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Means and Methods of Evaluating Reinforced Concrete Structures

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WEB SESSIONS

Condition Assessment and Concrete Repair Strategies at Water Treatment Structures

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Outline of Presentation

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

Background Information

Task:
- Comprehensive condition assessment

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

Background Information

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 H_2O

Typical Beams

Beams:

- 220 beams
- 1ft x 8in [305 mm x 203 mm]
- "Ears" support filter media

Typical Girder

Girders:

- 106 girders
- 18 in square [457 mm]
- 16 ft long [4.9 m]

Typical Pier

Piers:

- 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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Goals of Assessment

Task:
- Comprehensive condition assessment

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

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

Goals of Assessment

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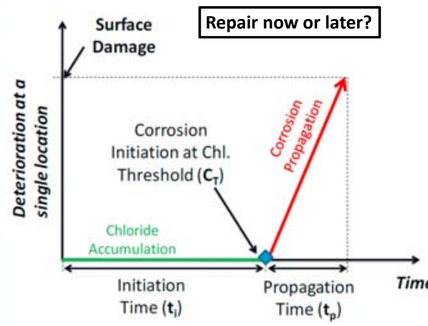


Assessment Strategies

- Tools for concrete assessment
  - Field Investigation
  - Laboratory Evaluation

Assessment Strategies

- Field Investigation
  - Visual Survey/ Acoustic Sounding
  - Cover Survey
  - Half-Cell Potential
  - Corrosion Rate
  - Carbonation Testing
  - GPR

Visual/Acoustic/Cover Survey

100% Visual and Acoustic Survey

Over 575 cover measurements

Avg. Cover: 1.19 in. [30 mm] to 2.06 in. [52 mm]

- 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

Visual/Acoustic/Cover Survey

Likely salt hydration distress (physical sulfate attack)

Test for sulfate in soil and concrete

- Paste erosion along soil line at exterior of perimeter wall

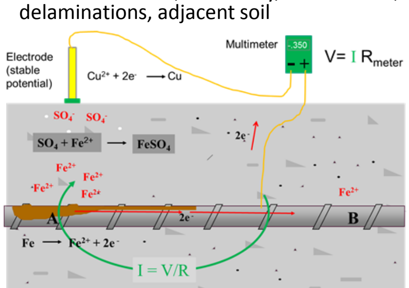
Half-Cell Potential

<u>ASTM C876:</u> *Corrosion Potentials of Uncoated Reinforcing Steel in Concrete*

>-200mV = 90% probability of no corrosion

<-350 mV 90% probability of corrosion

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

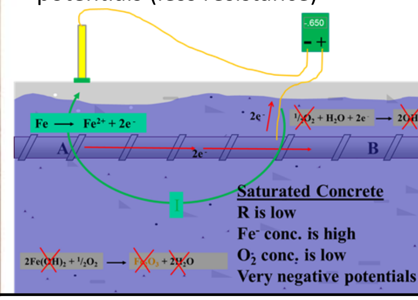


Half-Cell Potential

<u>Interpreting Results:</u>

- Dry in AZ!
- Moisture increases from beams→ girders→ piers→ slab
- Look for "hot" spots

- Saturated concrete= more negative potentials (less resistance)

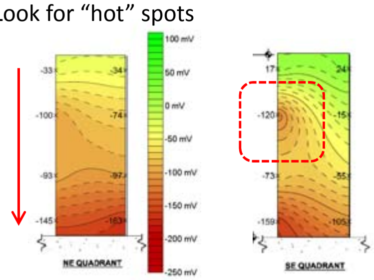


Half-Cell Potential

<u>Interpreting Results:</u>

- Dry in AZ!
- More moisture from beams→ girders→ piers→ slab
- Look for "hot" spots

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

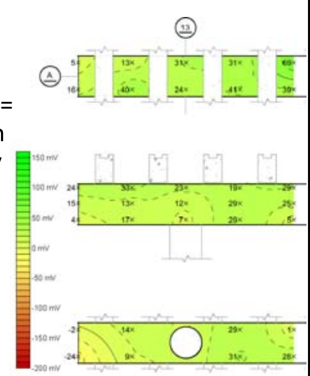


Half-Cell Potential

<u>Interpreting Results:</u>

- Dry in AZ!
- Moisture increases from beams→ girders→ piers→ slab
- Look for "hot" spots

