anode to concrete surface



Zinc Anode

Electro-Chemical Chloride Extraction (ECCE)

General

Electro-chemical extraction systems have been developed to remove chloride ions from contaminated concrete to overcome the problem of chloride-induced corrosion, and re-instate the passivity of steel bars. It is used when highly chloride contents have been accidentally caused, either through mix contamination or by contact with salt water either while the concrete is green or during its life service. It is a non-destructive and silent operation, less dust, no environmental pollution. It does not need any structural supporting systems and finally it has a major time saving for repair works.

Methodology

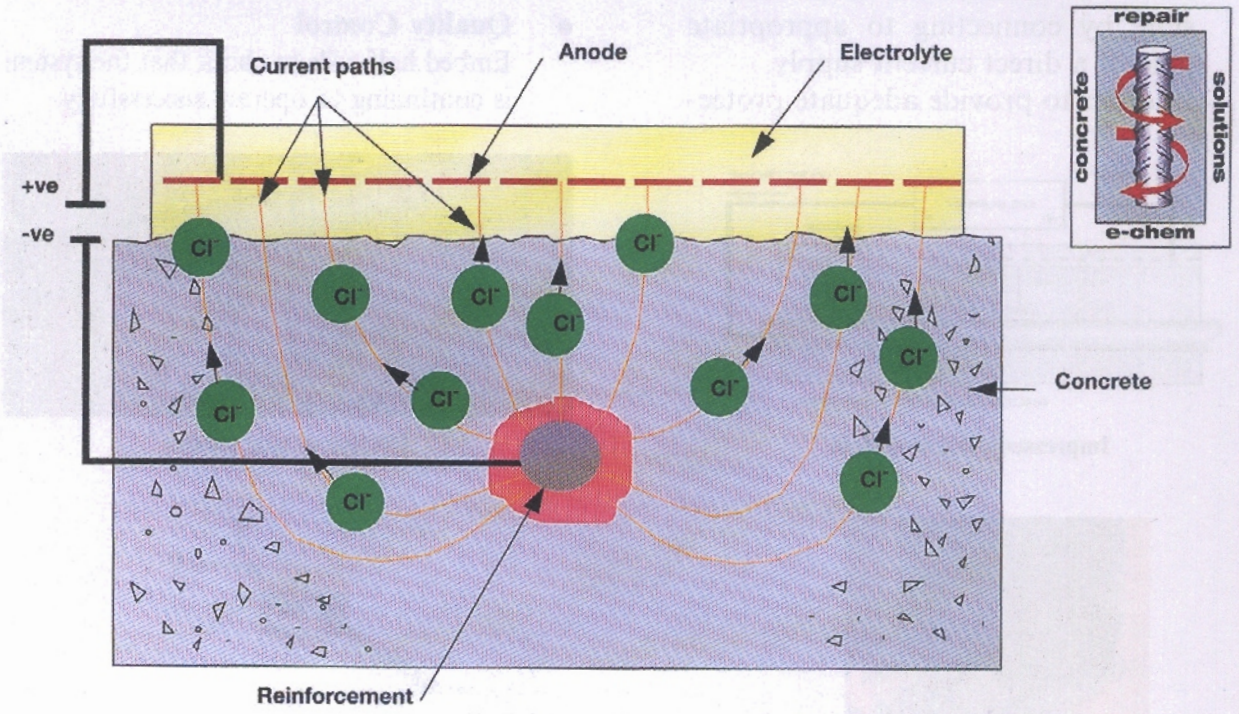
- Apply electrical field between the reinforcement and during externally mounted anode mesh
- During the process chloride ions are transported towards and out of concrete, in the same time electrolysis at the reinforcement surfaces produce a high PH environment around the steel bars

Quality Control

Extract concrete samples at intervals and measure the percentage of chloride content.

Precaution

In case of marine environment, and concrete surfaces are located in splash zones and in order to reduce possibility of recontamination, additional protection coating to concrete surface is highly recommended.



