

# ACI 562-16

# The Concrete Repair Code

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# Learning Objectives

- Describe why a concrete repair code was developed
- Give examples of the major changes in ACI 562-16
- Design of concrete repairs using ACI 562-16
- Summarize how ACI 562-16 improves concrete repair practice

# ACI 562 -16

An ACI Standard

Code Requirements for  
Assessment, Repair, and  
Rehabilitation of Existing  
Concrete Structures and  
Commentary

Reported by ACI Committee 562

ACI 562-16



An ACI / ICRI Manual

**Guide to the Code for Assessment, Repair, and  
Rehabilitation of Existing Concrete Structures**

A Companion to ACI 562-16



MNL-3(16)



# ACI 562 - 16

- Code for repair of existing concrete structures
- Designed to improve concrete repair practice
- First version published in 2013



# Guide to the Use of ACI 562

- Joint ACI / ICRI Document
  - First published in March 2013
- Discussion of ACI 562 Chapters
- Worked example problems using ACI 562



# ACI 562-16 – The Concrete Repair Code

- Developed to improve concrete repair practice
- Function with IEBC or as a stand-alone code
- Major changes in ACI 562-16
  - Improved definitions and IEBC integration
  - Demand / capacity ratios
  - Bond of repairs
  - Incorporate feedback on 2013 code

# Why a Repair Code?



How can we design durable repairs?

# Why a Repair Code?

- Long-term industry need
  - Variations in practice
  - Variations in repair performance
  - Establish required minimum practice
  - Help for building officials
- Large segment of construction industry
  - 20 Billion dollars
  - 8 Billion dollars in corrosion damage



# Challenges to a Repair Code?

- Complicated process
  - 10 years to date
- Lack of consensus on practice
- What are minimum requirements?
- Acceptance from community
- Concern about limiting creative solutions
- Fear of something new

# ACI 562 – Philosophy

- Emphasize ***performance*** based rather than prescriptive requirements
- Encourage ***creativity*** and ***flexibility***
- Promote ***innovation*** and ***new materials***
- Establish ***responsibilities***
- Enhance life safety (equivalent safety)
- Extend service life
- Provide ***sustainable*** and economic alternatives
- Reference ACI and other “code” documents

# How to Improve Concrete Repair Practice

- ACI Standard
  - Sets minimum requirements for repair
- Encourage evaluation
  - Confirm material properties
  - Better evaluation → better repairs
- Sustainable repaired structures
  - Long-term durability of repairs
  - Consistent reliability

# Existing Building Codes

- IBC – Chapter 34
  - Existing buildings
  - Not in 2015 IBC (reference to IEBC)
- IEBC – International Existing Building Code
  - First published in 2003
  - ACI 562 developed to work with IEBC

# Existing Building Codes

- IEBC – Alternate Procedure

**[A] 104.11 Alternative materials, design and methods of construction, and equipment.** The provisions of this code are not intended to prevent the installation of any material or to prohibit any design or method of construction not specifically prescribed by this code, provided that any such alternative has been approved. An alternative material, design, or method of construction shall be approved where the *code official* finds that the proposed design is satisfactory and complies with the intent of the provisions of this code, and that the material, method, or work offered is, for the purpose intended, not less than the equivalent of that prescribed in this code in quality, strength, effectiveness, fire resistance, durability and safety. Where the alternative material, design or method of construction is not approved, the *code official* shall respond in writing, stating the reasons the alternative was not approved.

2015 - IEBC

# ACI 562-16 - Organization

- **Part I – General**
  - General Requirements – Chapter 1
  - Terms / Definitions – Chapter 2
  - Standards / References – Chapters 3 and 11
- **Part II - Evaluation Requirements**
  - IEBC Criteria – Chapter 4
  - Stand-Alone Criteria – Appendix A
  - Loads – Chapter 5
  - Analysis of Existing Structures – Chapter 6
- **Part III – Implementation**
  - Structural Repair Design – Chapter 7
  - Durability – Chapter 8
  - Construction – Chapter 9
  - Quality Assurance – Chapter 10

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ACI 562-16

# How to Use ACI 562-16

- Applicability
- ACI 562 Process
  - Preliminary Evaluation – 1, 4 or Appen. A
  - Evaluation – 1, 4, 5, 6, App. A
  - Repair Design - 7
  - Durability - 8
  - Construction and Quality Assurance – 9, 10
  - Maintenance Requirements – 1

