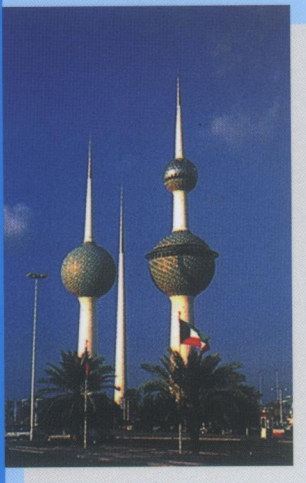


ACI/KC 01-98

GUIDE TO DAMAGE ASSESSMENT AND REPAIR OF CONCRETE STRUCTURES



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GUIDE TO DAMAGE ASSESSMENT AND REPAIR OF CONCRETE STRUCTURES (ACI/KC 01-98)

This guide provides information on the assessment and repair of concrete works under the specific conditions applicable to Kuwait.

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This document has been prepared by the Kuwait Chapter of the American Concrete Institute. Although it reflects years of experience and knowledge based on local conditions, it has been distributed only as a guide to professionals.

ACI Kuwait Chapter recommends that professionals should use their judgement in particular cases when applying the recommendations of this guide as ACI Kuwait Chapter will not be held liable in any circumstances for any consequences.

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Objective:

Recommendations to the professionals working in the field of concrete repairs.

Introduction:

Despite the high durability of concrete there are occasions when a reinforced concrete structure requires a decision for remedial or replacement treatment.

Damages may arise from a variety of causes:

- Fire Attack
- Corrosion of reinforcement
- Accidental overloading
- Foundation settlement
- Concrete deterioration
- Others

