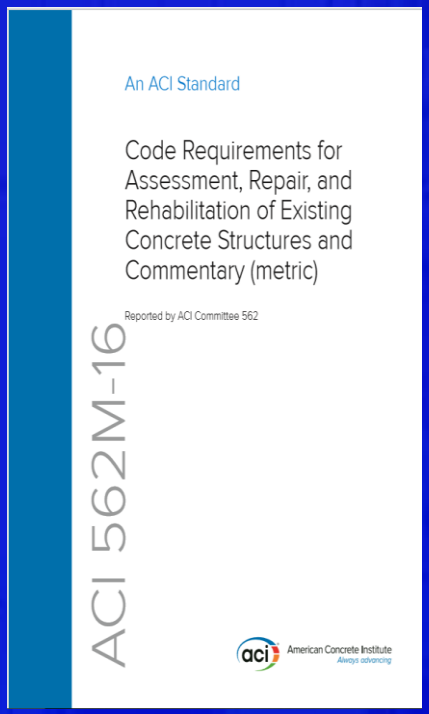
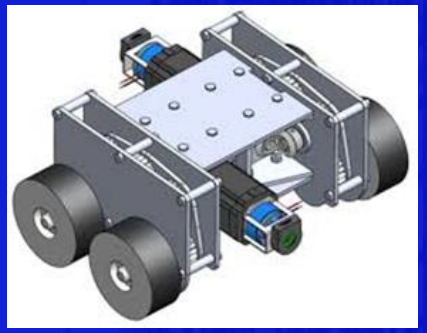
THE 20TH INTERNATIONAL OPERATIONS & MAINTENANCE CONFERENCE IN THE ARAB COUNTRIES

WORKSHOP

"Evaluation of Structures and Infrastructures using Laser Scanning, Geophysics, Photogrammetry and other Advanced NDT methods with Case Studies"





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Senior Advisor-
Engineering and Education, UAE

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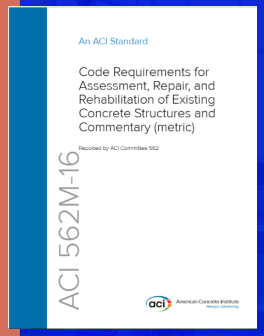
An Initiative by OMAINTEC المجلس العربي للتشغيل والصيانة Arab Operations & Maintenance Council

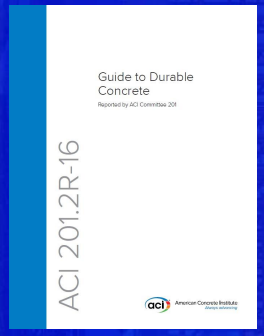
Organized by EXICON International Group مجموعة أكزيكون الدولية International Business Unit

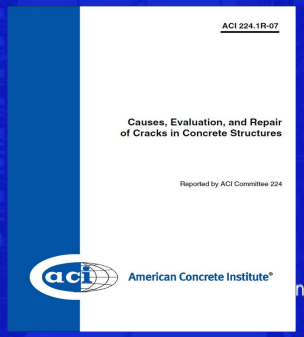
OMAINTEC 20 YEARS

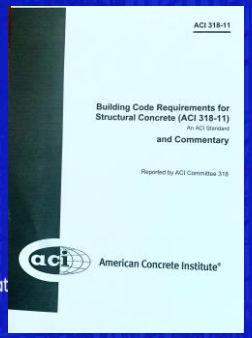
PART 1

INTRODUCTION TO MAINTENANCE AND CODES









IMPORTANCE OF MAINTENANCE

De Sitter's Law of Fives

A major repair can be expected to cost roughly five times what routine maintenance would have cost. An all-out replacement will cost five times what major repair would have cost.

The Difference in Repair Cost with Respect to Time (Actual Values)

REPAIR OF A DETERIORATED BUILDING

DATE	REPAIR COST
2014	250,000
2019	1,250,000

CORROSION PROTECTION INSTALLATION FOR A RAFT FOUNDATION

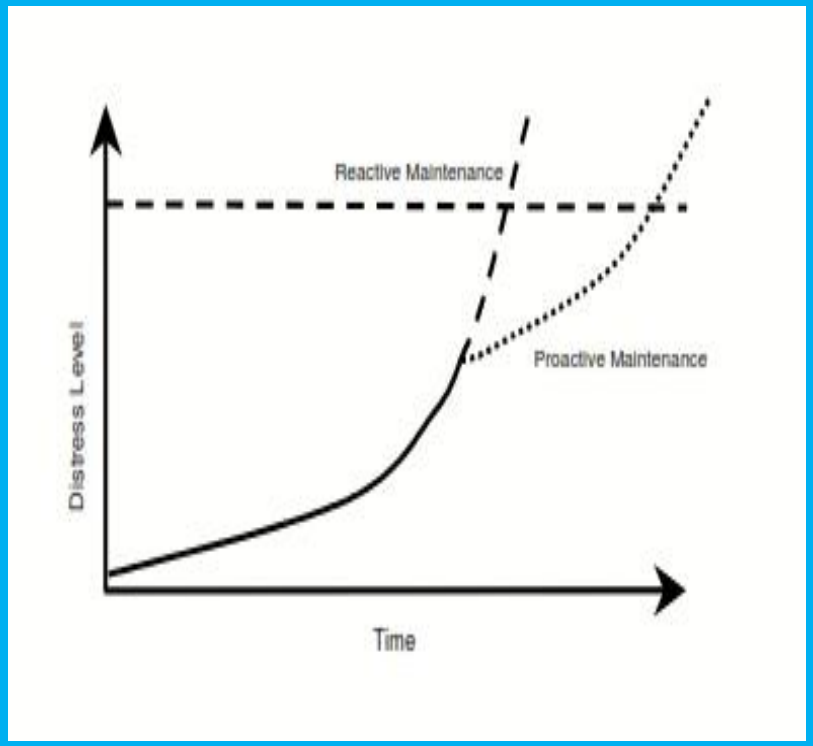
DATE	REPAIR COST
2015	1,000,000
2018	2,500,000

FACTORY REPAIR

DATE	REPAIR COST	TIME
2010	1,000,000	2 MONTHS
2018	5,000,000	10 MONTHS

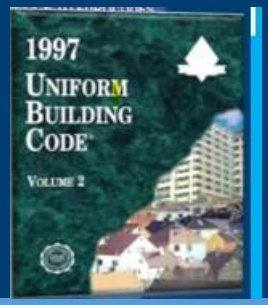
TYPES OF MAINTENANCE

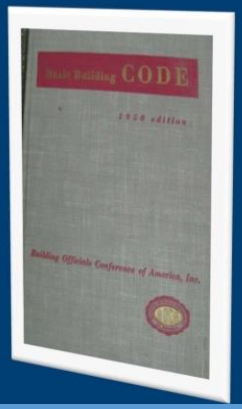
1. Routine Maintenance (Cyclic Maintenance) 30%
2. Preventive Maintenance (Scheduled Maintenance) 12%
3. Corrective Maintenance (Emergency maintenance) 58 %



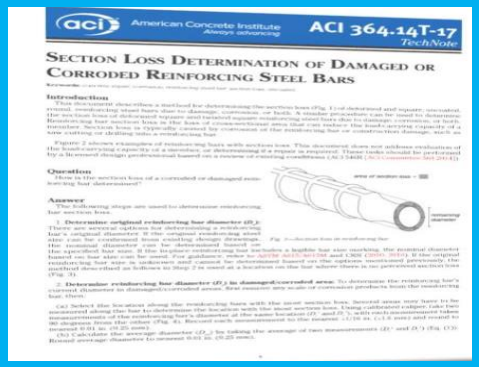
HISTORY OF REPAIR CODES

- UBC 1927
- SBC 1946
- BOCA 1950





HISTORY OF REPAIR CODES



History of Repair Codes

80s change in philosophy:

Leave undamaged, unaffected elements alone, and apply new construction rules only to elements of the construction that are damaged

ACI 562M Chapters

Chapter 1—General requirements	Preliminary Evaluation
Chapter 2—Notations and Definitions	
Chapter 3—Referenced Standards	
Chapter 4—Criteria when using this code with IEBC	
Appendix A—Criteria using this code as stand-alone code	
Chapter 5—Loads, factored load combinations, and ϕ	Structural Assessment
Chapter 6—Assessment, evaluation, and analysis	
Chapter 7—Design of structural repairs	Design
Chapter 8—Durability	
Chapter 9—Construction	Construction
Chapter 10—Quality assurance	

Codes vs. Guidelines

- Codes
  - Adopted by regulatory agencies
  - Mandatory language (**shall** not should)
  - Establish **required** practice
  - ACI 318, ASCE 7, IBC, IEBC - codes
- Guidelines
  - Non-mandatory language (**should** not shall)
  - Establish **recommended** practice
  - ACI 364, ICRI documents - guidelines

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PART TWO

DURABILITY AND CORROSION

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FACTORS AFFECTING DURABILITY