# ACI 562 - Applicability

- Existing concrete structures
- Superstructure, foundations (slabs), precast elements – structural load path
- Structural vs. nonstructural – “Unsafe”
- Composite members – concrete
- Nonbuilding structures when required



# Existing Structures

- Defined in ACI 562 and IEBC
  - Structure with a certificate of occupancy
  - Structure currently in use
- ACI 318
  - Deals with new construction
  - Repairs that satisfy new code requirements

# ACI 562 - Applicability

- Seismic retrofit
  - In accordance with general existing building code
  - Procedures in ASCE 41 and ACI 369
  - IEBC – references ASCE 41
- Voluntary seismic retrofit is permitted

# ACI 562 - Process

- *Preliminary Evaluation*
  - Determination of design basis code
  - Substantial structural damage
- Evaluation
- Repair design
- Durability considerations
- Construction and Quality Assurance
- Maintenance Recommendations

# ACI 562 - Process

- Preliminary evaluation
- *Evaluation*
  - Extent of problems
  - Extent of required repairs
- Repair design
- Durability considerations
- Construction and Quality Assurance
- Maintenance Recommendations

# ACI 562 - Process

- Preliminary Evaluation
- Evaluation
- *Repair design*
  - How repairs are to be made
  - Material selection considerations
- Construction and Quality Assurance
- Maintenance Recommendations

# ACI 562 - Process

- Preliminary Evaluation
- Evaluation
- Repair design
- *Durability considerations*
  - How to make structures last
  - Service life
- Construction and Quality Assurance
- Maintenance Recommendations

# ACI 562 - Process

- Preliminary Evaluation
- Evaluation
- Repair design
- Durability considerations
- *Construction and Quality Assurance*
- *Maintenance Recommendations*

# Preliminary Evaluation / Evaluation

- Start of process
  - Determination of design-basis code
  - Substantial structural damage
- Determines next steps
  - Detailed evaluation?
  - Repair design?



# Design Basis Code

- Building code under which repairs are designed
- Possible design basis codes:
  - IBC
  - IEBC
  - Local building code, i.e., NYC Building Code
  - ACI 318
  - Combination of ACI 318 and 562

# Substantial Structural Damage

- Defined in IEBC
  - Reduction of greater than 33% to the vertical elements of the lateral force resisting system
  - Reduction of greater than 20% of the vertical capacity in an area that supports more than 30% of the structures area
  - Requirements vary with IEBC edition
- Trigger for upgrade of structure to current code requirements

# Basis of Design Report

- New concept in ACI 562-16 – Section 1.5.3
  - Prepared for owner (expands IEBC requ.)
  - Summary of assessment results

Building description

Document unsafe conditions

Members needing strengthening

Past repair history

Current design-basis criteria

Etc.

**[BS] 404.2.1 Evaluation.** The building shall be evaluated by a *registered design professional*, and the evaluation findings shall be submitted to the *building official*. The evaluation shall establish whether the damaged building, if repaired to its predamage state, would comply with the provisions of the *International Building Code* for wind and earthquake loads.

# Maintenance / Future Inspection

- Documented in basis of design report
  - Types / frequency of maintenance
  - Types / frequency of inspection
- Why?
  - Inform current and future owners
  - Help design professionals

# Chapter 4 or Appendix A

- Criteria for determining extent of work
  - IEBC – use Chapter 4
  - Stand-alone code - Appendix A
- Based upon demand / capacity ratios
  - Unsafe conditions
  - Strengthening required
  - Repairs to original code

# 2015 IEBC Definitions

- Unsafe and Dangerous

**UNSAFE.** Buildings, structures or equipment that are unsanitary, or that are deficient due to inadequate means of egress facilities, inadequate light and ventilation, or that constitute a fire hazard, or in which the structure or individual structural members meet the definition of "Dangerous," or that are otherwise *dangerous* to human life or the public welfare, or that involve illegal or improper occupancy or inadequate maintenance shall be deemed unsafe. A vacant structure that is not secured against entry shall be deemed unsafe.

