American Concrete Institute

Minnesota Concrete Council
A CHAPTER OF aci

ACI 562-19:

Assessment, Repair, and Rehabilitation of Existing Concrete Structures

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Repair Code

ACI 562-19:

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Learning Objectives

- Recognize that ACI 562 is a performance code
- Realize that ACI 562 can be used as a stand-alone code or as a supplemental code to IEBC
- Identify what design-basis code is applicable for the assessment and repair of a concrete structure
- Understand the different load combinations and reduction factors in ACI 562

Presentation Outline

Part I

- Why do we need a uniform concrete repair code?
- Relative success with current repair methods
- Reasons for repair failures

Part II

- Goals of ACI 562 - Repair Code
- Brief overview of chapters in repair code
- Repair Example

Why a Repair Code?

- Create a uniform set of requirements
  - Consistent methods to decide governing code for repair work
  - Consistent methods to assess damage
- Identify flexibility in repair solutions
  - Performance base and prescriptive approach

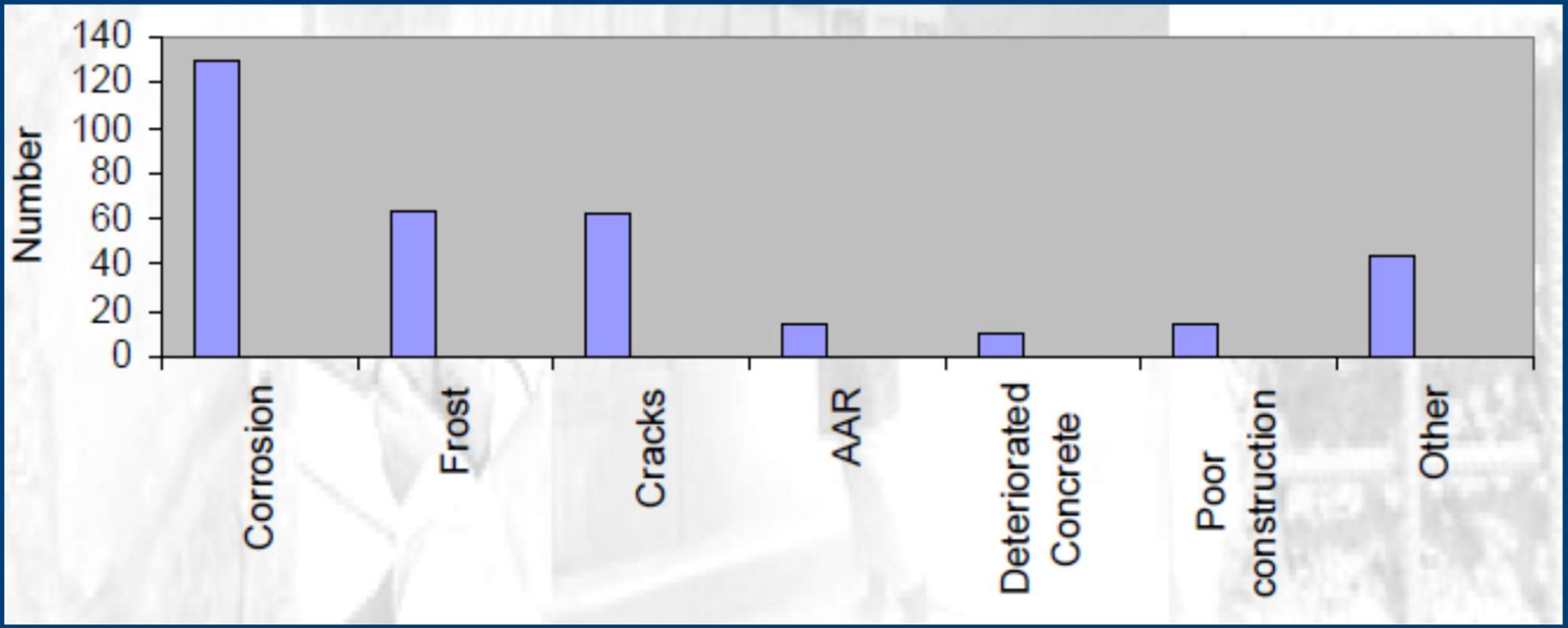
How big is the repair industry in the U.S.?

- $18 to 21 billion/year

Source: American Concrete Institute (ACI) Foundation's Strategic Development Council.

Source: https://www.nps.gov/tps/how-to-preserve/briefs/15-concrete.htm

Factors affecting concrete (case study)

