ACI 562 – Development of a Building Code for Existing Concrete Structures

by

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Presentation Topics

• Background on ACI 562
• Use of ACI 562 on typical project
• Key provisions
• What changes on a typical project
ACI 562 - 13

- Code for repair of existing concrete structures
- Developed to improve concrete repair practice
- Performance-based code
- Help design professionals and building officials
- Work in progress
  - Committee interested in feedback
  - Working on adoption into IEBC-18
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
Why a Repair Code?

• Repair performance
  – COE - 50% of repairs are not performing satisfactorily
    • Design errors
    • Construction errors
    • Material selection errors
  – Con Rep Net
    • 5 years – 80% of repairs are satisfactory
    • 10 years – 30% of repairs are satisfactory
    • 25 years – 10% of repairs are satisfactory
Why not a Repair Code?

• Complicated process
  – Took 7 years to develop
• Lack of consensus on practice
  – Lots of arguments
• Establish minimum practice requirements
  – What are minimum requirements?
• Concern about limiting creative solutions
• Fear of something new
Motivation

• ACI 318 Survey
  – One-half use for repair of existing structures
  – Use for non-building structures

• Conclusions from ACI 318 Survey
  – ACI 318 functioning beyond its intent
  – Code guidance for repairs is needed
Motivation

• Vision 2020

• #2 Goal - Create a repair/rehabilitation code:
  – Establish evaluation, design, materials and construction practices
  – Raise level of repair/protection performance
  – Establish clear responsibilities
  – Provide Building Officials with means to issue permits
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
• Use ACI and other “code” documents by reference
Building Codes

• Developed by consensus process (ANSI process)
  – Written by code writing organization
  – Code committee
    – Membership balance
    – Producers / Users / General Interest

• Written for design professionals
  – Architects and engineers

• Adopted in law
  – General building code
  – Feeder building codes – ACI 318, 562
ACI 562 - Applicability

• Existing concrete buildings
• Superstructure, foundations (slabs), precast elements – structural load path
• Structural vs. nonstructural – “Unsafe”
• Composite members – concrete
• Nonbuilding structures when required
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 repairs / repaired structure 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
How to Use ACI 562?

• General Requirements
  – Why is an LDP involved?
  – Is it an existing structure?
  – Where does the structure fit in code maze?
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
Design Basis Code

- General building code under which the repair project is completed
- Possible design basis codes:
  - IBC
  - IEBC
  - Local building code, i.e., NYC Building Code
  - ACI 318
  - Combination of ACI 318 and 562
When do existing structures need to satisfy current codes?

• IBC – Chapter 34*
  – If alterations or additions increase force in a structural element by more than 5%
  – Repairs to elements that are found to unsound or structurally deficient

• IEBC
  – When substantial structural damage has occurred

• When required by a local code or building official
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 code is not to force strengthening of “good” structures
Preliminary Evaluation

• Preliminary evaluation
  – Determine extent of structural damage present
  – Evaluation based upon in-place conditions
  – Can use assumed material properties
  – Establish design basis code

• Substantial structural damage
  – Determines if compliance with current code is required
Quasi - Case Studies

• Office Building
  – Constructed in 2007
  – Post-tensioned flat plate structure

• Parking Structure
  – Constructed in 1988
  – Reinforced concrete beams and slabs

• Mixed-Use Building
  – Constructed in 1960
  – Reinforced concrete beams and slabs
Office Building

• Owner and tenant complaints
  – Floor deflections
  – Cracking of partition walls
• Construction completed in 2007
• Drawings / construction records?
  – Full set of drawings and shop drawings
  – Full set of construction records
Office Building

• Preliminary Evaluation
Office Building

• Structural System
  – Flat plate post-tensioned slabs – 8” thick
  – 40 foot x 40 foot main bay
  – 12 inch square columns
  – No drop panels or column capitals
  – Shear walls for lateral loads

• Building Code
  – IBC (State modified) and ACI 318-02
Office Building

• Preliminary evaluation
  – Review design and construction records
  – Investigate distress
  – Examine code requirements
Office Building

• Preliminary evaluation findings
  – Excessive span to slab depth ratios
  – “Small” columns
  – Misplaced reinforcing steel – SPR survey

• Recommendation to Owner
  – Unsafe – close facility for repairs
Office Building