Mechanisms of Chloride extraction

Electro-chemical Re-alkalization (ERA)

Objective

To restore the alkalinity in carbonated concrete, and to re-establish a passive environment around the reinforcement with the minimum disruption to concrete.

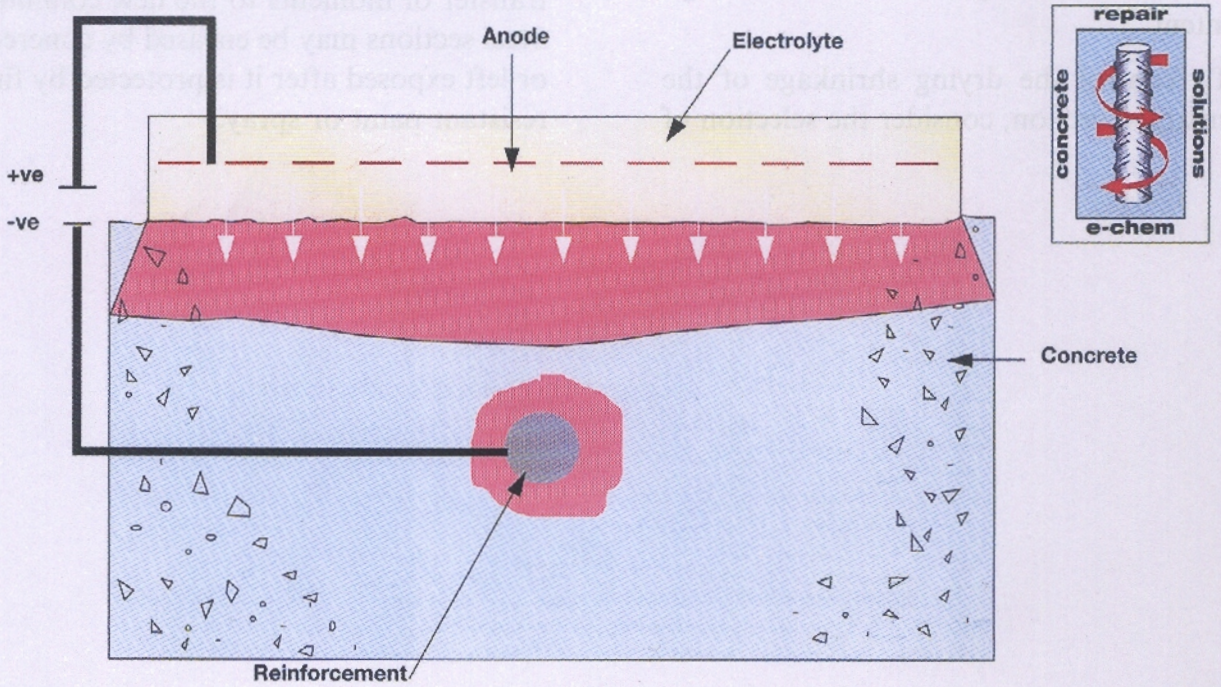
Methodology

The system involves passing an electric current through the concrete to the reinforcement using an externally applied anode, which is attached to the concrete surface. During this process re-alkalization is achieved as an alkaline electrolyte, generally a sodium carbonate solution is taken into the concrete. At the same time, electrolysis at the reinforcement surface produces a high pH environment

Quality Control

Testing

- Extract concrete samples at intervals to determine the degree of re-alkalization
- Use Phenolphthalein to measure the depth of re-alkalization



Mechanisms of realkalisation

2.3 Repair With Section Enlargement

General

Section enlargement is a repair method used either to restore or increase the load carrying capacity and stiffness of under capacity existing concrete members. The application is executed by bonding additional concrete and steel sections to concrete to form a monolithic section. This may be applied to any structural members i.e. columns, walls, beams and slabs.

2.3.1 Concrete Jacketing

Columns

Columns are enlarged in various configurations either by adding a new section abutting to the existing concrete column or encasing the existing section by steel reinforcement and concrete the new added will be designed to fulfill the design intent.