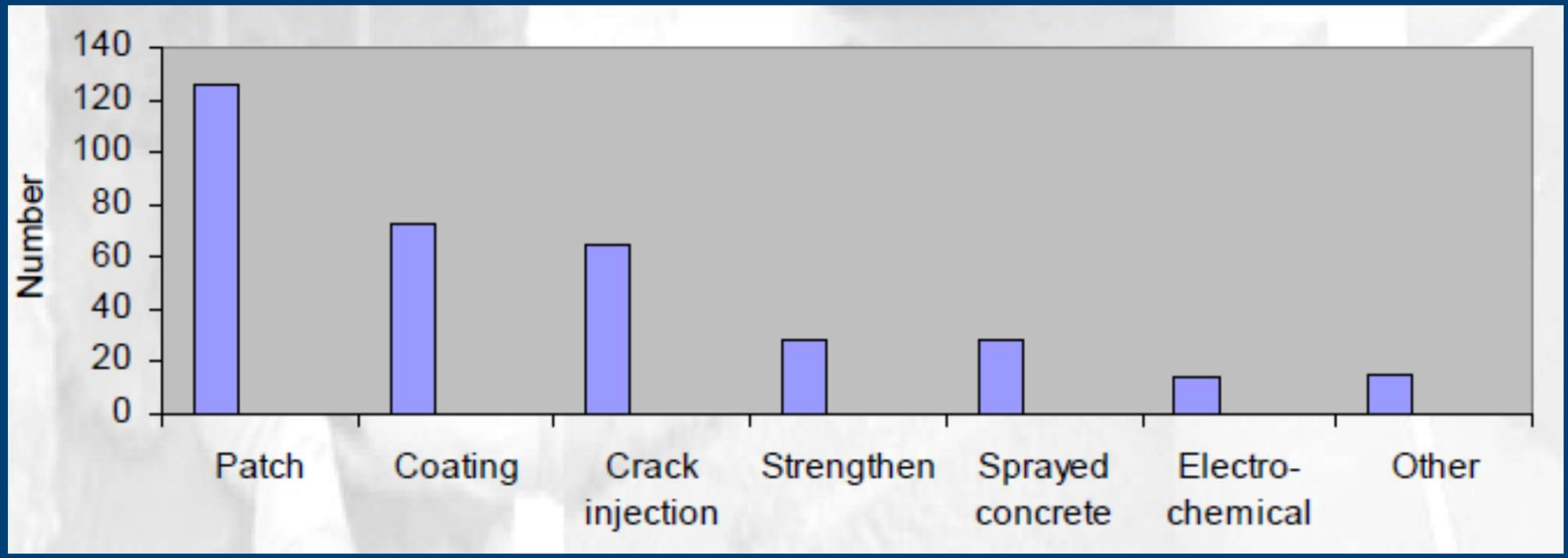


Source: projects.bre.co.uk/conrepnet/pdf/newsletter3.pdf

215 case histories

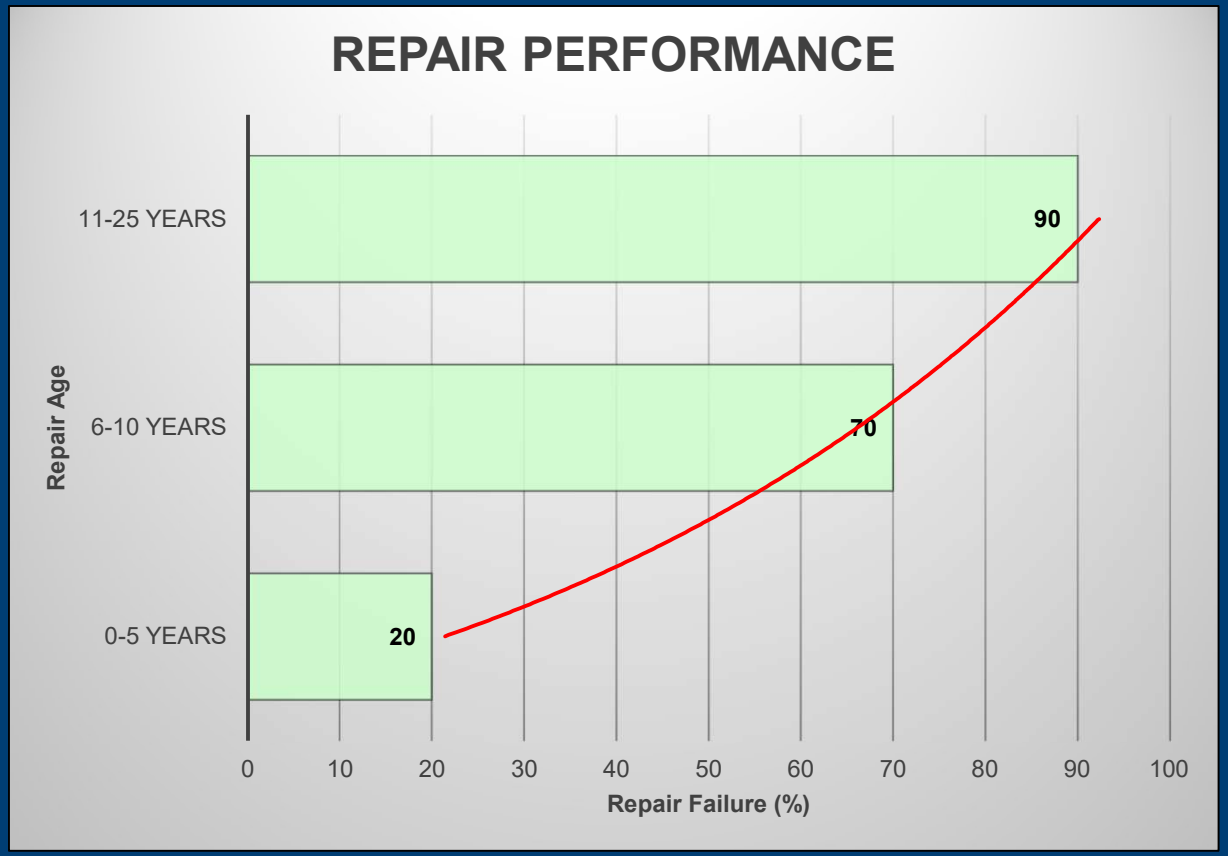
Repair methods

Using conventional approaches



Source: projects.bre.co.uk/conrepnet/pdf/newsletter3.pdf

Repair performance



Source: projects.bre.co.uk/conrepnet/pdf/newsletter3.pdf

Common Causes of Failed Repairs

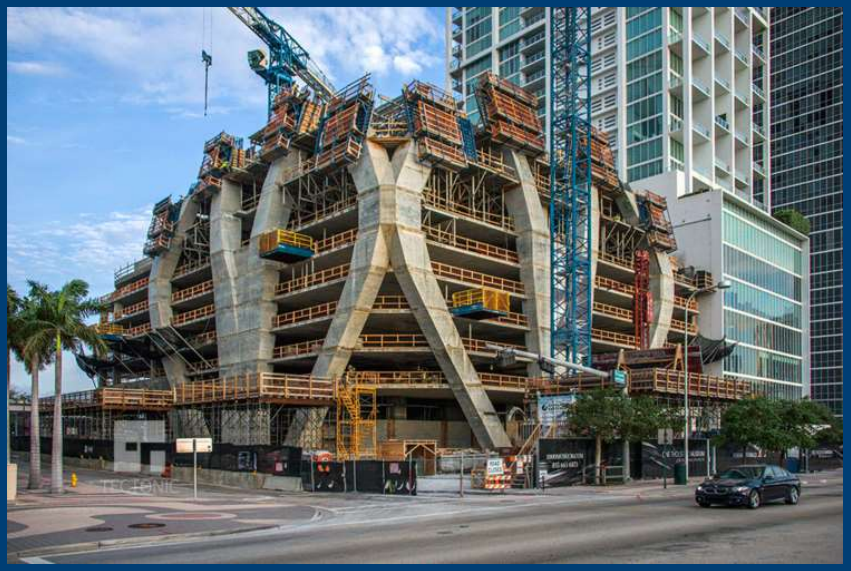
Engineering issues:

- Incorrect diagnosis of the cause of deterioration
- Incorrect design of the repair
- Selection of inappropriate repair material

Common Causes of Failed Repairs

Construction issues:

- Non standard design
- Nonconformance to design intent
- Accelerated construction
- Repair application
- Workmanship issues
- Material varying quality



Source: Technic Photo

Part II

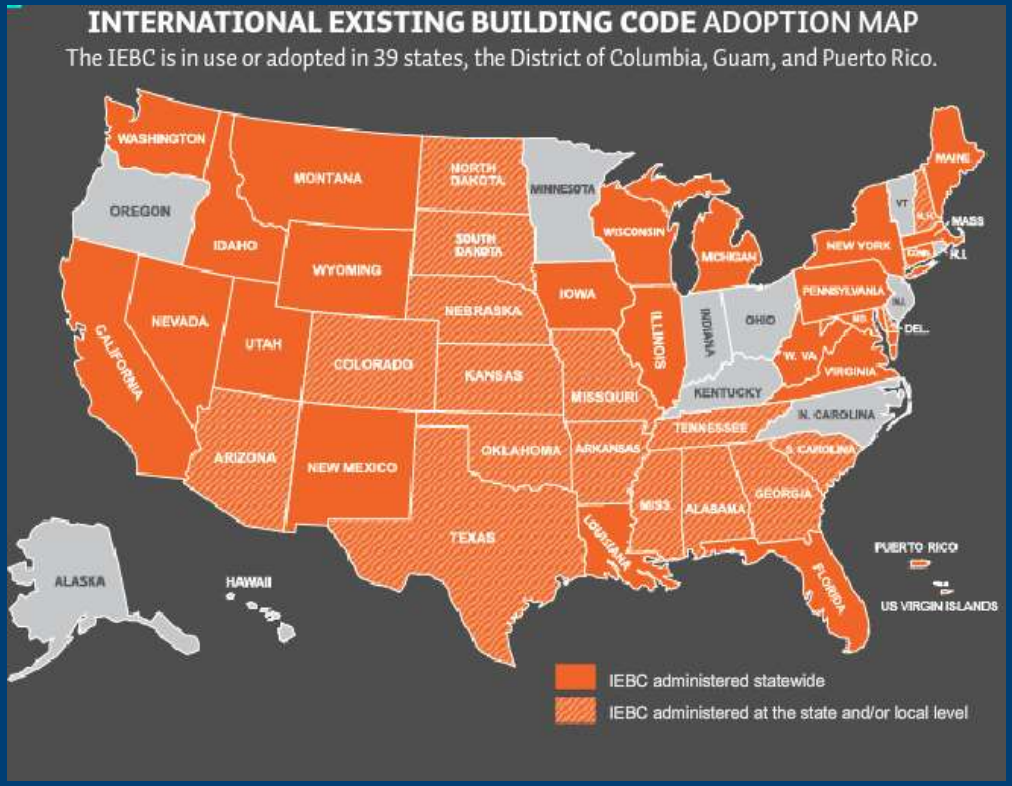
ACI 562-19:

Assessment, Repair, and Rehabilitation of Existing Concrete Structures

Codes

Repair/Rehabilitation of Existing Buildings

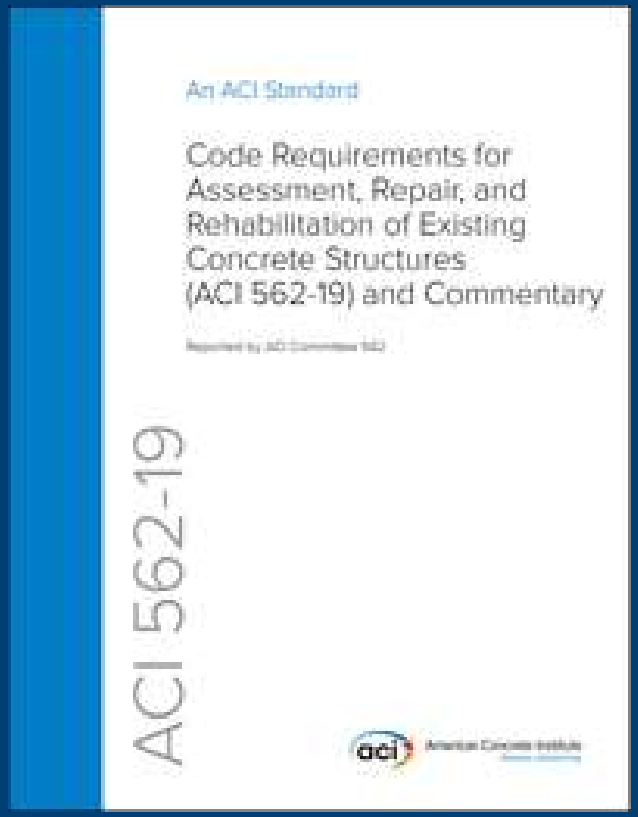
ICC → IEBC is the Model Code for Existing Buildings