• Design basis code options
  – ACI 318-02 and ACI 562 (if safe)
  – Current IBC and local codes (upgrade)

• Required option
  – Upgrade to current code requirements
  – ACI 318-11 and State Building Code
  – Building official’s mandate
Parking Structure

• Construction completed in 1986

• Owner concerns
  – Overhead concrete spalling
  – Leakage through concrete deck

• Drawings / Construction records?
  – Full set of structural drawings
  – No construction records
Parking Structure

• Structural system
  – Reinforced concrete beams and slabs
  – 20 foot slab span / 50 foot beam span
  – Expansion joints at 150 foot spacing

• Building codes
  – IBC / IEBC and ACI 1983
Parking Structure

• Preliminary Evaluation
Parking Structure

• Preliminary evaluation
  – Damage due to long-term chloride exposure
  – Lack of maintenance
  – No evidence of design / construction defects
Parking Structure

• Design basis code options
  – ACI 318-83 and ACI 562 (if safe)
  – Current IBC and local codes (upgrade)

• Selected option
  – Safe structure – use ACI 318-83 and ACI 562
  – Repair options – to be determined
Mixed-Use Building

• Construction completed around 1960

• Owner concerns:
  – New owner wants to convert into condos
  – Wants to add concrete balconies to structure
  – Capacity of existing structure?

• Drawings / Construction records?
  – Destroyed by fire or flood
Mixed-Use Building

• Preliminary evaluation
  – Is the structure safe for continued use
  – Structural system and geometry?
  – Extent and type of damage?

• Material properties – preliminary analysis
  – Testing / measurement
  – Assumed material properties
Mixed-Use Building

• Preliminary evaluation
Mixed-Use Building

- Preliminary evaluation findings
  - Structure is in good condition
  - Rational gravity and lateral load system
  - No evidence of distress
  - New balconies feasible

- Design basis code options
  - Original design code and ACI 562 or
  - Upgrade to current code requirements
Mixed-Use Building

• Design basis code – new balconies
  – ACI 318-11

• Design Basis Code - Building
  – Selected ACI 318-11 and ACI 562
  – Voluntary upgrade
Evaluation of Existing Structures

• Lack of design drawings
  – Determine geometry
  – Determine loads

• In-situ conditions
  – ACI 201
  – ACI 228.1
  – ACI 364
  – ACI 437
  – ASCE Guidelines
Evaluation of Existing Structures

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

- Built in the 1930s
- New HVAC system – October 2011
Requirements for Structural Evaluation

• 6.1.1 - A structural evaluation shall comprise a structural assessment, structural analysis, or both.

• 6.1.2 – “A structural evaluation shall be performed if, during the preliminary evaluation, as described in Section 4.3, it is determined that an existing member, portions of a structure, or entire structure exhibit signs of deterioration, structural deficiency, …..”
Visual Assessment

• **6.1.3** A structural evaluation shall be performed when there is a reason to question the design strength of the member or structure and insufficient information is available to determine if a member, portion, or all of the existing structure is capable of supporting existing or new design loads.
Structural Evaluation – Analysis

• 6.2.3 - If an analysis is required, the structural assessment shall document the requirements of 6.2.2 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.
Cross Section

• Inverted tee

2 - 5/8” dia. rods
Structural Analysis – Original Loading

Moment (kip-ft)
Chapter 6 – Default Strength

• Material properties
  – Concrete (Table 6.3.1a)

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Chapter 6 – Default Strength

- Material properties
  - Steel (Table 6.3.1b)

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Calculated Capacity – Historic Values

• Flexural strength
  – Concrete: 2,000 psi
  – Steel: 33 ksi
  – Demand: -13 kip-ft
Φ: 0.9 (evaluation)
Capacity: -16.0 kip-ft
D/C: 0.81

Beam okay
Structural Analysis – Revised Loading

Moment (kip-ft)
Calculated Capacity – Historic Values

• Flexural strength
  – Concrete: 2,000 psi
  – Steel: 33 ksi
  – Demand: -19.8 kip-ft

Φ: 0.9 (evaluation)
Capacity: -16.0 kip-ft
D/C: 1.24

Strengthen beam
Determine Material Strength (Testing)