**[BS] DANGEROUS.** Any building, structure or portion thereof that meets any of the conditions described below shall be deemed dangerous:

1. The building or structure has collapsed, has partially collapsed, has moved off its foundation, or lacks the necessary support of the ground.
2. There exists a significant risk of collapse, detachment or dislodgement of any portion, member, appurtenance or ornamentation of the building or structure under service loads.

# When do existing structures need to satisfy current codes?

- IBC / IEBC
  - If alterations or additions increase force in a structural element by more than 5%
  - Repairs to elements that are found to be unsound or structurally deficient
  - When substantial structural damage has occurred
- When required by a local code or building official
- D / C ratio greater than 1.5

# Repairs to Conform to Original Code

- When structure is safe
  - Most design and construction errors
- When undamaged structure satisfies original design code
  - Durability related repairs
- Goal of ACI 562 is not to force strengthening of “good” structures

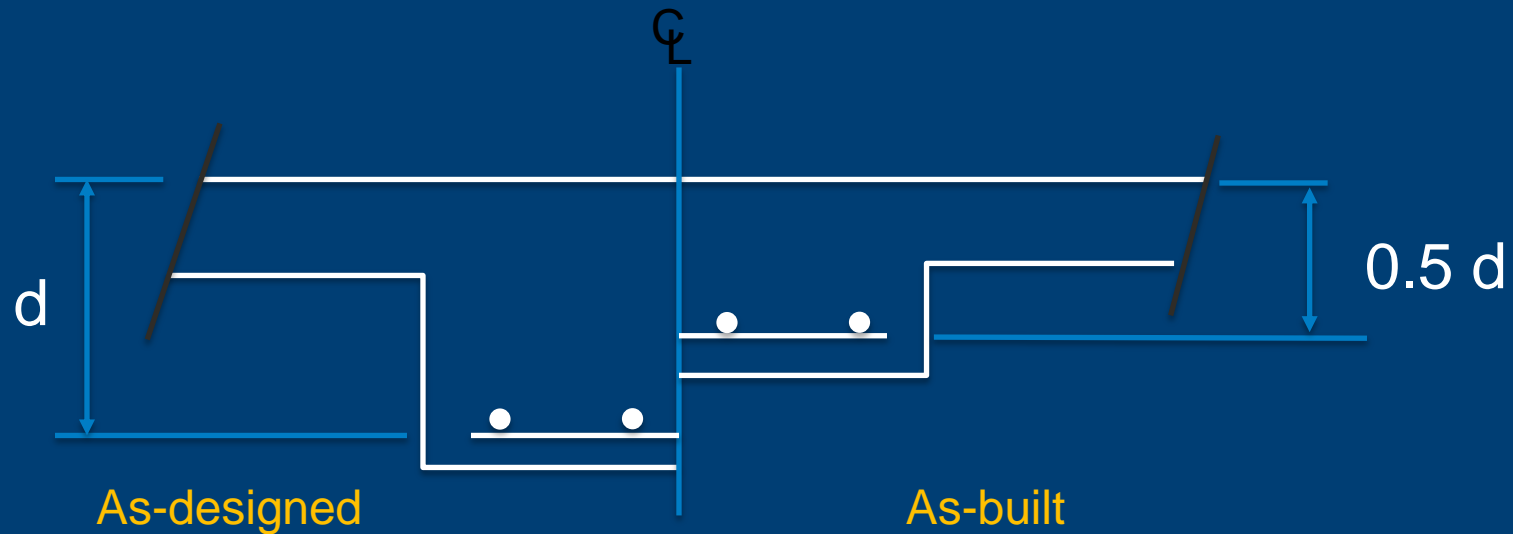


# Unsafe Conditions – Nonseismic

- Loose materials
- Falling debris hazards
- $U_c / \phi R_{nc} > 1.5$ 
  - Report consistent with 1.5.2
  - Gravity and wind loads
  - Current demand -  $U_c$
  - Current capacity -  $\phi R_{nc}$

# Demand / Capacity > 1.5

- Example – punching shear
- As built –  $d = 0.5 d_{\text{design}}$
- $V_u \leq \phi V_n = 0.75 (4) \sqrt{f'c} b_o d$   $D / C = 2.0$
- *Unsafe condition*