International Code Council (March 2014):
http://www.iccsafe.org/gr/Pages/adoptions.aspx

ACI 562 a New Repair Code

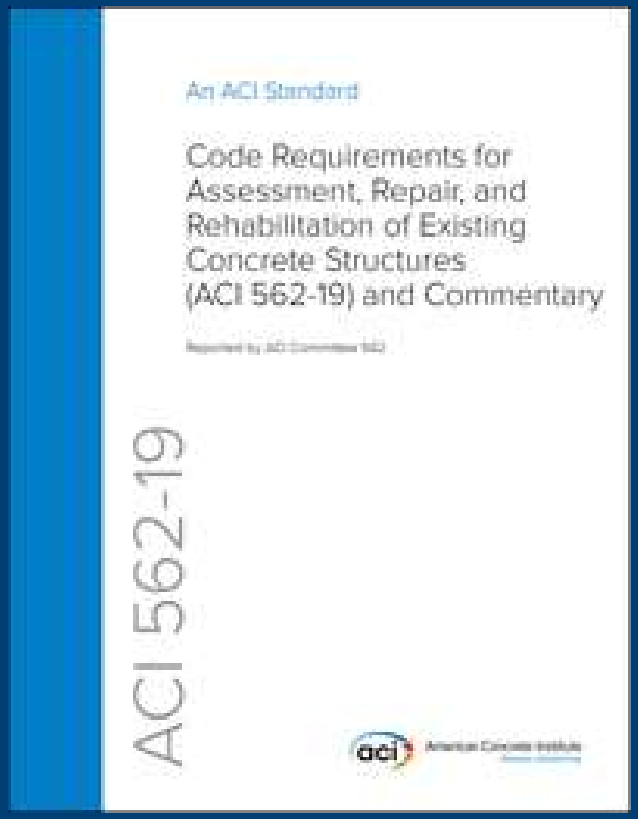
- Standardizes industry practice
- LDP
- Building inspectors
- Owners



ACI 562 a New Repair Code

ACI 562 applies to assessment, repair, and rehabilitation of existing concrete structures:

- A code supplementing the IEBC
- As part of a locally adopted code governing existing buildings or structures;
- Or as a stand-alone code for existing concrete structures.



Codes

Hawaii State Building Code Council has approved that ACI 562, "… shall be deemed to comply as a supplement to the requirements of this chapter or the International Existing Building Code."

Ohio State Building Code now references ACI 562, … The new changes add requirements for ACI 562 as follows: "… evaluation and design of structural concrete repairs and rehabilitation shall be in compliance with Chapter 34 of the IBC and ACI 562."

When is ACI 562 applicable?

Buildings that hold a legal certificate of occupancy

CITY OF ANY STATE

Certificate of Occupancy

This certificate issued pursuant to the requirements of Section 110.3 of the International Building Code certifying that at the time of issuance this structure was in compliance with the various ordinances of the city regulating building construction or use. For the following:

Bldg Permit No: 06358 **Building .**

Owners of Building: Sunrise International Development Company

Owners Address:

Scope of Work: New 8 Unit Commercial Building

Building Code Edition: 2006 International Building Code

Parcel No:

Occupancy Group: B **Construction Type:** V-B **Use Zone:** CH

Occupant Load: 126 **Sprinkler System:** No **Sprinkler System Required:** N/A

Special Stipulations/Conditions: None

Building Official

Void in a conspicuous place

ACI 562

What type of code is it?

- Performance and prescriptive
- Minimum material and design
- Minimum life safety and repair performance

ACI 562 Chapters

Chapter 1—General requirements
Chapter 2—Notations and Definitions
Chapter 3—Referenced Standards
Chapter 4—Criteria when using this code with IEBC
Appendix A—Criteria using this code as stand-alone code
Chapter 5—Loads, factored load combinations, and ϕ
Chapter 6—Assessment, evaluation, and analysis
Chapter 7—Design of structural repairs
Chapter 8—Durability
Chapter 9—Construction
Chapter 10—Quality assurance
Chapter 11—Commentary References

Preliminary Evaluation
Structural Assessment
Design
Construction

Codes Defined in ACI 562

- Current Building Code
- Original Building Code
- Existing Building Code

- Design Basis Code?

Chapter 1—General Requirements

Scope:
This code shall apply to assessment, repair, and rehabilitation of existing concrete structures

Intent:
Safeguard the public

User:
The engineer of record (LDP)

Source: Sandberg

Chapter 1—Applicability of ACI 562

This Code is applicable when performing assessment, evaluation, repair, rehabilitation, and strengthening of existing concrete elements of:

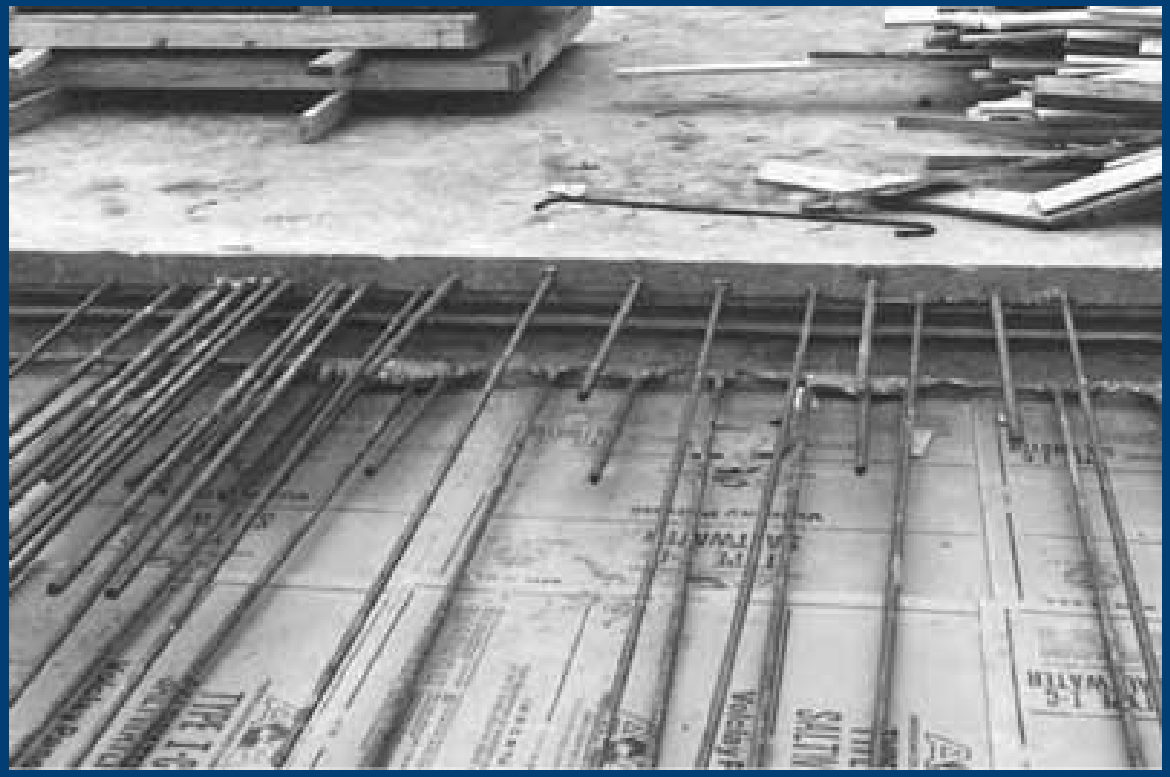
- Buildings or nonbuilding Structures (Section 1.3.1 and 1.4.1)

Scope of ACI 562

- Foundation (Section 1.3.3.1)