- Concrete cores
  - \( n = 8 \)
  - \( \overline{f}_c = 6,200 \text{ psi}, V = 0.15 \)
- §6.4.3-equlivalent specified concrete strength

\[
f_{ceq} = 0.9 \overline{f}_c \left[ 1 - 1.28 \sqrt{\frac{(k_cV)^2}{n}} + 0.0015 \right]
\]

- \( f_{ceq} = 5,100 \text{ psi} \)
- Measured dimensions of beam
Determine Material Strength (Testing)

• Steel coupons
  \(- n = 4 \)
  \(- f'_{y} = 40,000 \text{ psi}, V = 0.05 \)
• §6.4.6-equivalent specified yield strength (reinf.)
  \(- f_{yeq} = (f'_{y} - 3500)e^{-1.3k_{s}V} \)
  \(- f_{yeq} = 33,217 \text{ psi} \)
• Measured locations of bars
Calculated Capacity – Tested Values

• Flexural strength
  – Concrete: 5,100 psi
  – Steel: 33 ksi
  – Demand: -19.8 kip-ft
  
  Φ: 1.0 (evaluation)
  Capacity: -18.1 kip-ft
  D/C: 1.09

Strengthen beam
Strengthening Design

- Flexural strength
  - Concrete: 5,100 psi
  - Steel: 33 ksi
  - Demand: -19.8 kip-ft

Diagram:
- 2 layers of FRP
- Dimensions:
  - 6”
  - 9½”
  - 2½”
External Reinforcing Systems

• **5.5.1** For repairs achieved with unprotected external reinforcing systems, the required strength $U$ of a structure without repair shall be at least equal to the effects of factored loads in Eq. (5.5.1).

\[ U_{ex} = 1.2D + 0.5L + A_k + 0.2S \quad (5.5.1) \]
Key Evaluation Concepts

• Evaluation based on historic values
  – Quick check (ballpark)
  – Evaluate element with standard ϕ-factors

• Evaluation based on material testing
  – More refined analysis
  – Evaluate element with modified ϕ-factors (lower variability because material properties are known)
Key Evaluation Concepts

• Repair design consistent with relevant standards (ACI 318, ACI 440.2R, etc.)
  – Use standard ϕ-factors (because material properties will be unknown with repair work)
• Evaluation allows for lesser extent of repairs
  – Engineers can be engineers
  – Owner saves money
Repair Design with ACI 562

• Key Concepts
  • Satisfy strength and serviceability
  • Consider behavior of repaired structure
  • Interaction and repair sequence
  • Appropriate materials
7.1 General

562

• 7.1 Repaired structures, structural members, and connections shall be designed to have design strengths at all sections at least equal to the required strengths calculated for factored loads and forces in such combinations as stipulated in this code.

• Design Strength ≥ Required Strength

318

• 9.1 Structures and structural members shall be designed to have design strengths at all sections at least equal to the required strengths calculated for the factored loads and forces in such combinations as are stipulated in this Code.

• Design Strength ≥ Required Strength
7.2.1 Repaired members shall be designed to have adequate stiffness to limit deflections, vibrations, cracking, or any deformations that adversely affect strength or serviceability of a structure.

9.5.1 Reinforced concrete members subjected to flexure shall be designed to have adequate stiffness to limit deflections or any deformations that adversely affect strength or serviceability of a structure.
7.2 Strength and Serviceability

562

- **7.2.2** Repair design and construction procedures shall consider the loading, internal forces, and deformations in both the existing and repaired structure during the repair process.

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- **10.2.1** Strength design of members for flexure and axial loads shall be based on assumptions given in 10.2.2 through 10.2.7, and on satisfaction of applicable conditions of equilibrium and compatibility of strains.
7.3 Behavior of Repaired Structures

- **7.3.1** Repairs incorporating new members shall be designed to integrate the new members with the existing structure, creating a structural system capable of sharing and transferring loads.

- This is not addressed by ACI 318.

- However, 10.2.1 Strength design of members ... on satisfaction of applicable conditions of equilibrium and compatibility of strains.
7.3 Behavior of Repaired Structures

• 7.3.1.1 The design of the repair system shall consider the structural interaction between the existing structure and new members. The effect of the new members on the existing structure shall be evaluated according to the design basis code.

• Not directly addressed by ACI 318

• Provision addresses the possibility of added members changing the load path in an existing building.
7.3 Behavior of Repaired Structures

562

- 7.3.2 Repairs to existing members shall account for force transfer at the interface between the existing member and the repair material or repair system. It is permissible to use ACI 318-11 provisions in the design of force transfer between new and existing concrete.

