ACI / ICRI Guide to the Concrete Repair Code (ACI 562)
Chapter 12 Project Example – Parking Garage

Patrick Martin
Sr. VP Restoration – Carl Walker, Inc.
September 27, 2016

INTERNATIONAL CONCRETE REPAIR INSTITUTE 2016 Fall Convention | November 9-11 | Cleveland, Ohio

Presented by:
Patrick D. Martin, P.E.

Pat Martin, P.E., Senior Vice President, leads the Restoration Engineering Group for Carl Walker, Inc. out of their Chicago Office. He has over 15 years of experience in the Restoration field with a specialization in the evaluation and repair of parking structures, plazas, building facades, and other concrete structures. Mr. Martin holds a bachelor's degree in Architectural Engineering from Illinois Tech and is a registered professional engineer in 10 states. He is a subcommittee member of ACI 562 and past President of the Chicago Chapter of ICRI.

INTERNATIONAL CONCRETE REPAIR INSTITUTE 2016 Fall Convention | November 9-11 | Cleveland, Ohio

Learning Objectives

- Explain how the requirements of ACI 562 are used in a parking garage repair example to satisfy the code provisions.
- Compare and contrast two repair options for the parking garage.
- Summarize the role of the Licensed Design Professional (LDP) in the construction phase of the repair.
- Discuss the quality assurance and quality control measures in place for material approvals and field verification of quality.

INTERNATIONAL CONCRETE REPAIR INSTITUTE 2016 Fall Convention | November 9-11 | Cleveland, Ohio

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

INTERNATIONAL CONCRETE REPAIR INSTITUTE 2016 Fall Convention | November 9-11 | Cleveland, Ohio

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

INTERNATIONAL CONCRETE REPAIR INSTITUTE 2016 Fall Convention | November 9-11 | Cleveland, Ohio

Chapter 12: Project Example #1-Typical Parking Garage Repair

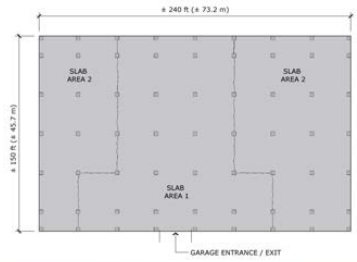
2 story enclosed garage.

Northern US

1960's construction

Conventionally reinforced flat plate with drop panels.

No design information available.



Chapter 12: Project Example #1-Typical Parking Garage Repair

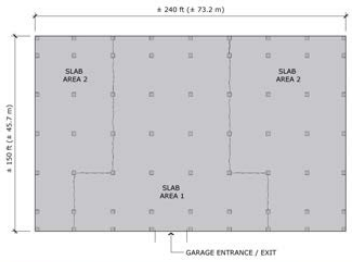
Middle level deck w/

9" slabs

10'x10'x2¼" drop panels

30" Square columns

1" asphalt topping



Project Initiation and Objectives

At the middle-level deck, the Owner noted potholes and unevenness in the asphalt topping and water leakage through cracks. A few small pieces of concrete had fallen from the underside of the slab. The project was initiated to determine the current condition of the parking structure and develop a plan for repair.

ACI 562 - Process

Evaluation

Repair design

Durability considerations

Construction and Quality Assurance

Maintenance Recommendations

Preliminary Evaluation Goal

- Examine available information for a structure and make an initial determination of its adequacy to withstand in-place environmental conditions and design loads.

Preliminary Evaluation Scope

- Determination of design basis code
- Review of available documentation
- Review of the structure (Visual or otherwise)

1.7—Preliminary evaluation

1.7.1 Preliminary evaluation of an existing structure shall include investigation and review of the structure, plans, construction data, reports, local jurisdictional codes, and other available documents of the existing structure. Existing in-place conditions shall be visually or otherwise investigated to verify existing geometry and structural conditions.

Preliminary Evaluation – Design Basis Code

Jurisdiction - Northern U. S. city.

Original building code - 1961 Uniform Building Code (1961 UBC). 1.2.3

Current building code - 2006 International Building Code (2006 IBC). 1.2.2

1.2.2 The "current building code" refers to the general building code adopted by a jurisdiction that presently regulates new building design and construction.

1.2.3 The "original building code" refers to the general building code applied by the jurisdictional authority to the structure in question at the time the existing structure was permitted for construction.

Preliminary Evaluation – Design Basis Code

Jurisdiction - Northern U. S. city.