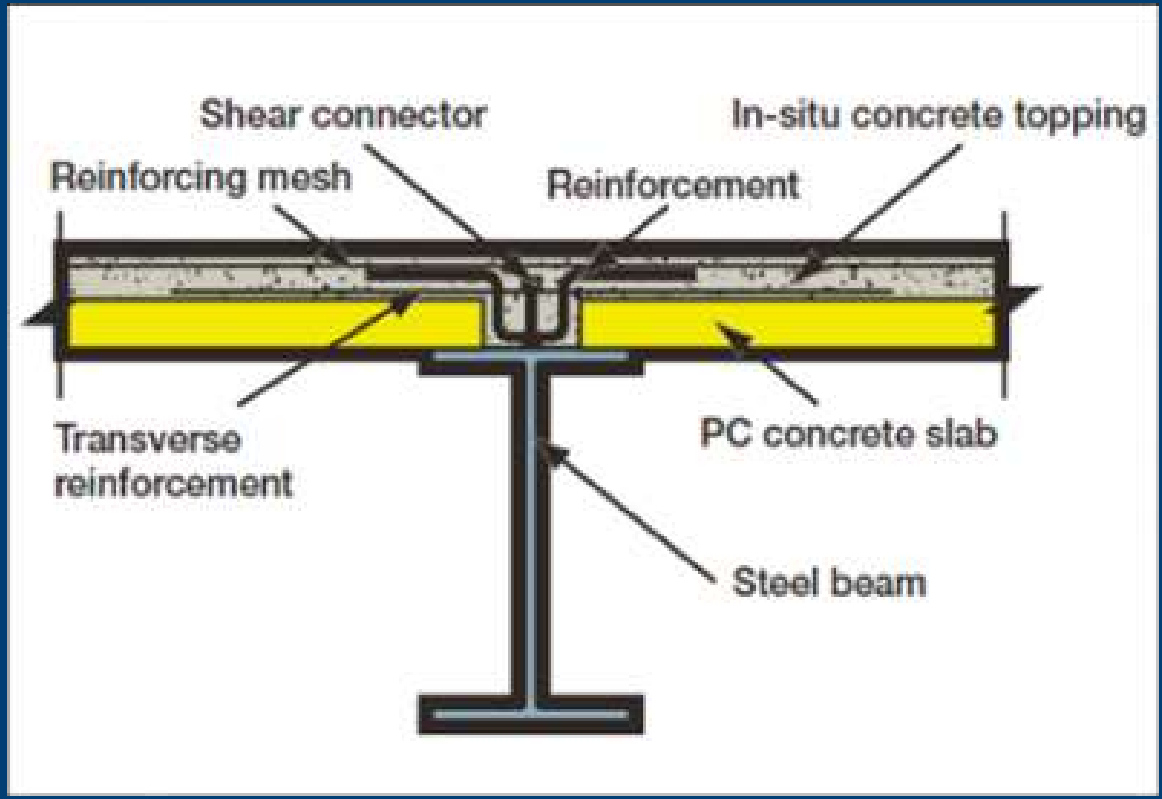
Scope of ACI 562

- Soil-supported structural slabs (Section 1.3.4.1)



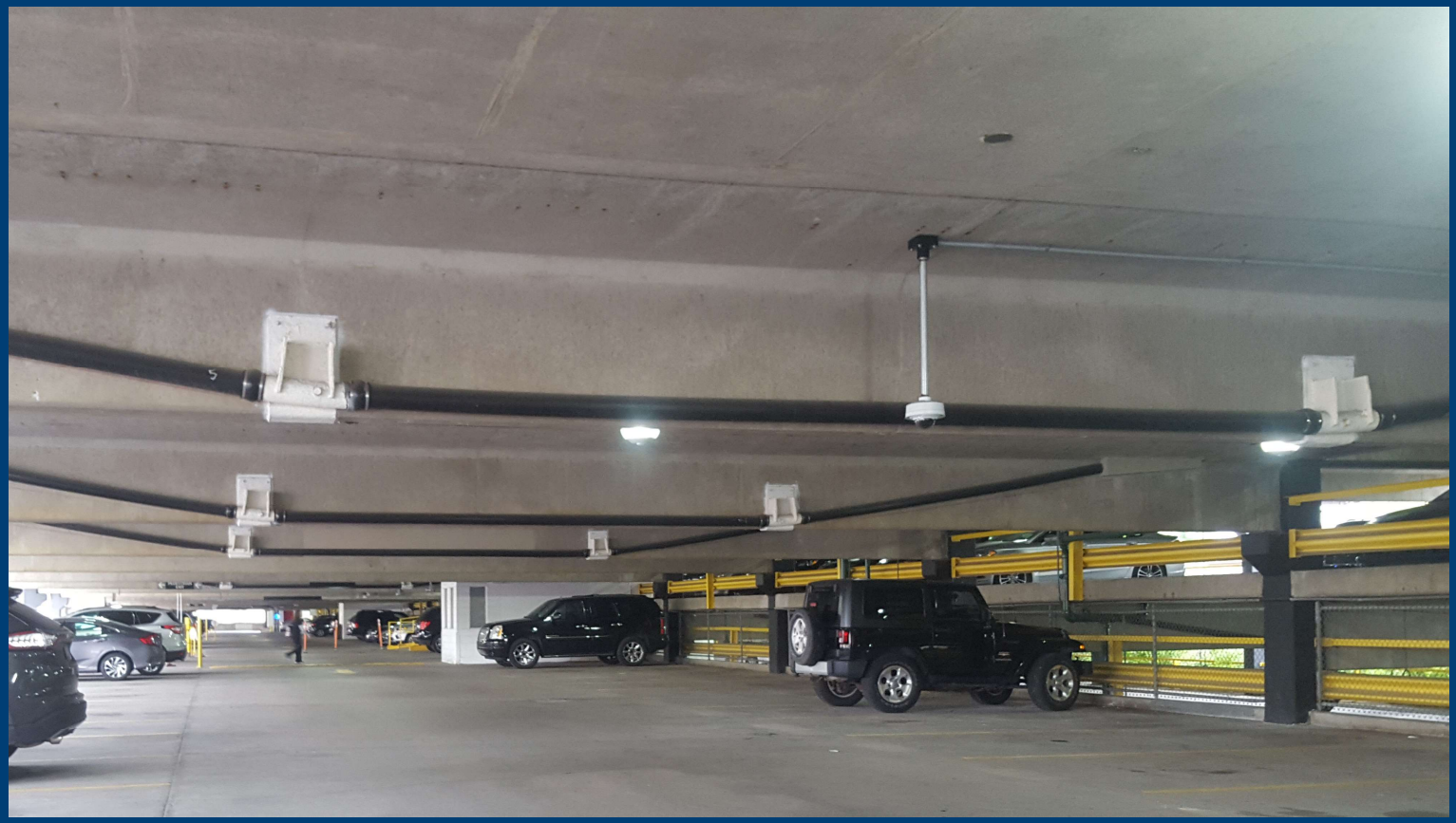
Scope of ACI 562

- Composite members (Section 1.3.5.1)



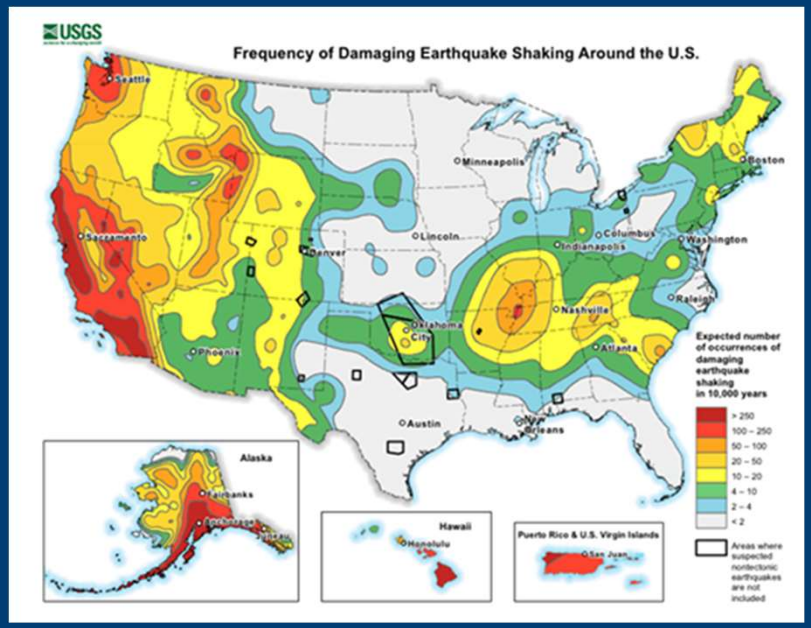
Scope of ACI 562

- Precast and prestressed concrete (Section 1.3.6.1)