- External Causes
  - Weathering
    - Freezing & Thawing
    - Temper-ature variation
    - Moisture Variation
  - Chemical Action
    - Inorganic Salts
    - Acids
  - Wear
    - Water
    - Wind
    - Traffic
- Internal Causes
  - Alkali-Aggregate Reaction
  - Volume Changes
  - Permeably & Absorption

Service Life Estimation
Clear's Simplified Equation

$$t = \frac{(2.5)(S)^{1.22}}{(R)(K)^{0.42}}$$

t: Service Life in Years

S: Concrete cover in mm

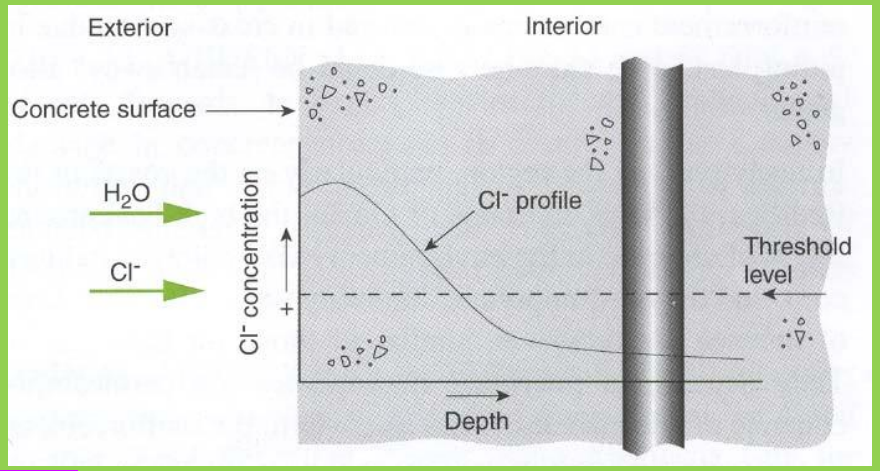
R= w/c ratio

K: Cl^- Content in PPM

Concrete cover S= 50 mm

R= w/c ratio= 0.5

Exposure sea water K= 23,300 ppm



$$t = \frac{(2.5)(S)^{1.22}}{(R)(K)^{0.42}} = \frac{(2.5)(50)^{1.22}}{(0.5)(23300)^{0.42}}$$

=8.7 years

SULFATE INGRESS INTO CONCRETE

The effect of SO_4^{-2} Ingress into concrete durability is significant for reinforced and non reinforced concrete

Critical SO_4 Level is reached → **Formation of Ettrengite** → **Gypsum filling air voids** → **Expanding And Spalling** → **Lead to other attacks CO_2, CL^-**

Factors Affecting Sulfate deterioration Rate (K_S):

- W/C
- C_3A Content
- Curing Period
- Temp: 40/ 50 °C
- SO_4

Carbonation of Concrete Cover

Time for carbonation to reach reinforcement (years)

External concrete sheltered from rain

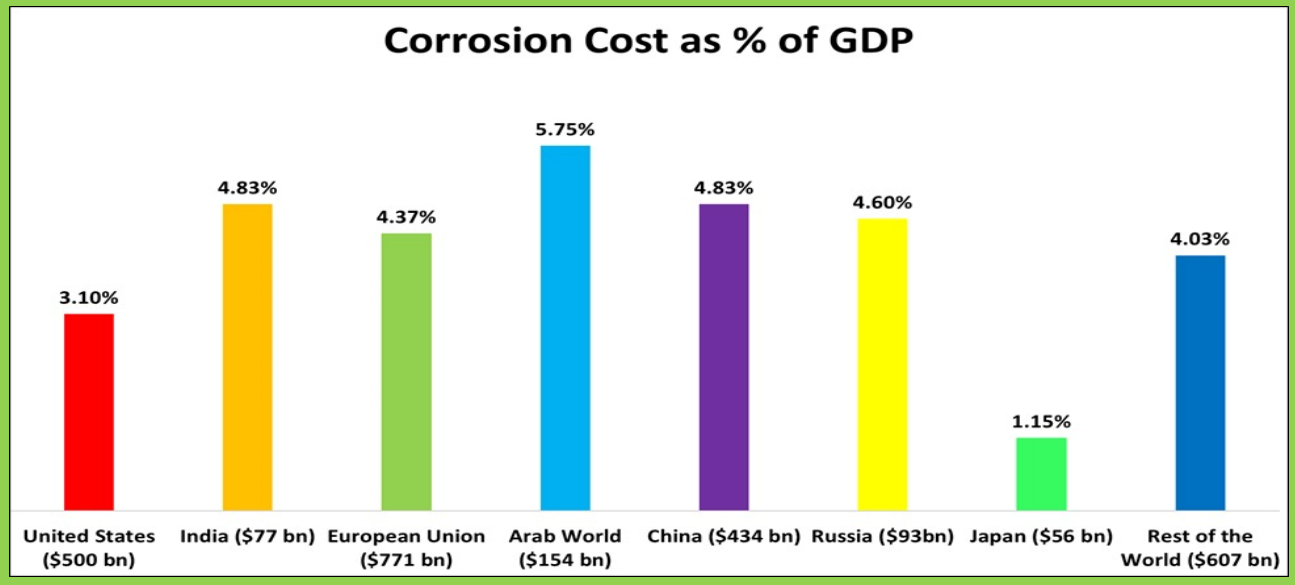
w/c \ cover	10 mm	30 mm
0.7	5	45
0.5	15	135

Concrete cover protects the reinforcing steel with its alkaline nature (PH level ~ 13). This protection diminishes by ingress of CO_2 from the atmosphere and reduces the PH level to 9. At this stage concrete is no longer protecting the steel and in the presence of moisture and O_2, steel begins to corrode

COST OF CORROSION

- **Report by Visiongain calculates that the global oil and gas corrosion prevention market was worth $18.72 billion.**

- **The annual cost of corrosion worldwide is estimated at USD $ 2.2 trillion which is about 3% of the world's GDP.**

