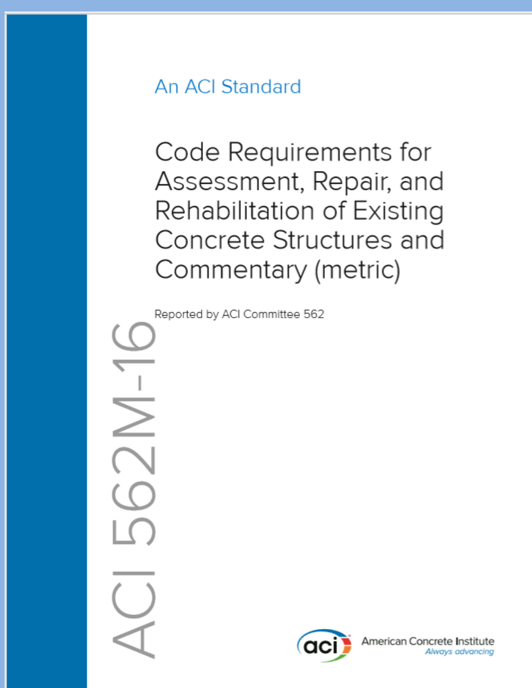

# WORKSHOP

## Advances in Evaluation, Testing, Repair and Maintenance Management of Structures: Overview of the New Modified ACI 562M-16 Code for Repair of Structures





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Sharjah Research Academy, UAE

## COURSE OBJECTIVES and CONTENT:


1. To familiarize the trainees with the only and the latest code ACI- 652M-16 on repair of structures.
2. To introduce the trainees to factors influencing durability and causes of structural failure of concrete.
3. Ability to distinguish the different types of cracks in the concrete elements and grasping the factors that causes corrosion of the reinforcement.
4. The latest and most common non-destructive in-situ testing for structures.
5. It will present maintenance and quality control systems.
6. Acquaint the trainee with examples and case studies related to maintenance using the ACI repair code.

## COURSE LANGUAGE:

English with Arabic support

# PART ONE:

- **IMPORTANCE OF MAINTENANCE**
- **MAINTENANCE AND ITS OBJECTIVE**
- **NEED FOR REPAIR OR STRENGTHENING**
- **HISTORY OF REPAIR CODES**
- **THE NEW ACI-562M**

# IMPORTANCE OF MAINTENANCE

- **In the United States conservative estimates of the current cost to rehabilitate deteriorating concrete structures are in the 18-21 billion dollar/year range.**

- **Within Europe it has been estimated that the value of the infrastructure built environment represents around 50% of the national wealth of most countries. Around 50% of the expenditure in the construction industry in Europe is spent on repair, maintenance and remediation**

- **The South African National Road Agency Ltd. (SANRAL) estimates that repair costs can rise to six times maintenance costs after three years of neglect and to 18 times after five years of neglect.**

# IMPORTANCE OF MAINTENANCE

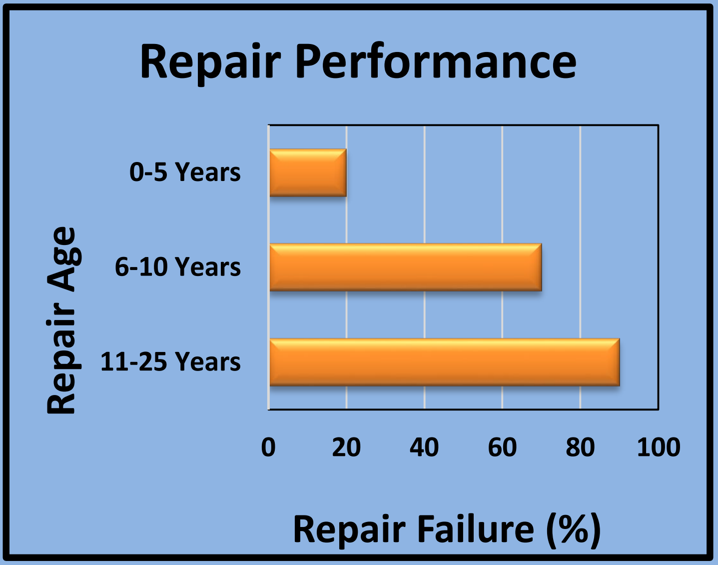
## De Sitter's Law of Fives

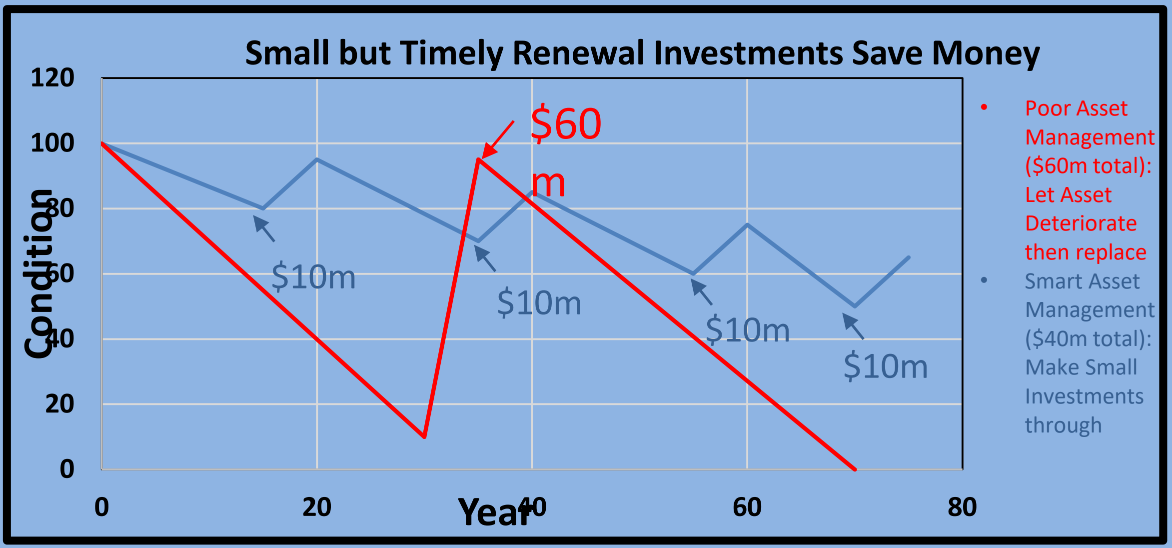
**A major repair can be expected to cost roughly five times what routine maintenance would have cost. An all-out replacement will cost five times what major repair would have cost.**

DET

# Importance of Maintenance Management

Maintenance management is not to repair broken equipment rapidly. **<u>Maintenance management is to keep the asset running at high capacity</u>** and produce quality products at lowest cost possible.



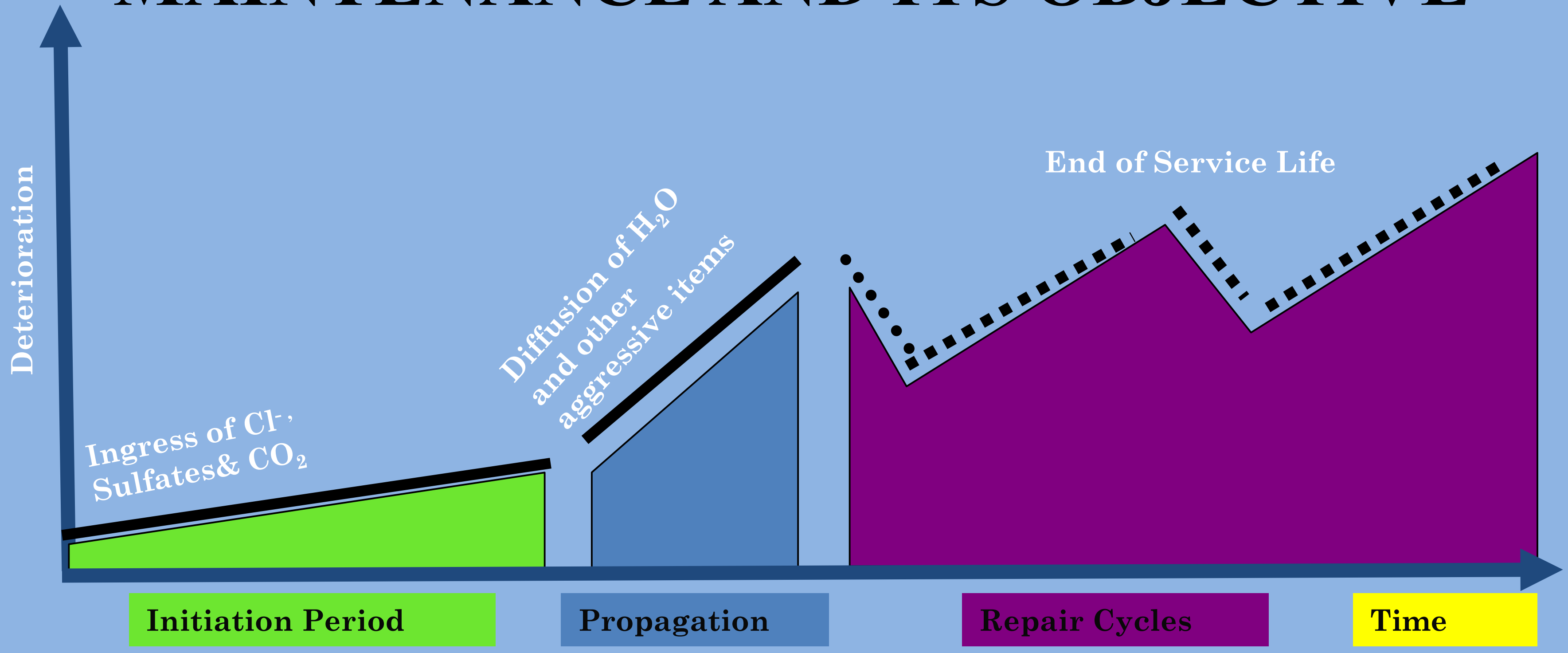
# MAINTENANCE AND ITS OBJECTIVES

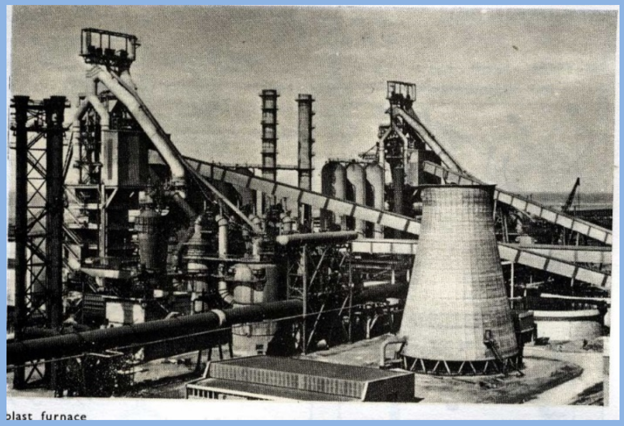
"Maintenance is a combination of any actions carried out to retain an item in ,or restore it to an acceptable condition."

**Improve the Maintenance Systems to :**

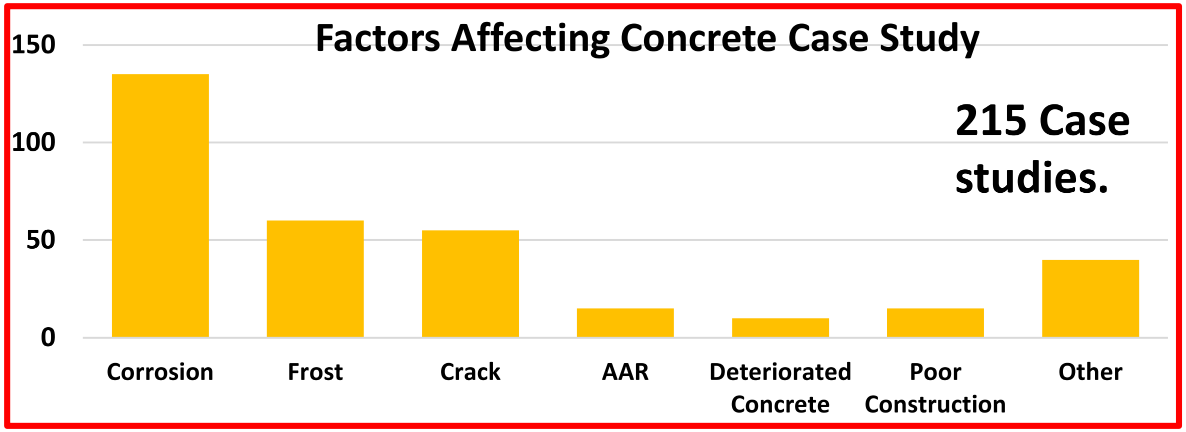
1. **Prevent failures.**
2. **Reduce the need to do maintenance.**
3. **Optimize the use of resources.**
4. **Make better quality lower cost.**

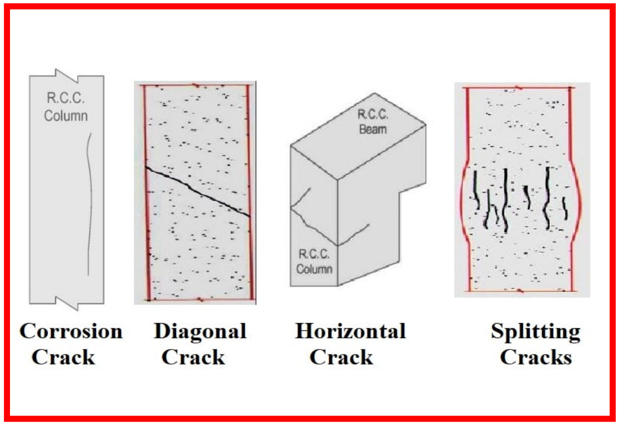
# MAINTENANCE AND ITS OBJECTIVE




# Causes of Failure and Need for Repair




# WHY DO STRUCTURES NEED REPAIR, STRENGTHENING, OR BOTH?

- **Overloading**
- **Deterioration or structural weaknes**
- **Use of inappropriate materials**
- **Design or construction errors**

Large spall area on all balconies of building [Photo Credit: Robert Pirro]

http://ascelibrary.org/doi/full/10.1061/(ASCE)CF.1943-5509.0000731

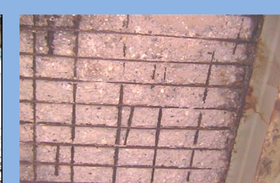
- **Undergoing expansion**
- **Accidental effects (fire, flood, EQ)**


- **Environmental effects**
  - **Chloride penetration**
  - **Carbonation of concrete**
  - **Freeze-thaw**

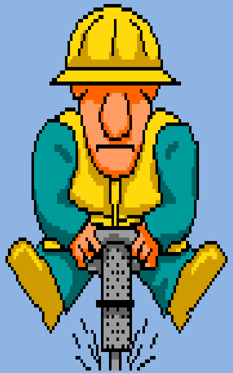
- **Change in use, Code upgrades**

- **Faulty Concrete**

  **Excess mixing water**
  **Improper aggregate**
  **Improper design**



# TYPES OF MAINTENANCE



1. Routine Maintenance (Cyclic Maintenance)
2. **PREVENTIVE MAINTENANCE (SCHEDULED MAINTENANCE)**
3. Corrective Maintenance (Emergency maintenance)

# HISTORIC OVERVIEW

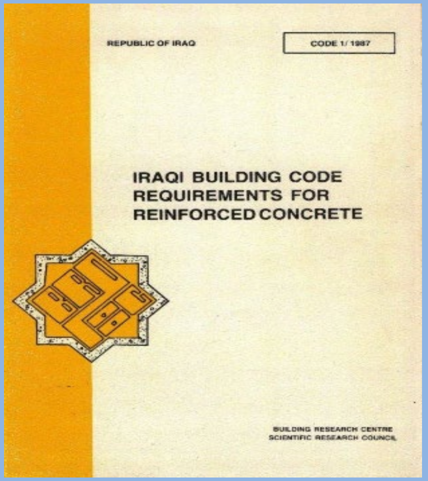
- USA Inaugural convention of the National Association of Cement Users (NACU) organized (1904-1909) .