Scope of ACI 562

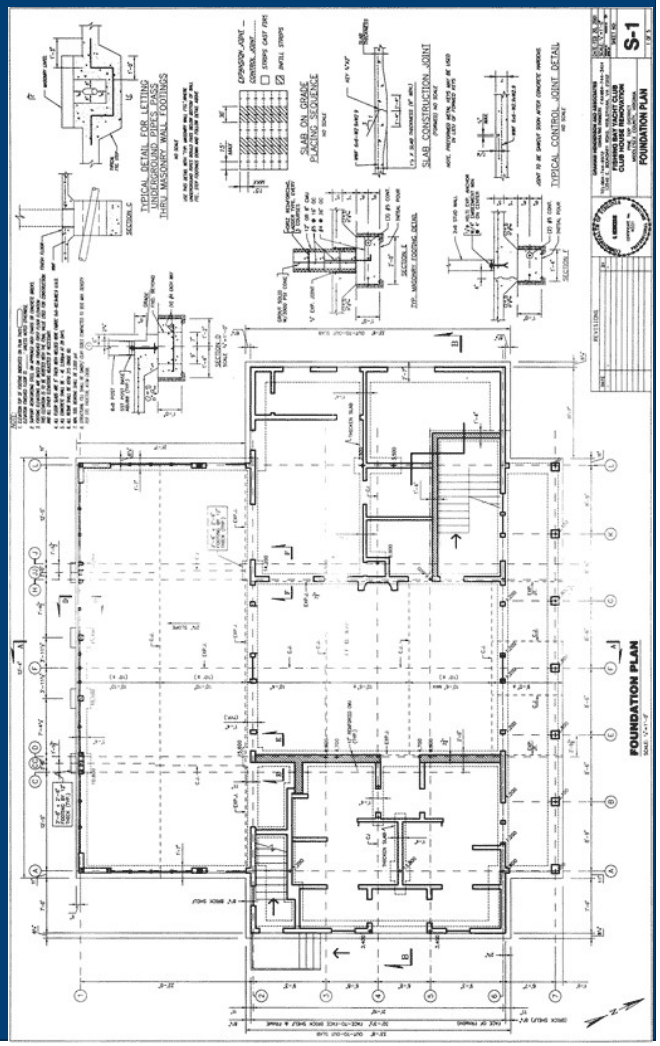
ACI 562 does not address damage of the seismic lateral force resisting systems



Perform Preliminary Assessment

Preliminary assessment is carried out to determine if a structure is in:

- Compliance with original concrete design code
- Safe



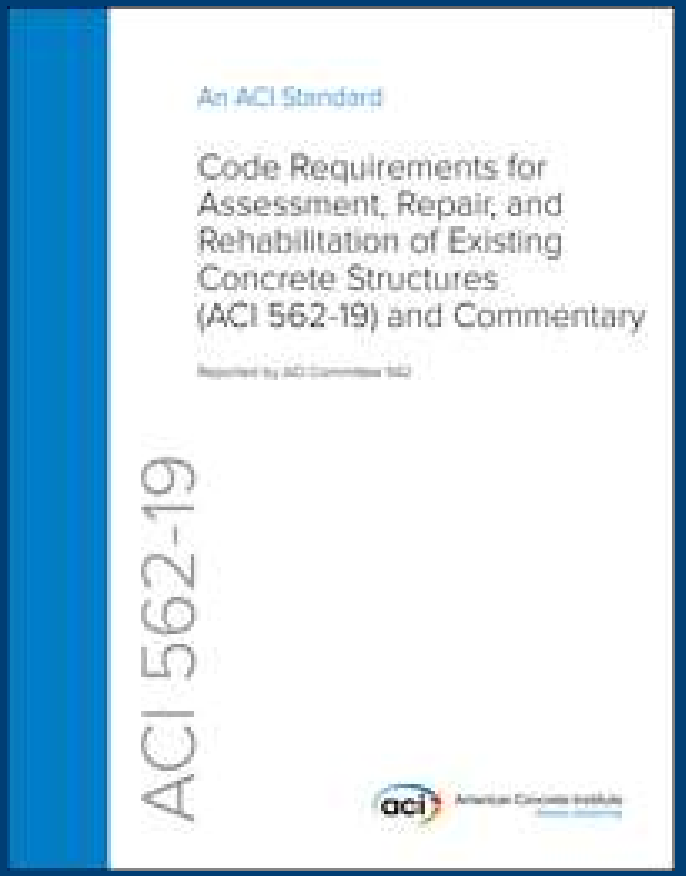
Perform Preliminary Assessment

Existing in-place conditions are visually investigated to verify existing geometry and structural conditions.

Source: WJE

Chapter 4—Criteria when using this code with IEBC

Chapter 4 applies if a jurisdiction has adopted the IEBC as the existing building code.



Condition	ACI 562 Section	Demand/capacity	Design-basis code
Unsafe condition	Gravity and wind load (A.3)	$U_c/\phi R_{cn} > 1.5$	Current building code and ASCE/SEI 7
	Seismic (A.3)		ASCE/SEI 41 and ACI 562
Substantial structural damage	Gravity load A.4.1b and A.4.1c	$\frac{\sum R_n - \sum R_{cn}}{\sum R_{cn}} > 0.20$ and $\frac{\sum U_c}{\phi_o R_{cn}} \geq 1.33$	Current building code demand supplemented by requirements of ACI 562
	Lateral-force-resisting system A.4.1a	$\frac{\sum R_n - \sum R_{cn}}{\sum R_{cn}} > 0.33$	Current building code demand supplemented by ASCE/SEI 41
	Seismic	–	ASCE/SEI 41
Deterioration, faulty construction, or damage less than substantial	Section A.5.1	$U_o/\phi_o R_{cn} > 1.0$	Original building code, new members use current building code
Alternate assessment criteria for Deterioration, faulty construction, or damage less than substantial	Section A.5.2C(a)	$U_c > 1.05U_o^*$ and $U_c/\phi R_{cn} > 1.1$	Current building code
		$U_c > 1.05U_o^*$ and $U_c/\phi R_{cn} < 1.1$	Strengthening not required
	Section A.5.2C(b)	$U_c < 1.05U_o^*$ and $U_o^*/\phi R_{cn} > 1.05$	Original building code
		$U_c < 1.05U_o^*$ and $U_o^*/\phi R_{cn} < 1.05$	Strengthening not required
Original building code only used allowable stress design and design service loads	Section A.5.3	$U_s/R_a > 1.0$	Original building code
		$U_s/R_a < 1.0$	Strengthening not required

Adding new members

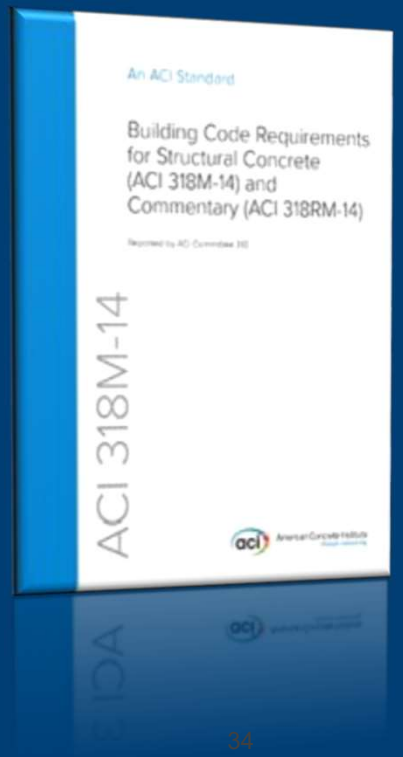
What is the design-basis code between new members or connections and existing construction?

ACI 318-19

Chapter A—Criteria when using this code as a Stand-alone Code

Current building code can be used for:

- All damage states in a structure
- Deterioration
- Faulty design, or
- Faulty construction



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Ch. 5—Loads, factored load combinations, and ϕ

Structural Assessment – loading considerations
ACI 562 is the existing building code

Gravity:

- Building occupied; loads per ASCE/SEI 7
- Building unoccupied; loads per ASCE/SEI 37

Seismic loads per **ASCE/SEI 41**

Chapter 5—Loads, Factored Load Combinations, and ϕ

Load Factors

Do **not** use load factors and load combinations from the original building code **with** strength reduction factors from ACI 562

$$\alpha D + \beta L + \gamma S \rightleftharpoons \phi R_n$$

$$\alpha D + \beta L + \gamma S \rightleftharpoons \phi R_n$$

Chapter 5—Loads, Factored Load Combinations, and ϕ

External non-mechanical strengthening systems

- Fiber reinforced polymer (FRP)
- ~~External post-tensioning (PT)~~

Source: Freyssinet

Source: Contech Services, Inc.