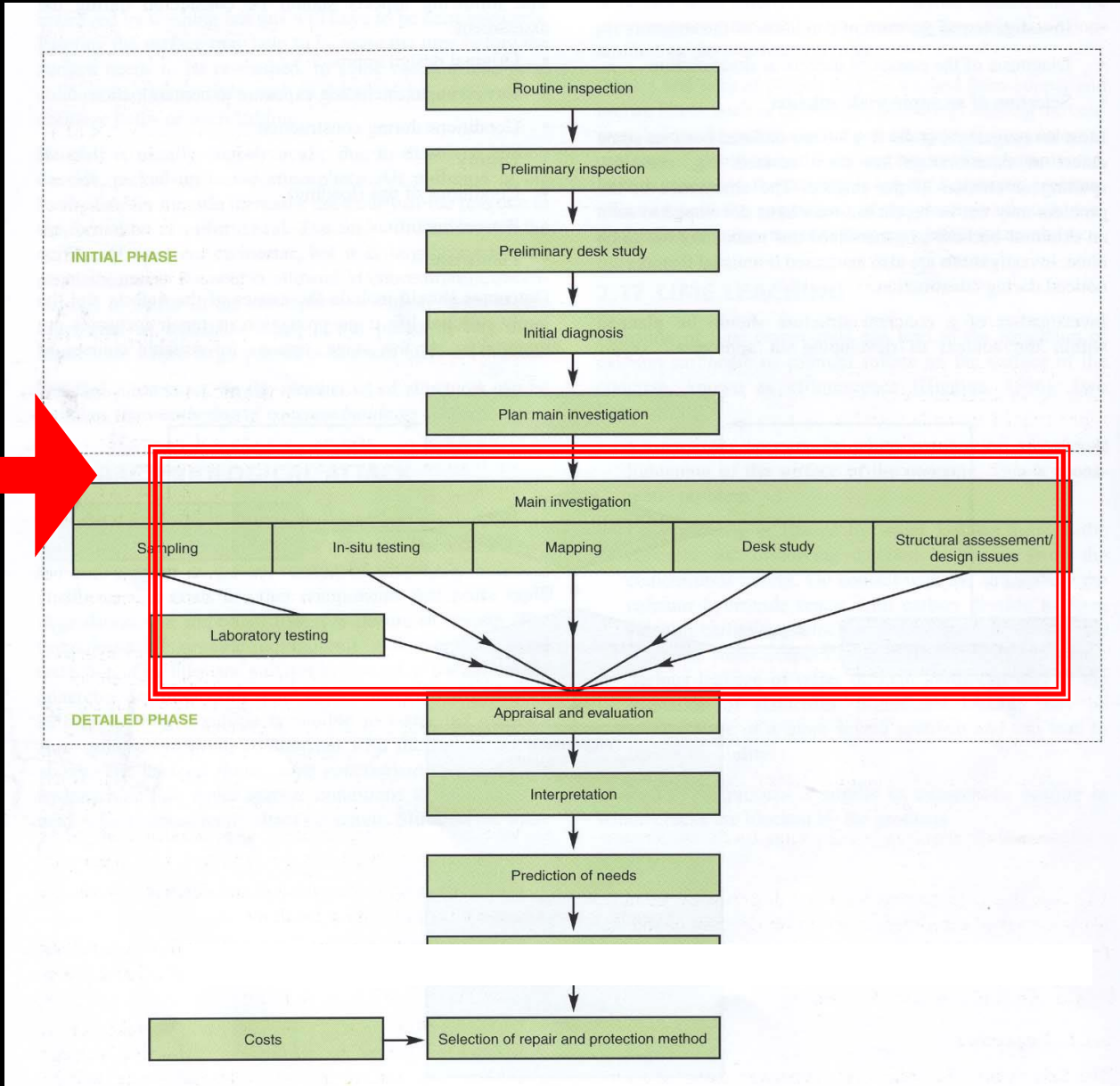


PART THREE

EVALUATION AND TESTING

Investigation

The 3-Stage Process Leading to repair



Sample of Preliminary inspection Form

Structure ..... / Part of structure ..... / Date of inspection	Rating 0 None	1 Very slight	2 Slight	3 Moderate	4 Severe	5 Very severe
Defects						
Cracking	☐	☐	☐	☐	☐	☐
Plastic shrinkage/settlement	☐	☐	☐	☐	☐	☐
Thermal contraction	☐	☐	☐	☐	☐	☐
Structural	☐	☐	☐	☐	☐	☐
Crazing	☐	☐	☐	☐	☐	☐
Rust staining	☐	☐	☐	☐	☐	☐
Water leakage	☐	☐	☐	☐	☐	☐
Pop-outs	☐	☐	☐	☐	☐	☐
Spalling	☐	☐	☐	☐	☐	☐
Loss of surface	☐	☐	☐	☐	☐	☐
Abrasion	☐	☐	☐	☐	☐	☐
Chemical attack	☐	☐	☐	☐	☐	☐
Efflorescence	☐	☐	☐	☐	☐	☐
Others (specify below)	☐	☐	☐	☐	☐	☐
Existing repairs (if any)						
Delamination/debonding	☐	☐	☐	☐	☐	☐
Cracking	☐	☐	☐	☐	☐	☐
Others (specify below)	☐	☐	☐	☐	☐	☐

Supplementary documentation	**Details** (including reference numbers etc)
Sketches	.....
Photographs	.....
Others (specify below)	.....

Additional comments (general condition of structure, local effects that may influence performance, such as damp areas).

ATC-20 Rapid Evaluation Safety Assessment Form

Inspection

Inspector ID: _____ Inspection date and time: _____ ☐ AM ☐ PM

Affiliation: _____ Areas inspected: ☐ Exterior only ☐ Exterior and interior

Building Description

Building name: _____

Address: _____

_____

Building contact/phone: _____

Number of stories above ground: ____ below ground: ____

Approx. "Footprint area" (square feet): _____

Number of residential units: _____

Number of residential units not habitable: _____

Type of Construction

☐ Wood frame ☐ Concrete shear wall

☐ Steel frame ☐ Unreinforced masonry

☐ Tilt-up concrete ☐ Reinforced masonry

☐ Concrete frame ☐ Other: _____

Primary Occupancy

☐ Dwelling ☐ Commercial ☐ Government

☐ Other residential ☐ Offices ☐ Historic

☐ Public assembly ☐ Industrial ☐ School

☐ Emergency services ☐ Other: _____

Evaluation

Investigate the building for the conditions below and check the appropriate column.

Observed Conditions:	Minor/None	Moderate	Severe	Estimated Building Damage (excluding contents)
Collapse, partial collapse, or building off foundation	☐	☐	☐	☐ None
Building or story leaning	☐	☐	☐	☐ 0–1%
Racking damage to walls, other structural damage	☐	☐	☐	☐ 1–10%
Chimney, parapet, or other falling hazard	☐	☐	☐	☐ 10–30%
Ground slope movement or cracking	☐	☐	☐	☐ 30–60%
Other (specify) _____	☐	☐	☐	☐ 60–100%
				☐ 100%

Comments: _____

Posting

Choose a posting based on the evaluation and team judgment. *Severe* conditions endangering the overall building are grounds for an Unsafe posting. Localized *Severe* and overall *Moderate* conditions may allow a Restricted Use posting. Post INSPECTED placard at main entrance. Post RESTRICTED USE and UNSAFE placards at all entrances.

☐ **INSPECTED** (Green placard) ☐ **RESTRICTED USE** (Yellow placard) ☐ **UNSAFE** (Red placard)

Record any use and entry restrictions exactly as written on placard: _____

Further Actions Check the boxes below only if further actions are needed.

☐ Barricades needed in the following areas: _____

☐ Detailed Evaluation recommended: ☐ Structural ☐ Geotechnical ☐ Other: _____

☐ Other recommendations: _____

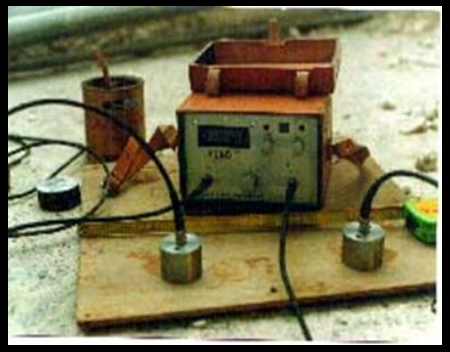
Comments: _____

TESTING OF REINFORCED CONCRETE STRUCTURES

Testing is performed in order to obtain sufficient information on the condition of the deteriorated structure so that the appropriate remedial repair method is implemented.

NO TESTS SHALL BE CARRIED OUT UNLESS IT IS KNOWN WHAT THE RESULTS WILL BE USED FOR





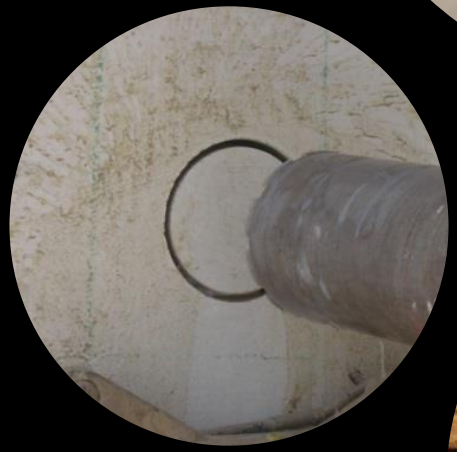

TYPES OF TESTS

- ***DESTRUCTIVE TESTS:***

These conventional methods enable the strength of the concrete to be measured by way of cores or cubes cut from the concrete. However, this is not possible in all cases and especially not for slender members.

- ***NON-DESTRUCTIVE TESTS:***

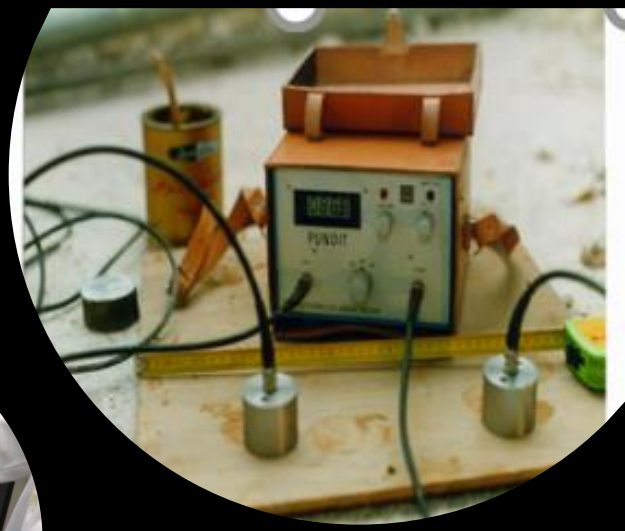
By definition, the strength properties are not measured directly so some other properties are measured and the strength estimated by calibration. Naturally, these methods have the great advantage that concrete is not damaged. For example: Ultra-sound test and Schemed Hummer Test.



- ***PARTIALLY DESTRUCTIVE TESTS:***

In these tests, the concrete is tested to failure but the destructive resulting is very localized and member under test is not weakened to any significant extent For example Core test. .

ULTRA SONIC MATERIALS ANALYSIS (PULSE VELOCITY)
(ASTM C 597)



- Detecting Cracks, Voids, And Flaws To Find The Damage Pattern

- It Can Be Used To Control The Effectiveness Of Repair By Injection Technique.