To control the drying shrinkage of the enlarged section, consider the selection of a proper mix design, which offers the lowest drying shrinkage value either by concrete encasement or concrete overlay. For slab soffites overlay, shotcreting method is applied.

2.3.2 Steel Sections, Steel Plates or Pre-Engineered sections

Repair by replacement is used whenever the existing concrete structures is beyond repair limits, and has insufficient load carrying capacity i.e. cases of severe fire damages. Steel sections are used to replace the existing columns, or placed under the beam soffites as a supplementary support. The replacement of the new supporting columns shall fulfill the design requirements and will be constructed by fixing the steel columns with steel plates which are fixed to the floor beams, the location will be aligned to ensure the concentric position in all floors to avoid transfer of moments to the new columns. Steel sections may be encased by concrete or left exposed after it is protected by fire resistant paint or spray.

2.3.1 Concrete Jacketing

Column Neck

- Fill gap between footing and column neck

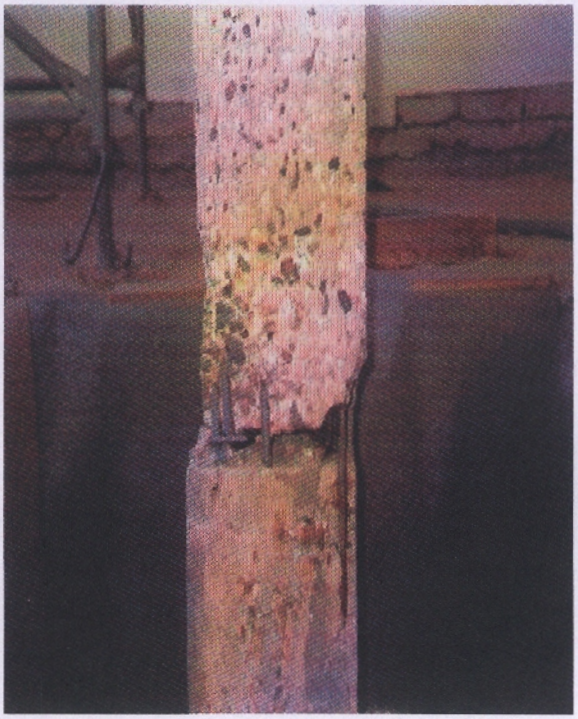
Section enlarged steel bars

Column neck after repair

- Jacketing for column neck with fluid/ micro-silica concrete

Apply bonding agent by brush

Columns and Tie Beams Jacketing



Eccentric Column before repair

Concrete Jacketing and surface applied protection

Prepare Tie Beam for section enlargement

Tie Beam Jacketing after completion

Columns Repair at different locations

Steel propping before start of repair

Cut back deteriorated concrete at the soffit of beams

Column after repair

Removal of deteriorated concrete above slab level

Column after repair

2.3.3 Carbon Fiber Reinforced Plastics (CFRP) Strips

CFRP strips are manufactured by pulltrusion, in which dozens of carbon fiber stands are impregnated in an epoxy resin bath and are shaped by being pulled through a die, then cured and hardened in an oven. The resulting material is very light, super strong, resistant to fatigue and does not corrode. CFRP strips could be up to 500 m long and may be rolled up. The tensile strength is in the range of 3000 Nmm2, in the direction of the fibers. The low strength across is not relevant for strengthening applications. Crosswise-applied strips may be used such as in concrete slabs weakened by cut out openings. CFRP strips are installed by epoxy adhesive without any lifting, supporting or clamping, even if the available space is limited. Applications requiring long strips can be done without lap joints, not like steel plates.

In some cases, it may be preferred to bond CFRP strips in tension (prestressed). The tensioning force relieves the strain on the steel reinforcement, reduce crack widths and increase deflection stability.