- Uniform HCP gradient = corrosion not likely

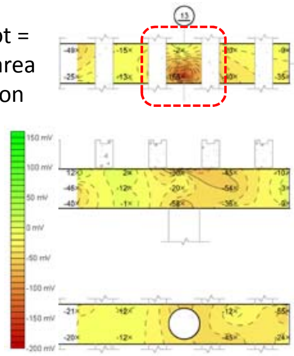


HALF-CELL POTENTIAL

Interpreting Results:

- **Dry in AZ!**
- **Moisture increases from beams→ girders→ piers→ slab**
- **Look for "hot" spots**

- "Hot" spot = possible area of corrosion



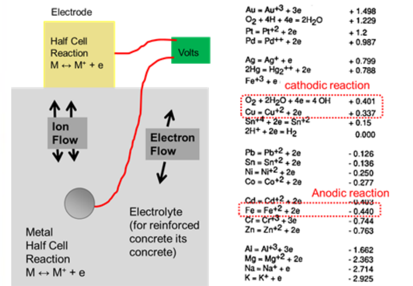
HALF-CELL POTENTIAL

ASTM C876:

>-200mV = 90% probability of no corrosion

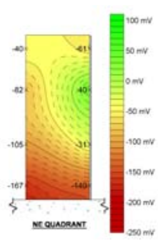
<-350 mV 90% probability of corrosion

- Measures potential difference between reinforcement and copper-copper sulfate electrode



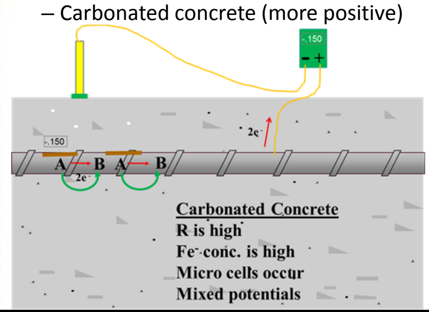
HALF-CELL POTENTIAL

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



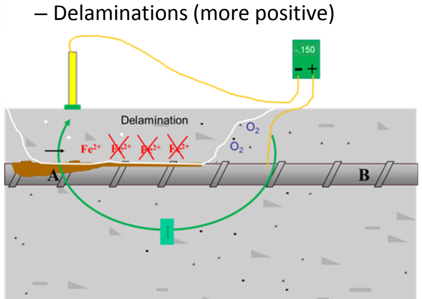
HALF-CELL POTENTIAL

- Interpreting results
  - Carbonated concrete (more positive)



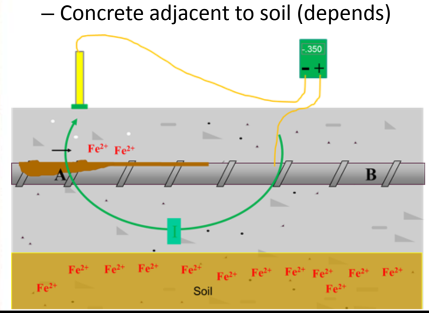
HALF-CELL POTENTIAL

- Interpreting results
  - Delaminations (more positive)



HALF-CELL POTENTIAL

- Interpreting results
  - Concrete adjacent to soil (depends)



Corrosion Rate Testing

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

Feliu et al. 1996; Andrade and Alonso 1996

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

Carbonation Testing

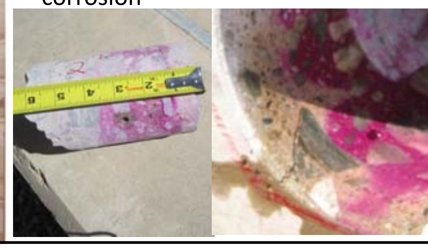
Typical concrete: pH 12-14

Passive layer of steel may deteriorate: pH 9.5-11

Phenolphthalein: pink = pH>9

25 yrs = ~1 in. [25 mm] typical concrete

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



Carbonation Testing

Typical concrete: 25 yrs = ~1 in. [25.4mm] typical concrete

Most rapid at R.H. 50-70%

Carbonation depth typ. less than 1 in. [25 mm] inside of tank

- Influenced by relative humidity
  - CO_2 transport limited when pores are saturated
- Carbonation depth: beams < girders <piers

Measured Carbonation Depths, in. [mm]

Element	Minimum	Maximum	Average
Beams	0.25 [6.4]	0.25 [6.4]	0.25 [6.4]
Girders	0.25[6.4]	0.75 [19.1]	0.53 [13.6]
Piers	0.38 [9.5]	1.00 [25.4]	0.57 [14.5]