HAMMER TAPPING OR CHAIN DRAGGING ASTM D4580

ADVANTAGES

- Rapid and well-established field collection method
- Ability to identify severe to moderate delamination
- Field method is simple
- Mapping is not difficult and Limited training required

LIMITATIONS

- cannot pick up the onset of delamination
- Must be performed when traffic noise is minimal
- Generally ineffective with asphalt overlays
- Results are subjective

REBOUND HAMMER (ASTM C803/C803M-17)

Advantages

Speed

Low Cost

Relatively low expertise required

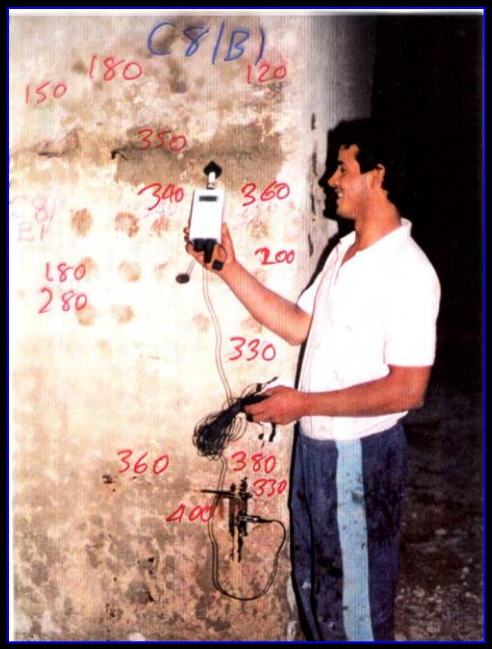
Limitations

- **Smoothness of the surface**
- **fixity of the samples**
- **Size shape**
- **Type of coarse aggregates**

HALF CELL POTENTIAL

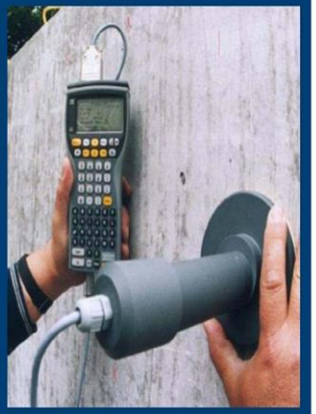
It measures the electrical potential on the surface of the steel to qualitatively estimate its likelihood of corrosion.

Potential P (mV)	Risk of corrosion
P > -200 mV	5 %
-350< P< -200	50 %
P< -350	95 %



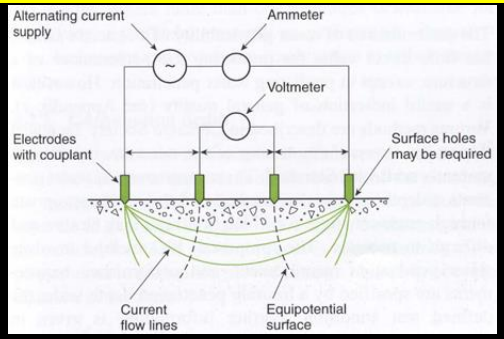
CORROSION POTENCIAL (ASTM C876)

- Corrosion Rate (ASTM G59)
  - Provides instantaneous corrosion rates



Source: PCTE

Resistivity :It used to qualitatively estimate the likelihood of corrosion Rate



Resistivity R (ohm cm)	Likely corrosion Rate
R <5000	Very High
5000< R< 10000	High
10000<R<20000	Low
R>20000	Negligible

DESTRUCTIVE TESTS
CORES

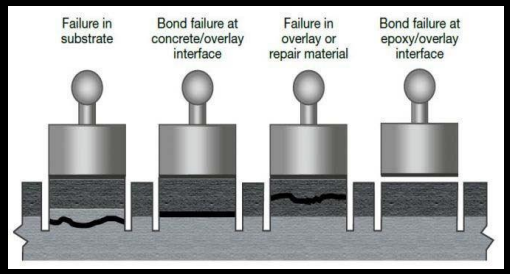
ASTM C 42-04, "Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete,"

Factors that influence measured core compressive strength:

Length/diameter ratio of core,
Diameter of core,
Direction of drilling,
Method of capping
Reinforcement)

The Concrete Society and BS 1881: Part 120 suggest that cores should be kept as short as possible (l/d = 1.0→ 1.2).
Correction factors are minimized if the core length/diameter ratio is close to 2.0 and this view is supported by ASTM C42

PARTIALLY DESTRUCTIVE TEST METHODS

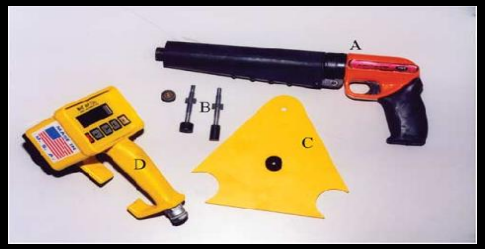


The most common partially destructive tests are-- pullout,-- pull-off, --penetration resistance-- break-off, Windsor Probe

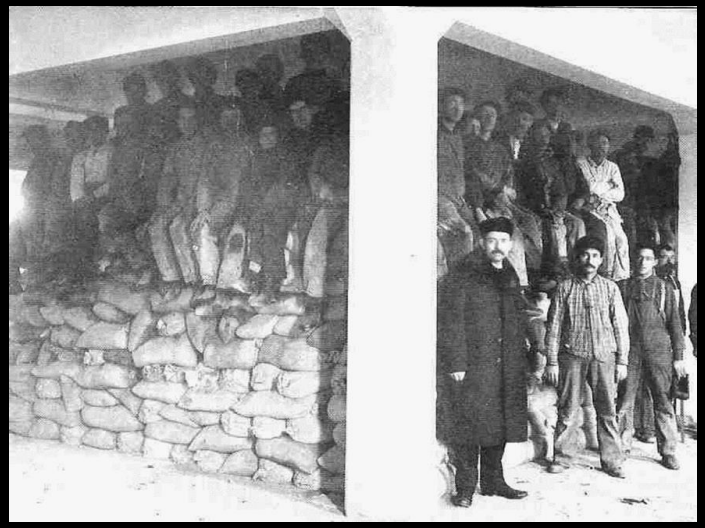
METHOD	STANDARDS		PRINCIPLE FEATURES
	ASTM	BS 1881	
Rebound hammer	C805		Existing concrete, best used comparatively
Pull out	C900	207	Existing concrete , high variability
Pull off		207	Existing concrete surface or partially cored
Break off	C1150	207	New construction or Exsisting concrete


Figure 4.26 'Limpet' equipment.

Windsor Probe Test:



LOAD TEST



437.2-13 Code Requirements for Load Testing of Existing Concrete Structures and Commentary

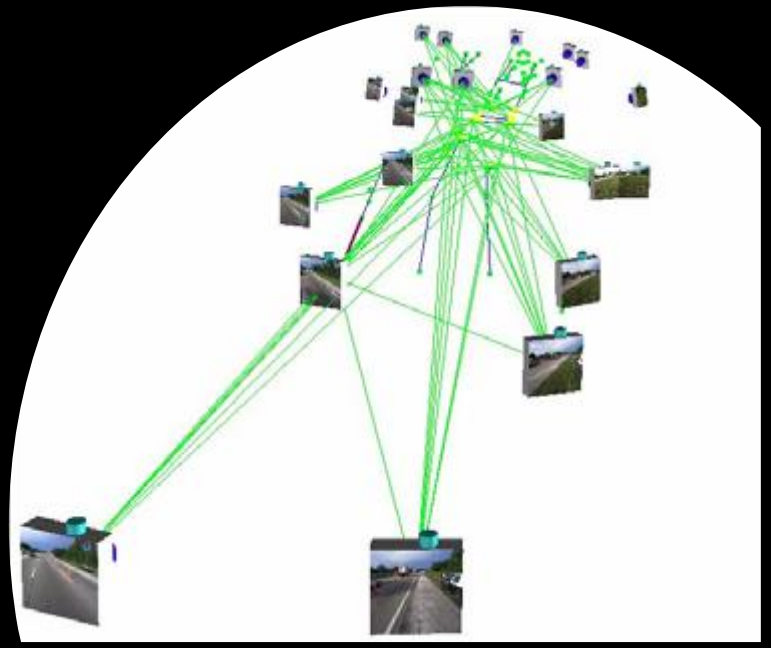
LASER SCANNING TECHNOLOGIES

- Laser scanning is a geomatic method that allows obtaining the 3D geometry of objects' surfaces automatically by using Light Detection and Ranging (LiDAR)

- The instrument can compute the relative position of the points measured from its surroundings providing the most primitive 3D model as a point cloud.

CLOSE RANGE PHOTOGRAMMETRY

- The precise geometric information obtained from photogrammetry is frequently used in structural analyses

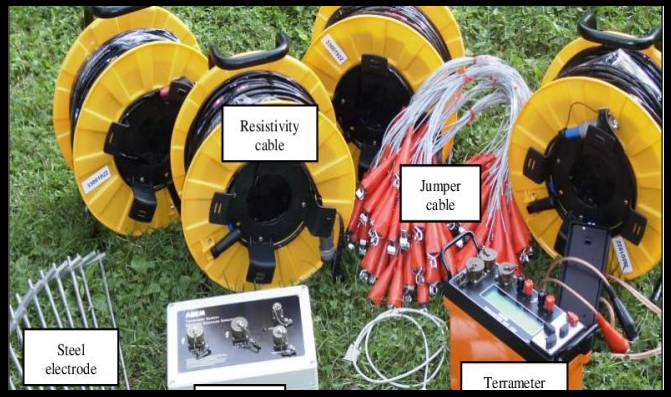


- Among the common applications to this domain is to obtain deformation measurement under laboratory tests and real structures.