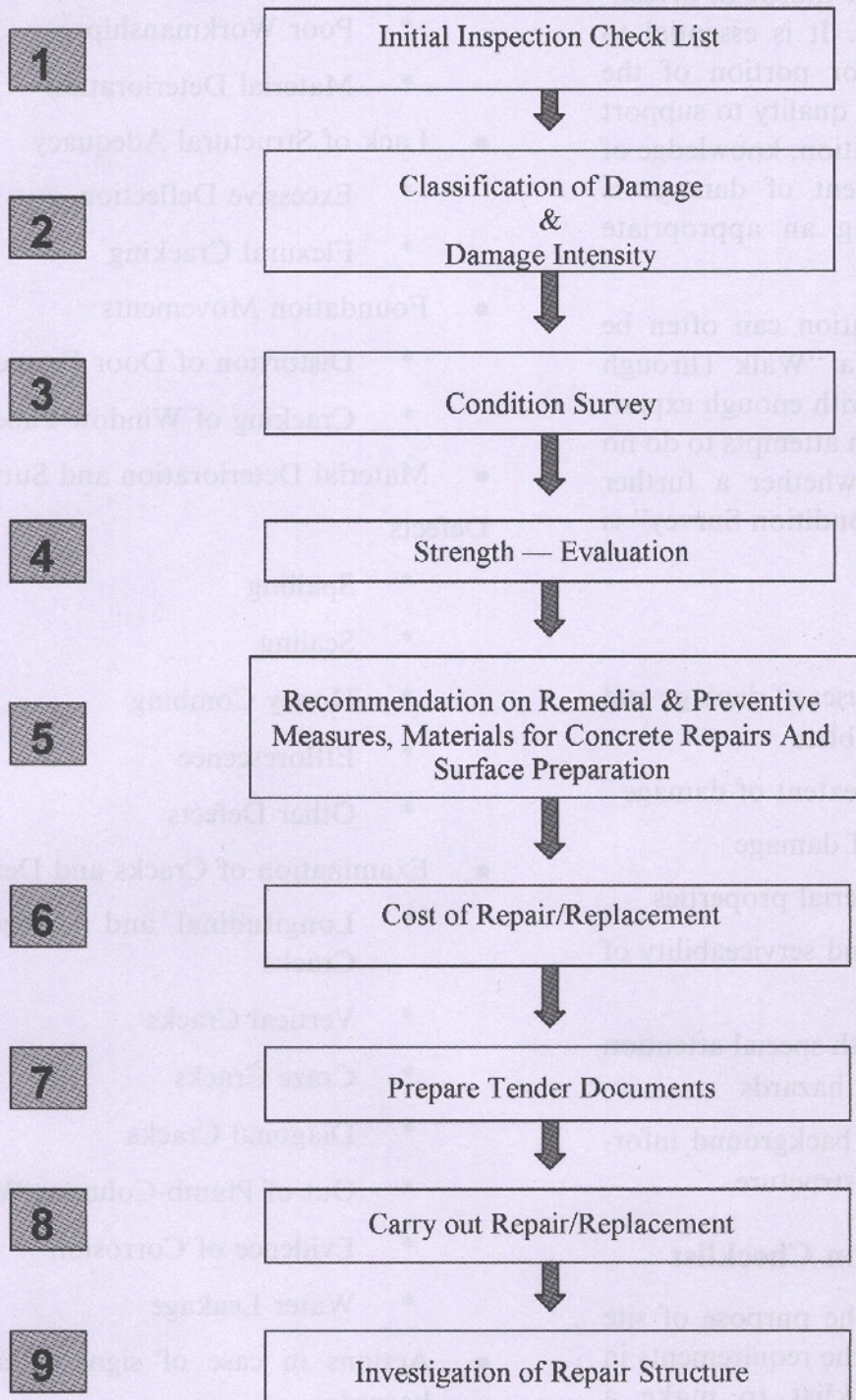
Procedural Steps for Damage

Assessment & Repair of Concrete

Works (Exhibit I)

- Carry out a thorough investigation of the damage
- Identify the causes of damage and source of the problem
- Determine the extent of damage
- Determine material properties
- Assess safety and serviceability of the structure
- Provide recommendation on remedial and preventive measures
- Estimate cost of repair or replacement
- Prepare tender document
- Carry out required repair or replacement
- Investigate the adequacy and performance of repaired structure

PROCEDURAL STEPS FOR DAMAGE ASSESSMENT AND REPAIR OF CONCRETE (EXHIBIT -1)



1. INITIAL INSPECTION

The first step in a successful concrete repair is to carry out a thorough investigation of the damage. It is essential to determine if the major portion of the structure is of suitable quality to support a sound repair. In addition, knowledge of the intensity and extent of damage is required for executing an appropriate repair scheme.

This type of investigation can often be done on the basis of a "Walk Through Survey" by someone with enough experience. This investigation attempts to do no more than find out whether a further investigation for a "Condition Survey" is justified.

1.1 Objectives

- To identify the causes of damage and sources of the problem
 - To determine the extent of damage
 - To classify type of damage
 - To determine material properties
 - To assess safety and serviceability of the structure
 - Inspect the site with special attention to potential safety hazards
 - To determine the background information about the structure.
- Type of Construction
 - Age of Construction
 - Visual defects related to either
 - * Poor Workmanship
 - * Material Deterioration
 - Lack of Structural Adequacy
 - * Excessive Deflection
 - * Flexural Cracking
 - Foundation Movements
 - * Distortion of Door Frames
 - * Cracking of Window Panels
 - Material Deterioration and Surface Defects
 - * Spalling
 - * Scaling
 - * Honey Combing
 - * Efflorescence
 - * Other Defects
 - Examination of Cracks and Defects
 - * Longitudinal and Horizontal Cracks
 - * Vertical Cracks
 - * Craze Cracks
 - * Diagonal Cracks
 - * Out of Plumb-Columns/Walls
 - * Evidence of Corrosion
 - * Water Leakage
 - Actions in case of signs of safety hazards
 - * Immediate closure
 - * Restriction of usage
 - * Temporary props

1.2 Initial Inspection Checklist

It is recommended for the purpose of site inspection to simplify the requirements in the form of a checklist to make a preliminary assessment of the existing condition of the structure.

The Initial Inspection Checklist shall include the following:

- Background Information about the Structure

- * Drawings and Design Calculations
- * Records of Construction
 - Concrete Test Results
 - Reinforcement
 - Modification of Original Design
 - Photographic Records of Construction Progress
 - Notes on difficulties during Construction
 - Records of occupancy and loading history

Who will do the initial checklist?

- * Qualifications: Structural Engineers
- * Experience (Expert knowledge): Design and Construction background

1.3 Conclusion

The initial checklist, if carefully planned and executed, unfolds the overall damaged state of the structure and allows the specialist to identify the scope of work required to execute the condition survey. The following items may be selected in accordance with the characteristics of each case:

- Dimensional surveys
- Survey of crack, spalling, steel pitting and potential mapping of corrosion of steel
- Carbonation depth
- Chloride content
- Sulphate content
- Concrete cover
- Cores for concrete strength
- Depth of discoloration in case of fire damage
- Ultrasonic test for honeycombing
- Schmidt hammer test for delamination
- Deflection of beams
- Deflection of slabs
- Verticality of columns/walls
- Petrographic examination
- Alkali reactivity
- Electro potential survey
- Resistivity Survey
- Permeability
- Structural load test

2. CLASSIFICATION OF DAMAGE AND DAMAGE INTENSITY

Interpreting the results of the condition survey requires expert knowledge and experience. In this process the test data and design / loading records should be cross referenced and filtered. Refer to (Exhibit 2).

