Means and Methods of Evaluating Reinforced Concrete Structures

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BACKGROUND INFORMATION

Task:
• Comprehensive condition assessment

Goals:
• 30 years of additional service life
• Develop scope for repair documents

Structure:
• In service since 1986
• 128 ft [39 m] diameter
• 5,000 psi [34.4 MPa]
• 10 years of noted distress
• Moderate amount of chlorides in H₂O

OUTLINE OF PRESENTATION

• Background
• Assessment Strategies
• Results
• Service Life Modeling
• Repair Approach
• Conclusions
• Questions

CONDITION ASSESSMENT AND CONCRETE REPAIR STRATEGIES AT WATER TREATMENT STRUCTURES

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**TYPICAL BEAMS**

- 220 beams
- 1 ft x 8 in (305 mm x 203 mm)
- “Ears” support filter media

**TYPICAL GIRDER**

- 106 girders
- 18 in square (457 mm)
- 16 ft long (4.9 m)

**TYPICAL PIER**

- 208 piers
- 14 in diameter (356 mm)
- 3 to 3 1/2 ft tall (0.9 to 1.1 m)

**PREVIOUS REPAIRS ON TF2**

- Cracked beam “ears”
- Cracking of slab
- Missing hairpin reinforcement at beams
- Beam end spalls
- Sealant joint at wall

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**Previous Repairs on TF2**
- Cracked beam "ears"
- Cracking of slab
- Missing hairpin reinforcement at beams
- Beam end spalls
- Sealant joint at wall

**Goals of Assessment**
- Develop wholesale understanding of the structure
- Focus maintenance strategies at critical locations
- Precision in repair documents
- Repair now or later?

**Assessment Strategies**
- Tools for concrete assessment
  - Field Investigation
  - Laboratory Evaluation

**Goals of Assessment**
- Repair now or later?

**Assessment Strategies**
- Field Investigation
  - Visual Survey/Acoustic Sounding
  - Cover Survey
  - Half-Cell Potential
  - Corrosion Rate
  - Carbonation Testing
  - GPR
**VISUAL/ACOUSTIC/COVER SURVEY**

- Identify concrete delaminations
- Document cracking patterns
- Non-destructive cover survey — verified by core and half cell locations
- Locate Half-Cell, Corrosion Rate, & Core locations based on visual results

**HALF-CELL POTENTIAL**

- Indication of corrosion risk for reinforcement
- Factors: moisture, continuity, carbonation, delaminations, adjacent soil

**ASTM C876:**

- Corrosion Potentials of Uncoated Reinforcing Steel in Concrete
- >200mV = 90% probability of no corrosion
- <350mV = 90% probability of corrosion

**HALF-CELL POTENTIAL**

- Saturated concrete = more negative potentials (less resistance)
- Look for “hot” spots

**HALF-CELL POTENTIAL**

- General potential gradient = more negative at bottom of Trickling Filter
- Look for “hot” spots

**HALF-CELL POTENTIAL**

- Uniform HCP gradient = corrosion not likely
HALF-CELL POTENTIAL

Interpreting Results:
- "Hot" spot = possible area of corrosion

Interpreting Results - Positive Values:
- Is concrete dry?
- Electrical interference
- Reversed leads
- Poor contact to reinforcement

Interpreting Results - Carbonated concrete (more positive)
- Carbonated Concrete
- $p_{O2}$ is high
- Fe conc. is high
- Micro cells occur
- Mixed potentials

Interpreting Results - Delaminations (more positive)

Interpreting Results - Concrete adjacent to soil (depends)
**CORROSION RATE TESTING**

- Measures instantaneous snapshot of corrosion rate by measuring polarization resistance (Stern-Geary Equation)
- Temperature and moisture will influence readings
- Beams: 0.05 μA/cm²
- Girders = Wall = 0.35 μA/cm²

> Gecor™
> 0.2 μA/cm² = passive
> >0.1 to <0.5 μA/cm² = low
> >0.5 to <1 μA/cm² = moderate
> >1 μA/cm² = very high corrosion

- Feby et al. 1996
- Andrade and Alonso 1996

**CARBONATION TESTING**

- Carbonation progresses ~0.04 in [1 mm]/year in typical concrete
- Moisture + oxygen + low pH = corrosion

**MEASURED CARBONATION DEPTHS, IN. [MM]**

<table>
<thead>
<tr>
<th>Element</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beams</td>
<td>0.25 [6.4]</td>
<td>0.25 [6.4]</td>
<td>0.25 [6.4]</td>
</tr>
<tr>
<td>Girders</td>
<td>0.25 [6.4]</td>
<td>0.75 [19.1]</td>
<td>0.53 [13.6]</td>
</tr>
<tr>
<td>Piers</td>
<td>0.38 [9.5]</td>
<td>1.00 [25.4]</td>
<td>0.57 [14.5]</td>
</tr>
</tbody>
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**GROUND PENETRATING RADAR**