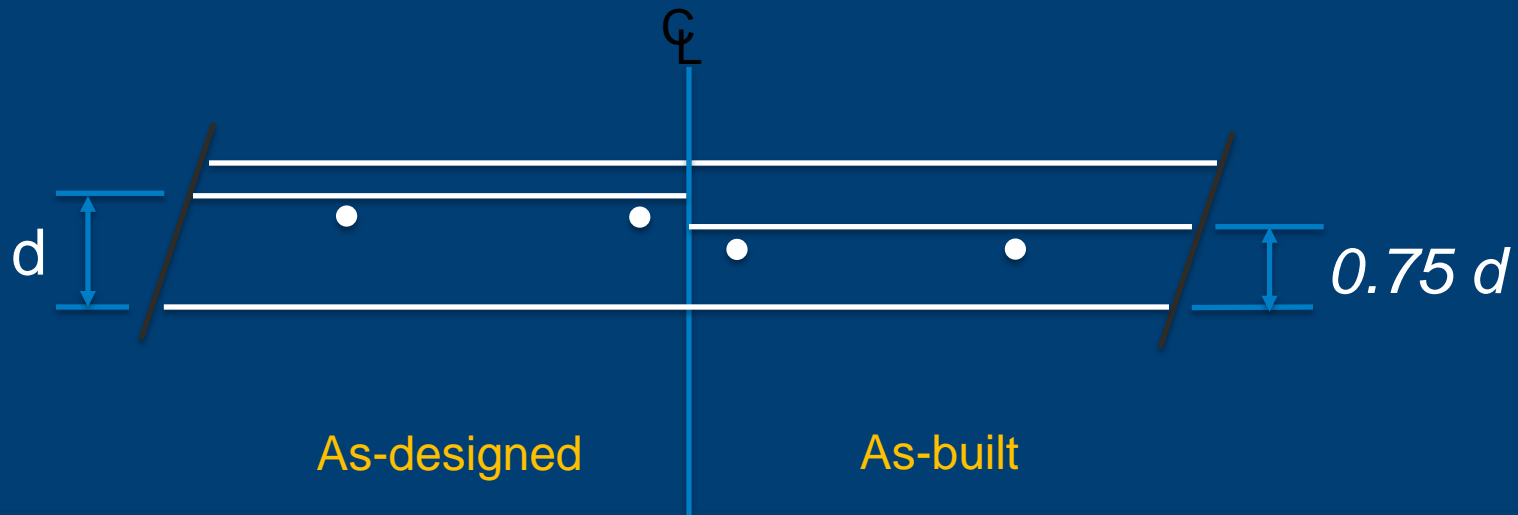
# Strengthening Required

- Less than substantial structural damage
- $U_o / \phi_o R_{nc} > 1.0$
- Design demand -  $U_o$
- Current capacity -  $\phi_o R_{nc}$
- Strengthening required
- Design to original building code

**[BS] 404.4 Less than substantial structural damage.** For damage less than *substantial structural damage*, repairs shall be allowed that restore the building to its predamage state. New structural members and connections used for this *repair* shall comply with the detailing provisions of the *International Building Code* for new buildings of similar structure, purpose and location.

# Demand / Capacity > 1.0

- Example – negative moment capacity
- As built –  $d = 0.75 d_{\text{design}}$
- $M_u \leq \phi M_n = 0.9 A_s f_y (d - a/2)$   $D / C \sim 1.25$
- *Strengthening required*



# Alternate Assessment Criteria

- Contained in commentary to ACI 562
- Changes in load intensity with time
- $U_c > 1.05U_o^*$ 
  - If  $U_c / \phi R_{cn} \geq 1.1$  – strengthen to demand of current code
- $U_c < 1.05U_o^*$ 
  - If  $U_o^* / \phi R_{cn} \geq 1.05$  – strengthen to demand of original code

# Demand / Capacity < 1.0

- No strengthening required
- $U_o / \phi_o R_{nc} < 1.0$
- Durability issues
- Serviceability issues



# Loads – Chapter 5

- Key points
  - Higher  $\phi$  factors with verification for assessment – ACI 318-14 Chap. 27
  - Load combinations for external reinforcement
    - FRP, External PT, etc.
    - Accidental damage
    - Fire damage

