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

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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.

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

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
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.

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.

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.

ACI 562 - Process

Evaluation
Repair design
Durability considerations
Construction and Quality Assurance
Maintenance Recommendations

Preliminary Evaluation Scope

- Determination of design basis code
- Review of available documentation
- Review of the structure (Visual or otherwise)
**Preliminary Evaluation – Design Basis Code**

Jurisdiction: Northern U.S. city.

1.2.2 The “current building code” refers to the general building code adopted by a jurisdiction that primarily 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.

**Design Basis Code Criteria**

Chapter 4 - Where local jurisdiction has adopted IEBC.
Appendix A – Where ACI 562 is used without IEBC.

1.2.1.4.2 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) to the existing building code. Appendix A applies if a jurisdiction has not adopted the IEBC or if the 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% delaminated or spalled
- Middle level slabs heavily contaminated with chlorides.
Preliminary Evaluation – Field Observations

Slab reinforcing determined using exploratory openings, magnetic survey, and exposed bars.
- Column strips: #7 at 7 3/4’ 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 Evaluation – Additional Findings

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

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Preliminary Capacity and Demand Check

Table 6.3.1b - Default tensile and yield strength properties for steel reinforcing bars for various periods, MPa

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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”
Slab Check – Area 1

- Column strip negative moment (top)
  - $\phi R_n = 344$ ft-kip (no delaminations)
  - $\phi R_{cn} = (344 \text{ ft-kip} \times 0.8) = 275$ ft-kip (delaminated)
  - $M_{u,c} = 285$ ft-kip
  - $U_{c}/\phi R_{cn} = 285$ ft-kip/275 ft-kip = 1.04<1.5

- Column strip positive moment (bottom)
  - $\phi R_n = 133$ ft-kip (no delaminations)
  - $\phi R_{cn} = (133 \text{ ft-kip} \times 0.85) = 113$ ft-kip (delaminated)
  - $M_{u,c} = 123$ ft-kip
  - $U_{c}/\phi R_{cn} = 133$ ft-kip/123 ft-kip = 1.08<1.5

Slab Check – Area 2

- Column strip negative moment (top)
  - $\phi R_n = 344$ ft-kip (no delaminations)
  - $\phi R_{cn} = (344 \text{ ft-kip} \times 0.8) = 275$ ft-kip (delaminated)
  - $M_{u,c} = 285$ ft-kip
  - $U_{c}/\phi R_{cn} = 285$ ft-kip/275 ft-kip = 1.04<1.5

- Column strip positive moment (bottom)
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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 $0.4$ for plain concrete.
- Slab shear capacity can be considered as having dropped significantly.
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

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

For 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 (Ud) and resistance calculated using allowable stresses (Rd) as shown in Eq. (A.5.3)

\[
\frac{U_d}{R_d} > 1.0 \quad (A.5.3)
\]

Strengthening Determination – Area 2

- Per A.5.3C
  - Using allowable stress design is consistent 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.

Strengthening Determination – Area 1

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

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.

\[
\frac{f_{c}}{f_{y}} > 1.5 \quad (A.3.2)
\]
\[
\frac{f_{c}}{\phi_{y} f_{y}} > 1.0 \quad (A.5.1)
\]

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
- AGI 318-14, Chapter 16
- ANSI/AISC 360-10, Chapter I

Interface Bond

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

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

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.
- Bond strength testing of in-place concrete for provisions of Table 7.4.1.2.

Project Close-out

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

Thank you