# Bridge Rehabilitation and Cost Effective Methods for Addressing Bridge Deterioration

**Presented at**

**Ohio County Engineers Conference**

**August 23, 2017**

by

**Siva Venugopalan**
**Principal Engineer**
**Siva Corrosion Services, Inc.**
**Siva@SivaCorrosion.com**

# Durability of Concrete

- Strength
- Chloride Ingress
- Carbonation Attack
- Sulfate Attack
- Alkali Silica Attack
- Abrasion (rapid moving water, floating ice)
- Freezing and Thawing

# Concrete Quality for 100-Year Life

- Concrete should have the following properties:
  - Strength, workability
  - Resistance to freeze thaw
  - Resistance to chloride penetration
  - Resistance to sulfate attack
  - Resistance to Alkali-Silica Reaction
  - Abrasion resistance

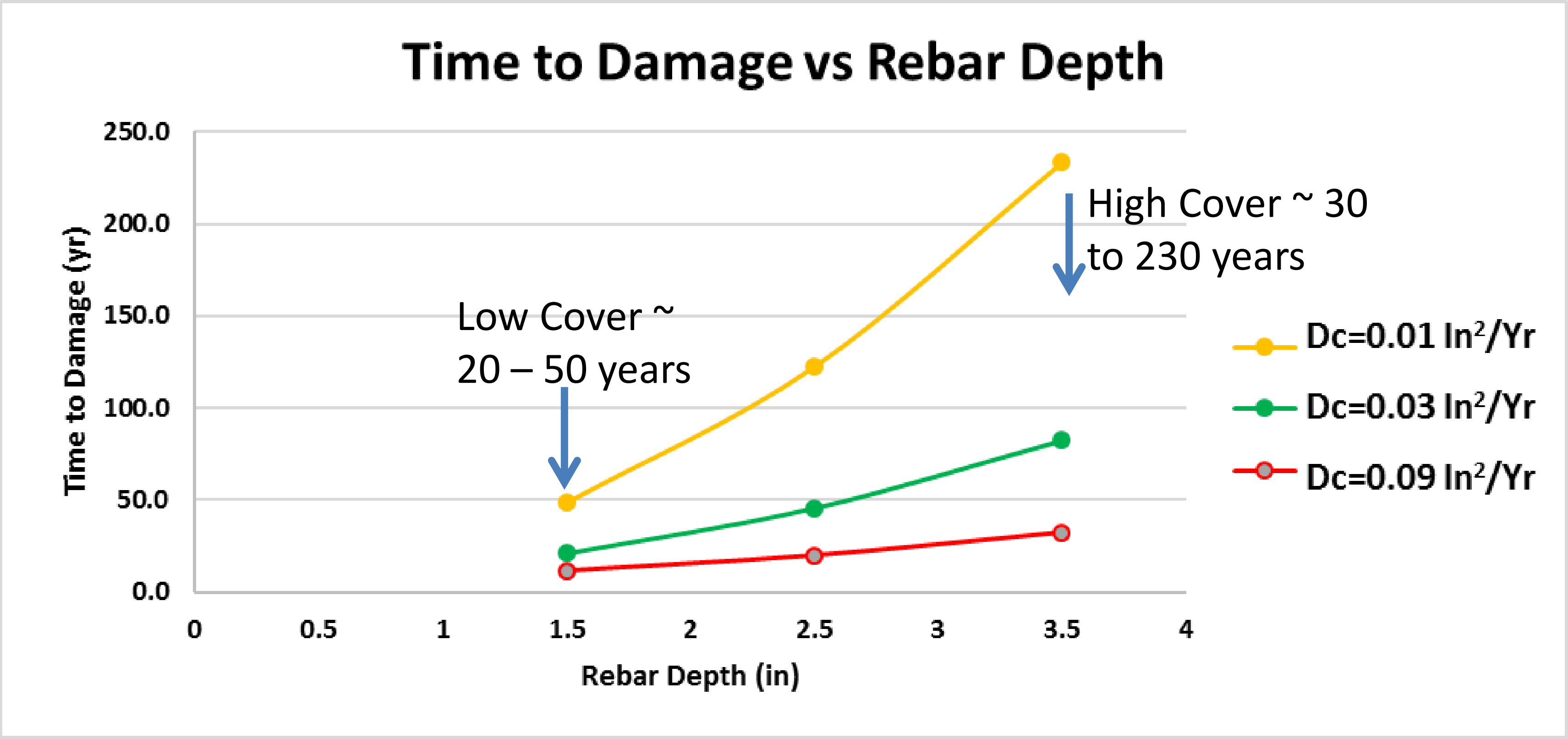
# Effect of Cover and Concrete Quality on Corrosion Initiation