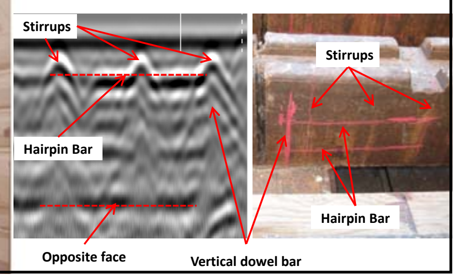
Ground Penetrating Radar

Results:
GPR on 74 of 196 beams with hairpins, randomly selected

Vertical and horizontal scans

All scans showed hairpins in place

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



Assessment Strategies

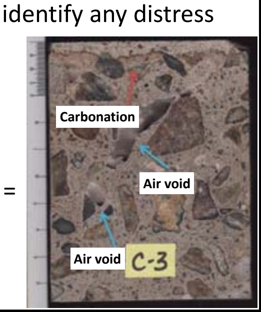
- Laboratory Evaluations
  - Petrography
  - Compressive Strength
  - Rapid Chloride Permeability (RCP)
  - Sulfate Content
  - Soil Testing
  - Chloride Content

Petrography & Compressive Strength

ASTM C856
Standard Practice for Petrographic Examination of Hardened Concrete

ASTM C42
Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete

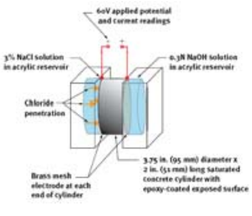
- Assess the general composition of concrete and identify any distress mechanism
- 0.4 to 0.5 w/c ratio
- No ASR/DEF
- Avg. strength = 6,740 psi [46.5 MPa]



Rapid Chloride Permeability

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

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



Charge passed, coulombs	Chloride ion penetrability
>4000	High
2000 to 4000	Moderate
1000 to 2000	Low
100 to 1000	Very low
<100	Negligible

Sulfate Content & Soil Testing

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

ASTM C1580
Test Method for Water-Soluble Sulfate in Soil

- 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

Chloride Content Analysis

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

ASTM C1218
Standard Test Method for Water-Soluble Chloride in Mortar and Concrete

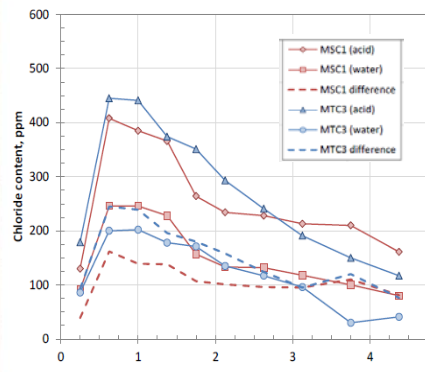
- Chloride content vs. depth – level of reinforcement
- Chloride corrosion threshold:
  - 0.2% by weight of cement
  - 350 ppm by weight of concrete
  - ~1 lb/cu yd of concrete
- Some chlorides bound in concrete (not available to promote corrosion)

Chloride Content Analysis

Background chloride content = 70 ppm

Revised Chloride Threshold → 420ppm

"Hump" due to transport method: Water flow→ Absorption→ Diffusion

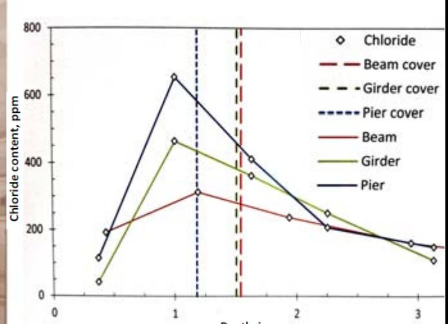


Chloride Content Analysis

Piers:
>500 ppm at reinforcement

Beams/Girders:
<400 ppm at reinforcement

Top of Wall:
500-800 ppm at reinforcement



Results of Assessment

- Beams
- Girders
- Piers
- Perimeter Wall
- Slab

Beam Results

Avg. Cover = 1.54 in. [39 mm]

Carbonation = 0.25 in. [6.4 mm]

HCP = 20% showed potential "hot spots"

Chloride content = <400 ppm at reinforcement

- 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

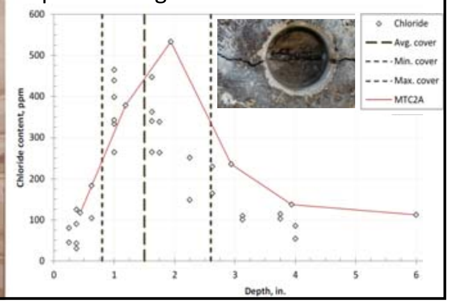
Avg. Cover = 1.5 in. [38 mm]

Carbonation = 0.53 in. [13.6 mm]