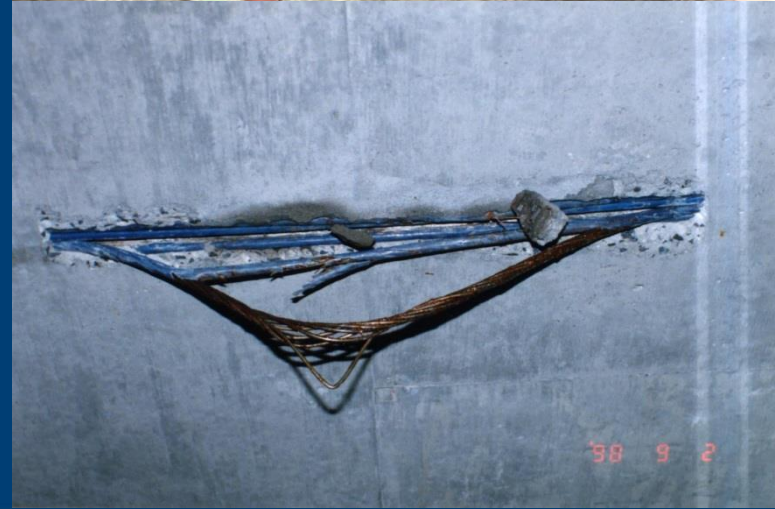
# Load combinations

- Min. capacity – no external reinforcement
  - $\phi R_n = 1.1D + 0.5L + 0.2S$  or
  - $\phi R_n = 1.1D + 0.75L$
- During fire event
  - $\phi_{ex} R = (0.9 \text{ or } 1.2)D + 0.5L + 0.2S$
  - Properties of structure during fire
  - Consider internal restraint



# Evaluation of Existing Structures – Chapter 6

- Process to determine:
  - Capacity of structure
  - Extent of damage
  - Impact of damage
  - Strength of materials



# Structural Assessment

- 6.2.1 – Investigation and structural evaluation required if the existing structure:
  - 1) exhibits signs of damage, displacement, deficiency, or behavior that is inconsistent with available construction documents or code requirements, or
  - 2) preliminary evaluation indicates strengthening is required

# Structural Assessment

- 6.2.3 - Where repairs are required on an element in a structure, it shall be determined if similar elements throughout the structure also require evaluation
  - Repetitive elements
  - Isolated repairs may not be acceptable

# Structural Evaluation – Analysis

- 6.2.5 - If an analysis is required, the structural assessment shall document the requirements of 6.2.4 and (a) through (c).
  - (a) As-measured structural member section properties and dimensions.
  - (b) The presence and effect of any alterations to the structural system.
  - (c) Loads, occupancy, or usage different from the original design.

# Unknown Structural Capacity

- Lack of design drawings
  - Determine geometry
  - Determine loads
- In-situ conditions
  - ACI 201
  - ACI 228.1
  - ACI 364
  - ASCE Guidelines



# Unknown Structural Capacity

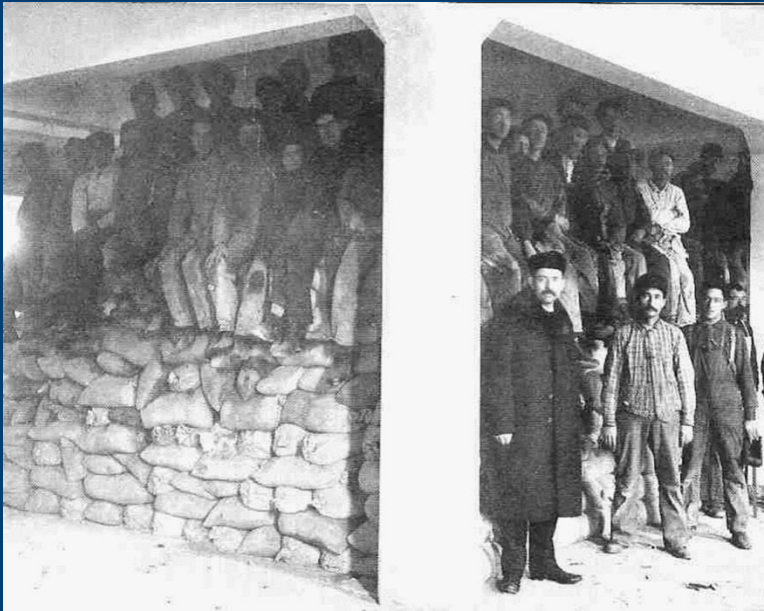
- Unknown material properties
  - Historical values
  - Physical testing
    - # of samples?
    - # of elements?
    - NDT – with correlation