Original building code - 1961 Uniform Building Code (1961 UBC). 1.2.3

Current building code - 2006 International Building Code (2006 IBC). 1.2.2

Existing building code – Not adopted. 1.2.1

ACI 562 supplements the *existing building code*, which is normally the *international existing building code* (*IEBC*) and the 2006 IBC, Chapter 34 and governs in all matters pertaining to concrete members in existing buildings, except wherever ACI 562 is in conflict with requirements in the 2006 IEBC, in which cases the 2006 governs. 1.1.2

1.2.1 The "existing-building code" refers to the code adopted by a jurisdiction that regulates existing buildings or structures.

Design Basis Code Criteria

Chapter 4 - Where local jurisdiction has adopted IEBC.

Appendix A – Where ACI 562 is used without IEBC.

1.2.4.2 Assessment and design-basis criteria and the requirements for applying these criteria are provided in Chapter 4 and Appendix A. Chapter 4 applies if a jurisdiction has adopted the International Existing Building Code (IEBC) as the existing building code. Appendix A applies if a jurisdiction has not adopted the IEBC or if a jurisdiction has adopted this code.

Preliminary Evaluation – Field Observations

Underside of roof in generally good condition.

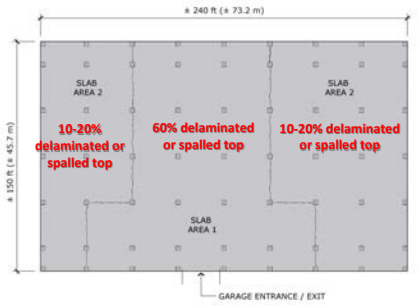
Middle level slab area 1 – 60% delaminated

Middle level slab area 2 – 10-20% delaminated

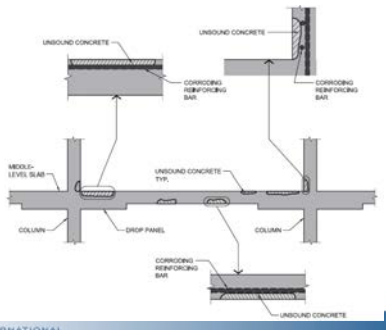
Underside of middle level slab – 10-20% delam

Middle level slabs heavily contaminated with chlorides.

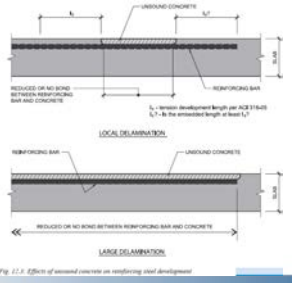
Preliminary Evaluation – Field Observations



Preliminary Evaluation – Field Observations



Preliminary Evaluation – Field Observations



Preliminary Evaluation – Additional Findings

Slab reinforcing determined using exploratory openings, magnetic survey, and exposed bars.

- Column strips: #7 at 7 ½" top, and #7 at 15" bottom
- Middle strips: #7 at 18" top and bottom
- ¾" concrete cover.
- Some surface corrosion and section loss documented.

Preliminary Capacity and Demand Check

Material properties assumed per Tables 6.3.1a and 6.3.1b of ACI 562

6.3.3 Nominal material properties shall be determined by (a), (b) or (c):

a) Historical material properties in accordance with Tables 6.3.1a through 6.3.1c.

b) Available drawings, specifications, and previous testing documentation.

c) Physical testing in accordance with 6.4.

Preliminary Capacity and Demand Check

Table 6.3.1a—Default compressive strength of structural concrete, psi

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

Note: Adopted from ASCE/SEI 41.

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

		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	—

Note: Adopted from ASCE/SEI 41.
*An entry of "X" indicates the grade was available in those years.
†The terms "structural," "intermediate," and "hard" became obsolete in 1968.

Preliminary Capacity and Demand Check

A comparison of the nominal loads in the 1961 UBC and the 2006 IBC shows no changes in these nominal loads for the parking structure. | A.5.2C

$$U_c = U_o^*$$

Where U_c is defined as demand using nominal loads of the current building code and factored load combinations of ASCE/SEI 7 for strength design provisions (LRFD) and U_o^* is the demand using nominal loads of the original building code and factored load combinations of ASCE/SEI 7 for strength design provisions (LRFD).