The damaged members of the structure may be classified systematically according to the condition of each member. Classification of damage intensity is related to:

- Type of Structure
- Cause of Damage

The damage grade of a structural member may have to be adjusted to account for the actual concrete strength relative to the design stresses. For corrosion related

damages the grade depends on the chloride content of the Concrete ACI 318-89. The proposed classification will produce a vivid picture of the damaged structure as a whole and the severity of the problem at hand.

2.1 Structural Damage

- **Accidental Overloading**
Shows up as excessive deflection and flexural or shear cracking.
- **Foundation Movements**
Shows as distortion of door frames, cracking of windowpanes and diagonal crack pattern.
The intensity of damage is classified into Four Grades ranging from light

to very severe (Refer to Table 1). The Grades based mainly on visible signs of distress are rather subjective.

2.2 Fire Attack Damage

Shows as a change in surface colour or concrete spalling and reinforcing exposure. Refer to Table (2)

2.3 Corrosion Damage

Shows as cracking with or without rust stains, spalling of concrete cover, corroded steel and may be associated with carbonation of concrete cover (upon performing carbonation test). Refer to Table (3).

Table 1 - Classification of Structural Damage

Grade	Intensity	Visual Damage	Residual Deformation
1	Light	Fine cracks (< 1mm); light spalling at isolated spots	Not apparent
2	Moderate	Medium cracks (1-2mm); light spalling; doors / windows slightly stuck	Slight
3	Severe	Wide cracks (> 2mm); medium spalling; doors / windows stuck	Medium
4	Very severe	Wide cracks everywhere; doors / windows distorted; utility pipes and glass broken	Slope of floor exceeding 1/125

Table 2- Classification of Fire Damage

Grade	Intensity	Plaster/finish	Surface colour	Crazing	Spalling	Reinforcing exposure
1	Light	Some peeling	Normal	Slight	Slight	None
2	Moderate	Substantial loss	Pink	Noticeable	Localized	10-25 percent; none buckled
3	Severe	Total loss	Buff	Extensive	Extensive	25-50 percent; not more than one bar buckled
4	Very Severe	Total loss	Buff	Extensive	Extensive	Over 50 percent; more than one bar buckled

Table 3- Classification of Corrosion Damage

Grade	Intensity	Cracking	Spalling	Carbonation of Concrete Cover
1	Light	Hairline cracks ($<0.1\text{mm}$) without rust stains	Not apparent	Partial
2	Moderate	Fire cracks ($<0.2\text{mm}$) with or without rust stains	At isolated spots	Partial
3	Severe	Extensive with rust stains	Extensive; corroded steel visible	Complete
4	Very Severe	Extensive and wide with rust stains	Extensive; substantial steel pitting visible	Complete

3. CONDITION SURVEY

The purpose of the survey is to collect sufficient data to pinpoint the causes and sources of the problem and to determine the extent of damage. Depending on the probable causes of damage the fieldwork involves a combination of the following processes:

- Detailed visual inspection
- Survey of cracks, spalls, steel pittings or corrosion and other defects.
- Potential mapping that identifies zones of high corrosion risk.
- Drilling holes or mini-cores for carbonation test and chloride content analysis.
- Coring of concrete for determination of strength.
- Measurement of concrete cover and reinforcing bar spacing.
- Schmidt Hammer Test for delamination or compressive strength (Comparison only).
- Ultrasonic test for honeycombing, depth of cracks.
- Assessment of depth of discoloration (in fire damage).

3.1 General

A structural survey is a certain assessment of the condition of the building, which is intended to detect any defects or deterioration requiring attention. Structural surveys are normally carried out by appropriately qualified engineers.

A reliable and realistic assessment of the structural condition should be carried out in phases, each phase would provide

information and data to start the next phase. Generally, these phases include:

- Phase I Visual survey
- Phase II Crack classification
- Phase - III Carry out investigation for concrete and steel of the damaged structure.

The phases can be planned with more confidence, if the surveyor knows the extent of scope of work and the factors to depend on. Generally, each phase include certain steps to be carried out, so that the next phase would start. The attached flow chart (Exhibit 2) summarizes the steps sequence, taking into consideration the type of structural assessment required for certain types of defects and cracking.

It is not intended for this work to be a comprehensive account of tests description or method statements of any step shown in the attached flow chart, instead the study should be considered as a guide for structural surveyors.

3.2 Phase I - Visual Survey

The first objective in most investigations, no matter what their size or scope, is to gather readily available information on the structure in question. As part of this objective in many cases the first activity is an initial walk around for inspection. Sometimes drawings or other details may be available before the first visit to the site and these will provide a useful introduction, although some caution is necessary as these records may not accurately represent the construction as built. Otherwise the visual inspection provides the opportunity to make initial assessments of the structural form and to take general note of the locations of any deterioration. It is also useful to note any

problems likely to be encountered with access to critical locations during the subsequent more detailed survey. The first phase visual survey is very important as the impression gained will often set the tone and direction of the later stage of survey.