GEOPHYSICS

- Geophysical prospection was developed as a set of methods to study the interior of the Earth with minimum intervention by measuring physical properties on its surface.

- Nowadays, these geophysical prospection surveys are the usual methodologies applied in the assessment of civil engineering structure and infrastructure



GROUND PENETRATING RADAR

- This method is related to the analysis of signals amplitude transmitted and received by dipole antennas

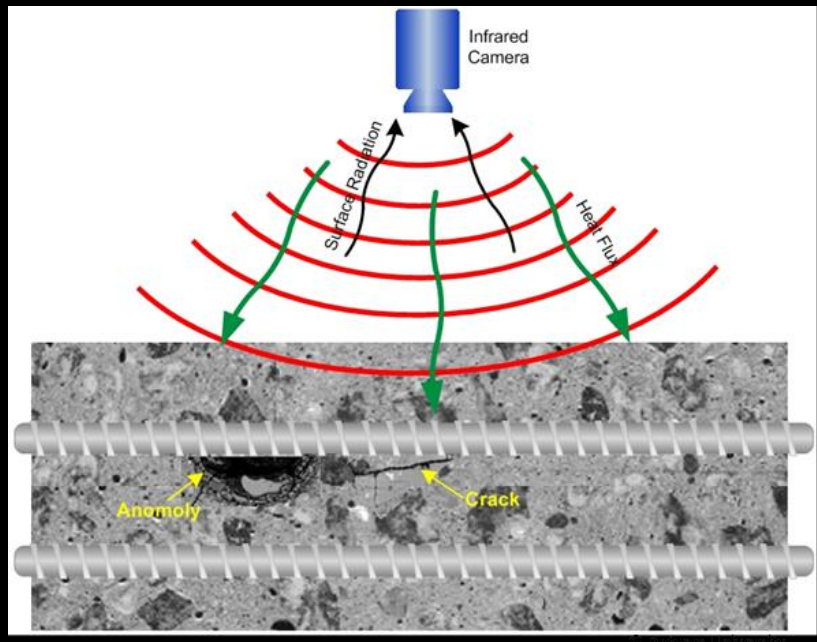
- This method is a geophysical technique that relies on the propagation of a short electromagnetic pulse (1-20ns) in the frequency band of 10 MHz-2.5 GHz to obtain information.

INFRARED THERMOGRAPHY

- Infrared thermography is a technique based on the acquisition of the thermal radiation of the bodies suing thermographic cameras.

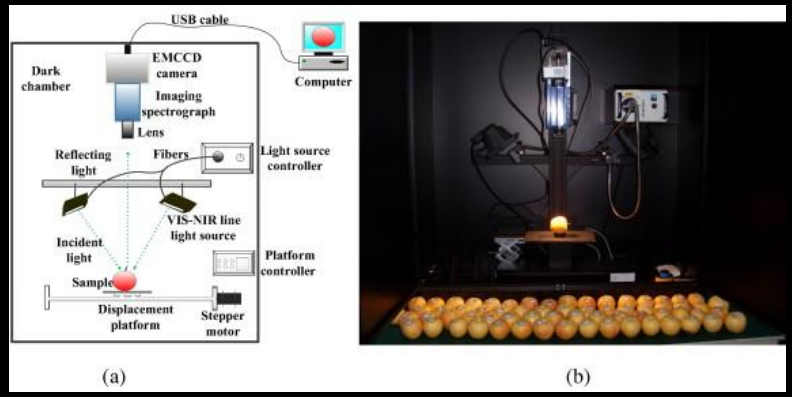
- It produce an image of the radiation captured thought conversion of the radiation values to temperature values.

- The infrared band presents wavelength values between visible (400-750mm) and microwave bands (1mm-1m)



MULTISPECTRAL IMAGING

- In this technique, different regions of the electromagnetic spectrum are extracted from one or more sensors and assessed in the form of a 2D image.



- It offers a decisive advantage and represents new ways to analyze building structures.

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PART FOUR

CRACKS, REPAIR TECHNIQUES, AND MONITORING

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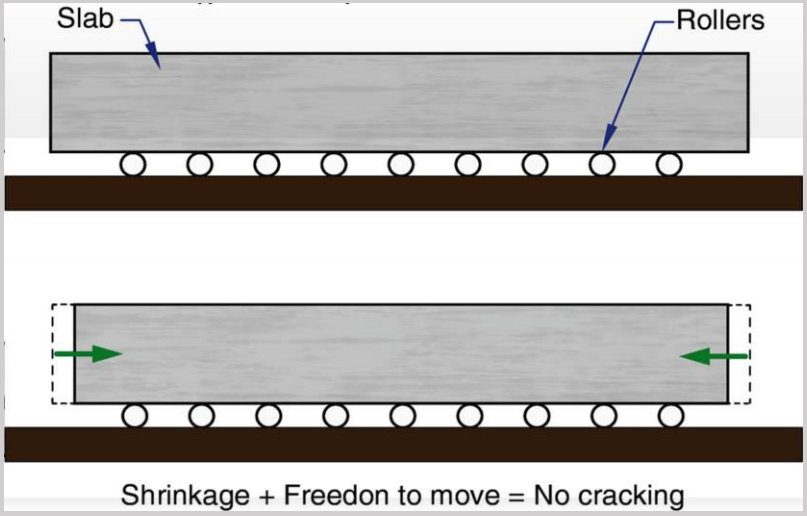
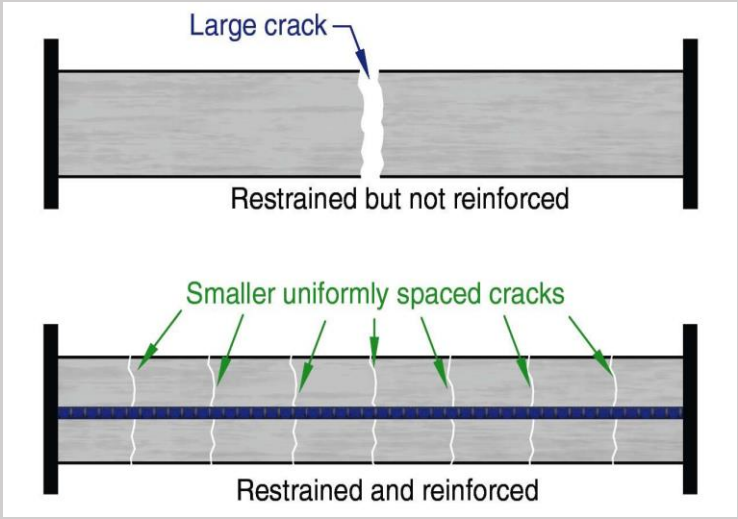
OMAINTEC 20 YEARS

INTRODUCTION TO CRACKING AND REPAIR

- **WHILE CONCRETE LOOK NICE WHEN THEY ARE NEW, OVER TIME THE CONCRETE CAN CHIP, CRACK AND CRUMBLE.**

- **CRACKS FORM WHEN THE TENSILE STRENGTH OR TENSILE STRAIN EXCEEDS THAT OF CONCRETE.**





CLASSIFICATION OF CRACKS

Cracks maybe separated into two classes for the purpose of deciding upon the type of repair.

a) DORMANT CRACKS .

1) fine cracks:

2) wide cracks:

3) fractures :

b) LIVE CRACKS.