  First “Building code "Appeared , Name Changed to American Concrete Institute (1910-1914) .
  ACI headquarters established in Detroit (1915-1919) .

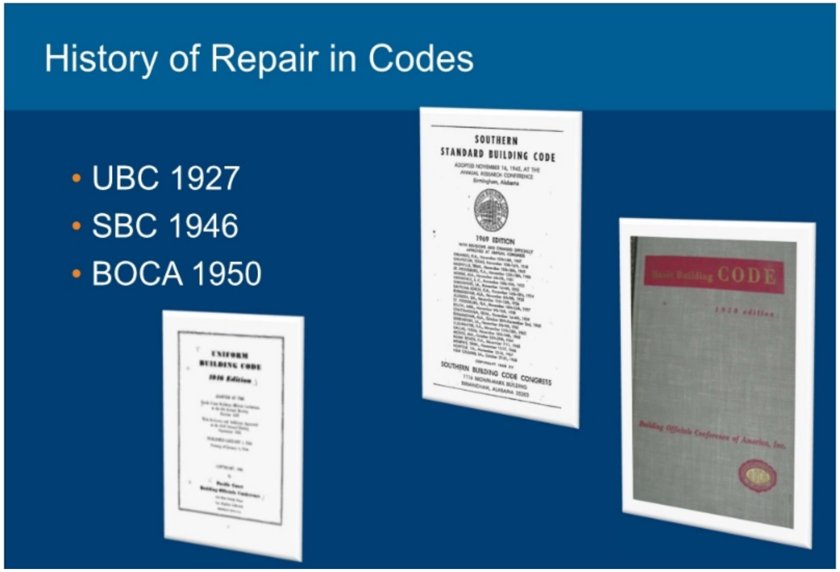
- Canada model code development and maintenance began in the 1930 with the first edition of the National Building Code of Canada being published in 1941.

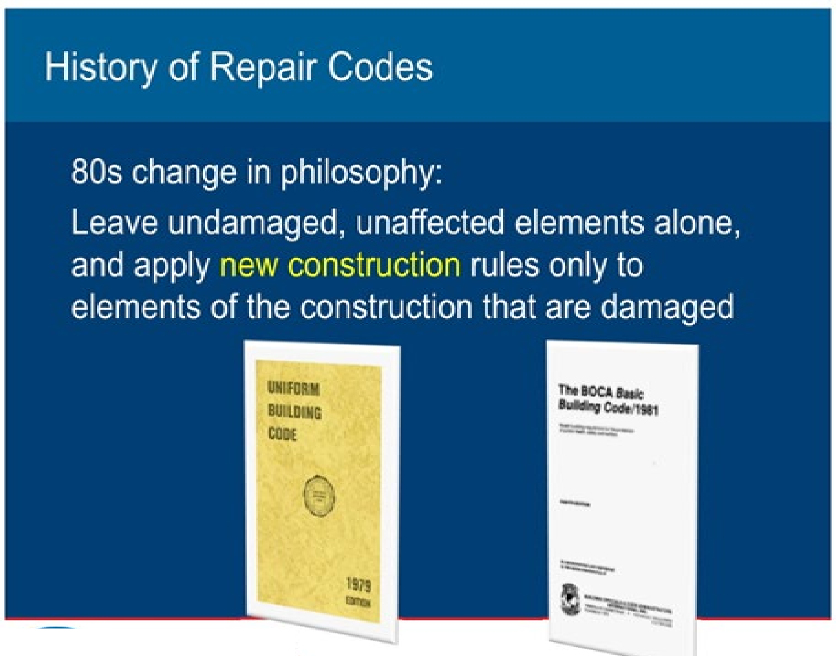

- The Indian Maintenance of Internal Security Act (MISA) was a controversial law passed by the Indian parliament in 1971
- The Egyptian Load Computing Code 1993
- Iraqi Building Code 1987

Making Concrete Blocks 1904



# History of Repair Codes



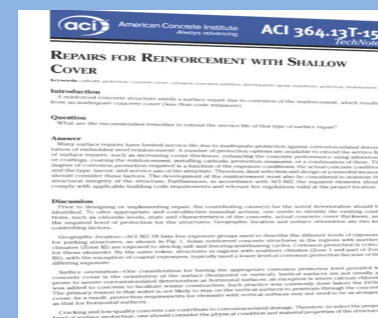




ACI 364.14T


American Concrete Institute — ACI 364.14T-17 TechNote

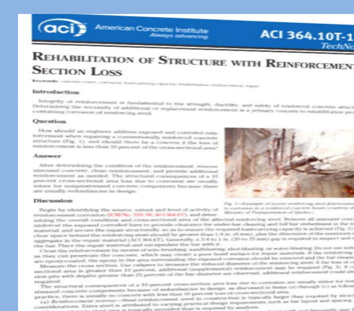
Section Loss Determination of Damaged or Corroded Reinforcing Steel Bars

ACI 364.13T


American Concrete Institute — ACI 364.13T-15 TechNote

Repairs for Reinforcement with Shallow Cover

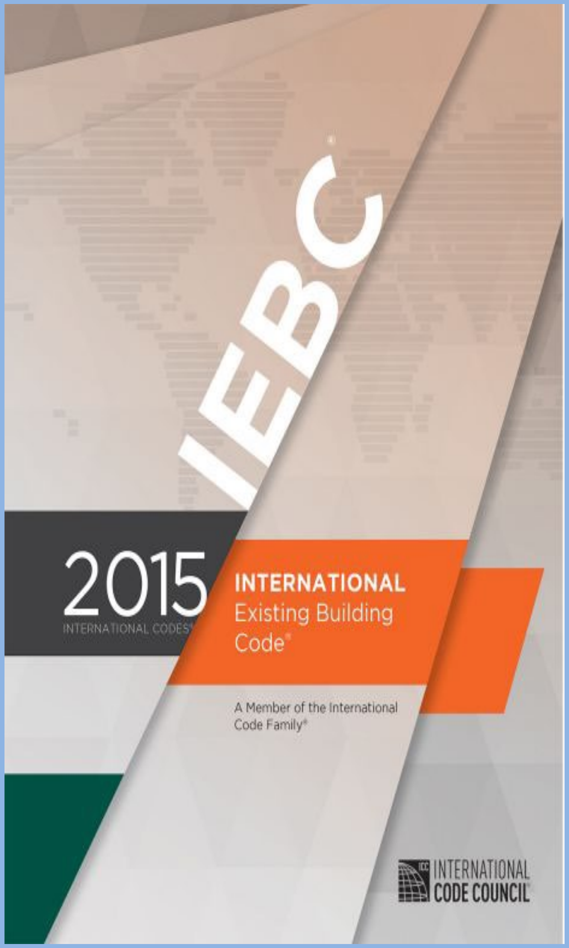
ACI 364.10T

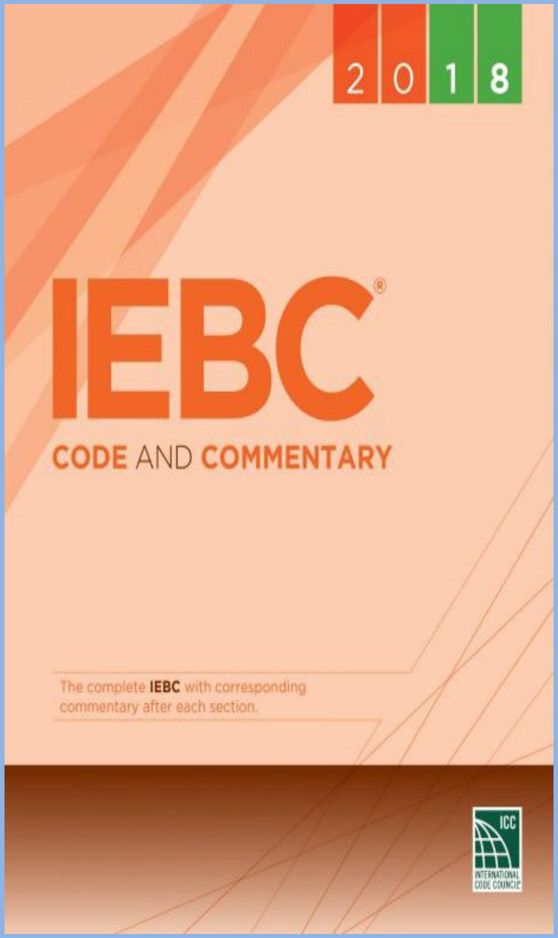

American Concrete Institute — ACI 364.10T-14 TechNote

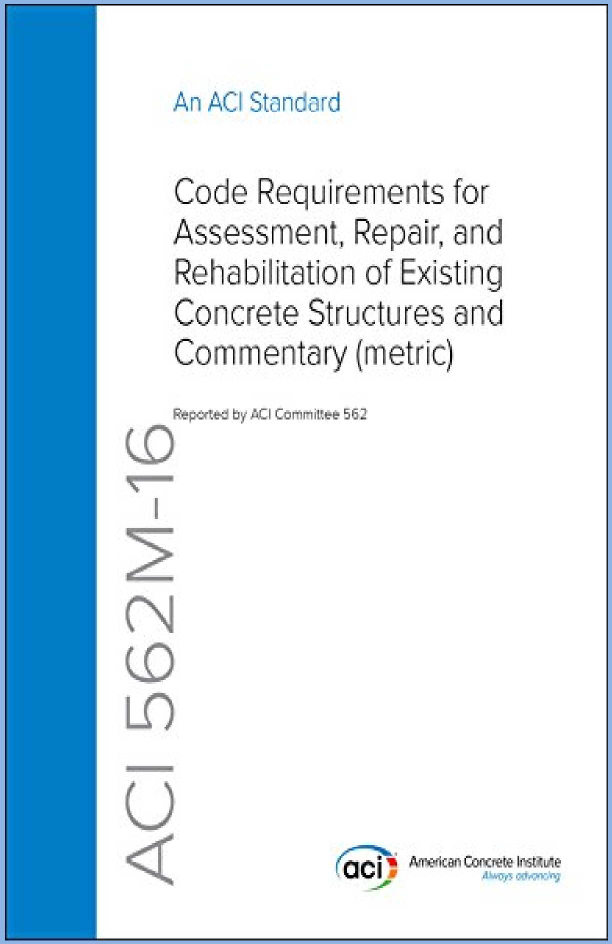
Rehabilitation of Structure with Reinforcement Section Loss

# International Existing Building Code (IEBC)

# ACI 562M a New Repair Code



## ACI 562M Chapters:

| | | |
|---|---|---|
| Chapter 1 | General Requirements | Preliminary Evaluation |
| Chapter 2 | Notations and Definitions | Preliminary Evaluation |
| Chapter 3 | Referenced Standards | Preliminary Evaluation |
| Chapter 4 | Criteria when using this code with IEBC | Preliminary Evaluation |
| APPENDIX A | Criteria using this code as stand-alone code | Preliminary Evaluation |
| Chapter 5 | Loads Factored load combinations and $\phi$ | Structural Assessment |
| Chapter 6 | Assessment, evaluation and analysis | Structural Assessment |
| Chapter 7 | Design of structural repairs | Design |
| Chapter 8 | Durability | Design |
| Chapter 9 | Construction | Construction |
| Chapter 10 | Quality Assurance | Construction |

| | ACI 562M-16 with IEBC | ACI 562M-16 as Stand Alone |
|---|---|---|
| **2.1-General** | This code will apply if a jurisdiction has received this code by reference. At the point when this code is utilized, IEBC will not matter. | jurisdiction has adopted the International Existing Building Code as the existing building code. When this code is used, ACI 562M-16 with IEBC does not apply. |
| **2.2-Unsafe Structural Conditions** | a structural evaluation will be performed to decide if unsafe structural conditions are available, when there is a condition to wonder the limit of the structure.<br>If the demand-capacity ratio exceeds 1.5 for structures, it should be reported as unsafe structure. And if the demand-capacity ratio between 4.4-4.9 will be utilized to decide the design basis criteria. | a structural evaluation will be performed to decide if unsafe structural conditions are available, when there is a condition to wonder the limit of the structure.<br>If the demand-capacity ratio exceeds 1.5 for structures, it should be reported as unsafe structure. |
| **2.3-Substantial structural damage** | Substantial structural damage shall be assessed and rehabilitated as referenced in Table 4.1.4. | Substantial structural damage will be evaluated by current building code demands and it should be reduced more than 33% from its pre-damaged condition.<br>$(\sum R_n - \sum R_{cn})/R_n > 33\%$ |
| **2.4-Conditions of deterioration** | If a structure has damage less than substantial structural deterioration, and there is a reason to wonder about the capacity of the structure, it shall be evaluated by checking the demand-capacity ratio $U_o/\varphi_o R_{cn}$. If $U_o/\varphi_o R_{cn}$ is greater than 1.0, repairs will be allowed to restore the structure to the pre-damage or pre-deteriorated states. | If a structure has damage less than substantial structural deterioration, and there is a reason to wonder about the capacity of the structure, it shall be evaluated by checking the demand-capacity ratio $U_o/\varphi_o R_{cn}$ . If $U_o/\varphi_o R_{cn}$ is greater than 1.0, repairs will be allowed to restore the structure to the pre-damage or pre-deteriorated states. |

| | ACI 562M-16 with IEBC | ACI 562M-16 as Stand Alone |
|---|---|---|
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If anticipated repair cost:

**Less than 25% of bldg. value**, then in-kind repair was typically allowed

**25-50% of bldg. value**, unaffected portions of bldg. did not have to be upgraded

**Exceeds 50% of bldg. value**, upgraded to new construction requirements

# 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

# PART TWO:

**Types and factors affecting durability**

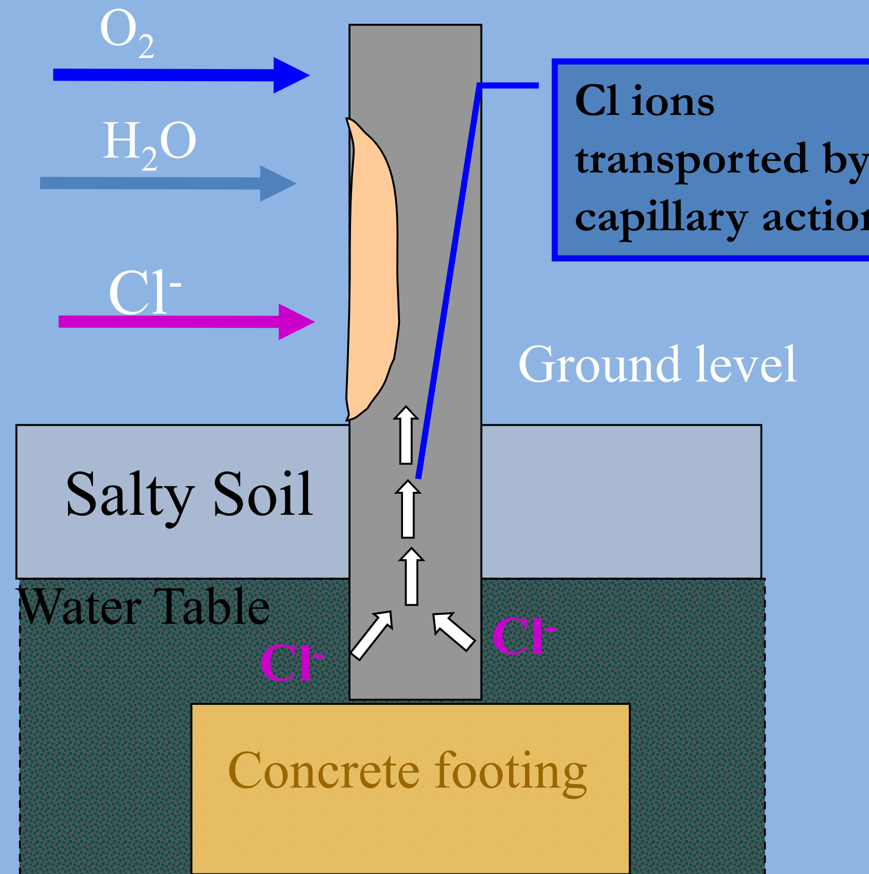
**Types and factors affecting corrosion**

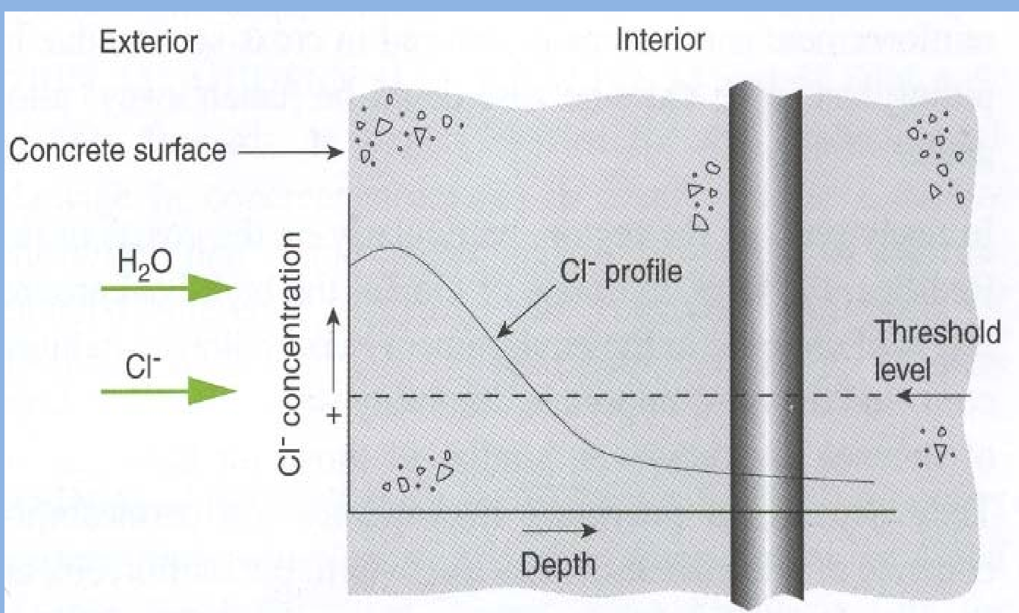
# FACTORS AFFECTING DURABILITY

- 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

# Micro Climatic and Chloride effect

**Moist air saturated with chloride (Content = 36.8 ppm) airborne by high wind onto concrete surfaces**




**Chloride Transport Mechanism**

# Service Life Estimation
# Clear's Simplified Equation

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

**Where t: Service Life in Years**

**S: Concrete cover in mm**

**R= w/c ratio**

**K: $Cl^-$ Content of exposure solution 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

This is a logical service life for a structure exposed to the splash zone. Try to find the required R for a t = 50 yrs & $S_{max}$=100 mm

# SULFATE INGRESS INTO CONCRETE

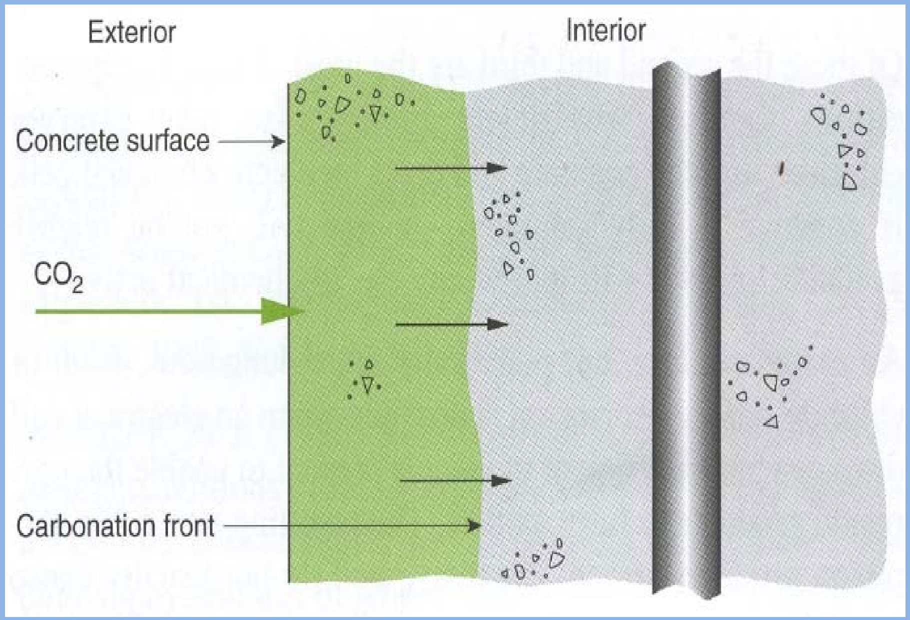
The effect of $SO_4^{-2}$ Ingress into concrete durability is significant for reinforced and non reinforced concrete

**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

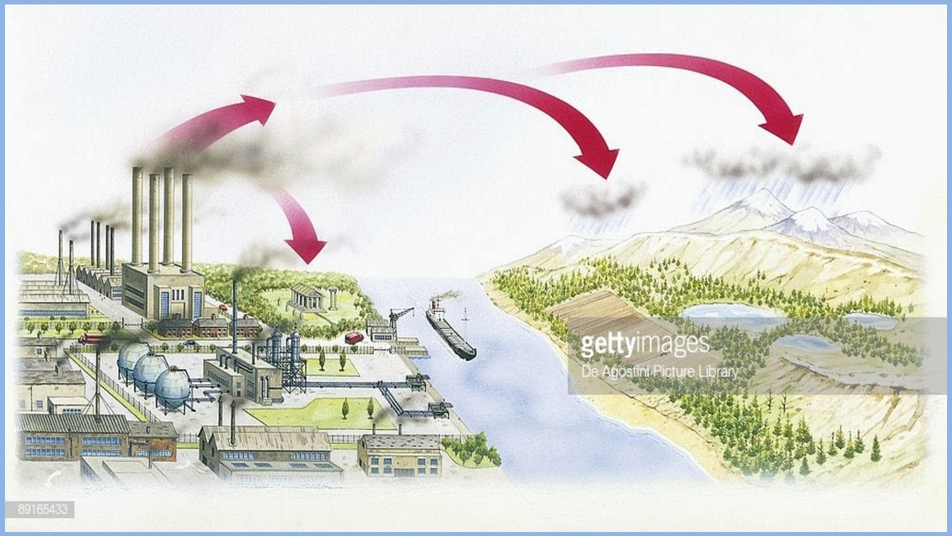
# Alkali/ Silica Reaction

Silicaceous aggregates chemically react with the cement in concrete to form a water absorbing gel.

The gel expands and cracks the concrete exposing it to chloride and carbonation attack.

# Acid rain

- The product of industrial pollution of the atmosphere, acid rain, containing dissolved oxides of sulfur and nitrogen, reacts with the alkali in the concrete to further lower the pH value.




# Durability of Concrete

| Des | C | Com In | S |
|---|---|---|---|
| Alka | Rea aggre i | Aggregate | with er |
| Sulf | I com su | Paste | so |
| Aci | | Past | Gene su |
| Reba | Rus | Reinforcem | abov rein |
| Fros | Freez p( | Paste | spa |
| D-c | Freez p( | Ag | Fine roug joints |
| Fir( | Deco hydrat develo st | Paste (aggr | |
| Ther Sh | Intern re con | Paste (aggr | |

# PART THREE

Evaluation of concrete structures

Testing of reinforced concrete structures

Evaluation of tests and its validity

Loads, Factored Load Combinations and

Load Factors

# ACI EVALUATION AND REPAIR DOCUMENTS

ACI 201.1R—Guide for Conducting a Visual Inspection of Concrete in Service

ACI 214.4R- Guide for Obtaining Cores and Interpreting Compressive Strength Results

ACI 224.1R—Causes, Evaluation, and Repair of Cracks in Concrete Structures

ACI 228.2R—Nondestructive Test Methods for Evaluation of Concrete in Structures

ACI 325.13R- Concrete Overlays for pavement Rehabilitation

ACI 341.3R- Seismic Evaluation and Retrofit Techniques for Concrete Bridges

ACI 364.1-13T Repair Tech Notes

ACI 364.1R—Guide for Evaluation of Concrete Structures before Rehabilitation
ACI 364.3R__Guide for Cementitious Repair Material Data Sheet
ACI 437R—Strength Evaluation of Existing Concrete Buildings
ACI 437.1R__Load Tests of Concrete Structures: Methods, Magnitude, Protocols, and Acceptance Criteria
ACI 503.5R__Guide for the Selection of Polymer Adhesives with Concrete
ACI 503.7__Specification for Crack Repair by Epoxy Injection
ACI 506.2__Specification for Shotcrete
ACI 546R—Concrete Repair Guide
ACI 546.3R__Guide for the Selection of materials of the Repair of Concrete
ACI E706__Repair Application Procedures (RAP) 1-14

# LICENSED DESIGN PROFESSIONAL

**Shall be understood to mean persons who possess the knowledge, judgment and skills to interpret and properly use this code and are licensed in the jurisdiction where this code is being used. The licensed design professional for the project is responsible for and in charge of the assessment or rehabilitation design, or both.**

# Investigation

The 3-Stage Process Leading to repair

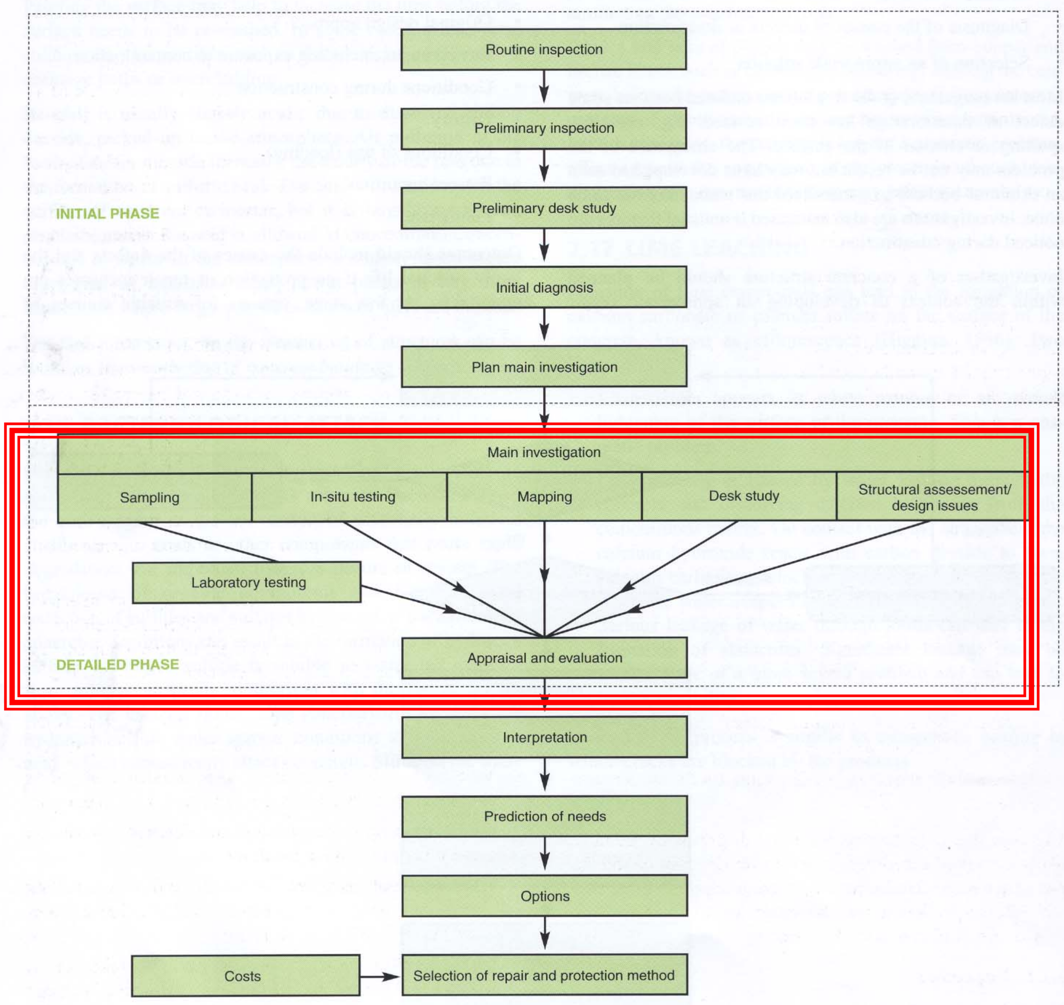



Figure 3.2: The whole assessment process.