Chapter 5—Loads, Factored Load Combinations, and ϕ

Minimum existing strength limit

For non-mechanically bonded external reinforcement and all FRP systems, the required strength of the structure without external reinforcement shall satisfy:

$$\phi R_n \geq 1.1D + 0.5L + 0.2S \qquad (5.5.2a)$$

$$\phi R_n \geq 1.1D + 0.75L \qquad (5.5.2b)$$

Loads, factored load combinations, and ϕ

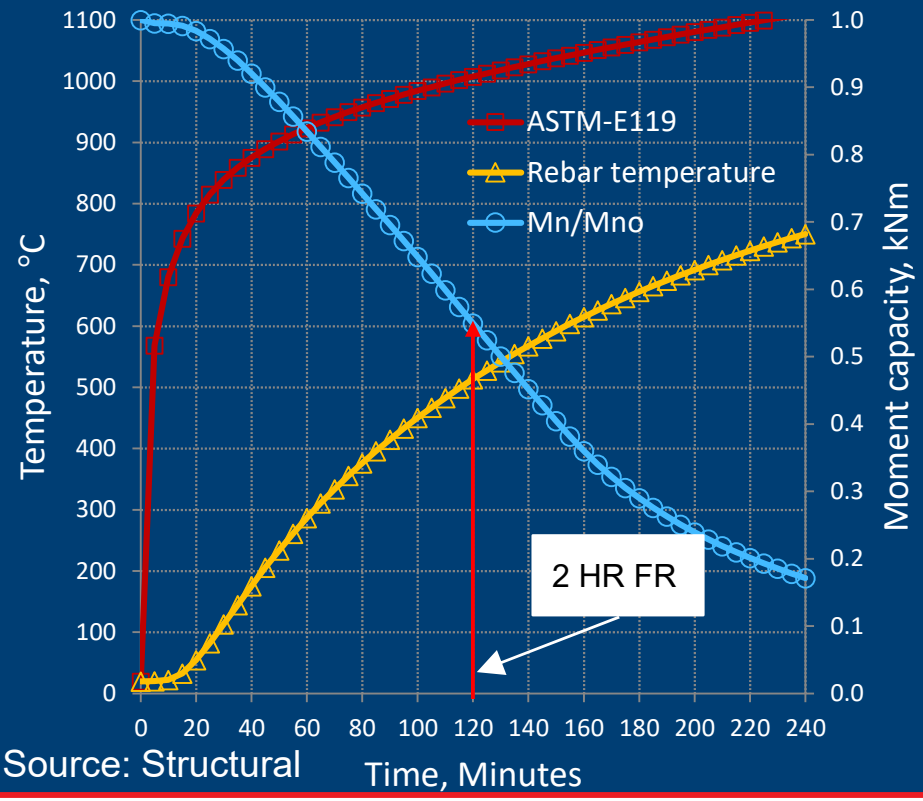
Section 5.3—Strength reduction factors for rehabilitation design

Section 5.4—Strength reduction factors for assessment

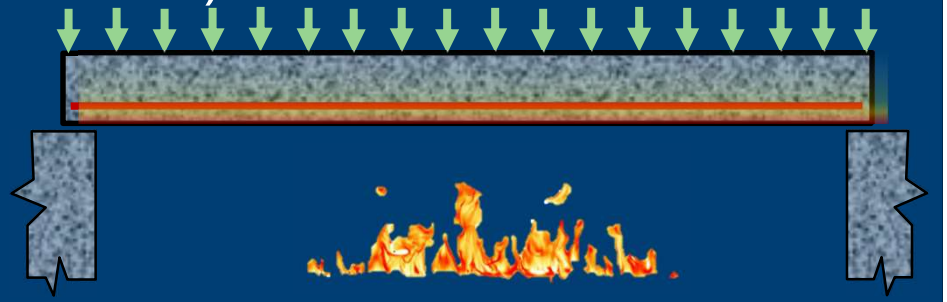
- Material properties done by site & lab tests (cores, NDT)

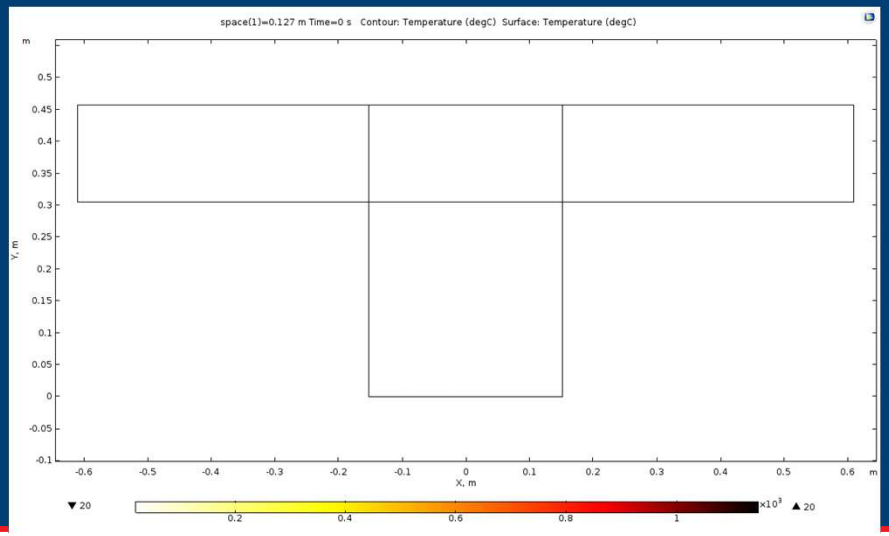
Chapter 5—Loads, Factored Load Combinations, and ϕ

Fire Resistance is the time in to fire exposure during which the member can support “fire” load without exceeding a predefined failure criteria (typically strength related)



Source: Structural





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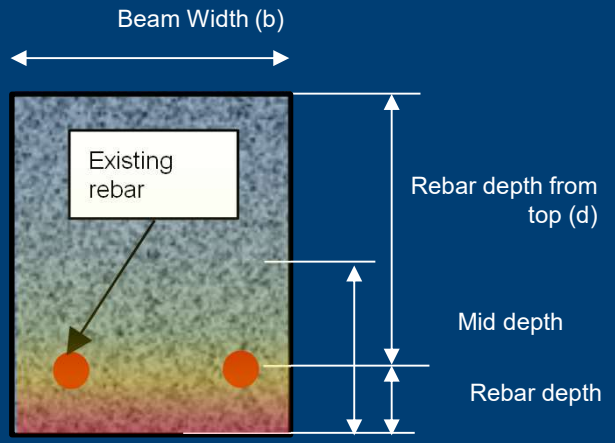
Chapter 5—Loads, Factored Load Combinations, and ϕ

Minimum strength during a fire event

without external reinforcement:

$$\phi_{ex} R \geq (0.9 \text{ or } 1.2)D + 0.5L + 0.2S \qquad (5.5.3)$$

$$\phi_{ex} = 1.0$$



R strength of affected portion of structure during a fire event based on **reduced** steel and concrete strengths

Chapter 6—Assessment, evaluation, and analysis

Structural assessment consists of:

- Structural analysis – if necessary
  - Section dimensions and properties
  - Modifications to load paths
  - Previous repairs and structural modifications
  - Location and size of cracks and spalls
  - In-place compressive strength of concrete
- Report

Obtaining Material Properties

Material properties are obtained from:

- Available contract documents
- Historical data Tables
- Physical testing of in-place or sampled materials

Test Methods to Determine Material Properties

Concrete compressive strength:

- f'_c by NDT only not acceptable
- Minimum two cores (ASTM C42 and ASTM C823)

Test Methods to Determine Material Properties

Concrete compressive strength:

- f'_c by NDT only not acceptable
- Minimum two cores (ASTM C42 and ASTM C823)
  - Locate bars by NDT before locating cores to be extracted

Test Methods to Determine Material Properties

Concrete compressive strength:

- f'_c by NDT only not acceptable
- Minimum two cores (ASTM C42 and ASTM C823)
  - Locate bars by NDT before locating cores to be extracted
- Historical data Table 6.3.1a

Time frame	Footings	Beams	Slabs	Columns	Walls
1900-1919	1000	2000	1500	1500	1000
1920-1949	1500	2000	2000	2000	2000
1950-1969	2500	3000	3000	3000	2500
1970-present	3000	3000	3000	3000	3000

Test Methods to Determine Material Properties

Steel reinforcement properties (d_b, n, and location):

- Construction documents: **not available**
- bar properties: **unknown**

⇒ Use historical values provided in Tables 6.3.1b & c

- Bar grade: **unknown**

⇒ Use lowest grade in Table 6.3.1b

- Minimum **three** samples

	Structural†	Intermediate†	Hard†				
Grade	33	40	50	60	65	70	75
Minimum yield, psi	33,000	40,000	50,000	60,000	65,000	70,000	75,000
Minimum tensile, psi	55,000	70,000	80,000	90,000	75,000	80,000	100,000
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	—

Serviceability, Analysis, and Testing

LDP must also consider actual performance and behavior of repaired structure:

- Structural analysis for repair design
- Structural serviceability
- Strength evaluation by load testing ACI 437.2-13

Chapter 7—Design of structural repairs

The basic requirement for strength design or evaluation is expressed as:

required strength (U) ≤ design strength (ϕR_n)

Demand/Capacity ≤ 1.0

Structural Analysis of Existing Structures

Design of repair:

- Existing loads on the structure
- Effects of load removal
- Sequencing of load application, construction and shoring loads

Structural Strengthening of Structures

What are the acceptable methods to strengthen existing concrete structures?