Plastic settlement
A-Over reinforcement
B- Arching
C- Change of depth

Crazing
J- Against formwork
K - Floated concrete

I - Long-term drying shrinkage

K - Floated concrete

Plastic shrinkage
D-Diagonal
E- Random
F- over reinforcment

C- Change of depth

N - Alkali silica reaction

B- Arching

Early thermal contraction
G- External restraint
H- Internal restraint

Corrosion of Reinf.
L - Natural
M- Calcium chloride

D- Diagonal

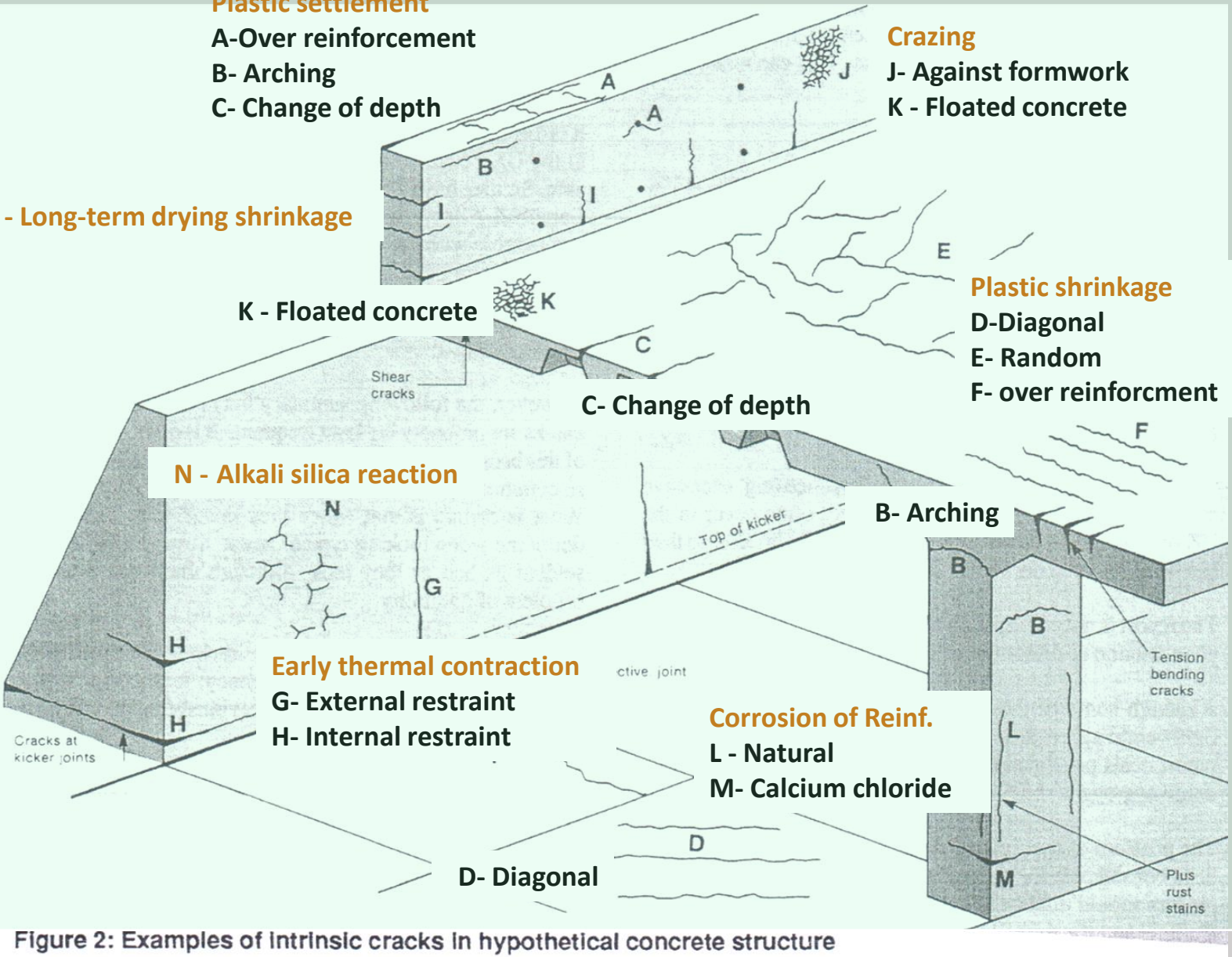
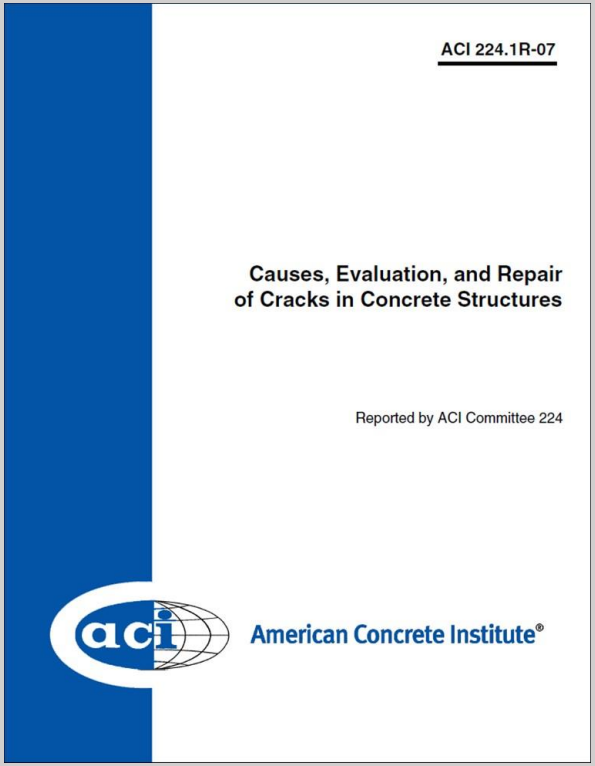
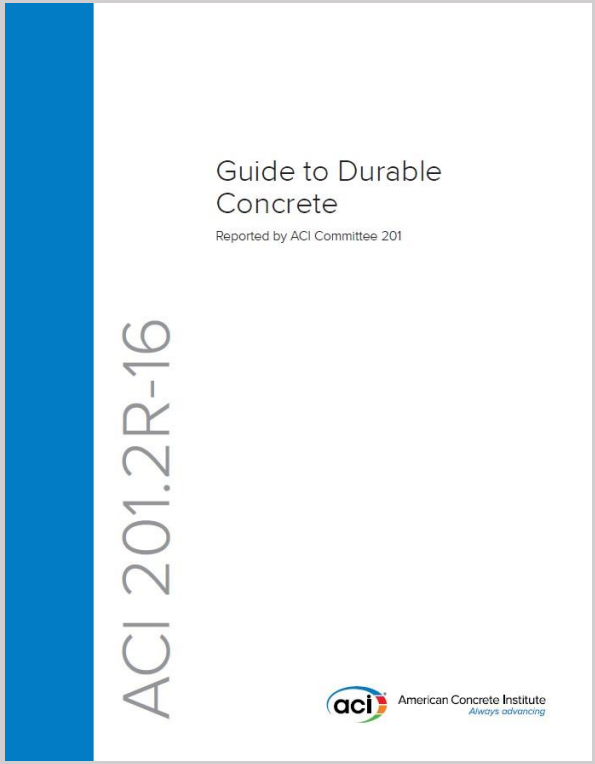


Figure 2: Examples of intrinsic cracks in hypothetical concrete structure

Causes and Control of Cracking





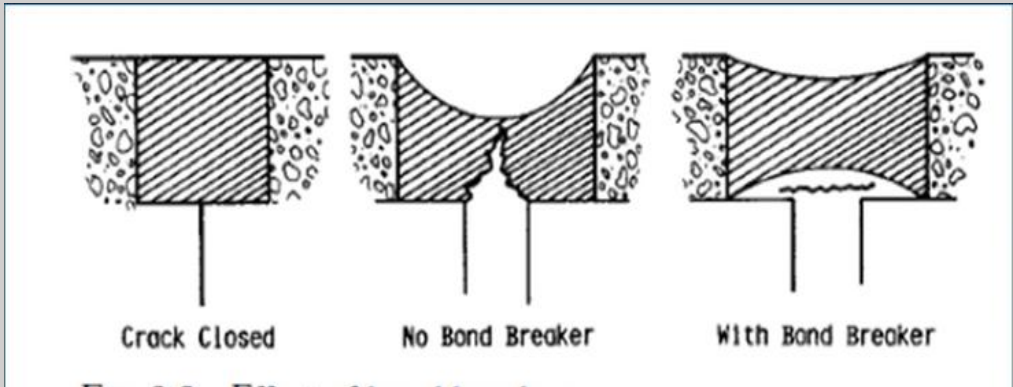
ACI 224.1R-07

ACI 201.2R-16

REPAIR OF CRACKS

Active cracks (Live cracks) are sealed with FLEXIBLE material to support the effect of its movements

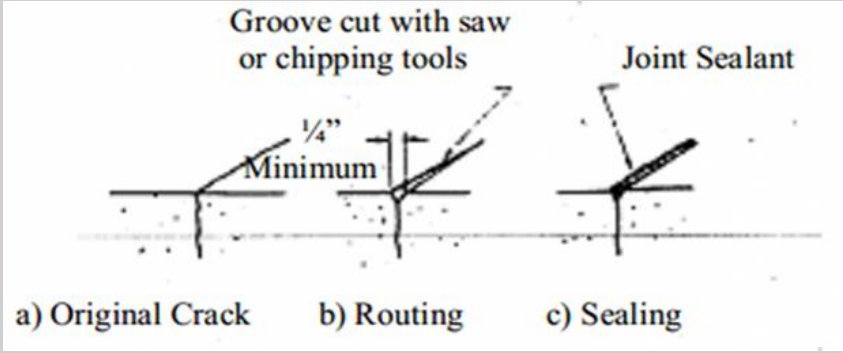
- sealing of cracks can be used where structural repair is not necessary
- A cut is made along the length of crack using a saw.
- Clean the crack by sandblasting or by using compressed air or a water jet.
- Provide bond breaker at base if crack is active
- Width-to-depth ratio ≥ 2



Repair of Cracks

Repair of cracks that are not expected to grow in the future (DORMAT or “DEAD" cracks):