Preliminary Capacity and Demand Check

- Area 1
  - Approximately 60% of the top slab reinf conservatively judged to be debonded due to delaminations.
  - Potential for "Unsafe Structural Condition"

A.3.2 For gravity and wind loads, unsafe structural conditions include: instability, potential collapse of overhead components or pieces (falling hazards), or structures where the demand-capacity ratio is more than 1.5, as shown in Eq. (A.3.2).

$$U_o/\phi R_{cn} > 1.5 \qquad (A.3.2)$$

Slab Check – Area 1

- Column strip negative moment (top)
  - ϕR_n = 344 ft-kip (no delaminations)
  - ϕR_{cn} = (344 ft-kip * .4) = 137 ft-kip (delaminated)
  - $M_{u,cs}^-$ = 285 ft-kip
  - $Uc/\phi R_{cn}$ = 285 ft-kip/137 ft-kip = 2.1>1.5

A.3.2 For gravity and wind loads, unsafe structural conditions include: instability, potential collapse of overhead components or pieces (falling hazards), or structures where the demand-capacity ratio is more than 1.5, as shown in Eq. (A.3.2).

$$U_c/\phi R_{cn} > 1.5 \qquad \text{(A.3.2)}$$

Slab Check – Area 1

- Column strip positive moment (bottom)
  - ϕR_n = 133 ft-kip (no delaminations)
  - ϕR_{cn} = (133 ft-kip * .8) = 106 ft-kip (delaminated)
  - $M_{u,cs}^+$ = 123 ft-kip
  - $Uc/\phi R_{cn}$ = 123 ft-kip/106 ft-kip = 1.2<1.5

A.3.2 For gravity and wind loads, unsafe structural conditions include: instability, potential collapse of overhead components or pieces (falling hazards), or structures where the demand-capacity ratio is more than 1.5, as shown in Eq. (A.3.2).

$$U_c/\phi R_{cn} > 1.5 \qquad \text{(A.3.2)}$$

Slab Check – Area 1

Column strip moment redistribution check

- $1.5*\phi R_{cn}^-$ = 1.5*137 ft-kip = 205 ft-kip
- $M_{u,cs}^+$ = 123 ft-kip + (285 ft-kip – 205 ft-kip) = 203 ft-kip (redistributed)
- $Uc/\phi R_{cn}^+$ = 203 ft-kip/106 ft-kip = 1.9>1.5

If the demand-capacity ratio exceeds 1.5 for structures, the design-basis criteria shall be the current building code. Unsafe structural conditions shall be reported as described in 1.5.2.

If the demand-capacity ratio does not exceed 1.5 for structures, A.4 through A.9 shall be used to determine the design-basis criteria.

Slab Check – Area 1

Shear capacity

- Regions around columns completely delaminated.
- Reinforcement debonded, no contribution to shear capacity.
- Shear based on plain concrete per ACI 318-14, Chapter 14
  - h = Bottom of slab to bottom of delamination.
  - Strength reduction factor of .6 for plain concrete.
- Slab shear capacity can be considered as having dropped significantly.

Slab Check – Area 2

- Column strip negative moment (top)
  - ϕR_n = 344 ft-kip (no delaminations)
  - ϕR_{cn} = (344 ft-kip * .8) = 275 ft-kip (delaminated)
  - $M_{u,cs}^-$ = 285 ft-kip
  - $Uc/\phi R_{cn}$ = 285 ft-kip/275 ft-kip = 1.04<1.5

If the demand-capacity ratio exceeds 1.5 for structures, the design-basis criteria shall be the current building code. Unsafe structural conditions shall be reported as described in 1.5.2.

If the demand-capacity ratio does not exceed 1.5 for structures, A.4 through A.9 shall be used to determine the design-basis criteria.

Slab Check – Area 2

- Column strip positive moment (bottom)
  - ϕR_n = 133 ft-kip (no delaminations)
  - ϕR_{cn} = (133 ft-kip * .85) = 113 ft-kip (delaminated)
  - $M_{u,cs}^+$ = 123 ft-kip
  - $Uc/\phi R_{cn}$ = 133 ft-kip/123 ft-kip = 1.08<1.5

If the demand-capacity ratio exceeds 1.5 for structures, the design-basis criteria shall be the current building code. Unsafe structural conditions shall be reported as described in 1.5.2.

If the demand-capacity ratio does not exceed 1.5 for structures, A.4 through A.9 shall be used to determine the design-basis criteria.

Slab Check – Area 2

- Slabs not considered "unsafe" per eqn. A.3.2
- Check A.5.2 or A.5.3 to determine if strengthening is required.