3.3 Phase II Crack Classification

Information and data collected from Phase I will enable the classification of various type of cracks, describes their symptoms and discuss the main factors that influence them. The factors and concrete properties which influence the cracks (chemical, physical and thermal) may be more variable and less predictable than those, which influence structural stresses and strains.

The defects or cracks may be caused by inadequacy of design, materials or construction deficiencies, which may not become evident until some time after completion. The immediate mechanism of deterioration may be for example, chemical action or corrosion of reinforcement but, in a large portion of cases, the fundamental cause can be traced back to something such as unrealistic detailing or poor workmanship. Phase II facilitates the mechanism of cracking without quantifying the depth of the problems in the damaged structure. The assessment of the damaged structures should be based on testing results, which includes the depth, area and volume of the problem in addition to locating the concentrated area of the problem on the damaged structure.

3.4 Phase III - Carry out Investigation for Concrete and Steel

Once the preliminary walkover survey and the search for existing records have

been completed and the crack classification has been put in hand. The details of Phase III can be planned with more confidence. The extent and scope of this work will depend on many factors, including the structural form, the quantity and quality of existing records, the degree of anticipated change of use and alteration of structure and the extent of deterioration.

Phase III includes the most common methods of testing utilized in the structural survey. However, many other methods are also valid for the same purpose. All tests described should be carried out by qualified personnel and reference should be made to the relevant standards and codes of these tests.

Planning the Condition Survey

Planning is recommended to include the following:

- Selection of the most appropriate tests.
- Determination of the extent or number of test points to reflect the existing conditions of the structural members.
- Determination of the location of the test points.
- Selection of the number of tests (compromise between reliability, time, cost and damage).
- Conduction of a preliminary survey with a few test points to establish the necessity for repairs.
- Based on the preliminary survey a thorough survey is planed to allow a repair-scheme to be designed and cost estimated.

Areas of Concern

Concentration on the following is recommended

- Location of cracking and spalling
- Adjacent areas
- Test results from unaffected areas which serves as datum of comparison

Preparations needed for Condition Survey

- Test pits for substructures.
- Substantial removal of finishes to expose concealed structural members.
- Areas under investigation have to be closed temporarily or partially cornered off.
- Investigation work to be performed during hours of little or no activity.
- Provision of adequate equipment and access facilities.
- Full specification for the survey work stating the objectives of the survey and indicating the locations to be tested.

Accuracy of Strength Assessment

- Accuracy depends upon the number of cores tested. For large areas choose cores to represent different batches of concrete.
- Strength of the reinforcement may be determined with specimens removed from the affected zone. Steel testing

is not routine in a condition survey unless evidence shows that the steel has been significantly over stressed or subjected to very high temperature. It is recommended to test only one or two samples. Steel to be removed from locations of low stresses.

4. STRENGTH EVALUATION

The strength evaluation is to determine if the structure is safe for the use under the design load, actual service load or even a reduced load that takes into account the damage.

Two alternative methods are available for the strength evaluation of the structure:

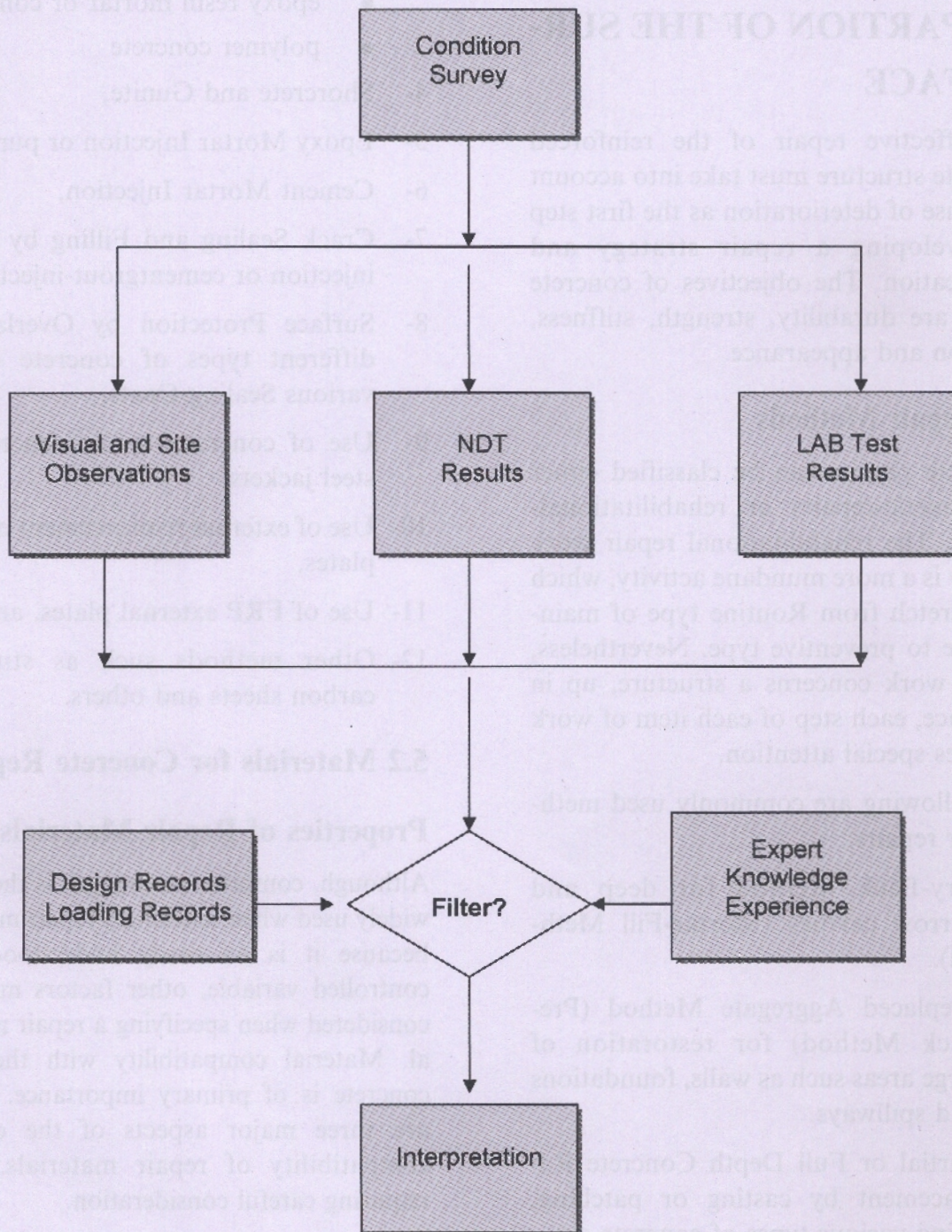
4.1 Analytical Method

It is often more economical and less disturbing. It will be conclusive only if sufficient information regarding dimensions and details of the members, properties of materials and intensity of damage are available.

4.2 Insitu Load Testing

Technical guidance for static load testing is given in ACI 437R-91. Load testing is practical only if the structural members, after investigation, are primarily flexural members (slabs & beams)

A decision has to be made whether to test the members under the existing conditions or after completion of certain repairs.

**ANALYSIS OF CONDITION SURVEY RESULTS
(EXHIBIT-2)**

NDT: Non Destructive Test

5. RECOMMENDATION ON REMEDIAL & PRE- VENTIVE MEASURES, MATERIALS AND PRE- PARTION OF THE SUR- FACE

The effective repair of the reinforced concrete structure must take into account the cause of deterioration as the first step in developing a repair strategy and specification. The objectives of concrete repair are durability, strength, stiffness, function and appearance.

5.1 Repair Methods

Concrete repairs can be classified either as cosmetic-repairs or rehabilitational-repairs. The rehabilitational repair work usually is a more mundane activity, which may stretch from Routine type of maintenance to preventive type. Nevertheless, as the work concerns a structure, up in the space, each step of each item of work deserves special attention.

The following are commonly used methods for repairs:

- 1- Dry-Pack Method for deep and narrow cavities (Mortar-Fill Method).
- 2- Preplaced Aggregate Method (Pre-pack Method) for restoration of large areas such as walls, foundations and spillways.
- 3- Partial or Full Depth Concrete Replacement by casting or patching, using various types of concrete e.g.
 - ordinary cement concrete, mortar

- low-slump highly-dense concrete
- high-alumina cement concrete
- magnesia-phosphate cement concrete
- latex-modified concrete
- epoxy resin mortar or concrete
- polymer concrete

- 4- Shorcrete and Guniting,
- 5- Epoxy Mortar Injection or pumping,
- 6- Cement Mortar Injection,
- 7- Crack Sealing and Filling by epoxy injection or cementgrout-injection,
- 8- Surface Protection by Overlays of different types of concrete or by various Sealing Coats,
- 9- Use of concrete, epoxy concrete or steel jackets,
- 10- Use of external reinforcement or steel plates,
- 11- Use of FRP external plates, and
- 12- Other methods such as stitching carbon sheets and others.