2.3.4 Fiber Reinforced Plastic (FRP)

FRP is a composite material consisting of fibers (such as glass, carbon and aramid) and resins (such as epoxy). Fibers are introduced in a certain

volume, direction and position in the matrix, to get the required strength properties. FRP plates may be used, as steel plates, to improve the load carrying capacity of a concrete beam and to reduce cracks and arrest its propagation. They may be bonded to the beam under rehabilitation using epoxy adhesive, mechanically bonded with bolts or both together. The advantages of FRP include high tensile strength to weight ratio, corrosion resistance due to its non-metallic nature and electromagnetic neutrality. In addition, FRP are versatile and can be formed in any desired shape. They also have high chemical resistance and impact resistance. FRP may also be used as reinforcing bars instead of steel, especially in cases where high risk of corrosion is anticipated

2.3.5 Shotcrete

Refer to item 2.2.1 same application to be implemented for section enlargement by shotcreting on layers and cure for an adequate period

Application of CFRP to brick walls and concrete girders

Chapter 3 Quality Assurance Q/A

- Testing of Repair Material
- Quality Control during execution Q/C
- Evaluation after repair

General

The quality Assurance should be planned prior to the start of any repair works.

The **HIT - OR - MISS** approach in repair methods should be prohibited.

There are some difficulties encountered for the realistic performance.

Testing requires being subject to a real world environment for a realistic duration.

Another aspect is that repair materials are continuously changed.

The most important performance based criteria between the repair material and host material are:

- Performance Compatibility
- Environmental Compatibility
- Dimensional Compatibility
- Electrochemical Compatibility

Testing of Repair Materials

General

Evaluate the repaired concrete performance by following the standard test methods for evaluating concrete.

ACI = American Concrete Institute

ASTM = American Society for Testing and Material

AASHTO = American Association of State Highway and Transportation officials

The following table lists the repaired concrete properties and the required standard tests

Repaired Concrete Properties	Standard Test Methods
Mechanical Properties Compressive Strength • Core-Testing • Rebound Hammer	 ASTM C42 ASTM C805
Quality of Concrete Ultra sonic Puls Velocity (UPV)	ASTM C 597
Tensile Strength	ASTM C 496
Flexural Strength	ASTM C 78 ASTM C 293
Abrasion Resistance	ASTM C 418
Chemical Make Up - Electro Chemical Activity	ASTM C 876
Carbonation Depth	Phenolphthalein Solution
Alkali Aggregate Reaction	ASTM C 856
Chloride Content	ASHTO T 259 ASHTO T 260 ASHTO T 277
Physical Condition • Uniformity • Air Void System • Water Absorption	 ASTM C 42 ASTM C 457 ASTM C 642
Delamination/ (Voids)	UPV - ASTM C 597
Modulus of Elasticity & Poissons Ratio	In accordance with ASTM C469
Compressive Creep	To ensure creep under compression in accordance with ASTM 512
Coefficient of Thermal Expansion	In accordance with ASTM C 531
Non-restrained Shrinkage	In accordance with ASTM C 157
Adhesion of Repair Material	Direct tensile tests/direct pull off test In accordance with ASTM E149
Shrinkage and Thermal Movements	Prism Test/Shrinkage Prism Test In accordance with ASTM C157

Quality Control before, during and after completion of repair

Before Starting

- **Resources:**

Prequalify specialized contractors

Based on skilled manpower, materials, equipment, past experience in similar repair projects

During Execution of Repair Work

Administrative system for:

- Approval of submittals, materials, workshop drawings, method statement for each repair technique
- Check List system for each repair phase
- Mock up to ensure the performance of the material and workmanship
- Record for each test samples

Evaluation after repair

Objective

To assess the future behavior of the repair material

- Carbonation tests:

Assess the rate at which the carbonate front moves into concrete from the surface. This evaluation is done after 5 years and before issuance of the final completion certificate to the contractor. The following formula presents the relation between carbonation depth and time.

$D = K_c\sqrt{t}$

Where

D = Carbonation depth

K_c = Carbonation factor

t = Time (5 Years)

- **Chloride Profiles:**

Define a threshold of chloride level (0.3%) by weight of cement. This is recommended for the Gulf Area Environment. Measurements of chloride content are taken at increments from the concrete surface. Check if the chloride near the reinforcement is safe or unsafe. Determine the depth at which the chloride contents to reach 0.3%.