# 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 |
|---|---|---|---|
| Collapse, partial collapse, or building off foundation | ☐ | ☐ | ☐ |
| Building or story leaning | ☐ | ☐ | ☐ |
| Racking damage to walls, other structural damage | ☐ | ☐ | ☐ |
| Chimney, parapet, or other falling hazard | ☐ | ☐ | ☐ |
| Ground slope movement or cracking | ☐ | ☐ | ☐ |
| Other (specify) ______ | ☐ | ☐ | ☐ |

**Estimated Building Damage** (excluding contents)

☐ None
☐ 0–1%
☐ 1–10%
☐ 10–30%
☐ 30–60%
☐ 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: ______

# ACI 562 Chapter 6—Assessment, Evaluation, and Analysis

Table 6.3.1a – Default compressive strength of structural

| Time frame | Footings | Beams | Slabs | Columns | Walls |
|---|---|---|---|---|---|
| 1900-1919 | 7 | 14 | 10 | 10 | 7 |
| 1920-1949 | 10 | 14 | 14 | 14 | 14 |
| 1950-1969 | 17 | 21 | 21 | 21 | 17 |
| 1970-present | 21 | 21 | 21 | 21 | 21 |

- Table 6.3.1b – Default tensile and yield strength
- properties for steel reinforcing bars for various periods*

| | Structural† | Intermediate† | Hard† | | | | |
|---|---|---|---|---|---|---|---|
| Grade | 230 | 280 | 350 | 420 | 450 | 485 | 520 |
| Minimum yield, MPa | 230 | 280 | 350 | 420 | 450 | 485 | 520 |
| Minimum tensile, MPa | 380 | 485 | 550 | 620 | 520 | 550 | 690 |
| 1911-1959 | X | X | X | — | X | — | — |
| 1959-1966 | X | X | X | X | X | X | X |
| 1966-1972 | — | X | X | X | X | X | — |
| 1972-1974 | — | X | X | X | X | X | — |
| 1974-1987 | — | X | X | X | X | X | — |
| 1987-Present | — | X | X | X | X | X | — |

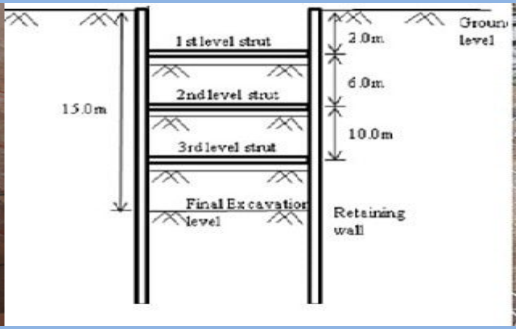
**Note: Adopted from ASCE/SEI 41.**

***An entry of "X" indicates the grade was available in those years.**

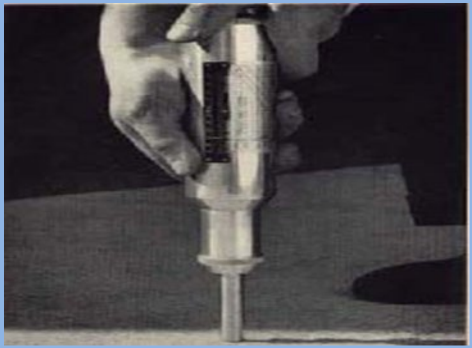
**†The terms "structural," "intermediate," and "hard" became obsolete in 1968.**

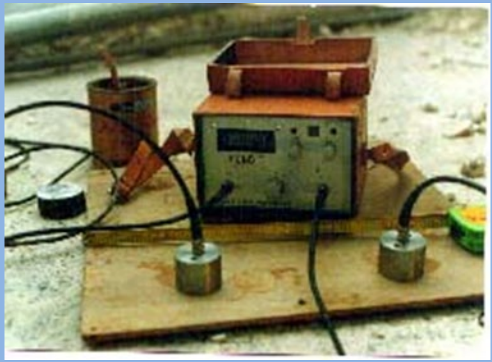
# LOAD FACTORS AND COMBINATIONS

- **Do not** use load factors and load combinations from ACI 562M **with** strength reduction factors from the original building code.
- Requirements for shoring and temporary support
  - **Building occupied during repair “loads per current code (ASCE/SEI 7)“**
  - **Building unoccupied during repair “loads may be based on ASCE/SEI 37 “**
  - **Building subjected to seismic loading “loads per seismic code (ASCE/SEI 41)“**




# TESTING OF REINFORCED CONCRETE STRUCTURES






# Testing- Scope and Guidance

**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. The sampling rate, type and location of tests shall include:**

- **Different elements (Columns, beams, Slab)**
- **Typical deteriorated areas**
- **Typical Non-deteriorated areas**
- **Areas with Different exposure conditions**
- **Previously repaired areas**

**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.

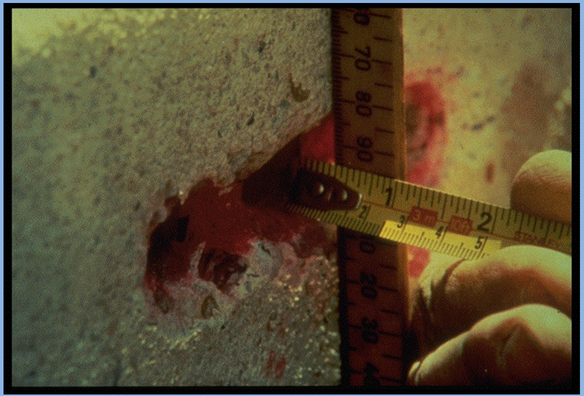
- ***PARTIALLY DESTRUCTIVE TESTS:***

  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. .

## Non-destructive Testing

- Sounding or chain drag (ASTM D 4580)
- Rebound hammer (ASTM C803/C803M-17)
- Penetration resistance (ASTMC803/C803M & C805)
- Reinforcing steel cover meter (pachometer ASTM D4748)

- Impact echo (ASTM C 1383)
- Ultrasonic pulse velocity (ASTM C 597)
- Corrosion potential (ASTM C 876)
- Ground-penetrating radar (extrapolation of ASTM D 6432)

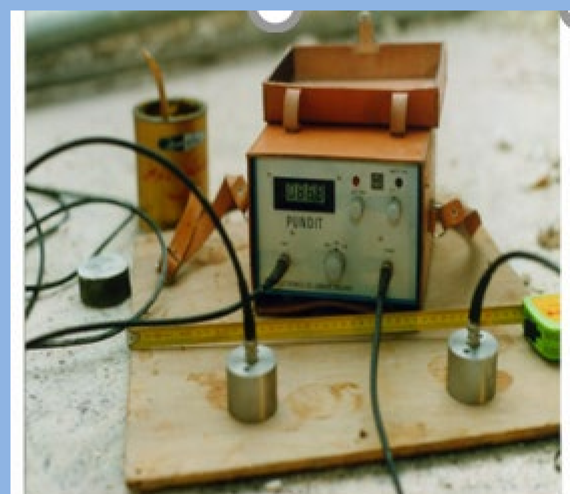


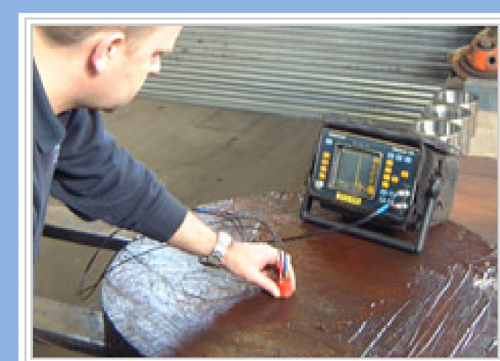
# Ultra Sonic Materials Analysis ( PULSE VELOCITY )

(ASTM C 597)

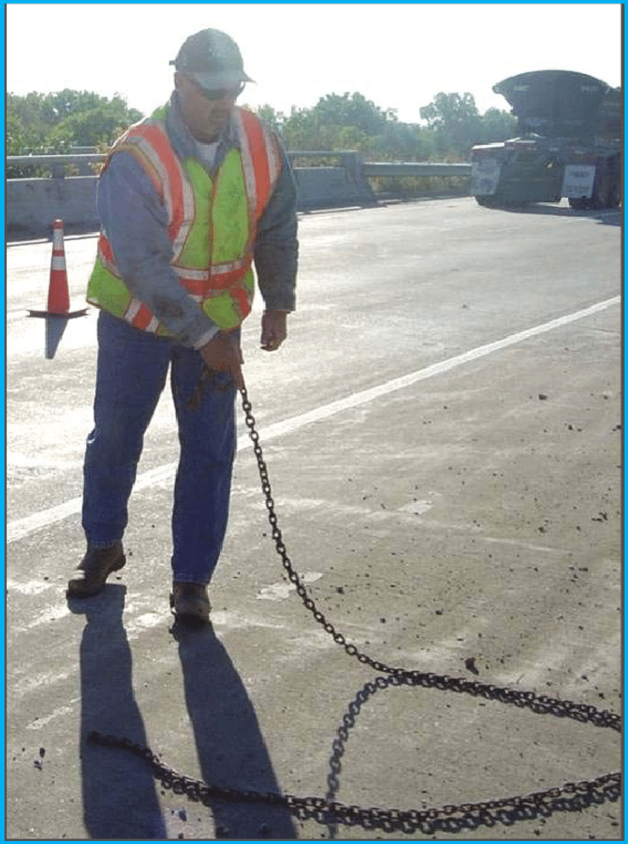
( DETECTING CRACKS , VOIDS AND FLAWS TO FIND THE DAMAGE PATTERN ) ,

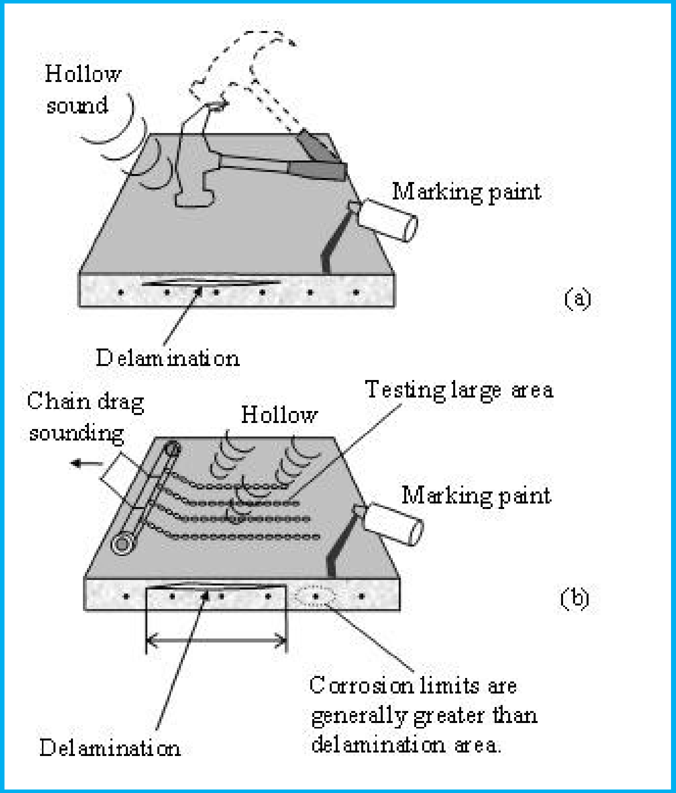
It can be used to control the effectiveness of repair by injection technique .