# Load Testing

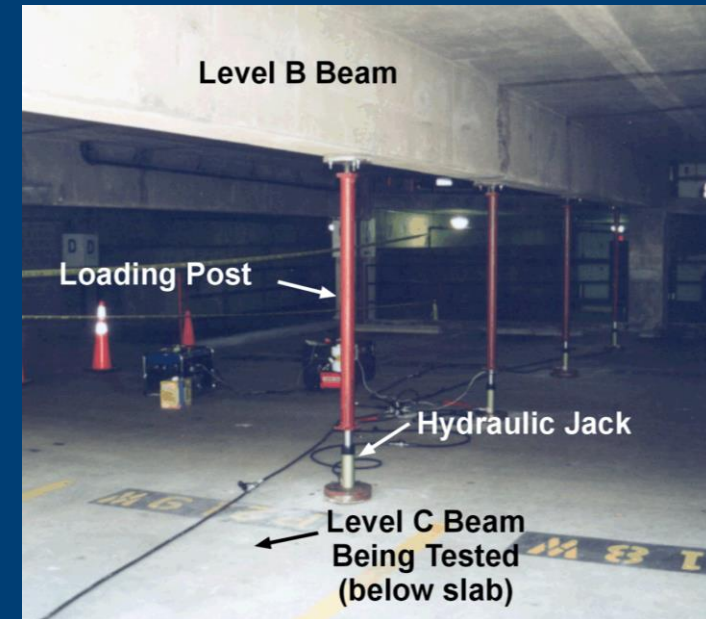
- ACI 437.2-13
- Code for load testing
- Why not ACI 318-14 Chapter 27?

[6.8]



# Load Testing

- Load testing (ACI 437.2-13) [6.8]
  - More rational for existing structures
  - Lower DL
  - Cyclic - accepted
  - Service load evaluation
- Model testing
  - Supplement analysis





# Repair Design – Chapter 7

- Key concepts
  - Satisfy strength and serviceability
  - Behavior of repaired structure
  - *Bond of materials*
  - Interaction and repair sequence
  - Appropriate materials

# Strength and Serviceability

- Strength to resist applied loads
- Stiffness to satisfy serviceability



# Interface Bond – 7.4

- Interface bond strength
  - $v_u \leq \phi V_{ni}$
- $v_u$  – interface demand
  - Loads – shear, tension
  - Volume change effects
- $V_{ni}$  – interface capacity



# Interface Bond – 7.4

- Quality assurance requirements - bond
- Function of interface demand

$V_u$	Refer.	Reinforcement	QA Requ.
Less than 30 psi	7.4.2	No	Bond-integrity testing
30 to 60 psi	7.4.3	No	Quant. testing – bond strength
Greater than 60 psi	7.4.4	Yes	Quant. testing – bond strength

- Bond-integrity testing

Hammer sounding, NDE, other methods

# Interface Bond – 7.4

- Bond capacity
  - Based upon ACI 318-14
  - Testing –  $v_u > 60$  psi
- Bond testing
  - ASTM C1583
- Interface reinforcement
  - No testing required



# Interaction and Repair Sequence / Detailing

- Consider in repair design
  - Interaction / engagement of existing structure
- Repair detailing
  - Maximize performance
  - ICRI Guidelines
  - ACI 546



# Repair Design with ACI 562

- Design Basis Code + Engineering Logic
- Key Concepts
  - Strength and stiffness requirements
  - Consider
    - In-situ structure
    - Integration of repair with structure
    - Sequence of work

# Durability – Chapter 8

- General
- Cover
- Cracks
- Corrosion and deterioration of reinforcement and metallic embedments
- Surface treatments and coatings



# Design Service Life

- A goal established by the licensed design professional (LDP) to achieve an economical repair that satisfies both safety and serviceability requirements
- Estimated by LDP in consultation with the owner and consideration of the properties of the materials
- ACI 562 **does not** establish a design service life

# Durability

- Performance-based requirements
- Durability considered by LDP in repair design
  - Individual repairs
  - Overall repaired structure
  - Interaction of repair area and structure



# Durability - General

- Repair materials and methods shall be selected that are intended to be compatible with the structure, durable within the service environment, and consider the ***anticipated maintenance***.



# Durability - General

So what does this mean?