Depth = depth at which 0.3% chloride content is found from which the K_C factor is calculated. The following formula presents the relationship between depth and time.

$D = K_c\sqrt{t}$

Where D is the depth at which 0.3% chloride content is measured t is time (5 years)

From which the

K_c = Factor at 0.3% Chloride Content is defined.

To calculate the time required for corrosion to reach the embedded steel reinforcement i.e. If the depth of cover is D1, then the time will be equal to:

$t = (D_1 / K_c)^2$

- **Concrete Strength & Density**

  Cut cores for concrete compressive strength (columns) compression members. It is recommended that the minimum compressive strength for structural repairs to be 27.6 MPa (4000 psi) after 28 days commonly used ASTM C-42 concrete coring for concrete compressive strength.

- **Ultra Sonic Pulse Velocity**
  Gives indication of the repaired zone about the following characteristics:
- Quality
- Changes in quality
- Cracking and its depth

Note: the results can, in some circumstances, be calibrated against the known strength of appropriate sample

This test for concrete strength should be performed after 28 days of repair

- **Initial Surface Absorption Test (ISAT)**
  The following table shows how (ISAT) results and the cumulative absorption over two hours period may be related to concrete quality

Interpretation of the ISAT results (BS1881)

Concrete quality	Absorption	2 Hours cumulative absorption ML/m2
Good	Low	< 1000
Average	Average	1000 - 2000
Poor	High	> 20000

- **Electrical Potential mapping**

The interpretation of potential in relation to the chance of corrosion is given in the following table:

Relationship between Potential and risk of corrosion

Half-Cell Potential (cu/cuso4)*	Risk of corrosion
Less negative than - 200 mV	5%
From - 200 to - 350 mV	50%
More negative than - 350 mV	95%

* Cu/CuS04 = Copper/Copper Sulphate [Rod of metal in a saturated solutions i.e. Copper in Copper Sulphate Half-Cell].

Note: The measurement may be affected by a number of factors, so care and experience are needed to avoid misleading results.

The method is described in ASTM C 876. Numerous commercial systems are available for collecting half-cell potential data. This includes single cells, multi cell arrays and the Taywood Potential wheel that enables rapid scanning of large areas. A map can be obtained of equal potential contours.

- **Insitu Load Testing:**
  - For repaired Flexual structural members (beams & slabs)
  - For partial or full depth repair replacement (form & cast)

or shotcrete repairs recommended in case of fire damage repair or severely corroded slab soffites and beams. Test to be performed in accordance with ASTM 437-R-91.

Chapter 4 Tender Documents

4.1 Forms of Contract.

The Rehabilitation/Repair contractor may enter into a contract directly with the owner or the ultimate user of the facility or may enter into a sub contract with a general contractor or a construction manager who sublets on behalf of the owner.

Several Forms of Contract are most likely used.

4.1.1 A Lumpsum Contract.

AIA: American Institute of Architects standard Form of Agreement between owner, and contractor, for a stipulated sum.

4.1.2 A Cost-Plus Fee Type Contract.

AIA Form A III "Standard term of agreement between owner and contractor, cost of the work plus a fee. The fee could be as a percentage of the cost of the work or as a lumpsum amount added to the cost work.

4.1.3 A Unit Price Contract.

This type of contract will be based on assumed estimated quantity for each of the types of works to be performed.

When the work is completed an accurate measurement can be made for each type of work that was actually performed and the unit price previously agreed upon for the calculation of the money payable to the contractor.

Recommend Form of Contract for Rehabilitation/Repair.

Based on the experience gained from concrete repair projects in Kuwait and the impact of contractual disputes arising from the interpretation of the contract documents and due to uncertainty of the extent of damage and dealing with unknown repair items especially the concealed structural members (sub-structure or above False ceiling during the preparation of conditions of contract). For a fair and balanced contract we recommend the UNIT PRICE Form of Contract.