# Chain Dragging





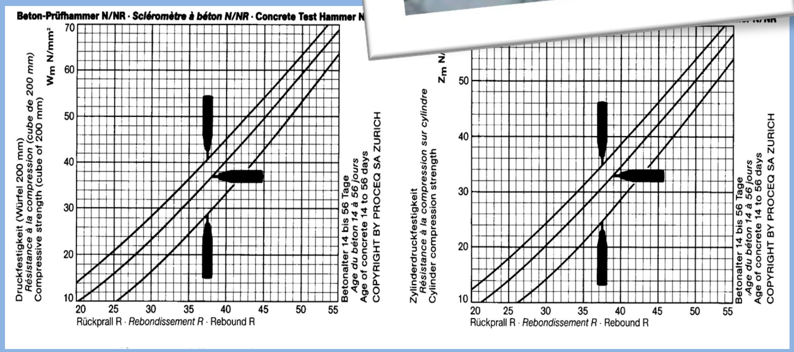
# REBOUND HAMMER (ASTM C803/C803M-17)

## Advantages

Speed

Low Cost

Relatively low expertise required




## Limitations

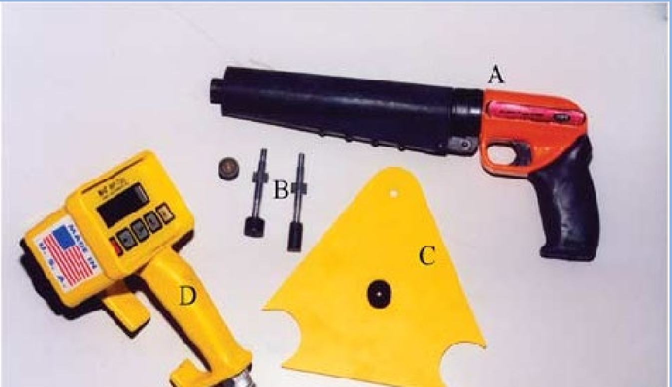
- Relates to only surface zone
- Results influences by
  - Surface texture
  - Moisture condition
  - Type of aggregate
  - Carbonation
  - Type of cement
  - Movement of concrete under test

# 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:

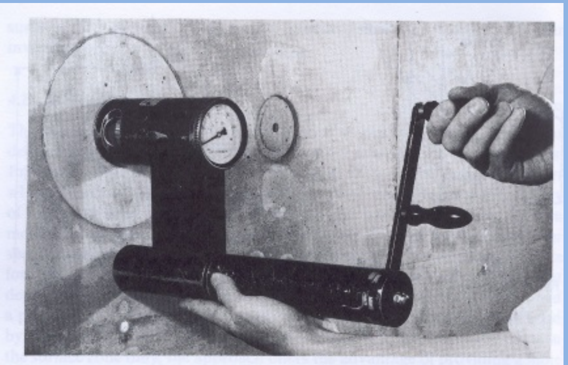
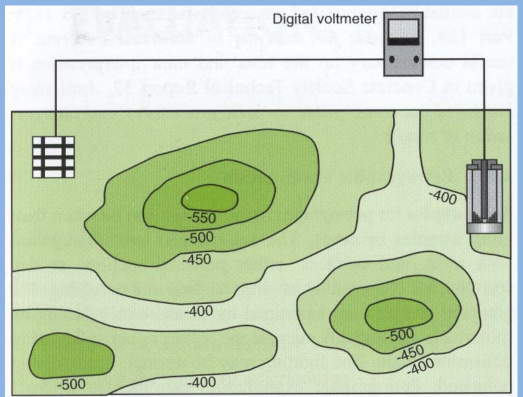


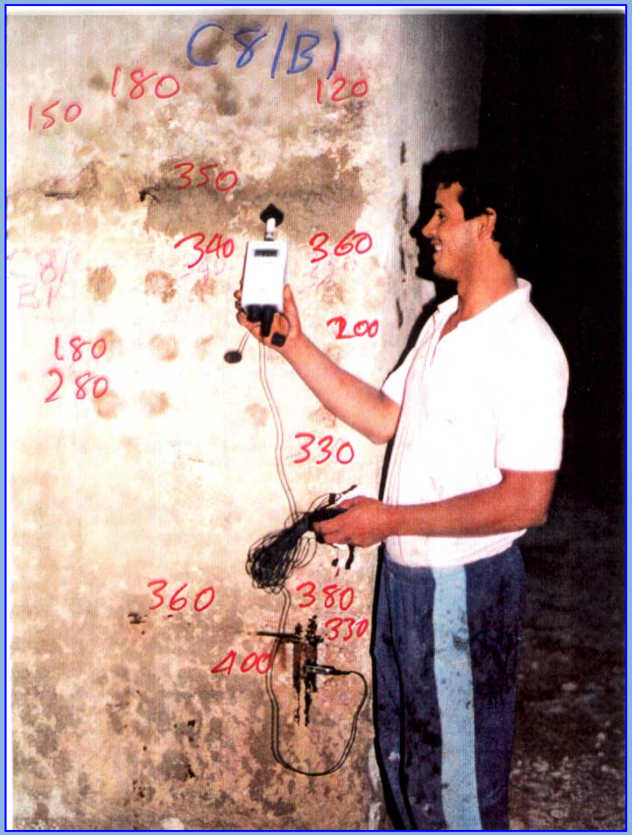
Figure 4.10 Lok-test equipment (photograph by courtesy of Lok-test Aps.)

# IN-SITU Testing

- **Half Cell potential: It measures the electrical potential on the surface of steel to qualitatively estimate the its likelihood of corrosion.**

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

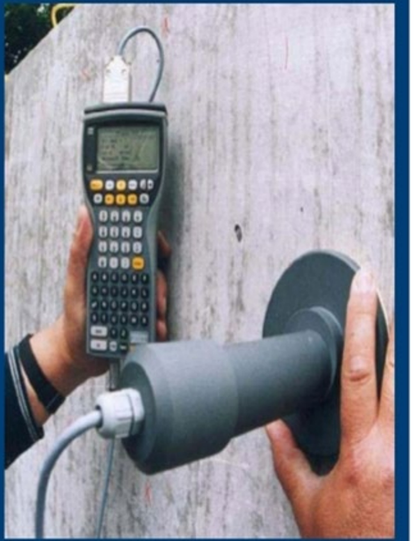


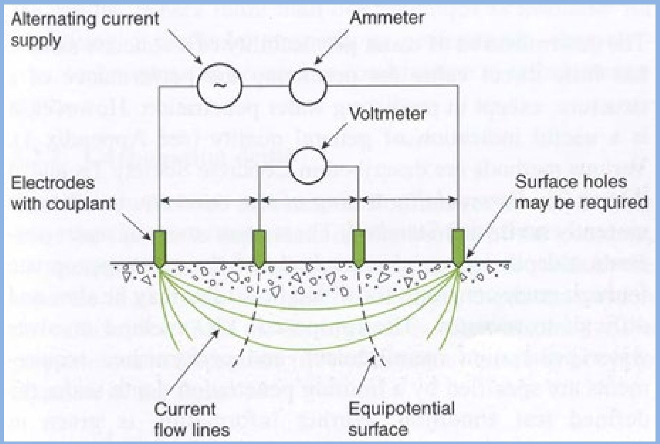
# CORROSION POTENCIAL (ASTM C876)

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

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



Source: PCTE




| 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,"**

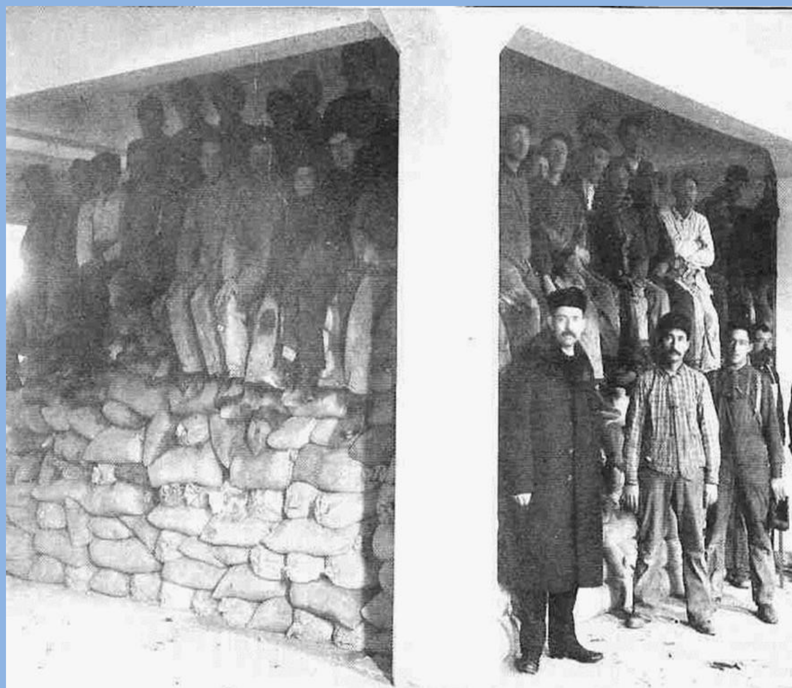
Factors that influence measured core compressive strength:

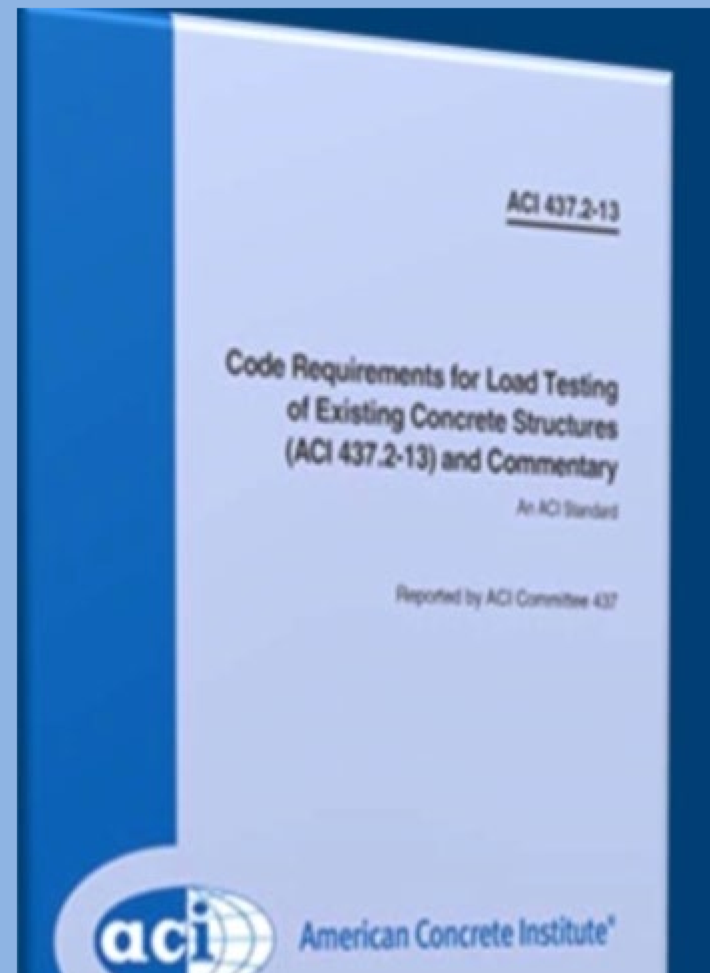
Concrete characteristics and testing variables: (Length/diameter ratio of core, Diameter of core, Direction of drilling, Method of capping and reinforcement)