**Use Diffusion Equation:**

$$C_{x,t} = C_o\left[1 - erf\left(\frac{x}{2\sqrt{Dt}}\right)\right]$$

- **Using**
  - Cover of 1.5", 2.5", and 3.5"
  - Average surface chloride for deck, substructure, and piles in marine environments
  - Chloride at the rebar = 400 ppm
  - Diffusion coefficients ($in^2$/yr.) of:
    - ✓ 0.01 $in^2$/yr. – Excellent durability,
    - ✓ 0.03 $in^2$/yr. – Good to fair durability,
    - ✓ 0.09 $in^2$/yr. – Poor Durability

# Time to Concrete Damage for Various Rebar Depth



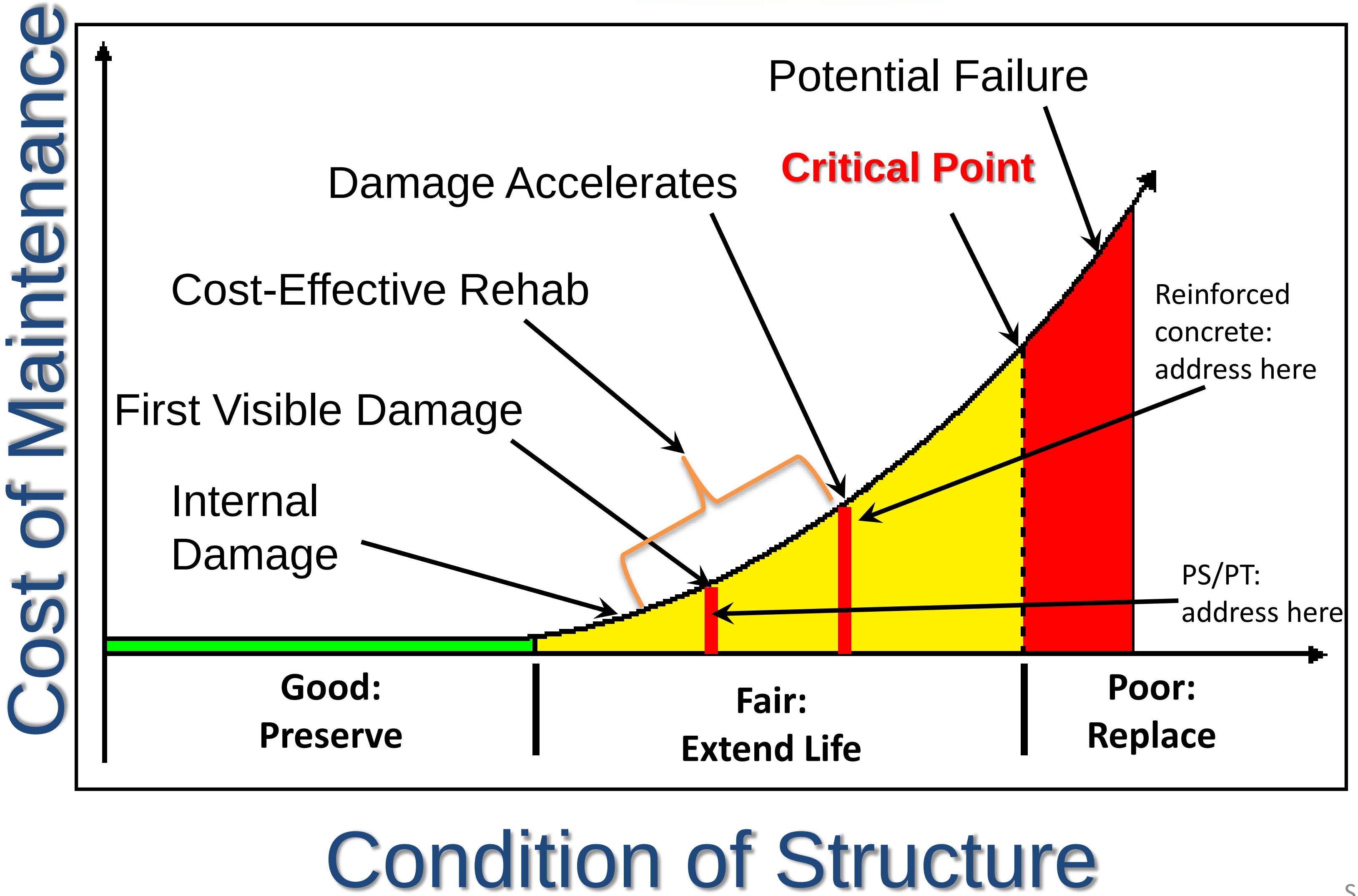
# Chloride-Induced Corrosion

- Chloride from deicing salt application diffuses into concrete
- When chloride at rebar level exceeds 1.2 lb/CY, passive film breaks down and corrosion initiates
- If pH <11, corrosion can initiate at lower chloride levels
- If sulfate is present, chloride may not be required for corrosion to begin

# Bridge Preservation

- When a bridge experiences corrosion, we want to answer the questions:
  - How bad is bad?
  - What is the rate of deterioration?
  - How do we cost effectively extend the life?
- SCS develops a strategic inspection/evaluation plan to quickly indentify/quantify problems.
- Average preservation cost for owners: **20 to 25%** compared to replacement.

# Corrosion-Related Concrete Damage



# Assessment of Concrete Structures

1. Non-Destructive Evaluation (earlier identification)
   - Identify and quantify deterioration of concrete and steel
2. Electrochemical Testing
   - Quantify time-to-failure, corrosion rates, future section losses
3. Laboratory Testing
   - Additional material and corrosion analysis
4. Estimate Service Life
   - Recommend cost effective solution

# Non-Destructive Testing (NDT)

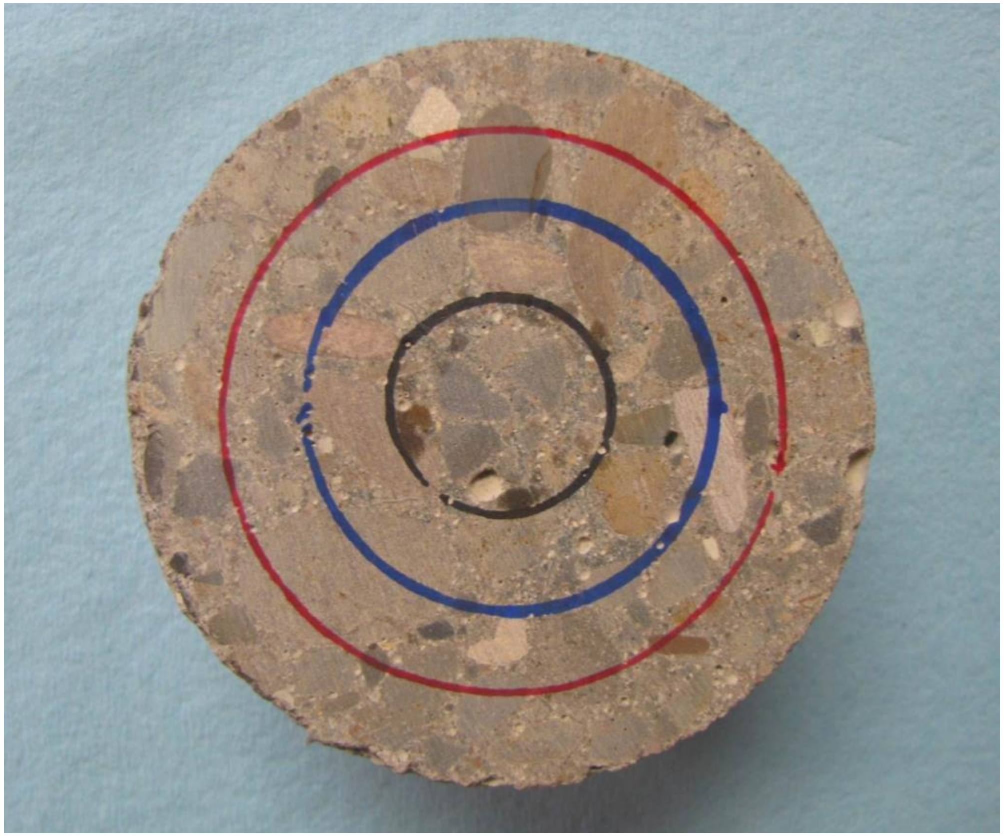
- Use NDT to see hidden problems
- Minimize inspection time and damage to the structure
- Primary NDT tools:
  - Ground Penetrating Radar (GPR)
  - Infrared Thermography
  - Impact-Echo
  - Ultrasonic Tomography

