Evaluation of Existing Structures Using ACI 562

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Historic Structure

Air Force Base – Academic Center
Academic Building

- Built in the 1930s
- New HVAC system
- October 2011
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, ……”
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.
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
Chapter 6 – Default Strength

- Material properties

Concrete (Table 6.3.1a)

<table>
<thead>
<tr>
<th>Time frame</th>
<th>Footings</th>
<th>Beams</th>
<th>Slabs</th>
<th>Columns</th>
<th>Walls</th>
</tr>
</thead>
<tbody>
<tr>
<td>1900-1919</td>
<td>1000 psi</td>
<td>2000 psi</td>
<td>1500 psi</td>
<td>1500 psi</td>
<td>1000 psi</td>
</tr>
<tr>
<td>1950-1969</td>
<td>2500 psi</td>
<td>3000 psi</td>
<td>3000 psi</td>
<td>3000 psi</td>
<td>2500 psi</td>
</tr>
<tr>
<td>1970-present</td>
<td>3000 psi</td>
<td>3000 psi</td>
<td>3000 psi</td>
<td>3000 psi</td>
<td>3000 psi</td>
</tr>
</tbody>
</table>
Chapter 6 – Default Strength

- **Material properties**

Steel (Table 6.3.1b)

<table>
<thead>
<tr>
<th>Time frame</th>
<th>Grade</th>
<th>33</th>
<th>40</th>
<th>50</th>
<th>60</th>
<th>65</th>
<th>70</th>
<th>75</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$F_{y,\text{min}}$ (ksi)</td>
<td>33</td>
<td>40</td>
<td>50</td>
<td>60</td>
<td>65</td>
<td>70</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>$F_{t,\text{min}}$ (ksi)</td>
<td>55</td>
<td>70</td>
<td>80</td>
<td>90</td>
<td>75</td>
<td>80</td>
<td>100</td>
</tr>
<tr>
<td>1911-1959</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>—</td>
<td>X</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>1959-1966</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>1966-1972</td>
<td>—</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>—</td>
</tr>
<tr>
<td>1972-1974</td>
<td>—</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>—</td>
</tr>
<tr>
<td>1974-1987</td>
<td>—</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>—</td>
</tr>
<tr>
<td>1987-present</td>
<td>—</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>—</td>
</tr>
</tbody>
</table>
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)

1 2 3 4 5 6 7 8
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
  
  \[ n = 8 \]
  
  \[ \bar{f}_c = 6,200 \text{ psi}, V = 0.15 \]

- § 6.4.3-equivalent specified concrete strength

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

\[ f_{ceq} = 5,100 \text{ psi} \]

- 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.)
  
  \[ f_{yeq} = (f_y - 3500)e^{-1.3k_sV} \]
  
  \[ f_{yeq} = 33,217 \text{ psi} \]

- 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
Repair

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

Diagram:
- (2) layers of FRP
- 6"
- 9½"
- 2½"
Repair

- Flexural strength
  Φ: 0.9 (design)
  Demand: -19.8 kip-ft
  Capacity: -37 kip-ft
  D/C: 0.54

(2) layers of FRP

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Always advancing
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).

$$U_{ex} \geq 1.2D + 0.5L + A_k + 0.2S \quad (5.5.1)$$
Key Concepts

• Evaluation based on historic values
  Quick check (ballpark)
  Evaluate element with standard $\phi$-factors

• Evaluation based on material testing
  More refined analysis
  Evaluate element with modified $\phi$-factors (lower variability because material properties are known)
Key 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)
New Structure

Turner-Roberts Recreation Center
Project Background

- Construction in 2008
- 7,700 sf joint-use facility
- Reinforced-concrete beams, drilled piers, and steel joist roof
- Indoor gymnasium, multi-purpose rooms, weight room, and other rooms
Zoning of Structure

- Indoor gymnasium
- Multi-purpose rooms, weight rooms, arts & craft rooms, etc.
Problems at Turner-Roberts

• Problems identified in 2009
• Issues
  Hairline cracks in structure
  Carton void form filled
  Expansion clays
  Construction errors
• Center closed July 2011

Evaluate structure
Evaluation Approaches for Existing Structures

• Analytical (sectional analysis based on construction drawings)
• Experimental (load test)

ACI 437
Demolition of Structure

Load test this area

Owner directed demolition of this area
562 Load Test Procedures – Two Types

• Monotonic
  Apply load in four equal increments and measure response
  Hold load for 24 hours
  Measure response and unload load
  Measure final response

• Acceptance criteria
  Evidence of failure
  Maximum and residual deflections
Load Test Procedures

• Cyclic

• Acceptance criteria

  Evidence of failure
  Deviation from linearity and permanency ratio
Monotonic Load Test

- Performed phased approach
- Test Load Magnitude (TLM)
  \[ TLM = 1.0 \times D_W + 1.1 \times D_S + 1.6 \times L \]
- Superimposed load (ATL)
  166 psf (32 inches of water)
Monotonic Load Test

- Performed phased approach
- Test Load Magnitude (TLM)
  \[ TLM = 1.0 \times D_W + 1.1 \times D_S + 1.6 \times L \]
- Superimposed load (ATL)
  166 psf (32 inches of water)
Load Test

Loading increments
Behavior During Loading - Linear

- Maximum is less than ACI criteria & no cracks were identified.
Behavior After 24 Hour – Increase in Deflection

- Slab
- Pier
- Grade beam
Behavior During Unloading

The graph illustrates the behavior of different structural elements (Slab, Pier, Grade beam) under varying applied loads. The x-axis represents the measured deflection (in.), while the y-axis shows the applied load (psf).

Key observations:
- The Grade beam did not satisfy the residual criterion.
- The Slab shows a significant deflection at lower applied loads compared to the other elements.

The graph highlights the comparative performance of these structures under load, indicating differences in their load-bearing capacities and deflection characteristics.
Key Concepts

• Monotonic testing is essentially a proof test
  Slower to perform (24-hr hold)
  Generally easy to perform (water, sand, etc.)
  Criteria is based on deflections

• Cyclic testing is more of a performance standard
  Faster to perform with hydraulics (no 24-hr hold)
  Can be difficult to perform (hydraulics need to react against something)
  Criteria is based on stiffness
Thank you

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