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

# Load Testing

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



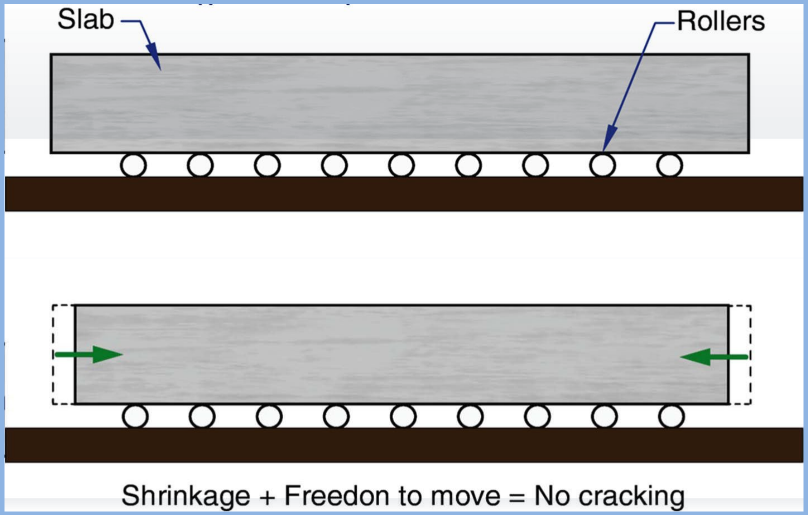


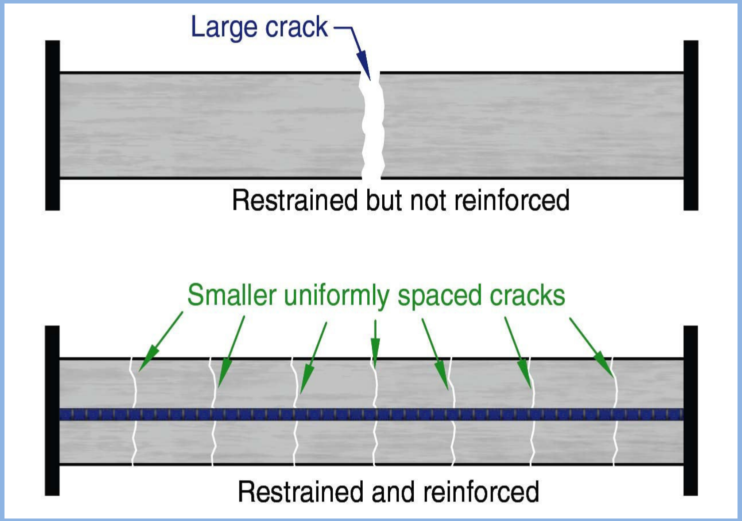
# •PART FOUR

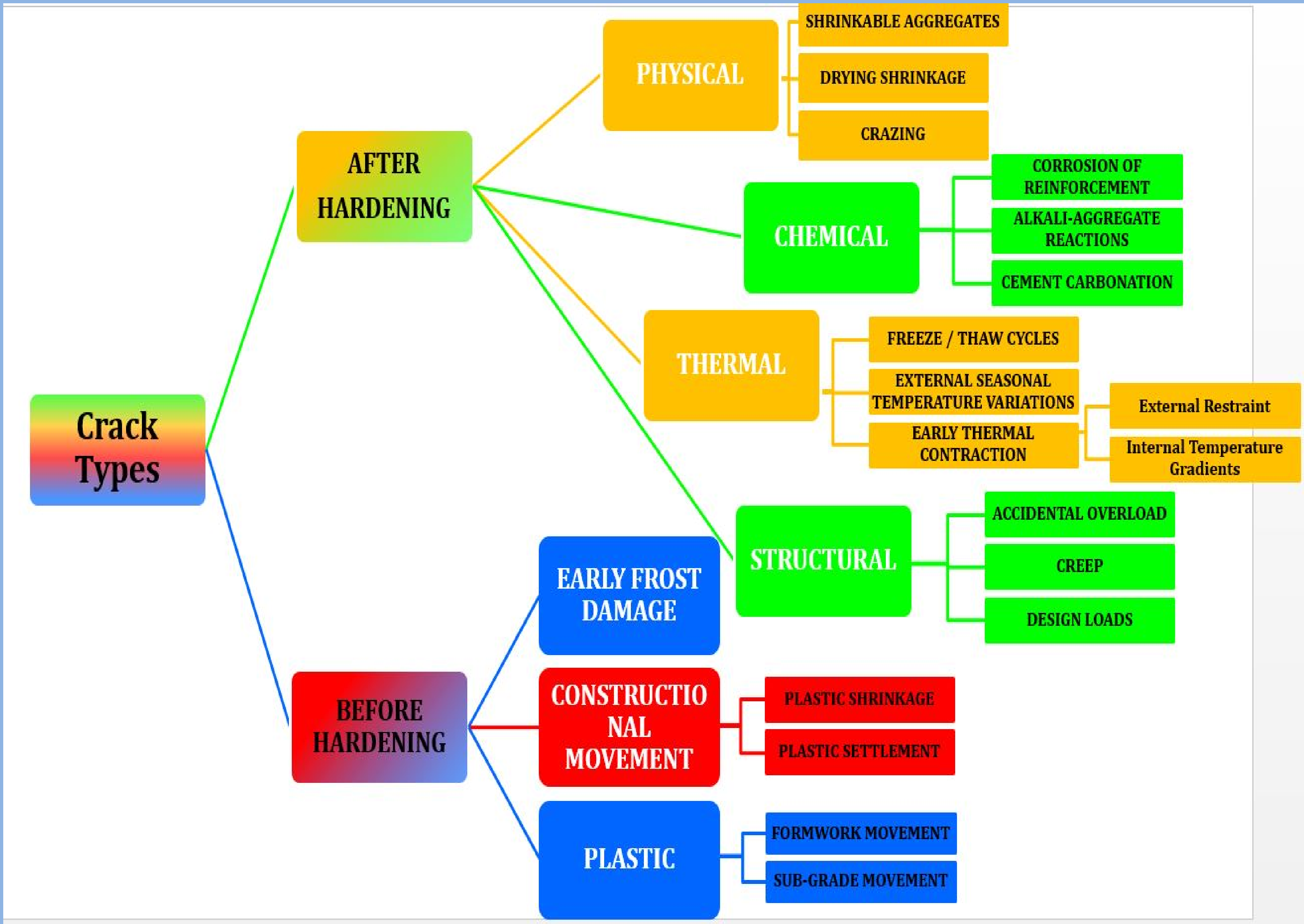
- Causes and repair of cracks
- Repair techniques and processes
- Repair materials
- Monitoring of Structures
- Case Study

# 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.**




Crack Types
AFTER HARDENING
PHYSICAL
SHRINKABLE AGGREGATES
DRYING SHRINKAGE
CRAZING
CHEMICAL
CORROSION OF REINFORCEMENT
ALKALI-AGGREGATE REACTIONS
CEMENT CARBONATION
THERMAL
FREEZE / THAW CYCLES
EXTERNAL SEASONAL TEMPERATURE VARIATIONS
EARLY THERMAL CONTRACTION
External Restraint
Internal Temperature Gradients
STRUCTURAL
ACCIDENTAL OVERLOAD
CREEP
DESIGN LOADS
BEFORE HARDENING
EARLY FROST DAMAGE
CONSTRUCTIONAL MOVEMENT
PLASTIC SHRINKAGE
PLASTIC SETTLEMENT
PLASTIC
FORMWORK MOVEMENT
SUB-GRADE MOVEMENT

# 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 cracs:**
**3) fractures :**

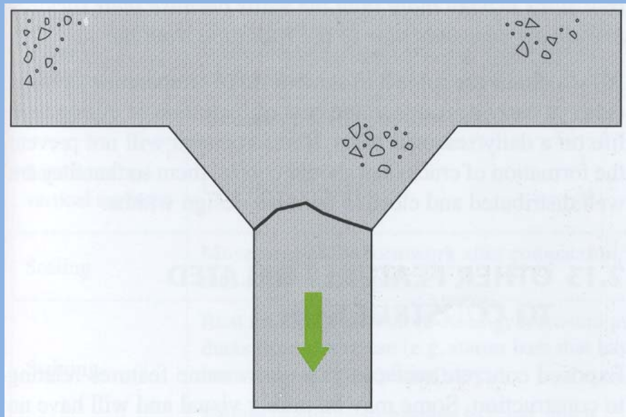
**b) LIVE CRACKS.**

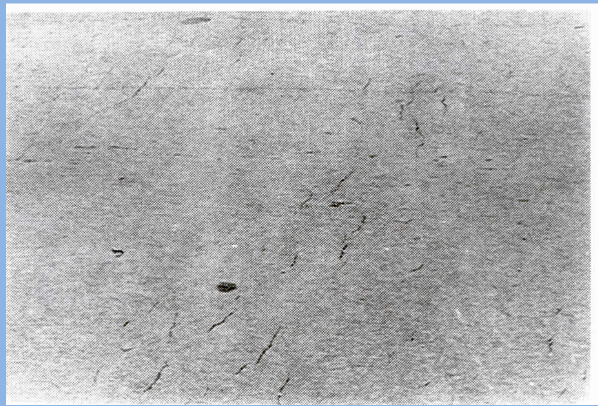
# Plastic cracks

- Plastic cracks occur in concrete before it hardens, say **1 to 8** hours after placing - although they are often not noticed until the following **day**.
- Generally they can be identified as one of **two types**, namely:

1. **plastic settlement.**
2. **plastic shrinkage.**

- Most plastic settlement cracks appear in **deep sections**, but plastic shrinkage cracks are most common in **flat slabs** exposed to high rates of evaporation.
- Both types are governed in contradictory ways by the phenomenon of **BLEEDING.**





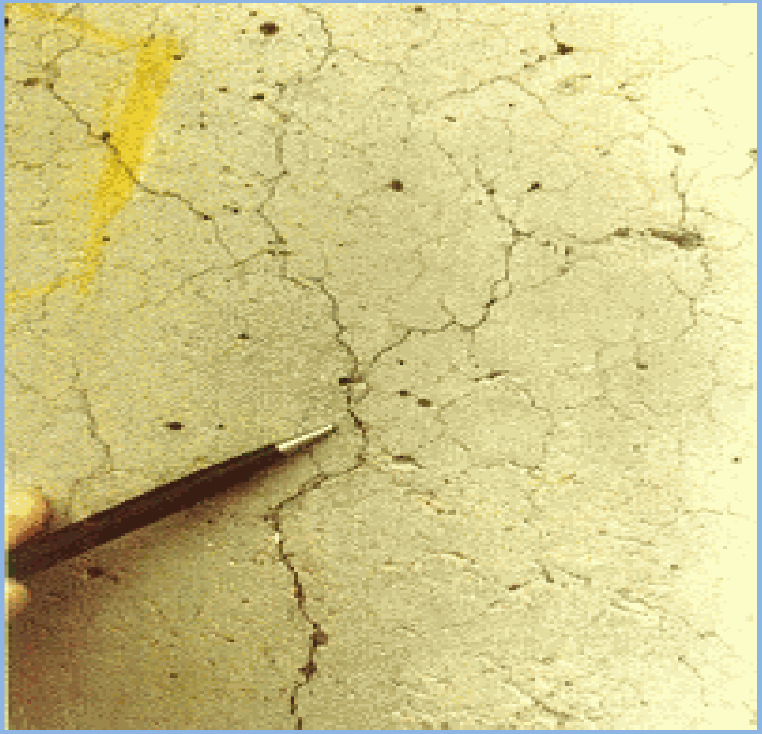
## Alkali-Silica Reaction (ASR) – Damage

- Cracking (alligator pattern)
- Gross expansion of concrete

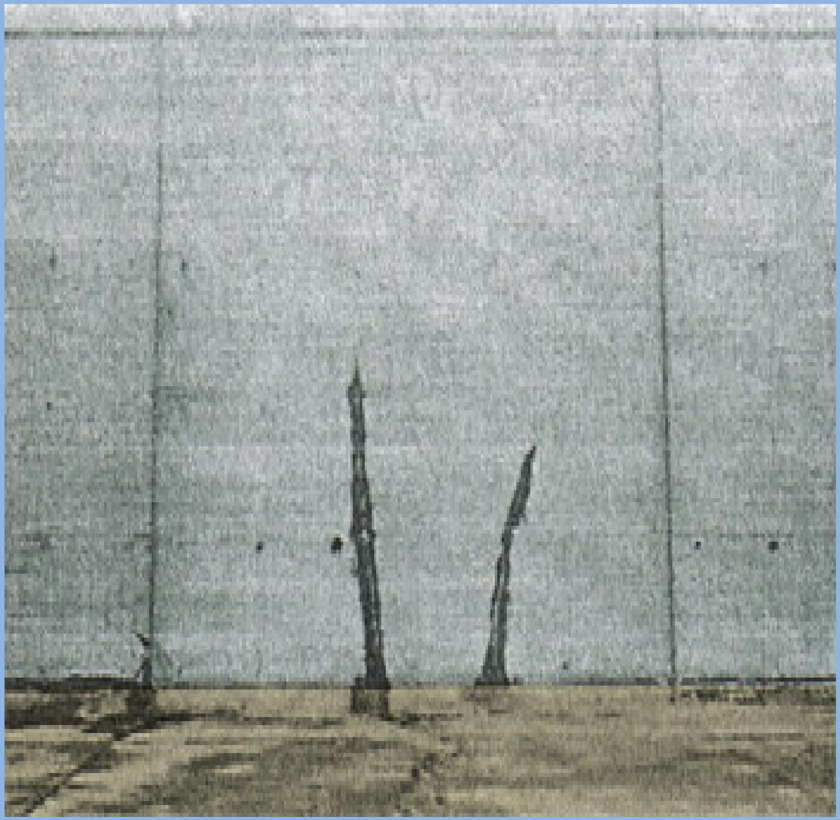
## Drying Shrinkage Cracks

Shallow, closely spaced, fine cracks

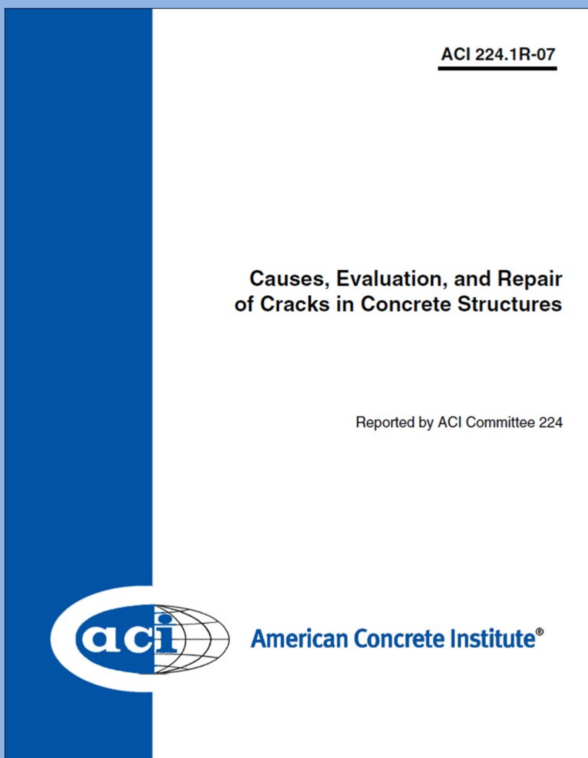
Thermal stress > tensile strength → cracking