Strengthening Determination – Area 2

Location	Reinforcement	Demand, U_s $A_{s,req'd}$ in.^{2} (mm^2)	Capacity, R_a $A_{s,prov.}$ in.^{2} (mm^2)	U_s / R_a
Column strip	A_s^-	12.5 (8065)	13.5 (8710)	0.93 < 1
	A_s^+	6.8 (4387)	7.2 (4645)	0.94 < 1
Middle strip	A_s^-	5 (3226)	6 (3871)	0.83 < 1
	A_s^+	5 (3226)	6 (3871)	0.83 < 1

A.5.3 If the concrete design regulations of the original building code used only allowable stress design and design service loads, the demand capacity ratio shall be based on service load demand (U_s) and resistance calculated using allowable stresses (R_a) as shown in Eq. (A.5.3)

$$U_s/R_a > 1.0 \qquad \text{(A.5.3)}$$

Strengthening Determination – Area 2

- 2-way shear capacity = 89psi
- Allowable required = .03f'c = 90psi (Ok)

A.5.3 If the concrete design regulations of the original building code used only allowable stress design and design service loads, the demand capacity ratio shall be based on service load demand (U_s) and resistance calculated using allowable stresses (R_a) as shown in Eq. (A.5.3)

$$U_s/R_a > 1.0 \qquad \text{(A.5.3)}$$

Strengthening Determination – Area 1

- Slabs determined to be unsafe per A.3.2
- Repair required consistent with the Current Building Code. (2006 IBC)

Strengthening Determination – Area 2

- Per A.5.3C

Using allowable stress design is inconsistent with the reliability principles of strength design. To adequately address safety, consideration should be given to verification using A.5.2 and a check of seismic resistance using ASCE/SEI 41.

- Seismic resistance not a factor in the region and is excluded from the analysis.

Report to Owner

Notify of safety concerns

- Install shoring at Slab Area 1
- Remove loose/hanging concrete.
- With safety concerns promptly addressed, notification of authorities having jurisdiction

Repair Design - Considerations

- Preliminary "unsafe" determination based assumption of full debonding of rebar at all delaminations.
- No excessive cracking or deflections noted.
- Structural elements outside Area 1 found to be in satisfactory condition.
- Repair to full compliance with current codes impractical.
  - Changes in detailing requirements
  - Structure demonstrated 50 years of service.
  - Region on minimal seismic
- Design basis code will be 1961 UBC except Area 1 to be brought into conformance with 2006 IBC where practical.

Structural Evaluation – Existing Conditions

- Verified through
  - Field measurements
  - Concrete coring and compressive strength testing
  - Rebar yield strength testing.
  - Excavations
  - GPR/rebar scanning

Existing conditions and material properties were found to be consistent with assumptions made during the preliminary analysis.

Check of Preliminary Findings

Revise calculations to include data obtained.

For this example:

- Preliminary evaluation based on direct design method
- Final assessment based on finite element analysis.
- Actual depths of delaminations utilized in modeling.
- Load factors per ASCE/SEI 7-05
- Reassessment of provisions A.3.2 and A.5.1 confirmed preliminary findings.

$$U_c/\phi R_{cn} > 1.5 \quad \text{(A.3.2)}$$

$$U_c/\phi_s R_{cn} > 1.0 \quad \text{(A.5.1)}$$

Structural Analysis for Repair Design

Based on final loads and configuration.

Account for repair approach.

For this example:

- Assume composite action between new and existing concrete.
- Loads removed from existing structure via shoring during repair.
- Existing reinforcement layout, supplemented for section loss.
- No change in dimensional properties of structure.

Demand-capacity ratio of repaired Areas 1 and 2 were below 1.0, the repair design is acceptable for bending.

Interface Bond

- Repair design assumes composite action.
- Interface bond must be checked per 7.4.1
- ACI 318-14, Chapter 16
- ANSI/AISC 360-10, Chapter I

7.4—Interface bond

7.4.1 Repair design shall include an analysis to determine the interface shear and tension stresses across bonded interfaces between repair materials and the existing substrate. The interface analysis shall use factored loads in addition to internal forces resulting from restrained volume change to calculate the resultant interface stress demand (v_{ni}) from the transfer of tension and shear.

Interface Bond

- At face of column: 22psi
- At face of drop panels: 28psi
- Review per table 7.4.1.2

7.4.1.1 Interface shear stress shall be designed based on:

$$v_{ni} \le \phi v_{ni} \quad (7.4.1.1)$$

where v_{ni} is nominal interface shear stress and ϕ is in accordance with 5.3.2.