1. Conventional

Structural Strengthening of Structures

Several methods to strengthen a structure:

1. Conventional
2. Post-Tensioning

Structural Strengthening of Structures

Several methods to strengthen a structure:

1. Conventional
2. Post-Tensioning
3. FRP

Reinforcement

- Damaged or corroded bars can remain
- Effective bar cross-sectional area
- Effect of corrosion damage on bar development
- Deformations are no longer present

Chapter 8—Durability

Establish design service life of repairs and repaired structure to achieve economical repair satisfying:

- Strength
- Safety
- Serviceability
- Service life ACI 365.1R

Durability

Selected repair materials and methods are intended to be:

- Compatible with the structure
- Durable within the service environment
- Consider anticipated maintenance

Durability

Factors affecting durability are:

(a) Cover: ACI 362.1R, ACI 216.1

(b) Corrosion: ACI 201.2R, 222R, 222.2R, 423.4R, 423.8R, ICRI 310.1R, ICRI 510.1, TR 50

(c) Cracks: ACI 224.1R and ACI 503.7

(d) Surface treatments and coatings: ACI 515

Chapter 9—Construction

Contractor is responsible for all methods and means of construction and for job site safety

(a) Temporary shoring and bracing by Contractor's LDP

(b) Temporary conditions

(c) Environmental issues

Chapter 10—Quality Assurance

LDP must ensure that:

- Work is inspected as required by IEBC by LDP or qualified person
- Testing and inspection requirements are in the contract documents

Set up Quality Assurance Program

- Existing conditions and reinforcement are not concealed prior to inspection

Set up Quality Assurance Program

- Existing conditions and reinforcement are not concealed prior to inspection
- Material tests and test frequencies are specified

Set up Quality Assurance Program

- Existing conditions and reinforcement are not concealed prior to inspection
- Material tests and test frequencies are specified
- Test records

FIRST TIME QUALITY

INSPECTION TEST PLAN AND LOG

CONTRACT NUMBER	PROJECT NAME	CONTRACTOR
EXAMPLE	EXAMPLE	EXAMPLE

Item	Spec #	Specifications Section	Subsection	Test Required	Frequency	Test By (All tests verified by Superintendent and/or QC Manager)	Date Completed	Date Forwarded To Contr. Off.	Remarks
1.	033000	Cast-in-Place Concrete	2.12	Mixing and Delivery	Each Truck	Concrete Redimix Supplier			
2.	033000	Cast-in-Place Concrete	3.12	Concrete – three cylinders, slump, air, temperature	1 composite per truck load delivered	Third party inspector			
3.	074113		1.4A	Installer	Prior to				

http://www.firsttimequality.com/inspection-test-plan-form-completed-example

Example

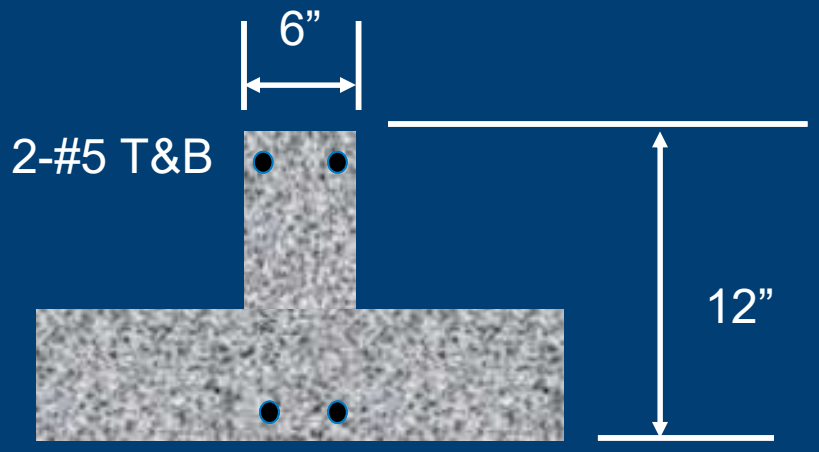
Example—Determining Material Properties

Historical Building: 1930s

Addition: Mechanical unit within the attic

Structural system: Concrete framing, concrete slab with inverted T-beams

Material properties unknown



Evaluation (Guide 562)

- ACI 562 is applicable

LDP has to:

- Evaluate beams capacity w/new mechanical unit
- Obtain as-built dimensions
- Determine cover depth to bars (cover meter).

Evaluation

Existing documents do not provide sufficient information to characterize f'_c and f_y.

Table 1: Default compressive strength of structural concrete, psi* (ACI 562, Table 6.3.1a)

Time frame	Footings	Beams	Slabs	Columns	Walls
1900-1919	1000	2000	1500	1500	1000
1920-1949	1500	2000	2000	2000	2000
1950-1969	2500	3000	3000	3000	2500
1970-present	3000	3000	3000	3000	3000

*adopted from ASCE/SEI 41-06

Evaluation

Table 6.3.1b—Default tensile and yield strength properties for steel reinforcing bars for various periods* (ACI 562, Table 6.3.1b)

		Structural†	Intermediate†	Hard†				
	Grade	33	40	50	60	65	70	75
	Minimum yield, psi	33,000	40,000	50,000	60,000	65,000	70,000	75,000
Year	Minimum tensile, psi	55,000	70,000	80,000	90,000	75,000	80,000	100,000
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	—

*An entry of "X" indicates the grade was available in those years.
†The terms "structural," "intermediate," and "hard" became obsolete in 1968.

Evaluation

- Obtain reduction factors from ACI 562, Section 5.3.2 (**ϕ = 0.9 and 0.75 for flexure and shear**)
- Calculated demand capacity ratio **(D/C) of 0.90** for existing condition Eq. 5.5.2
- **Calculated D/C of 1.27** with new mechanical unit Eq. 5.5.2
- Therefore, beams require strengthening (**D/C > 1.0**).

Material Testing

LDP recommends a material sampling program

- Samples were obtained, tested, and results evaluated
- The equivalent concrete strength (f_{ceq}) (Eq. 6.4.3.1)
- The equivalent yield strength (f_{yeq}) (Eq. 6.4.6)

Material testing

Table 6.3: Concrete core results based on ACI 562

Eq. 6.4.3.1

$$f_{ceq} = 0.9\overline{f_c}\left[1 - 1.28\sqrt{\frac{(k_c V)^2}{n}} + 0.0015\right] \qquad (6.4.3.1)$$

Variable	Results
n	8
$\overline{f_c}$	6218 psi
V	0.15
k_c	1.10
f_{ceq}	5095 psi

→ no. of core samples tested

→ $f_{ceq.actual} > 2 f'_{c\ historical}$

Results from the use of Equation 6.4.6

Table 6.4: Steel reinforcement results ACI 562 Eq. 6.4.6

$$f_{yeq} = (\overline{f_y} - 3500)e^{(-1.3k_s V)} \qquad (6.4.6)$$

Variable	Results
n	4
$\overline{f_y}$	42,225 psi
V	0.05
k_s	2.34
f_{yeq}	33,261 psi

→ no. of coupons tested

~ 33,000 psi historical

Evaluation

Material properties determined in accordance with ACI 562, Section 6.3.5

- increase ϕ (1.0 flexure and 0.8 shear—section 5.4)
- revised D/C = 1.06 for beams with mechanical unit

Evaluation

Two options:

1. Strengthen beams
2. Collect additional samples for yield strength testing (2 additional tests)

Variable	Results
n	6
$\overline{f_y}$	42,860 psi
V	0.04
k_s	1.69
f_{yeq}	36,049 psi

→ no. of coupons tested

$$f_{yeq} = (\overline{f_y} - 3500)e^{(-1.3k_sV)}$$

D/C = 0.99 < 1.0 satisfies strength requirements

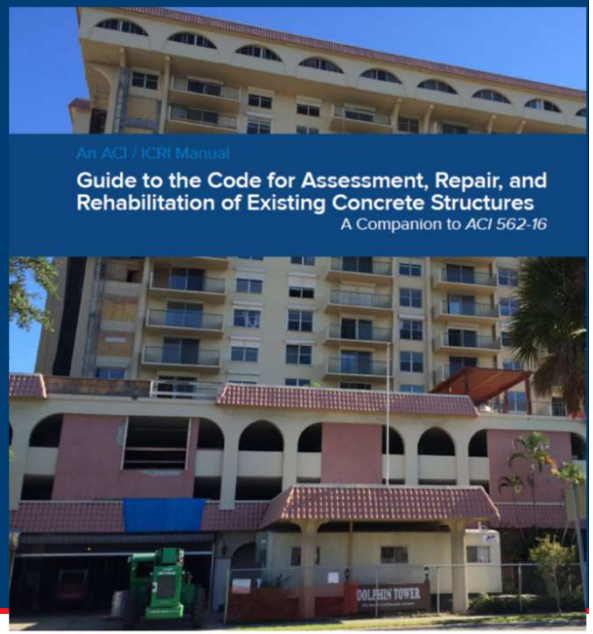
Summary Steps of ACI 562

- Determining design basis code
- Assessing of structure (report)
- Designing, detailing, and specifying material requirements
- Establishing criteria for executing the work
- Preparing construction documents
- Specifying a quality assurance program
- Submitting a final report to owner