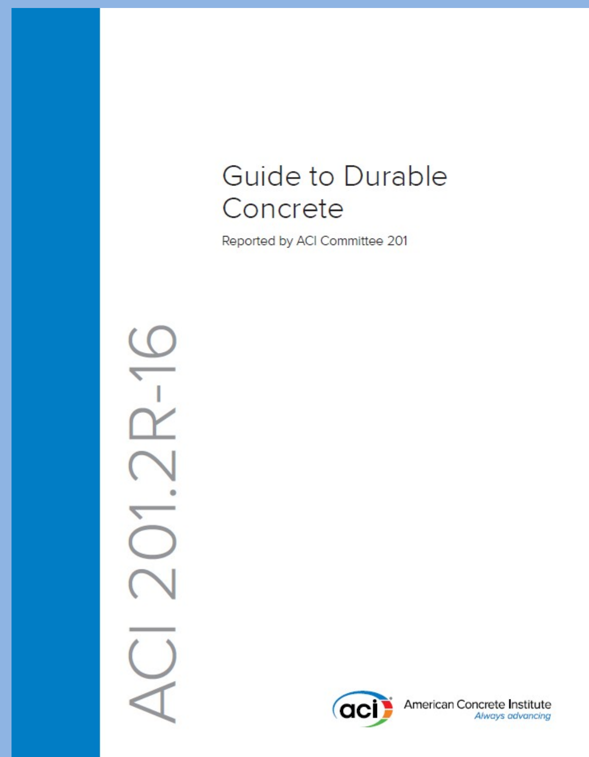


# Thermal Cracking – Damage



# Causes and Control of Cracking




ACI 224.1R-07

ACI 201.2R-16

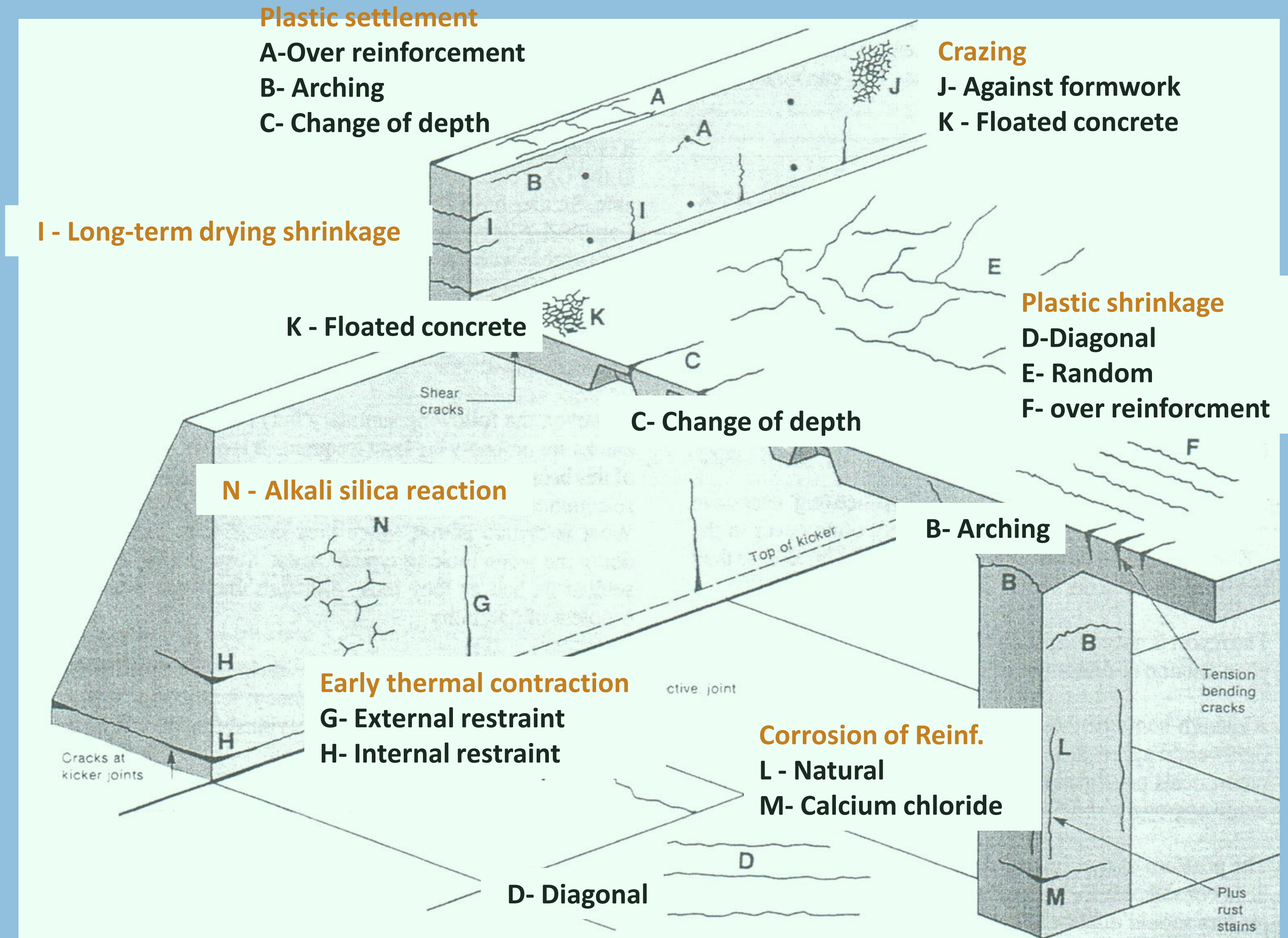



Figure 2: Examples of intrinsic cracks in hypothetical concrete structure

| Type of cracking | Letter (see Figure 2) | Subdivision | Most common location | Primary cause (excluding restraint) | Secondary causes/ factors | Remedy (assuming basic redesign is impossible) In all cases reduce restraint | Further details see section ... | Time of appearance |
|---|---|---|---|---|---|---|---|---|
| Plastic settlement | A | Over reinforcement | Deep sections | Excess bleeding | Rapid early drying conditions | Reduce bleeding (air entrainment) or revibrate | 5.2 | Ten minutes to three hours |
| | B | Arching | Top of columns | | | | | |
| | C | Change of depth | Trough and waffle slabs | | | | | |
| Plastic shrinkage | D | Diagonal | Roads and slabs | Rapid early drying | Low rate of bleeding | Improve early curing | 5.3 | Thirty minutes to six hours |
| | E | Random | Reinforced concrete slabs | | | | | |
| | F | Over reinforcement | Reinforced concrete slabs | Ditto plus steel near surface | | | | |
| Early thermal contraction | G | External restraint | Thick walls | Excess heat generation | Rapid cooling | Reduce heat and/or insulate | 6 | One day to two or three weeks |
| | H | Internal restraint | Thick slabs | Excess temperature gradients | | | | |

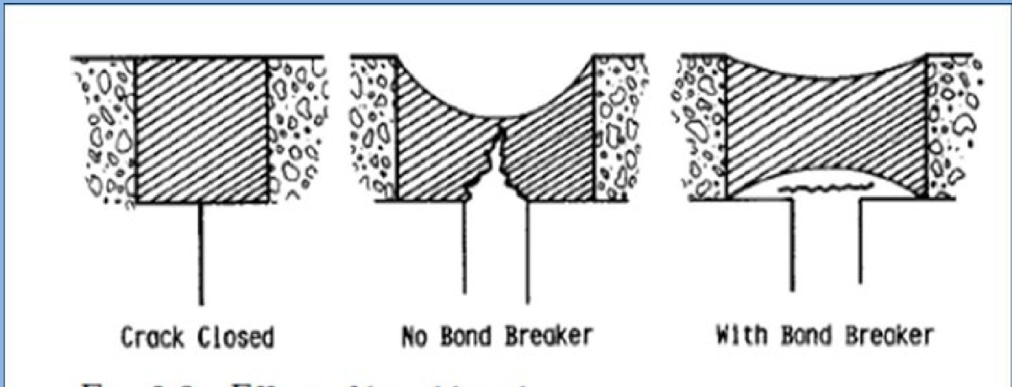
| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Long-term drying shrinkage | I | | Thin slabs (and walls) | Inefficient joints | Excess shrinkage Inefficient curing | Reduce water content Improve curing | 7 | Several weeks or months |
| Crazing | J | Against formwork | 'Fair faced' concrete | Impermeable formwork | Rich mixes Poor curing | Improve curing and finishing | 8 | One to seven days, sometimes much later |
| | K | Floated concrete | Slabs | Over-trowelling | | | | |
| Corrosion of reinforcement | L | Natural | Columns and beams | Lack of cover | Poor quality concrete | Eliminate causes listed | 9.1 | More than two years |
| | M | Calcium chloride | Precast concrete | Excess calcium chloride | | | | |
| Alkali-silica reaction | N | | (Damp locations) | Reactive aggregrate plus high-alkali cement | | Eliminate causes listed | 9.2 | More than five years |

**Table 1: Classification of intrinsic cracks**

# REPAIR OF CRACKS

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

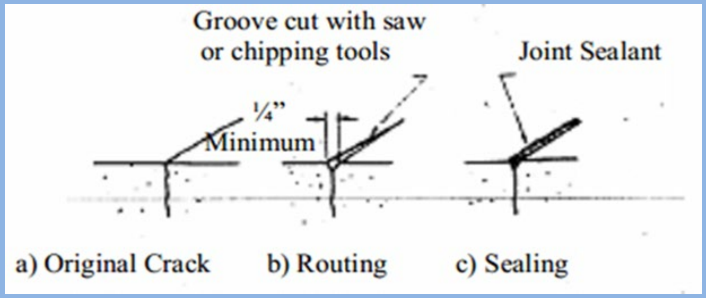
- sealing of cracks can be used where structural repair is not necessary
- A cut is made along the length of crack using a saw.
- Clean the crack by sandblasting or by using compressed air or a water jet.
- Provide bond breaker at base if crack is active
- Width-to-depth ratio ≥ 2



# 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





# ACI REPAIR DOCUMENTS

ACI 201.1R—Guide for Conducting a Visual Inspection of Concrete in Service

ACI 214.4R Guide for Obtaining Cores and Interpreting Compressive Strength Results

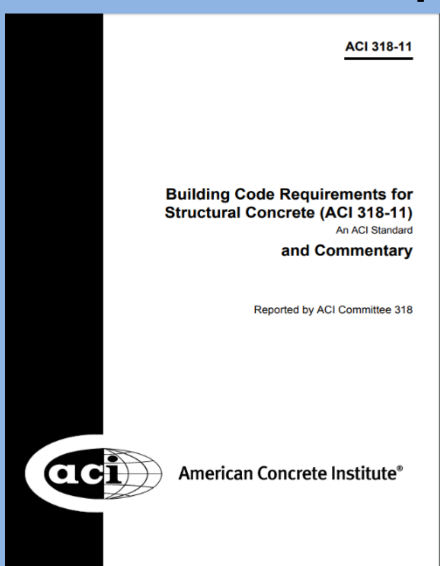
ACI 224.1R—Causes, Evaluation, and Repair of Cracks in Concrete Structures

ACI 228.2R—Nondestructive Test Methods for Evaluation of Concrete in Structures

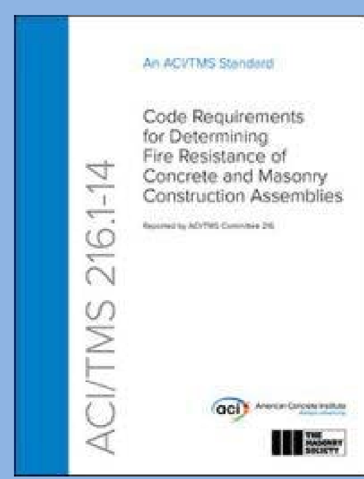
ACI 325.13R_ Concrete Overlays for pavement Rehabilitation

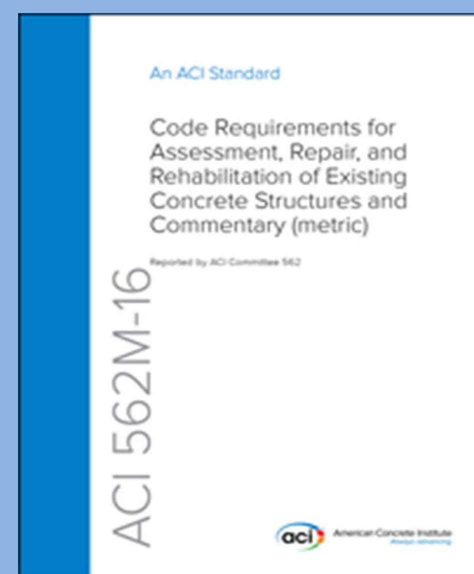
ACI 341.3R Seismic Evaluation and Retrofit Techniques for Concrete Bridges

**ACI 364.1-13T Repair Tech Notes**







# ACI Repair Documents

ACI 364.1R—Guide for Evaluation of Concrete Structures before Rehabilitation

ACI 364.3R_Guide for Cementitious Repair Material Data Sheet ACI 437R—

Strength Evaluation of Existing Concrete Buildings

ACI 437.1R Load Tests of Concrete Structures: Methods, Magnitude, Protocols, and Acceptance Criteria

ACI 503.5R Guide for the Selection of Polymer Adhesives with Concrete

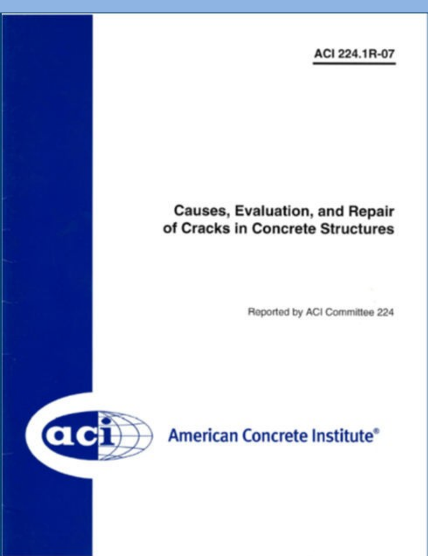
ACI 503.7 Specification for Crack Repair by Epoxy Injection Specification for

ACI 506.2 Shotcrete

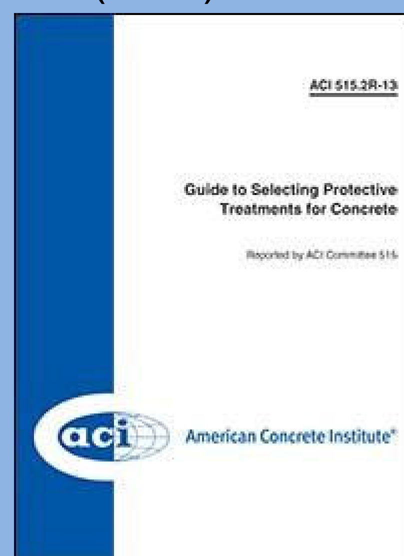
ACI 546R—Concrete Repair Guide

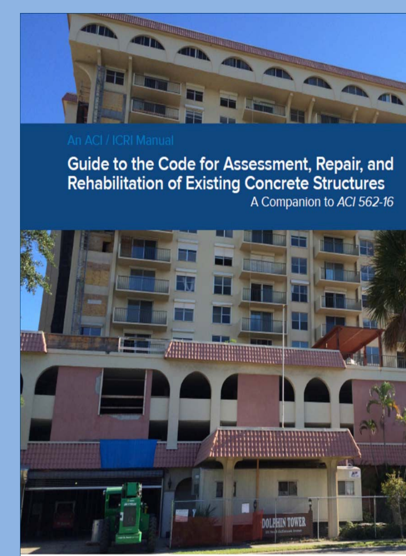
ACI 546.3R Guide for the Selection of materials of the Repair of Concrete

ACI E706 Repair Application Procedures (RAP) 1-14







# REPAIR MATERIAL SELECTION

General consideration:

Physical properties Adhesion

Thermal movement

Environmental conditions

Curing requirements

Type of application

Volume stability

Installation methods

Durability

Corrosion resistance

**1) <u>Resin mortars:</u>**

**To resist a wide range of aggressive chemicals.**

**Having the ability to cure under environmental condition.**

**2)Epoxy mortars:**

**In a well formulated epoxy mortar the shrinkage can be as low as 20 micro strains.**

**3)Bonding coats:**

**bonding coats are used to promote the adhesion of the repair composition to the concrete substrate.**

# 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

↓

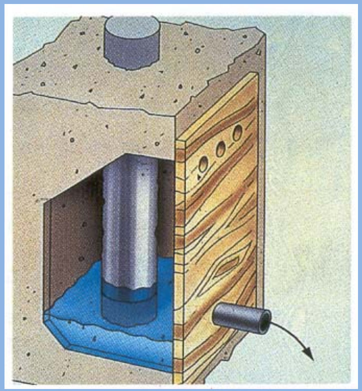
5- Install formworks for slurry type mortar