5.2 Materials for Concrete Repairs

Properties of Repair Materials

Although, compressive strength is the most widely used when selecting a repair material because it is an easily understood and controlled variable, other factors must be considered when specifying a repair material. Material compatibility with the host concrete is of primary importance. There are three major aspects of the overall compatibility of repair materials, each requiring careful consideration.

Performance Compatibility: Defining the basic physical characteristics of the repair, which should be closely matched to

those of the host concrete (Compressive strength, bond strength, elastic modulus).

A range of materials are available to provide the desired characteristics. The most important characteristics from a structural view point should then be decided by the structural engineer.

Environmental compatibility: Defining the permeability of the repair, and thus its resistance to the prevailing corrosive elements.

The repair material must exhibit low permeability to the ingress of sulphate ions, chloride ions, carbon dioxide and water due to the detrimental effects of these elements on deterioration of the concrete and corrosion of the reinforcement.

Dimensional compatibility: Defining the long term integrity/durability of the repairs. The two issues to be considered here are thermal expansion and drying shrinkage.

If the thermal coefficient of expansion of the repair is considerably higher or lower than that of the host concrete, then a risk of delamination exists under temperature changes. This has been seen many times with epoxy resin repairs.

Drying shrinkage should be the major consideration in the specification of cementitious repair materials. The selected repair material should have low shrinkage.

Types of Repair Materials

For major deterioration involving loose or spalled concrete, there are a number of options for the selection of repair materials such as shotcrete, hand applied mortars and formed concrete. There is a

less expensive alternative that may be used, either where appearance is not critical or where an appropriate architectural covering can be provided. In such cases, simply chip away the deteriorated materials, clean all surfaces, and then coat the exposed sound concrete and reinforcing steel with an epoxy sealer or other weatherproof coating. Epoxy injection can be effective for cracks where no spalling has occurred. Epoxy-sand mortars are convenient for small, shallow patches. However, thicker repair with epoxy mortars must be executed very carefully using specially formulated materials to avoid problems caused by the thermal shrinking and

mechanical properties of the two materials (epoxy and existing concrete). Whatever repair material is selected, it is important to follow closely the established guidelines from the manufacturers and other sources with respect to temperatures, surface preparation and application techniques. Below are some of the suggested materials to be used for repair works:

1. Shotcrete:

Description: A mixture of water, cement and aggregate combined and sprayed.

Advantages: Only limited forming is needed. Bond to properly prepared old concrete is usually excellent.

Disadvantage: The rebound of a significant amount of material as the material bounces away from the surface being shotcreted and thereby lost.

2. Hand Applied Latex or Polymer modified Portland cement mortars:

Advantages: Low permeability to water. Good bond to properly prepared old concrete. High durability, crack resistance and tensile strength.

Disadvantages: Relatively high cost.

3. Low water-cement ratio concrete with entrained air and appropriate mixture:

Advantages: Lower cost repair material. Suitable for large repairs.

Disadvantage: Forms are necessary and may be difficult to support in some installations.

4. Polymer concrete and mortars:

Advantages: High strength, high durability and good bond to properly prepared concrete.

Disadvantages: Relatively expensive. Forms are needed for deep vertical repairs. Some are inflammable and toxic.

5. Epoxy Injection:

Crack surface sealed except for injection ports inserted at intervals along crack. Epoxy is then pumped through parts.

Advantages: Very little surface preparation needed. Strong bond and durability of patch.

Disadvantages: Scar marks may be left on surface where crack was injected. Limited to areas where concrete has not yet spalled.

6. Steel Plates and Steel Jackets:

Advantages: May be considered as ex-

ternal reinforcement, which increases both the stiffness and the load carrying capacity of the member and reduce deflection. Jackets also increase the concrete confinement.

Disadvantages: May be subjected to corrosion or debonding. It is recommended to use both mechanical and epoxy bonding to assure fixation.

7. FRP and Carbon:

Advantages: FRP or carbon may be used as external plates or as bars embedded in concrete jackets to improve stiffness and load carrying capacity. They are resistant to corrosion. Carbon may be also used as thin flexible sheets that may epoxy bonded and easily wrapped around the member.

Disadvantages: FRP may be subjected to deterioration by alkalis while carbon plates or sheets are generally expensive.

5.3 Surface Preparation

5.3.1 General

Proper preparation of any surface to receive an epoxy application is of primary importance, no matter how carefully other phases of the application procedure have been performed. Bond failure may be expected if surface preparation is inadequate. Proper preparation of a given surface is an art and a science and must be given careful attention.