7.4.1.2 Testing requirements shall be in accordance with Table 7.4.1.2.

Table 7.4.1.2—Testing requirements where v_{ni} is partially or totally resisted by the concrete

v_{ni}	Reference	Testing requirements
Less than 30 psi	7.4.2	Bond-integrity testing
Between 30 and 60 psi	7.4.3	Quantitative bond strength testing
Greater than 60 psi	7.4.4	Quantitative bond strength testing

Structural Analysis for Repair Design

Area 1 assumptions:

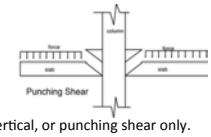
- 60% negative moment capacity lost.
- Loads removed from existing structure via shoring during repair.
- Composite action of the repaired section.

Area 2 assumptions:

- 20% negative moment capacity lost.
- Composite action of the repaired section.

Shoring not required in Area 2, structure found to be adequate with redistribution of moments.

Structural Analysis for Repair Design



Punching Shear

- 1961 UBC considers vertical, or punching shear only.
- ACI 318-05 also considers eccentricity of shears due to moment distribution.
- Result: Inadequate punching shear indicated at some columns.

Visual review of areas revealed no cracking or distress related to punching shear.

To provide additional shear capacity would require considerable additional efforts. Not considered practical.

Basis of Design Report – 1.5.3

- Provides a summary of the assessment of the existing structure, and a summary of, or reference to, the construction documents used for rehabilitation.
- Provided to Owner
- Included two repair design options for Area 1 and Area 2

The basis of design report shall include:
a) a description of the building, including age of construction, structural systems, identified original building code, and past and current uses
b) documentation of unsafe structural conditions in the work area of the structure determined in the assessment
c) documentation of substantial structural damage in the work area
d) members and systems of the work area requiring increase in capacity beyond the demand of the original building code
e) modifications such as additions, alterations, or changes in occupancy
f) conditions and details of the proposed rehabilitation work
g) past history of concrete repairs and rehabilitations
h) assessment criteria and findings
i) design-basis code criteria and basis of rehabilitation design
j) material selection parameters
k) shoring needs
l) quality assurance and quality control (QA/QC) requirements
m) types and frequency of future inspection
n) types and frequency of future maintenance

Area 1 – Repair Options

- Option 1: Removal and replacement of deteriorated concrete only.
- Option 2: Removal and replacement of top 3-4" of concrete in entire

Area 1 – Repair Option 2 Advantages

- Removal of chloride-contaminated concrete and reduction of corrosion-cell locations.
- Enhanced concrete properties eliminate need for initial deck coating application.
- New epoxy-coated bars to replace existing.
- Consistent concrete cover over rebar.
- Lower maintenance costs.
- Less future disruption of service.

Area 1 – Repair Option 2 Disadvantages

- Additional perimeter detailing to account for shear and moment transfer and reinforcing steel development.
- Increased shoring.
- Potential for cracking in overlay.
- Higher initial cost.

Area 2 – Repair Options

- Localized repair only consistent with Option 1.
- Option 2, as described for Area 1 would not be cost-effective.
- Additional design considerations
  - Patch preparation and installation.
  - Galvanic anodes at patches.
  - Traffic-bearing membrane installation.

Repair Implementation

- Construction documents to
  - Satisfy governing regulatory requirements.
  - Convey necessary information to perform the work.
    - Repair design
    - Phasing limitations
- Periodic review during construction.
  - ACI 562-16, Chapter 9

Quality Assurance – Chapter 10

- Material submittal review
- Periodic visual review of work performed.
- Hammer sounding of prepared, and final surfaces.
- Testing of concrete repair materials.
- Bond strength testing of in-place concrete for provisions of Table 7.4.1.2.

Table 7.4.1.2—Testing requirements where v_a is partially or totally resisted by the concrete

v_a	Reference	Testing requirement
Less than 30 psi	7.4.2	Bond-integrity testing
Between 30 and 60 psi	7.4.3	Quantitative bond strength testing
Greater than 60 psi	7.4.4	Quantitative bond strength testing

Project Close-out

- Review ongoing maintenance recommendations with Owner
  - Periodic inspection every 3-5 years.
  - Limited concrete repairs every 5.
  - Limited deck coating repairs every 3-5 years.
  - Recoat traffic coating every 15-20 years.
- Record documents
  - Construction documents and as-builts
  - Warranties
  - Recommended monitoring and
  - maintenance plan.

1.6.3 The licensed design professional shall provide the owner with copies of basis of design report, assessment reports, project documents, field reports, and other project documents produced by the licensed design professional in addition to documenting the location of the completed repairs to the extent of the licensed design professional's contractual obligations. The licensed design professional shall notify the owner if this information is filed with the jurisdictional authority.

Thank you