

ACI 562-16 – The Concrete Repair Code

Minnesota Concrete Council
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by
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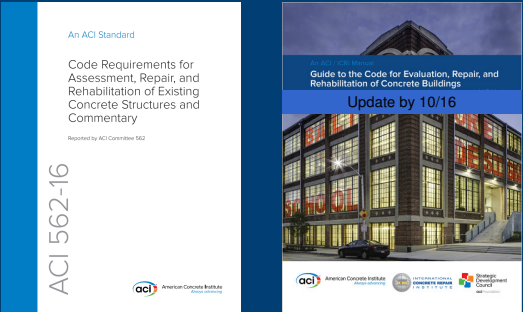
Learning Objectives

- 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

Presentation Overview

- ACI 562 – 16
 - Overview of code development
 - Major changes in 2016
- How to Use ACI 562-16
- Design of repairs using ACI 562-16

ACI 562 -16



The image shows two book covers. The left cover is for 'ACI 562-16: Code Requirements for Assessment, Repair, and Rehabilitation of Existing Concrete Structures and Commentary'. The right cover is for 'Guide to the Code for Evaluation, Repair, and Rehabilitation of Concrete Buildings', updated by 10/16. Both covers feature the ACI logo and a photograph of a modern building.

ACI 562 - 16


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



The image contains two photographs. The left photo shows a construction site with a grid of rebar laid out on a prepared surface. The right photo shows a close-up of a worker in a hard hat and safety vest using a tool to work on a concrete surface.

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




The image contains two photographs. The left photo shows a cross-section of a concrete structure with rebar protruding from a hole. The right photo shows a circular concrete repair patch on a wooden board.

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?

06/10/2015 06:01

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
 - First published in 2003
 - ACI 562 developed to work with IEBC
- IPMC
 - Referenced in IBC and IEBC



IPMC

- 2015 IPMC referenced in IBC and IEBC
- Defines unsafe conditions for various building materials

2. Concrete that has been subjected to any of the following conditions:

- 2.1. *Deterioration;*
- 2.2. *Ultimate deformation;*
- 2.3. *Fractures;*
- 2.4. *Fissures;*
- 2.5. *Spalling;*
- 2.6. *Exposed reinforcement; or*
- 2.7. *Detached, dislodged or failing connections.*

IEBC

- Provides code requirements repair of existing structures
- When structures need to satisfy current codes
 - Substantial structural damage
 - Repairs to noncompliant buildings
- Does not provide guidance on:
 - How to evaluate existing structures
 - Repair design
 - Repair durability

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

ACI 562-16

An ACI Standard

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

Replaces ACI Committee 562

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

Quasi - Case Studies

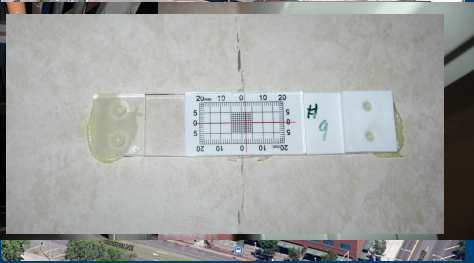
- Office building
 - Constructed in 2007
 - Post-tensioned flat plate structure
- Parking structure
 - Constructed in 1988
 - Reinforced concrete beams and slabs

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



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

Preliminary Evaluation / Evaluation

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

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

Basis of Design Report

- New concept in ACI 562-16 – Section 1.5.3
- Prepared for owner
- Summary of assessment results
 - Building description
 - Document unsafe conditions
 - Members needing strengthening
 - Past repair history
 - Current design-basis criteria
 - Etc.

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

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 - ϕR_{nc}

Demand / Capacity > 1.5

- Example - punching shear
- As built - $d = 0.5 d_{\text{design}}$
- $V_u \leq \phi V_n = 0.75 4 \sqrt{f'c} b_o d$
- **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

Demand / Capacity > 1.0


- Example - negative moment capacity
- As built - $d = 0.75 d_{\text{design}}$
- $M_u \leq \phi M_n = 0.9 A_s f_y (d - a/2)$
- **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
- $U_o / \phi R_{nc} < 1.0$
- Durability issues
- Serviceability issues



Loads – Chapter 5


- Key points
 - Higher ϕ 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



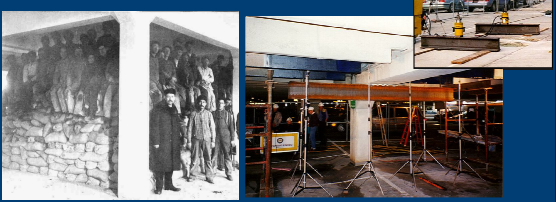
Unknown Structural Capacity

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



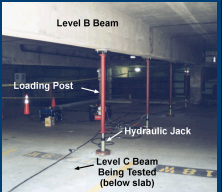
Load Testing

- ACI 437.2-13 [6.8]
 - Code for load testing
 - Why not ACI 318-14 Chapter 27?