5.3.2 Preparing Surfaces to Receive Epoxy Coating (Without Removal of Concrete)

All substrates to be coated must be clean and sound. Remove any substance detrimental to bond of epoxy compounds,

such as laitance, curing membranes, dust, dirt, and other debris.

This cleaning can be accomplished by thorough washing with high-pressure water jets or by jetting the surface with compressed air. Care must be exercised to assure that any water used in cleaning is itself clean and also no contaminants are present in any compressed air.

5.3.3 Preparing Surfaces Requiring The Removal of Concrete

The Surface must be mechanically prepared. Areas to be repaired must be clean, sound and free of contaminants. All loss and deteriorated concrete shall be removed by mechanical means. Saw cut perimeter 1/2" maximum. Chip concrete substrate to obtain a surface profile with a new fractured aggregate surface. Where reinforcing steel with active corrosion is encountered: Sandblast reinforcing steel to remove all contaminants and rust. Determine section loss and splice where more than 15-25% loss or as directed. Spacing of steel must be 3 times the largest aggregate size. If half of the diameter of the rebar is exposed, chip

out behind the reinforcing steel, 1/2" minimum for mortar only and 3 times the largest aggregate size for extended mixes.

6. COST OF REPAIR OR REPLACEMENT

The findings of the condition survey are crucial for major decisions by the Owners or facility users. The structural safety declared either a possible rehabilitation program, partial replacement or complete demolition and re-build.

The impact will be significant on both cost and time for reinstating the facility to its safe functional operation.

The implementation comprises of a complete set of tender documents including specifications (performance spec) drawings and BOQ (due to uncertainty of the damage extent - a remeasured contract is the fair one to be applied).

Contract documents may include in-situ load testing after repair work for (flexural members) to ensure the safety after repair.

Suggested specification criteria for repair materials:

Characteristic	Suggested minimum requirement
Physical properties	Compatibility with substrate requirement
Permeability	?Permeability of high quality concrete (set water absorption limits).
Shrinkage	< 500 microstrain at 28 days ASTM C157-1991

7. CONCLUSION

The projection of life expectancy for buildings of 25 years or more and subject to repairs is rather a debatable item and a condition survey every 5 years is a must and proposed especially for structural damage suspected members or members in contact or close to the ground. This survey will indicate any time dependant deterioration, Localized defect or distress.

Routine maintenance of buildings must be strictly carried out. Moreover, the capacity of the repaired structure, reserve capacity and load restriction shall be cleared to the user.

8. REFERENCES

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- ACI Committee 201.2R-92, Guide to Durable Concrete, American Concrete Institute, Detroit.
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- ANSI/ASCE 11-90, Guideline for Structural Condition Assessment of Existing Buildings, American Society of Civil Engineers, New York.

Characteristic	Suggested minimum requirement
Physical properties	Compatibility with substrate requirement
Permeability	Permeability of high quality concrete (see water absorption limits)
Shrinkage	< 500 microstrain at 28 days ASTM C157-1991

INITIAL INSPECTION CHECKLIST

Subject : Age :
 Type of Structural Element : Date :
 Location : Page :

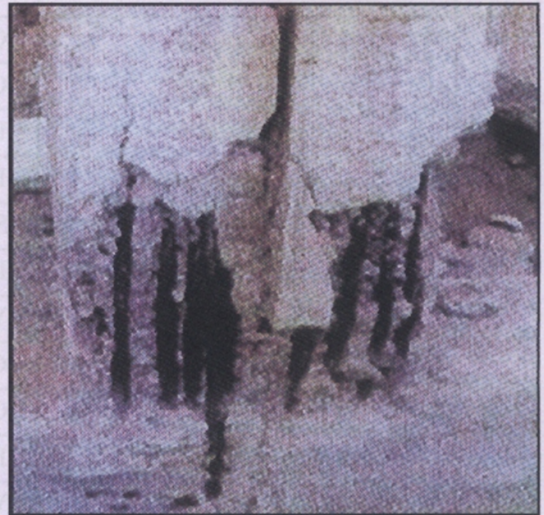
No.	Item Description	Cause of Damage	Y	N	Remarks
1	Visual Defects	* Poor Workmanship			
		* Material Deterioration			
2	Lack of Structural Adequacy	* Excessive Deflection			
		* Flexural/Shear Cracking			
3	Foundation Movements	* Distortion of Doors Frames			
		* Diagonal Cracks			
		* Cracking of Window Panels			
4	Materials Deterioration	* Concrete Spalling			
		* Concrete Scaling			
		* Honey combing			
		* Efflorescence			
		* Steel Reinforcement Corrosion			
5	Examination of Cracks and Defects	* Longitudinal Horizontal Crack			
		* Vertical Crack			
		* Craze Crack			
		* Out of Plumb Columns/Walls			
		* Evidence of Corrosion			
		* Water Leakage			
		* Fire Attack			
		* Corrosion Attack			
6	Action in Case of Safety Hazard	* Immediate Closure			
		* Restriction of Usage			
		* Temporary Props			
7	Background Information about the Structure	* Drawings & Design Calculations			
		* Concrete Test Results			
		* Steel Reinforcement			
		* Modification of Original Design			
		* Photographic Records			
		* Notes & Difficulties during Construction			
		* Records of Loading History			