New Guide to ACI 562

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

- Expands knowledge base and provides options
- Chapters summary
- Real-world project examples



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MNL-3(16)

Specifications for Repair of Concrete Bldgs.

http://www.firsttimequality.com/inspection-test-plan-form-completed-example

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 364.1-17T 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

ACI 506.2__Specification for Shotcrete

ACI 564R—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

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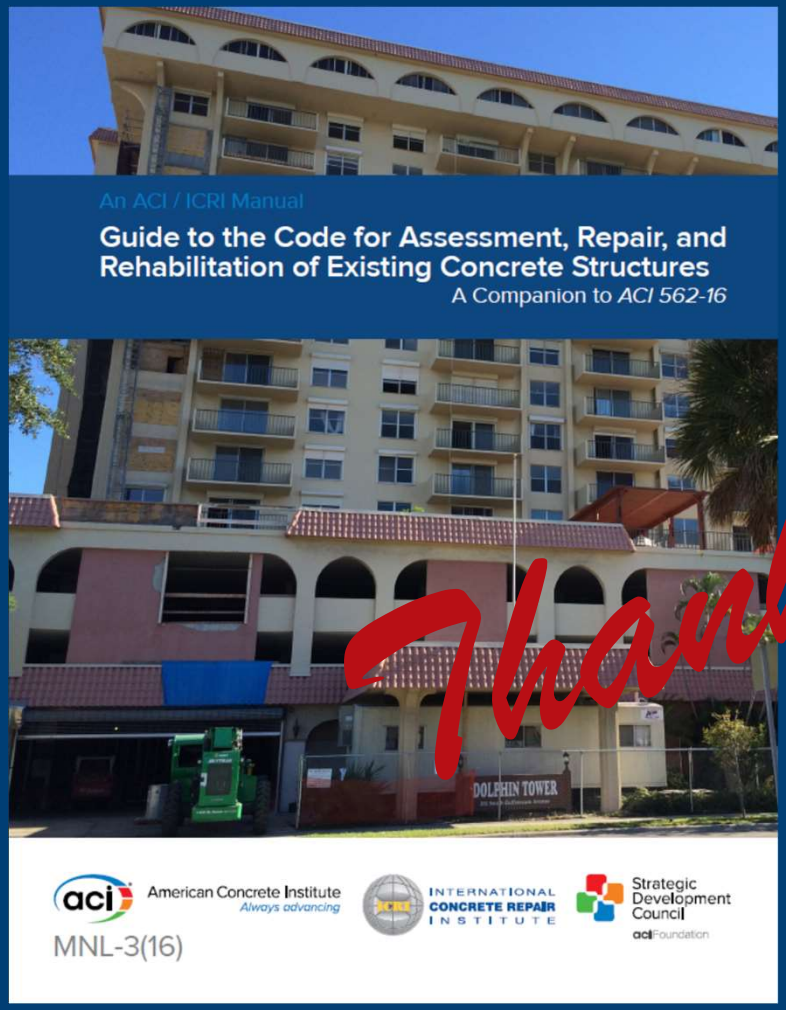
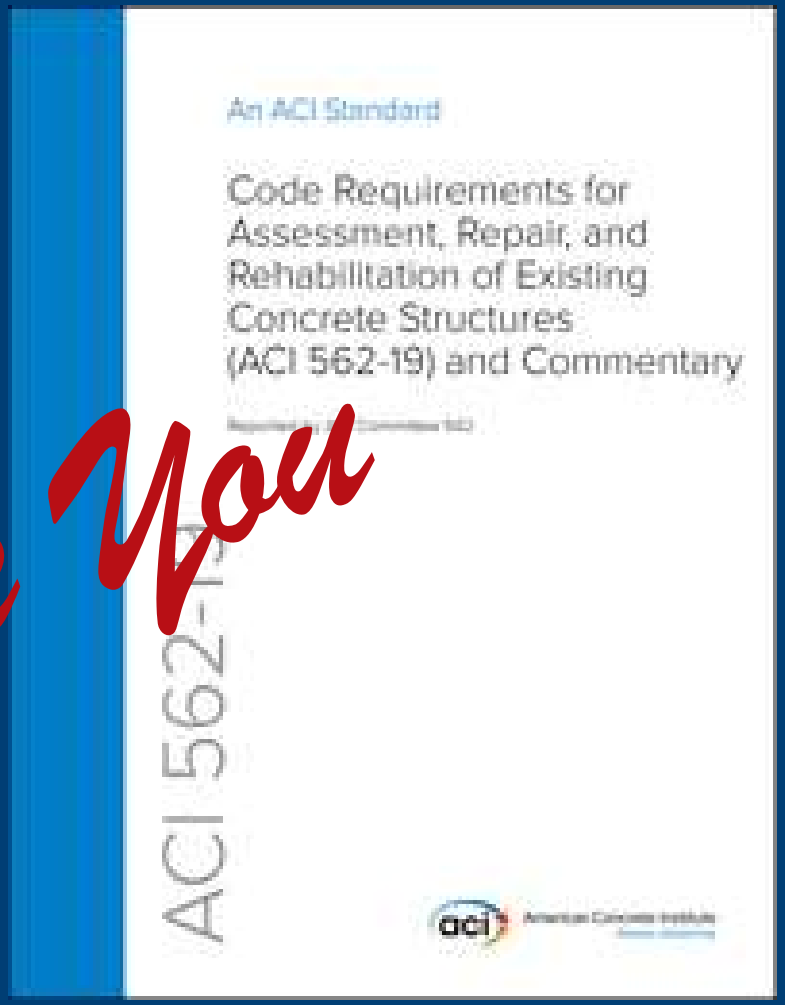
What is repair?





Thank You

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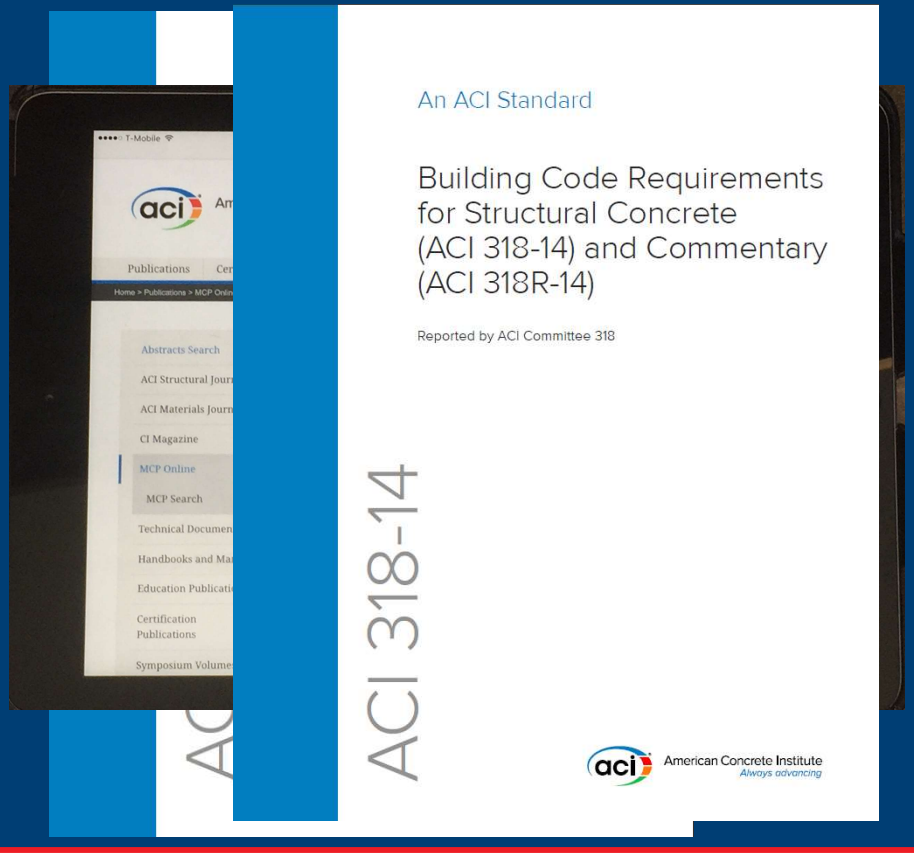

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And the winner is…

WINNER !!