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




Behavior of Repaired Structure

- Integrate repair into existing structure
- Recognize what loads will occur on repaired structure
 - Live and dead?
 - Live only?
 - Lateral?



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



Design Example: Transit Mall Bonded Overlay

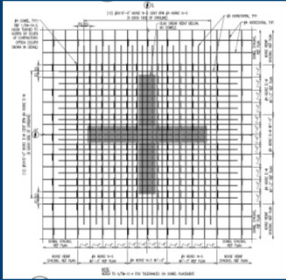
- Existing Condition
- Problem / Solution
 - Deficient in:
 - Flexure
 - Punching shear
 - Solution
 - Reinforced bonded overlay
 - MLEO wearing surface



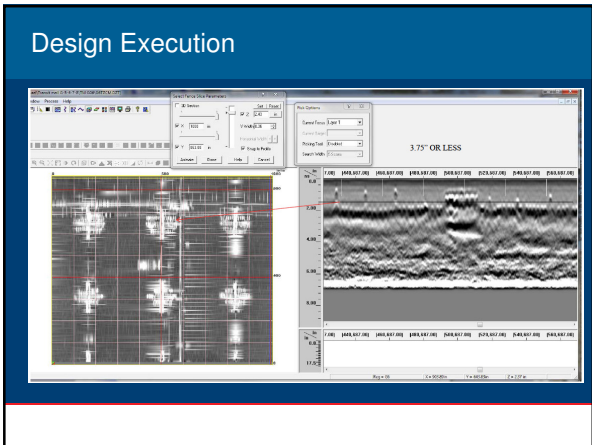
Design Example: Transit Mall Bonded Overlay

Dowels detail at the column locations.

Very high congestion of existing reinforcement at topside of existing column (about 40 strands plus 120 #4 (T12) - 4 legs closed stirrups spaced at 3 in. (75 mm O.C.)











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

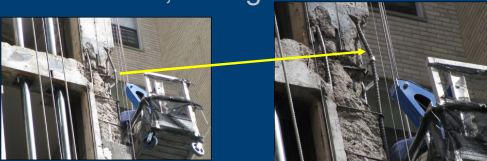
What does this mean?

- 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



Concrete Surface Repair Technician  INTERNATIONAL CONCRETE REPAIR INSTITUTE

- **Competency Based Program**
 - Knowledge using current best practices for training and evaluation. Presented and tested online
 - Performance components assessed by observable criteria (live or video recorded)
- **Effective, Consistent, Affordable, and Convenient**
- Tier 1 will complete the knowledge components only
- Tier 2 will be qualified to perform Pre and Post-placement inspections and testing (full certification)

Certified Concrete Surface Repair Technicians will:



- Be aware of the causes and problems associated with embedded metal corrosion
- Understand the requirements for a quality repair
- Be aware of the various repair materials and methods
- Be qualified to perform pre-placement and post-placement inspections and testing

Certified Concrete Surface Repair Technicians will:



- Be aware of the various repair materials and methods
 - Dry-Packing
 - Trowel Applied
 - Poured Flatwork
 - Form and Pour
 - Form and Pump
 - Pre-placed Aggregate
 - Shotcrete
- Be qualified to perform pre-placement and post-placement inspections
 - Hammer Sounding (ASTM D4580)
 - Chloride Content and Carbonation of Existing Concrete
 - Inspecting for Proper Removal of Concrete Behind Rebar (ICRI 310.1R)
 - Inspecting for Surface Cleanliness of Existing Concrete
 - Inspecting for Moisture Condition
 - Measuring Rebar Section Loss
 - Inspecting for Rebar Cleanliness (ICRI 310.1R)
 - Inspecting Proper Storage, Mixing, Placement of Repair Material (ICRI 320.3 R)
 - Measuring Slump (ASTM C143) and SCC Slump Flow (ASTM C1611)
 - Making Cylinders (ASTM C31)
 - Fabricating a Shotcrete Test Panel (ASTM C1140)
 - Pull off Test (ASTM C1583/ICRI 210.3R)

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 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

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Thank You

- Questions?