- Non-destructive technique to verify presence of steel hairpins at the ends of beams

**ASSESSMENT STRATEGIES**

- Laboratory Evaluations
  - Petrography
  - Compressive Strength
  - Rapid Chloride Permeability (RCP)
  - Sulfate Content
  - Soil Testing
  - Chloride Content

**PETROGRAPHY & COMPRESSIVE STRENGTH**

- Assess the general composition of concrete and identify any distress mechanism
- 0.4 to 0.5 w/c ratio
- No ASR/DEF
- Avg. strength = 6,740 psi [46.5 MPa]
RAPID CHLORIDE PERMEABILITY

- Measures resistance of concrete to chloride penetration
- Results:
  - 480 to 1015 coulombs
  - Avg = 800 coulombs = very low permeability

ASTM C1202
Standard Test Method for Electrical Indication of Concrete’s Ability to Resist Chloride Ion Penetration

SULFATE CONTENT & SOIL TESTING

- Concrete: 1.4% (by mass) sulfate at depth of 0 to 1 in. [25 mm] = 1.5 x background content
- Soil: 0.1% (by mass) = “moderate sulfate exposure” per ACI 318

ASTM C265
Standard Test Method for Water-Extractable Sulfate in Hydrated Hydraulic Cement Mortar

ASTM C1152
Standard Test Method for Acid-Soluble Chloride in Mortar and Concrete

CHLORIDE CONTENT ANALYSIS

- Chloride content vs. depth – level of reinforcement
- Chloride corrosion threshold:
  - 0.2% by weight of cement
  - 350 ppm by weight of concrete
  - ~1 lb/cu yd of concrete
- Some chlorides bound in concrete (not available to promote corrosion)

ASTM C1352
Standard Test Method for Acid-Soluble Chloride in Mortar and Concrete

RESULTS OF ASSESSMENT

- Beams
- Girders
- Piers
- Perimeter Wall
- Slab
### Beam Results
- Cracking along the beam “ears” that support the filter media
- Transverse cracking on top of beams across girder support
- Cores taken at HCP “hot spots” – no significant corrosion

### Girder Results
- Transverse cracking at ~20% of top portion of girder between beams

### Pier Results
- Cracking and corrosion at transverse reinf. – many repaired with epoxy previously
- Limited oxygen & saturated concrete = “black” rust, less expansive than “red” rust

### Perimeter Wall Results
- Deteriorated sealant joint at slab
- Isolated delaminations at interior
- Distress / delams along top of wall
- Paste erosion / scaling along soil line

### Slab Results
- No systemic visual/acoustic distress
- Isolated discrete surface delaminations (~1-2 sq. ft.)
- Cores taken at delaminations; no corrosion observed
**SERVICE LIFE MODEL**

**Goal:**
30 years of additional service life

Fix it now or later?

How much damage if we wait? And when?

**Estimate rate of deterioration**
Predicts percentage to exhibit damage over time

Calibrate propagation time based on results of assessment = 22 years

**Model based on:**
- Exposure conditions
- Concrete quality
- Cover depth
- Cracking

More data = More reliable model

Beams & Girders: 25 to 30 years until 10% threshold

**Results for Piers**

**REPAIR STRATEGIES**

- **Goal:** 30 years of additional service life
- **Repair all observed damage**
- **Focus long-term maintenance strategies at critical areas**
  - Piers
    - Shortest remaining service life
  - Top of Wall
    - High chlorides
    - 50% delamination

**Repair areas with observed damage:**
- Beam "ears"
- Salt hydration distress
- Low viscosity epoxy at Beam "Ears"
- Partial depth repair at soil line

**Repair top of girders; Coat with membrane**

**Repair beams and girders at standpipe**
REPAIR STRATEGIES

Focus Long-Term Maintenance at critical areas:
- Pier jackets
- Coating system

Alternate:
- Stay-in-place for with sacrificial cathodic protection system

RECOMMENDATIONS FOR WALL

Focus Long-Term Maintenance at critical areas:
- Top of wall

CONCLUSIONS

- Advantages of comprehensive condition assessment
  - Develop wholesale understanding of the structure
  - Focus maintenance strategies at critical locations
  - Creates precision in repair documents
  - Final repair quantities ±10% from Construction Documents

QUESTIONS?