Inspected by : Signature:

Corrosion Damage



C1 - Severe Crack due to corrosion



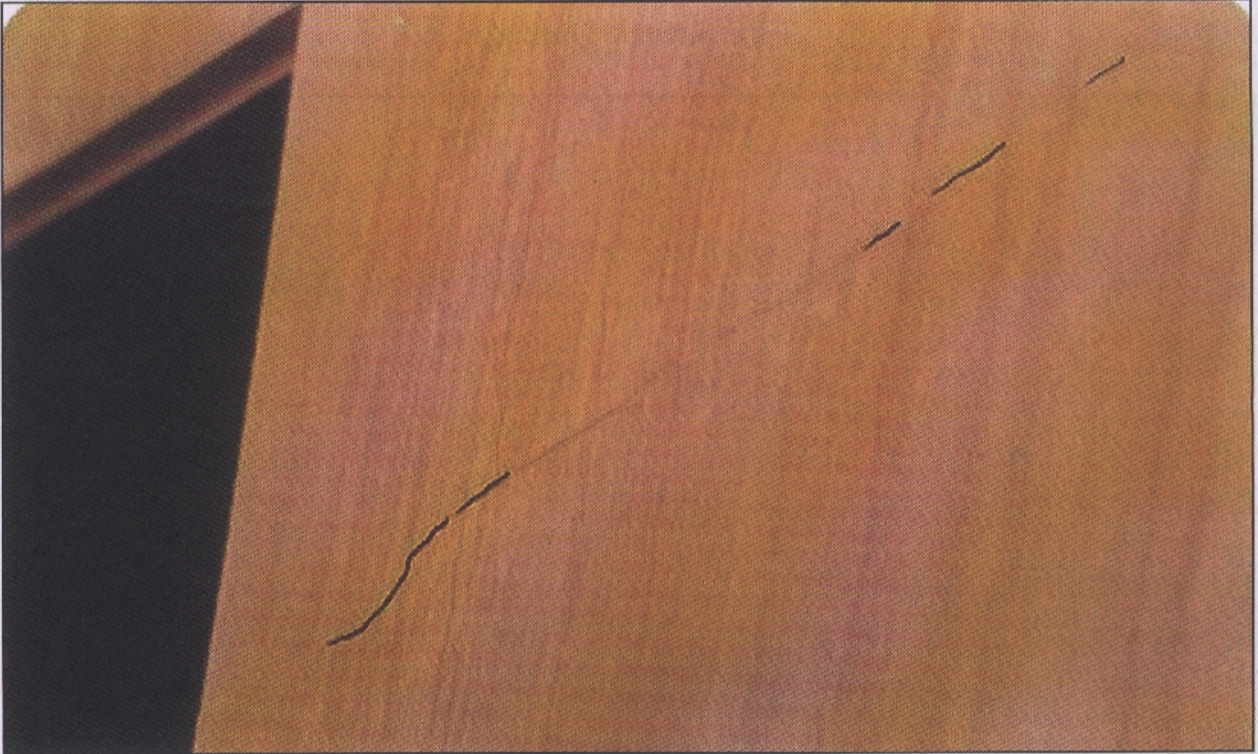
C2 - Severe Column reinforcement corrosion



C2 - Close up of corroded reinforcement

Fire Attack Damage





Structural Damage



Marble cracks due to settlement

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was founded in 1905 as a nonprofit membership organization dedicated to public service and to representing user interests in the field of concrete. It gathers and distributes information on the improvement of design, construction and maintenance of concrete products and structures. The work of the Institute is done by individual members and by volunteer committees.

The committees, as well as the Institute as a whole, operate under a consensus format which assures all members the right to have their views considered. Committee action requires a two-thirds majority vote. The development of building codes and specifications is a major activity of the Institute, and the presentation of research results is a primary function.

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The committees, as well as the Institute as a whole, operate under a consensus format, which assures all members the right to have their views considered. Committee activities include the development of building codes and specification standards; analysis of research and development results; presentation of construction and repair techniques; and education.

Anyone interested in the activities of the Institute is encouraged to seek membership. There are no educational or employment requirements. Engineers, architects, scientists, constructors and representatives from a variety of companies and organizations from the Institute membership.

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