- Specify materials based upon service environment
- New materials need to be compatible with existing
- Identify potential maintenance issues
- Make owner aware of maintenance requirements

Goals

- Reduce common causes of repair material failures
- Greater repair durability
- Reduce future problems for LDP

# Cover

- In accordance with the design basis code
- Alternative materials and methods, an equivalent cover that provides sufficient corrosion protection and fire protection shall be in accordance with 1.4.2 \*
- Sufficient anchorage and development for the reinforcement shall be provided regardless of methods used to provide corrosion protection

# Cracks

- The design of repairs shall consider the effects of cracks on the expected durability, performance, and design service life of the repair.
- Consider the causes, movement, size, orientation, width, complexity of the network of cracks, characteristics of the substrate, location, and evidence of water transmission

# Cracks



## Crack Repair Considerations:

- Cause
- Orientation
- Deleterious materials
- Performance of structure
- Movement
- Etc.

# Corrosion and deterioration of reinforcement and metallic embedments

- Considered in the durability design
- Quality of existing concrete and ability to protect reinforcement from corrosion and deterioration shall be considered
- Address anodic ring effect





# Coatings and Surface Treatments

- Consider moisture transmission through the structure & influence of surface treatment on the durability of the structure
  - Surface treatments, coatings, sealers, and membranes may have a shorter service life than the concrete
  - Encapsulation of moisture and deleterious materials by surface treatment may cause or accelerate deterioration

# Coatings and Surface Treatments

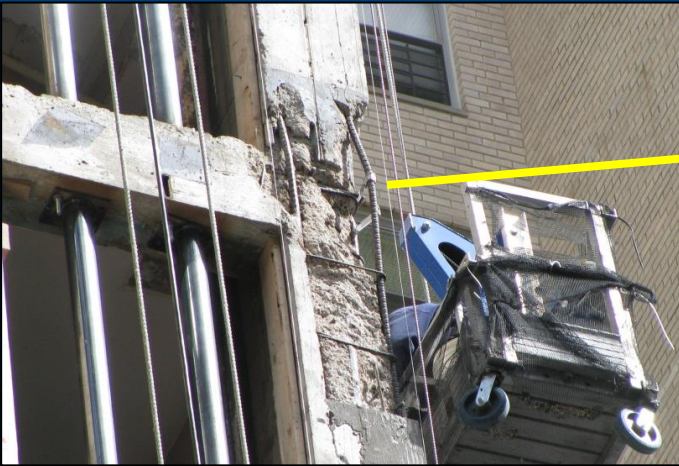
What does this mean?

- Coating service life
  - Future maintenance problem
- Coatings can trap water
- Trapped water can lead to coating failures
- Trapped water can lead to corrosion problems

Goal of provision is to make LDP aware of potential issues with coatings

# Construction – Chapter 9

- Stability and shoring
  - Designed by an LDP
  - Consider: sequence, in-situ conditions, changes in conditions



# Construction – Chapter 9

- Temporary conditions
  - ASCE/SEI 37 when feasible
  - Stalled projects?
- Environmental
  - Instructions to contractor
    - Report new conditions
    - Control of debris



# Quality Assurance – Chapter 10

- Inspection
  - Consistent with general building code
  - Detailed commentary listing possible inspection items
  - Concealed conditions
- Testing and Construction Observations
  - Consistent with project specifications

# ICRI – Concrete Repair Technician

- Concrete repair inspectors
- Project personnel
- Written and field training
  - QA / QC procedures
  - Understand
    - Why and how of good repair practices



# ACI 562-16 - Summary

- Performance-based code
  - Can be used as a reference standard
- Existing concrete structures
  - Not intended for new design
- Evaluation, design, durability, QA, and maintenance provisions

# Impact of ACI 562 on Concrete Repair Practice

- ACI Standard
  - Sets minimum requirements for repair
- Encourage evaluation
  - Confirm material properties
  - Better evaluation = better repairs
- Sustainable repaired structures
  - Long-term durability of repairs
  - Consistent reliability



# Additional Resources

- ACI 563 – Specifications
  - To be published in 2016
  - Specifications for common concrete repair types
- Concrete International
  - ACI 562-16 – article series
  - Expanded information on ACI 562

# Acknowledgements

- Members of ACI 562 Committee, especially
  - Larry Kahn
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# Thank you

- Questions???