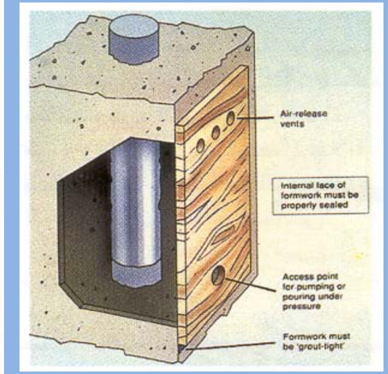
↓

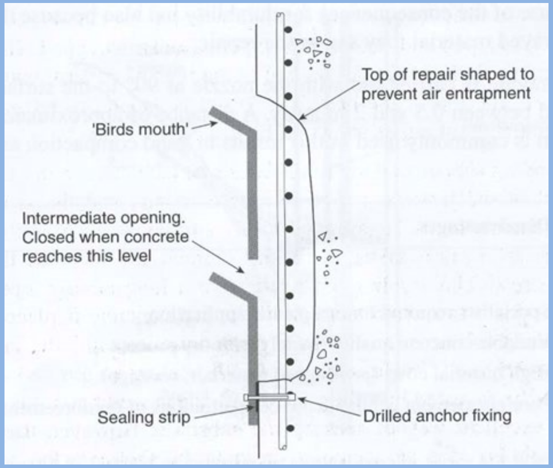
6- Reinstatement with mortar (Patching)

↓

7- Curing

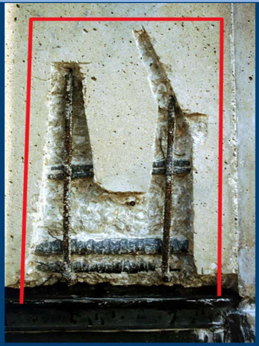




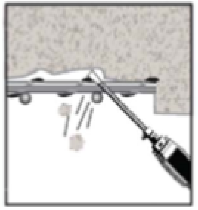



# Repair to spalled concrete

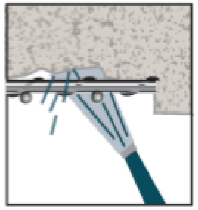
- **Install structural supporting system as necessary.**
- **Remove spalled concrete in stages observing structural restrictions to a depth of 50mm behind the reinforcement .**
- **Delineate the area to a void feathering affects.**
- **Welding new bars.**
- **Apply epoxy coating to provide adhesion to concrete.**
- **Apply replacement concrete of cementations mortar.**


Poor concrete patch geometry and preparation.

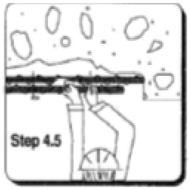
# Repair of Corroded Bars



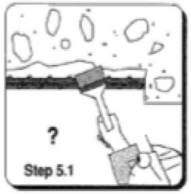
**Step 1**
Surface preparation requires removal of loose and deteriorated concrete, and includes concrete removal behind exposed bar.



**Step 2**
Heavy oxides or other bond-inhibiting materials must be removed by any acceptable cleaning method.




**Step 3**
Bars damaged during removal operations or with critical section loss may require repair or replacement

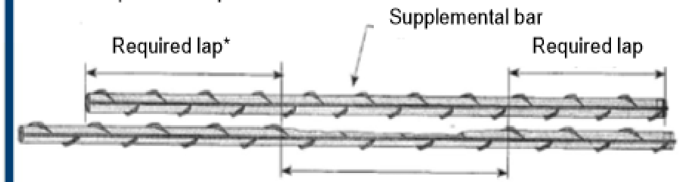


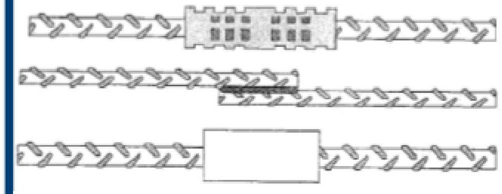

**Step 4**
In certain situations special coatings may be applied to add additional protection to bars.


If bar has lost more than 10% of its cross section, then bar repair is generally required.

If repairs are required for bars, then one of the following methods should be used:

1. Supplemental bar over affected length. New bar may be mechanically spliced to affected bar or placed || to existing bar.
2. Complete bar replacement




*Lap length must be determined in accordance with ACI 318


Source: Concrete Repair and Maintenance Illustrated

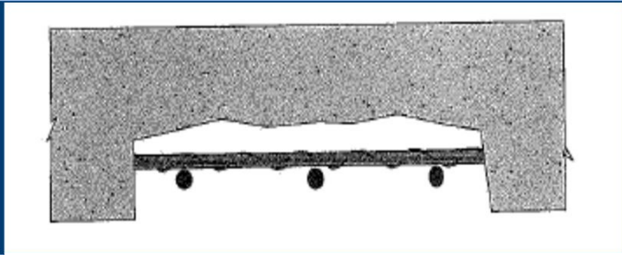
T. Alkhrdaji, K. Nahlawii

# Shoring

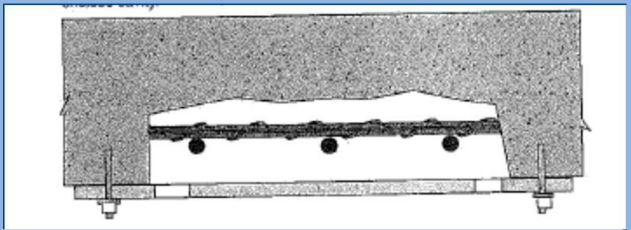
**Shoring** is the process of temporarily supporting a building, vessel, structure, or trench with shores (props) when in danger of collapse or during repairs or alterations. **Shoring** comes from shore a timber or metal prop. Shoring may be vertical, angled, or horizontal.

The shoring and temporary bracing shall maintain the structural stability of members and systems before construction and during the repair phases.

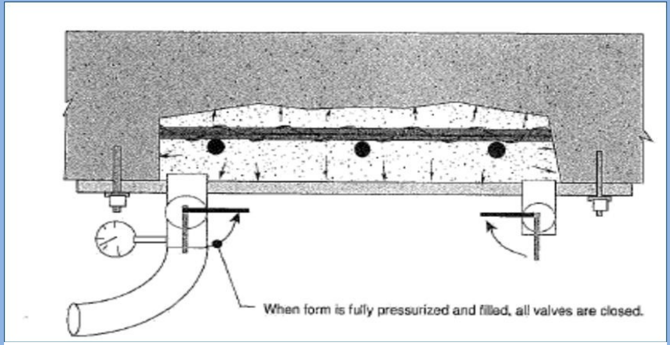
# Concrete Placement



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.



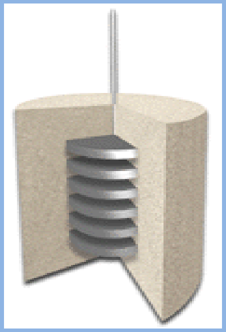

When form is fully pressurized and filled, all valves are closed.

Source: Concrete Repair and Maintenance Illustrated

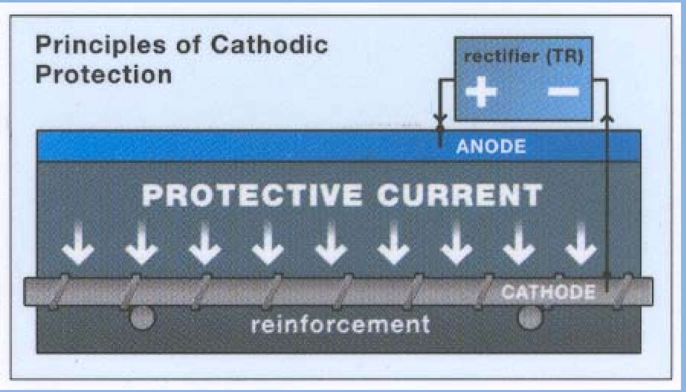
# Repair- Cathodic Protection

**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



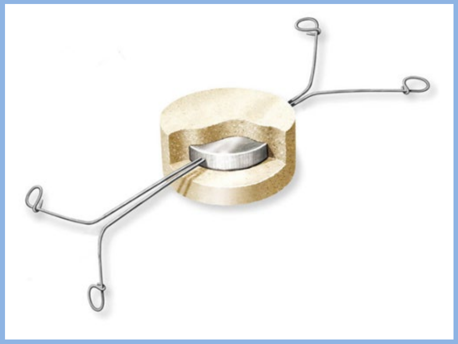
# REPAIR METHOD (Galva shield )

Galva shield XP anodes provide localized corrosion protection in reinforced concrete buildings and structures. The palm-sized anode consists of a galvanic zinc core surrounded by an active cementitious matrix

## The Benefits

- Can be used in corrosive environments including chloride contaminated and carbonated concrete
- Extends service life of patch repairs
- User-friendly and easy to install



# 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

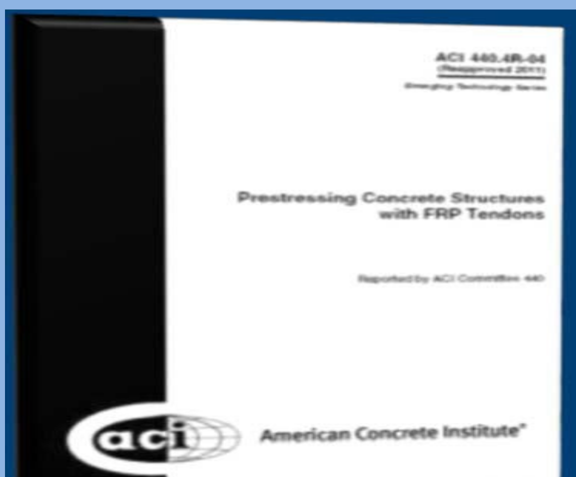
# Application of FRP composites

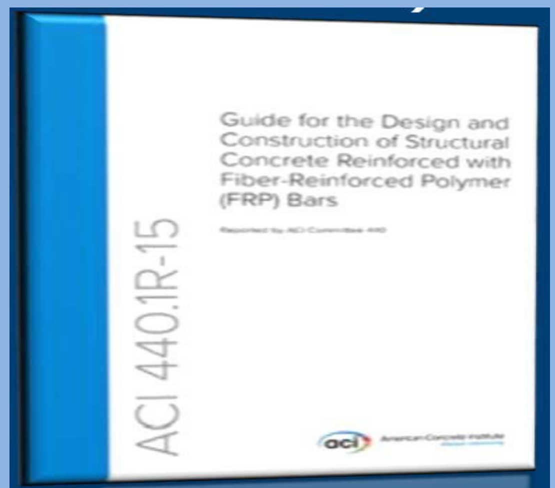
- The lightweight, high strength and corrosion resistance of fiber reinforced polymers (FRP) make them ideally suited for quick and effective structural repairs.
- As a result, they have been favoured for conducting emergency bridge repairs where speed is of essence.

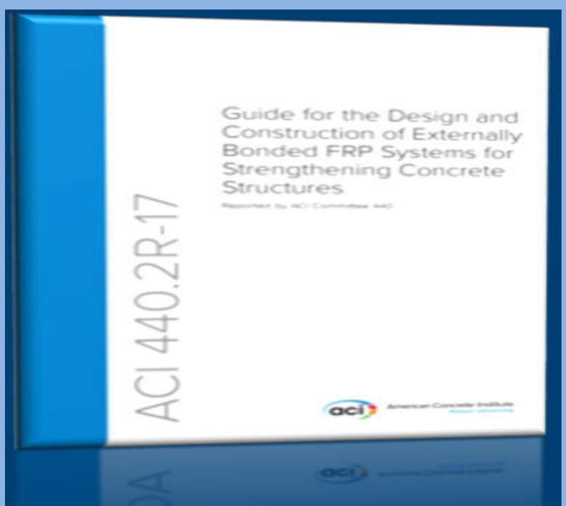
# DESIGN OF STRUCTURAL REPAIRS

**FRP Externally bonded (ACI 440.2R)**

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




| | ACI 562M-16 with IEBC | ACI 562M-16 as Stand Alone |
|---|---|---|
| **2.1-General** | This code will apply if a jurisdiction has received this code by reference. At the point when this code is utilized, IEBC will not matter. | jurisdiction has adopted the International Existing Building Code as the existing building code. When this code is used, ACI 562M-16 with IEBC does not apply. |
| **2.2-Unsafe Structural Conditions** | a structural evaluation will be performed to decide if unsafe structural conditions are available, when there is a condition to wonder the limit of the structure.<br>If the demand-capacity ratio exceeds 1.5 for structures, it should be reported as unsafe structure. And if the demand-capacity ratio between 4.4-4.9 will be utilized to decide the design basis criteria. | a structural evaluation will be performed to decide if unsafe structural conditions are available, when there is a condition to wonder the limit of the structure.<br>If the demand-capacity ratio exceeds 1.5 for structures, it should be reported as unsafe structure. |
| **2.3-Substantial structural damage** | Substantial structural damage shall be assessed and rehabilitated as referenced in Table 4.1.4. | Substantial structural damage will be evaluated by current building code demands.<br>And it should be reduced more than 33 percent from its pre-damage condition<br>$(\frac{(\sum R_n - \sum R_{cn})}{R_n}) > 33\%$ |
| **2.4-Conditions of deterioration** | If a structure has damage less than substantial structural deterioration, and there is a reason to wonder about the capacity of the structure, it shall be evaluated by checking the demand-capacity ratio $U_o/\varphi_o R_{cn}$ .<br>If $U_o/\varphi_o R_{cn}$ is greater than 1.0, repairs will be allowed to restore the structure to the pre-damage or pre-deteriorated states. | If a structure has damage less than substantial structural deterioration, and there is a reason to wonder about the capacity of the structure, it shall be evaluated by checking the demand-capacity ratio $U_o/\varphi_o R_{cn}$ .<br>If $U_o/\varphi_o R_{cn}$ is greater than 1.0, repairs will be allowed to restore the structure to the pre-damage or pre-deteriorated states. |

If anticipated repair cost:

**Less than 25% of bldg. value**, then in-kind repair was typically allowed

**25-50% of bldg. value**, unaffected portions of bldg. did not have to be upgraded

**Exceeds 50% of bldg. value**, upgraded to new construction requirements

# CASE STUDY -1
# (According to ACI Code 562M-16)

REINFORCED CONCRETE BUILDING WITH SIGNS OF DETERIORATION

# Exercises

**CASE STUDY AND EXERCISES WILL DISTRIBUTED DURING THE WORKSHOP**