4.2 Tender Documents.

The Tender Documents will include:

- Design Drawings / Calculation Sheets for repairs
- Specifications.
- Material Specification
- Application
- Performance Specification to ensure quality control Q/C and Quality Assurance (Q/A)
- Bill of Quantities (B.O.Q) (items and unit rates only incase of unit price contracts)
- Method of Measurement

4.3 Method of Measurement

Quantitative repair measurement differs in all aspects from normal concrete construction.

- **Post contract condition survey**
  More detailed investigations for localized areas prior the start of repair work may be required. Table # 3 illustrates the most common types of tests.
- **Work Executed**
  The recommended method of mea-

surement for executed repair works includes the majority of expected items as shown in table # 2, however, other new items may be added for special repair techniques.

- Table # 3 includes the method of measurement to cover the cost of required tests after signing the contract (Post contract condition survey)
- Table # 4 includes the method of measurement for the type of repair work executed, the method of measurement and unit rate of each item.

Both tables # 3 and # 4 shall be filled by the bidders as part of the contract documents for bid evaluations

4.4 Cost Of Repair Or Replacement

The findings of the condition survey, strength evaluation and material selection are crucial for major decision to:

Repair or Demolish and Rebuild

Key Questions

- Will the safety of structure be of major concern?
- Will the concrete repair extend the life span of the building at a low cost?
- Will it be less than demolish and rebuild?
- Does the building have a historical or commercial value?

If the answer to any of these question is Yes?

Then proceed with the repair

4.5 Legal Conditions

Consider the following important legal items, which differ from the normal contracts:

- **Final Completion Certificate**
  The Engineer shall issue the final completion certificate after 5 years and proof of successful Q/A tests.
- **Performance Bond**
  The retained value of (10%) by the owner shall be paid to the repair contractor after issuance of the final completion certificate.i.e. after 5 years.
- **Safety** (Structural Liability & Insurance Policy)
  10 years after the issuance of the substational completion certificate.

Table # 3

Method of Measurement
Post Contract Condition Survey

Type of Test	Unit	Cost
Scaffolding	Area m^2	
Visual Inspection	Lump sum	
Ultra sonic pulls velocity (UPV)	Area m^2	
Crack Mapping	Area m^2	
Cover depth	Area m^2	
Core testing	Unit	
Chloride Profile	Unit	
Carbonation depth	Unit	
Half Cell Potential and Potential mapping	Area m^2	
Water Absorption	Unit	
Water Permeability	Unit	
Corrosion rate	Area m^2	

Table # 4
Method of Measurement Work Executed

TYPE OF WORK	METHOD OF MEASUREMENT	UNIT	RATE	TOTAL
Sand Blasting	Actual executed work	M^2		
Supporting system (propping)	Actual supported area	M^2		
Patching Mortars: Cut back concrete surfaces, blast steel and repair with specified mortar • Up to 15 mm • 40 to 80 mm • 80 mm +	Actual work executed	M^2 M^2 M^2		
Fluid Repair Cut concrete surface, blast and repair as specified • 40 to 80 mm • 80 to 120 mm • 120 mm +	Actual work executed	M^2 M^2 M^2		
Crack Injection Inject and seal cracks as described in concrete repair method, clean, inject and make good after removal of peckers	Actual work executed per linear meter For columns and beams up to 20 cm Prorate for more depth	MR		
Jacketing with Fluid/Micro- silica concrete • Up to.05 m • Up to 1.0 m • Up to 2.0 m • Up to 4.0 m Thickness (50 to 100 mm)	Actual executed work	M^2		
Jacketing with Fluid/Micro-silica concrete for beams Thickness (50 to 100 mm)	Actual executed work Linear meter	M^2		
Filling gabs and voids	Actual executed work	Per number		
Jacketing with reinforced concrete	Actual executed work	M^2		
Shotcrete application • Walls • Ripped slabs Thickness (7.5 to 10 cm)	Actual working areas (vertical for walls) Vertical & horizontal for ribbed slabs/beams	M^2 M^2		
Concrete Protection Apply primer, two coats of specified coats	Actual work executed	M^2		
Joint sealant Sealing joints with specified material Material including racking	Actual work executed per Linear meter	LM		

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