HCP = 35% showed potential "hot spots"

No distress on sides or bottom

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



Girder Results

Avg. Cover = 1.5 in. [38 mm]

Carbonation = 0.53 in. [13.6 mm]

HCP = 35% showed potential "hot spots"

No distress on sides or bottom

- Cracking / delaminations at beam bearing at the center standpipe
- Restrained thermal contraction of beams


Pier Results

Avg. Cover = 1.2 in. [30 mm]

Avg. Carbonation = 0.57 in. [14.5 mm]

HCP = 40% of piers showed "hot spots" along transverse reinforcement

Chlorides = 300-500 ppm at reinforcement

- 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

Cover : < 1 in. [25 mm] in some locations on top

High chlorides at top of wall (400 - 800 ppm)

- Deteriorated sealant joint at slab
- Isolated delamaninations at interior
- Distress / delams along top of wall
- Paste erosion / scaling along soil line


Slab Results

Avg. Cover = 2 in. [51 mm]

Avg. Carbonation = 0.5 in. [13 mm]

Chloride content = 100-200 ppm at reinforcement

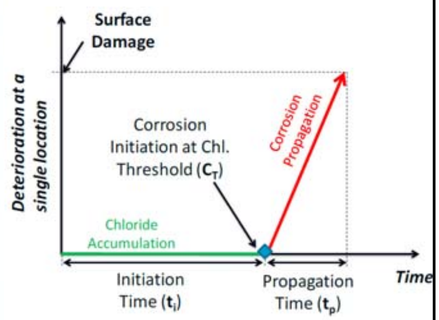
- No systemic visual/acoustic distress
- Isolated discrete surface delaminations (~1-2 sq. ft.)
- Cores taken at delaminations; no corrosion observed

SERVICE LIFE MODEL

Goal:
30 years of additional service life

Fix it now or later?

How much damage if we wait? And when?

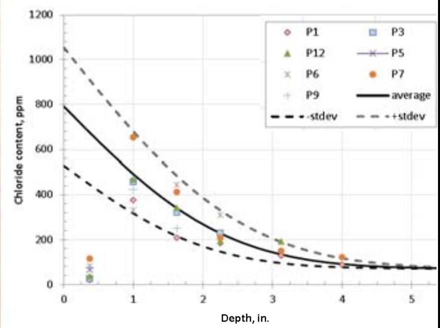


SERVICE LIFE MODEL

Estimate rate of deterioration

Predicts percentage to exhibit damage over time

Calibrate propagation time based on results of assessment = 22 years



Calibration for Piers

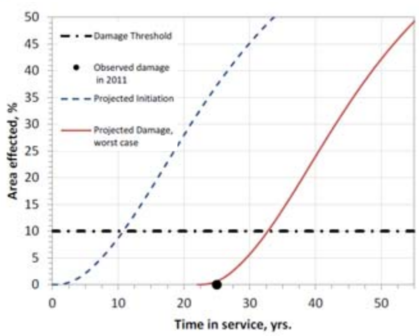
SERVICE LIFE MODEL

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 STRATEGIES

Repair areas with observed damage:

- **Beam "ears"**
- **Salt hydration distress**

Low-viscosity epoxy at Beam "Ears"

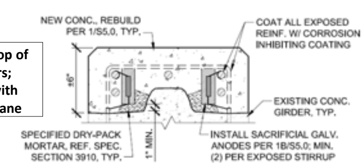
Partial depth repair at soil line

REPAIR STRATEGIES

Repair areas with observed damage:

- **Top of Girder cracking**
- **Girder-Beam connection at Standpipe**

Repair top of girders; Coat with membrane



Repair beams and girders at standpipe

Repair Strategies

Focus Long-Term Maintenance at critical areas:

- Pier jackets

Alternate:

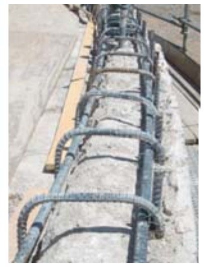
- Coating system

- Stay-in-place for with sacrifical cathodic protection system

Recommendations for Wall

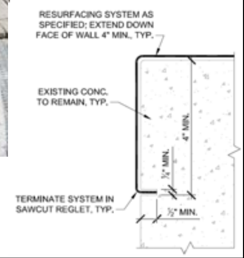
Focus Long-Term Maintenance at critical areas:

- Top of wall



Repair top of wall install galvanic anodes

Coating system to prevent ingress of chlorides



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

Condition Assessment and Concrete Repair Strategies

QUESTIONS?