318

- 11.6 Shear-friction
- 17.5 Horizontal shear strength
7.3 Behavior of Repaired Structures

562

• **7.3.2.1** Structural repairs shall maintain composite behavior under service loads. Repairs shall be designed for the material and existing substrate to perform as a composite section at service loads.

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• Composite concrete flexural members — Concrete flexural members of precast or cast-in-place concrete elements, or both, constructed in separate placements but so interconnected that all elements respond to loads as a unit.
7.4 Bond

- **7.4.1** The required bond strength shall be at least 1.5 times greater than the calculated design bond force at the repair material to existing concrete interface.

- Not explicitly covered
7.4 Bond

- **7.4.2** The licensed design professional shall verify the concrete substrate has adequate strength to sustain and transfer design forces of externally attached reinforcement.

- Not addressed in ACI 318 except this is similar to Appendix D.
7.5 Materials

- **7.5.2** Materials already in use in a structure shall be permitted to remain in use where such materials conform to the design basis code.

- **7.5.3** Materials conforming to ACI 318-11 or permitted by this code shall be used for repairs and alterations.

- **7.5.4** Alternate materials shall be permitted according to the licensed design professional’s approval and in accordance with Section 1.4.
7.6 Design and detailing considerations

• **7.6.1** Repair design shall be based upon the member conditions identified in Chapter 6.

• **7.6.2** *Concrete*—The in-place properties of the existing concrete, as identified in Chapter 6, shall be used in the repair design.
7.8 Repair using fiber-reinforced polymer (FRP)composites

562

- **7.8.1** Fiber-reinforced polymer in conformance with ACI 440.6 shall be permitted to repair existing concrete structures.

• Not permitted

Repair design utilizing FRP is now permitted.
Repair Design with ACI 562

• Straightforward – Chapter 7
  - Design Basis Code + Engineering Logic
• Key Concepts
  - Satisfy strength and stiffness requirements
• Consider
  - In-situ structure
  - Integration of repair with structure
  - Sequence of work
ACI 562 - Durability

Chapter 8—Durability

• 8.1—General
• 8.2—Cover
• 8.3—Cracks
• 8.4—Corrosion and deterioration of reinforcement and metallic embedments
• 8.5—Surface treatments and coatings
8.1—General

- **8.1.1** Durability of all materials incorporated into a repair shall be considered for individual repairs, the overall durability of the repaired structure, and the interaction of the repair system with the existing structure.
8.1—General

• **8.1.2** 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.
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 service life
8.2—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.
8.3—Cracks

• **8.3.1** 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
8.4—Corrosion and deterioration of reinforcement and metallic embedments

- Considered in the durability design
- Not contain intentionally added constituents that are corrosive to reinforcement within the repair area.
- Existing reinforcement corrosion encapsulated within new repair materials to be considered for long term durability and strength
- Quality of existing concrete and ability to protect reinforcement from corrosion and deterioration shall be considered.
  - address anodic ring effect
8.5—Surface treatments and coatings

• 8.5.1 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
Maintenance

• To assure durable repairs
• Protect design professionals
• “Maintenance recommendations shall be documented...” [1.5.2 & 1.7]
• “A maintenance protocol should be provided...” [1.7C]
Quality Assurance

• Require testing and inspection
  – Commentary list of items to inspect
• Repair inspectors should be qualified by demonstrating competence
• LDP may inspect their projects
• Testing as required by LDP
• Existing conditions shall not be concealed
  – Construction observation
Typical Repair Project

• Quality Assurance Plan [10.1]
  – Required by general building code
  – Part of contract documents

• Maintenance Plan [1.5.2 and 1.7]
  – Document specific requirements for owner
  – Protect design professional
So What Changes?

• What improves with ACI 562?
  – Design basis options
  – Materials

• What is different with ACI 562?
  – Performance-based code
  – Maintenance requirements
  – Durability
  – QA Requirements
ACI 562 - 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
- Evolving document
Acknowledgements

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Thank You

Questions?

ACI 562-13

Code Requirements for Evaluation, Repair, and Rehabilitation of Concrete Buildings (ACI 562-13) and Commentary

An ACI Standard

Reported by ACI Committee 562

American Concrete Institute®