1. Painting
2. Chemical grouting
3. Routing and Sealing
4. Dry Packing
5. Drilling and Plugging
6. Epoxy Injection
7. Grouting
8. Polymer Impregnation
9. Autogenous Healing



Repair- Reinstatement with Mortar

1- Breaking Out Spalled Concrete

2- Cleaning The Exposed Reinforcement & Substrate

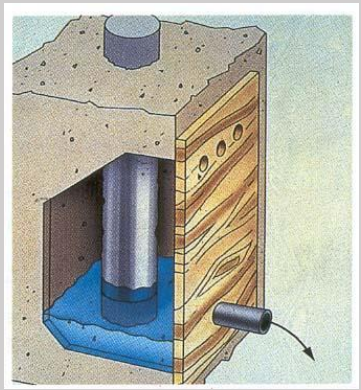
3- Applying protective Coating to exposed steel

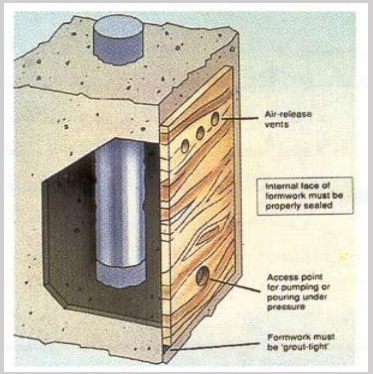
4- Soaking or applying Bonding agent to substrate

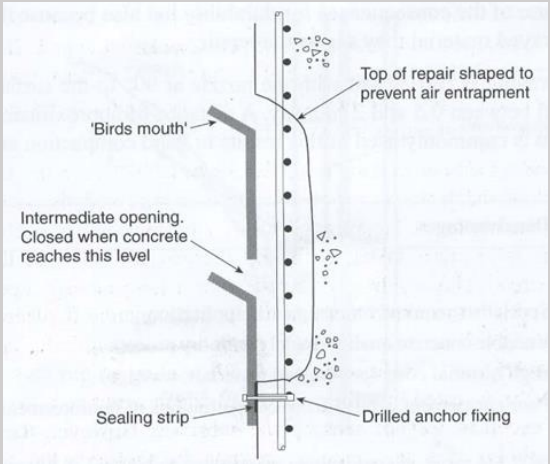
5- Install formworks for slurry type mortar

6- Reinstatement with mortar (Patching)

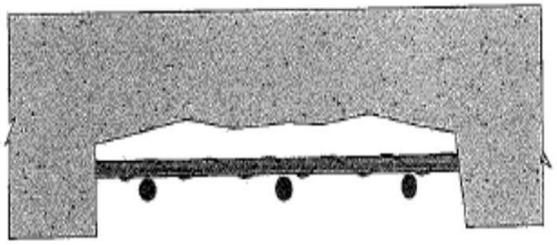
7- Curing



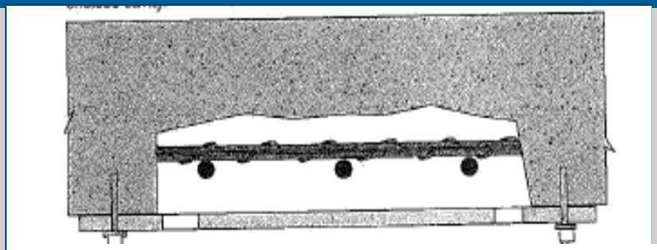




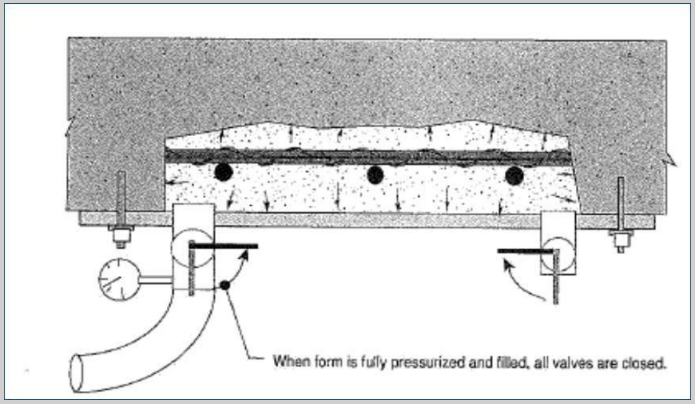
Concrete Placement



Surface preparation requires removal of loose and deteriorated concrete, and also includes concrete removal behind exposed bars.



After completion of removals and cleaning, formwork is erected to enclose cavity.



When form is fully pressurized and filled, all valves are closed.

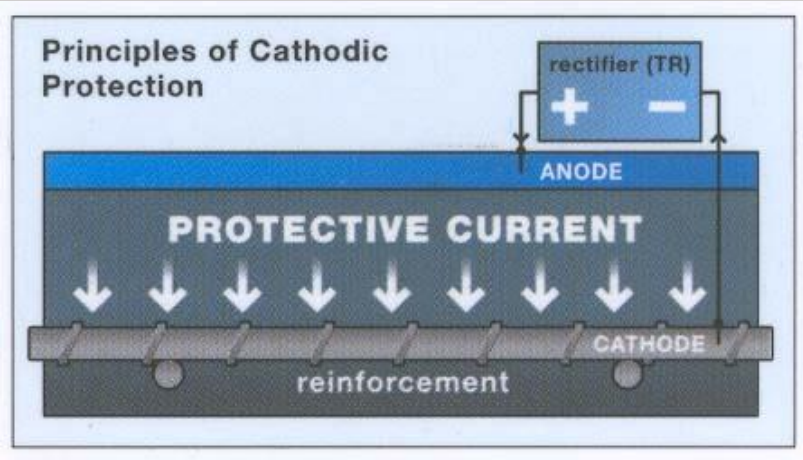
Source: Concrete Repair and Maintenance Illustrated

Repair- Cathodic Protection

It is used to prevent or reduce corrosion rates . It works by connecting the metal reinforcement to another material which is anodic in relation to the metal reinforcements. The metal becomes a cathode and its corrosion is reduced. Two systems are used:

Sacrificial anode: It consists of small zinc, or magnesium blocks tie around reinforcements at 50 to 75 cm. They are more reactive than steel and reacts with chloride faster.

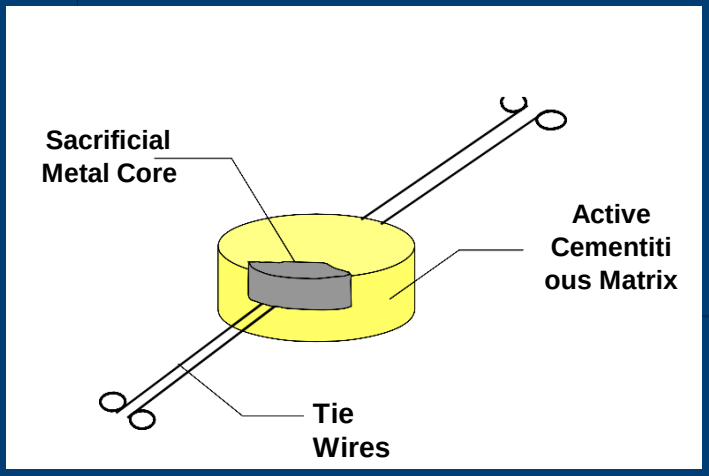
Impressed Current System: Inert material (mesh) connected to a DC power supply so that the reinforcement will stay protected in a cathode state

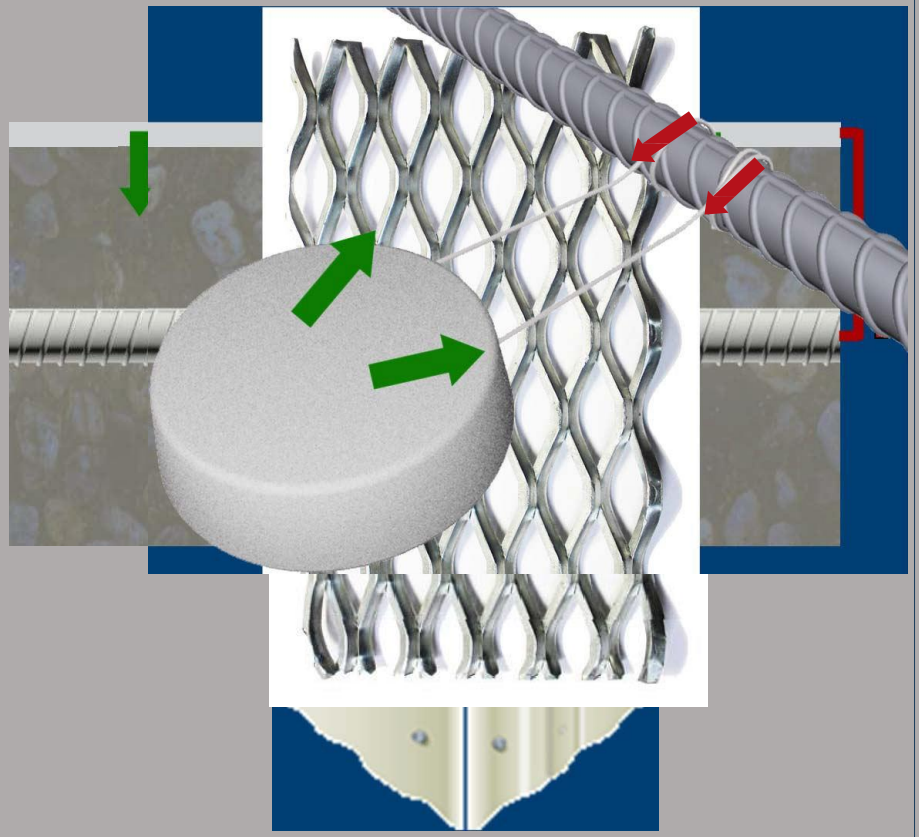


Galvanic Cathodic Protection System

Types:

- Point Anodes
- Embedded and Mesh Anodes
- Surface Mounted Anodes
- Jacketing Systems





SEVERAL METHODS TO STRENGTHEN A STRUCTURE:

Conventional:

- Concrete enlargement
- Supplemental structural steel

Post-Tensioning

FRP

Structural strengthening is required to address:
Existing strength deficiency
Higher new design loads
Effects of wind and earthquake loads

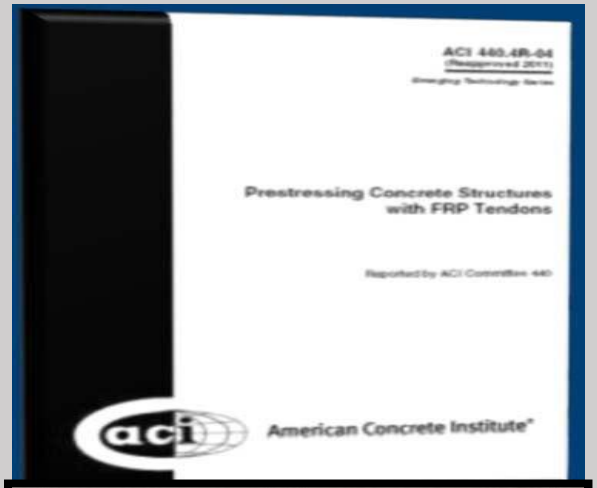
APPLICATION OF FRP COMPOSITES

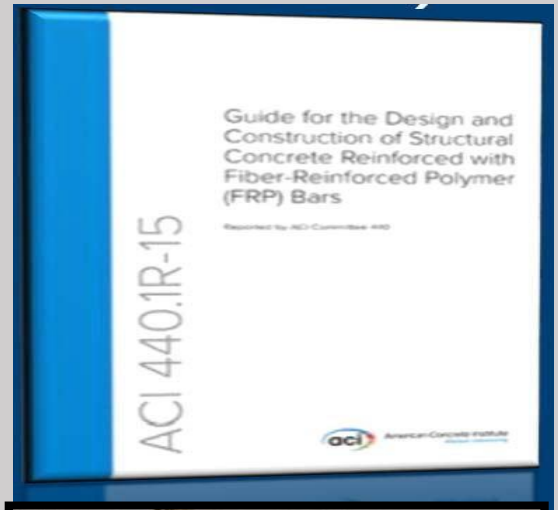
- The lightweight, high strength and corrosion resistance of fiber-reinforced polymers (FRP) make them ideally suited for quick and effective structural repairs.
- As a result, they have been favored for conducting emergency bridge repairs where speed is of the essence.

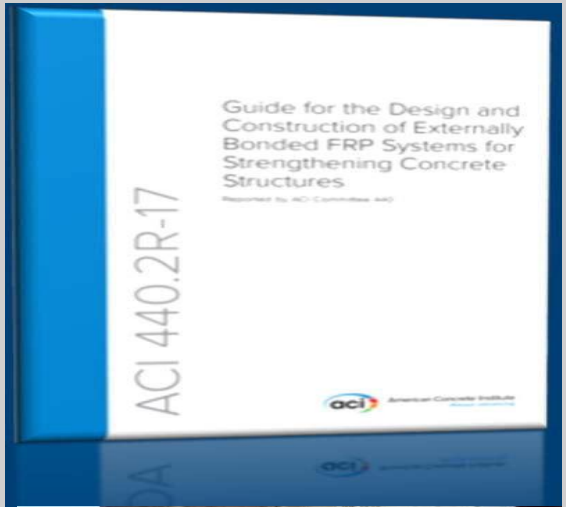
DESIGN OF STRUCTURAL REPAIRS

FRP Externally bonded (ACI 440.2R)

- **Internal reinforcement (ACI 440.1R)**
- **Internal P-T (ACI 440.4R)**







Strengthening Using FRP Application

- A strengthening system was designed and applied to gain at least 30 % extra shear load carrying capacity.
- ACI 440.2R guideline was used to calculate the additional shear strength provided using carbon fiber reinforced polymer (CFRP) sheets.
- The CFRP sheets used in this case study has the following properties mentioned in the table below:

Properties	Value
Type	Carbon flexible sheet
Configuration	U shape discrete strips in vertical scheme
Width (W_{FRP})	100 mm
Spacing (S_{FRP})	200 mm center to center of CFRP strips
Thickness (t_{FRP})	0.167 mm
Tensile Modulus (E_{FRP})	230 GPa
Elongation at rupture (ε_{FRP})	2.1%

- Before applying FRP sheets, the major cracks in the members were injected with structural epoxy.

Epoxy injection

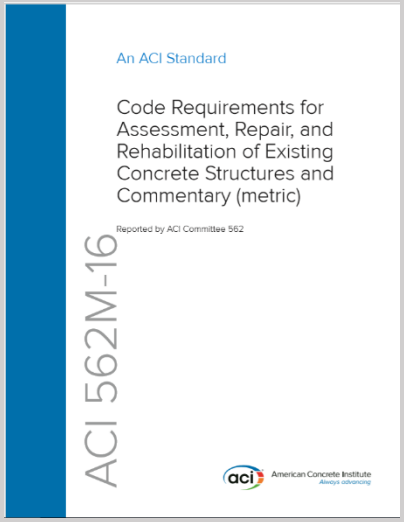
Primer coat application

CONFERENCE OMAINTEC 2023 EXHIBITION

THE 20TH INTERNATIONAL OPERATIONS & MAINTENANCE CONFERENCE IN THE ARAB COUNTRIES

- **Assessment & Repair of a Reinforced Concrete Building with Signs of Deterioration using ACI 562M-16 Code**

CASE STUDY



Prof. Mufid Samarai,
Senior Advisor-
Sahara Consultancy
Management

EXERCISES

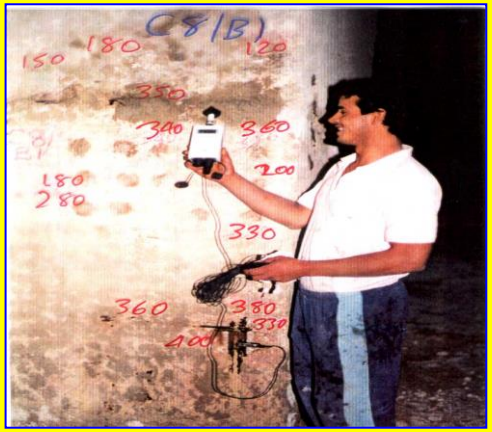


Image	Type of Deterioration and Cracking		
	cracking	Deusting	Frozen fersh concrete
	delamination	Excessive retarder	sulfates
	Surface Scaling	Corrosion of steel	Dusting
	Chloride induced corrsion	sulfates	Excessive retarder
	cracking	Delamination	sulfates

Image	Type of Crack		
	Crazing	delamination	Plastic Settlement
	scaling	Drying Shrinkage	Crazing
	Constructional movement- Loss of Support	Structural Crack	Plastic Settlement
	Constructional movement- Loss of Support	Structural Crack	D-Cracking

Image	Test		
	Half-cell electrical potential (Corrosion Detection)	Ultrasonic velocity	Schemidt Rebound hummer
	Permeability test	Schemidt Rebound hummer	Penetration Resistant
	Schemidt Rebound Hummer	Ultrasonic Velocity – Drone Inspection	Half-cell electrical potential (Corrosion Detection)

Image	Method of Repair		
	Crack Injection	Cathodic Protection	Anchor Resin
	Crack Injection	Cathodic Protection	Anchor Resin
	Water Jetting	Non-Explosive Demolition Agent	Power Breaker
	Fiber Reinforced Polymer	Crack Injection	Cathodic Protection

Image	**Method of Repair**		
	Preliminary evaluation	Faulty concrete, poor workmanship	Chlorides Attack
	Preliminary evaluation	Cathodic Protection	Anchor Resin
	Cathodic Protection	Fiber Reinforced Polymer	Load Test
	Non-Explosive Demolition Agent	Shotcrete	Crack Injection