# Laboratory Testing

- Laboratory Testing
  - Chloride Content Profiling (AASHTO T-260, ASTM C1152)
  - pH Indicator (Phenolphthalein)
  - Compressive Strength (ASTM C39)
  - Petrographic Analysis to Examine:
    - General Concrete Properties (density, air-void, w/cm) (ASTM C876)
    - Alkali-Silica Reactivity
    - Freeze-Thaw Damage (ASTM C472)

# Proper Sampling Size and Number

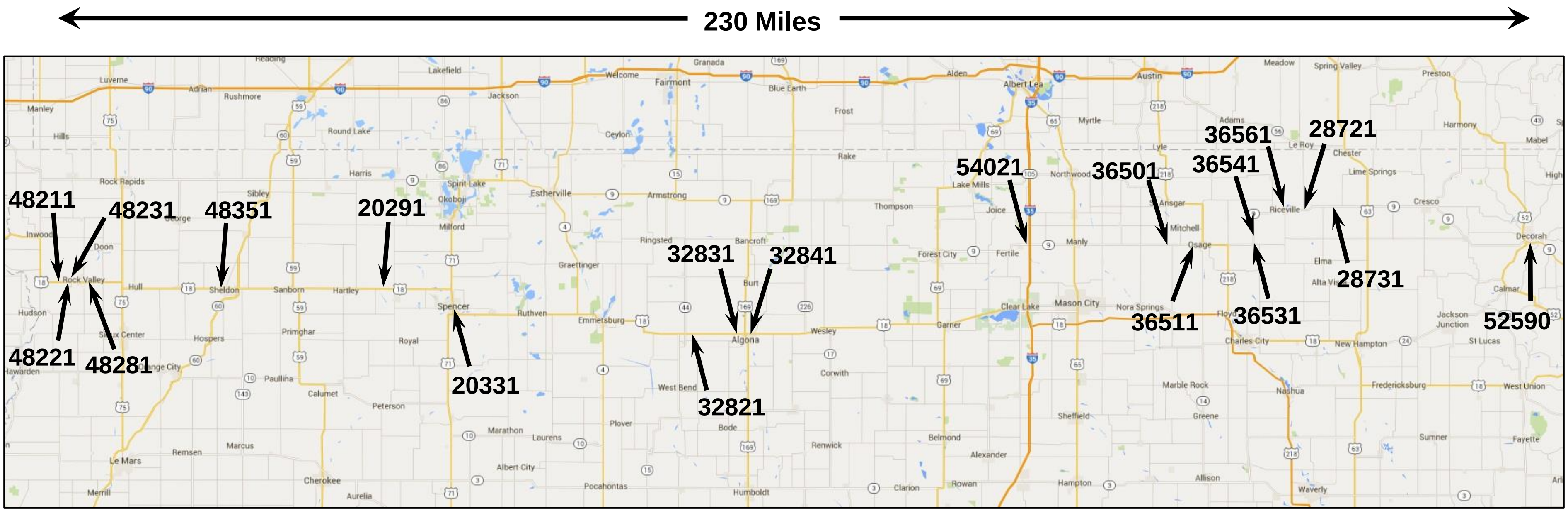
- Chloride cores shall be 4-inch diameter, at least 3-inch diameter.
- A smaller core or powder samples can lead to significant variation in chloride level leading to erroneous decisions.
- Sampling number – sufficient to represent the entire structure.



# Processing Chloride Cores for Service Life Analysis

- Mark 0.5-inch horizons along the depth of the core.
- Dry cut through the core at each horizon into concrete discs (slices).
- Pre-crush each slice into ~0.25-inch maximum size pieces.
- Pulverize each pre-crushed slice and pass through #50 sieve.
- Thoroughly clean after each pre-crush and pulverize session.
- Digest each sample in acid to extract chloride from the concrete powder.
- Titrate each sample to determine the chloride content.
- Process titration data to obtain chloride content.
- Perform chloride test at various depths of the core to obtain chloride profile for each core.
- Tabulate chloride data at various depths for analysis and service life calculations.

# US-18 & IA-9 Bridges



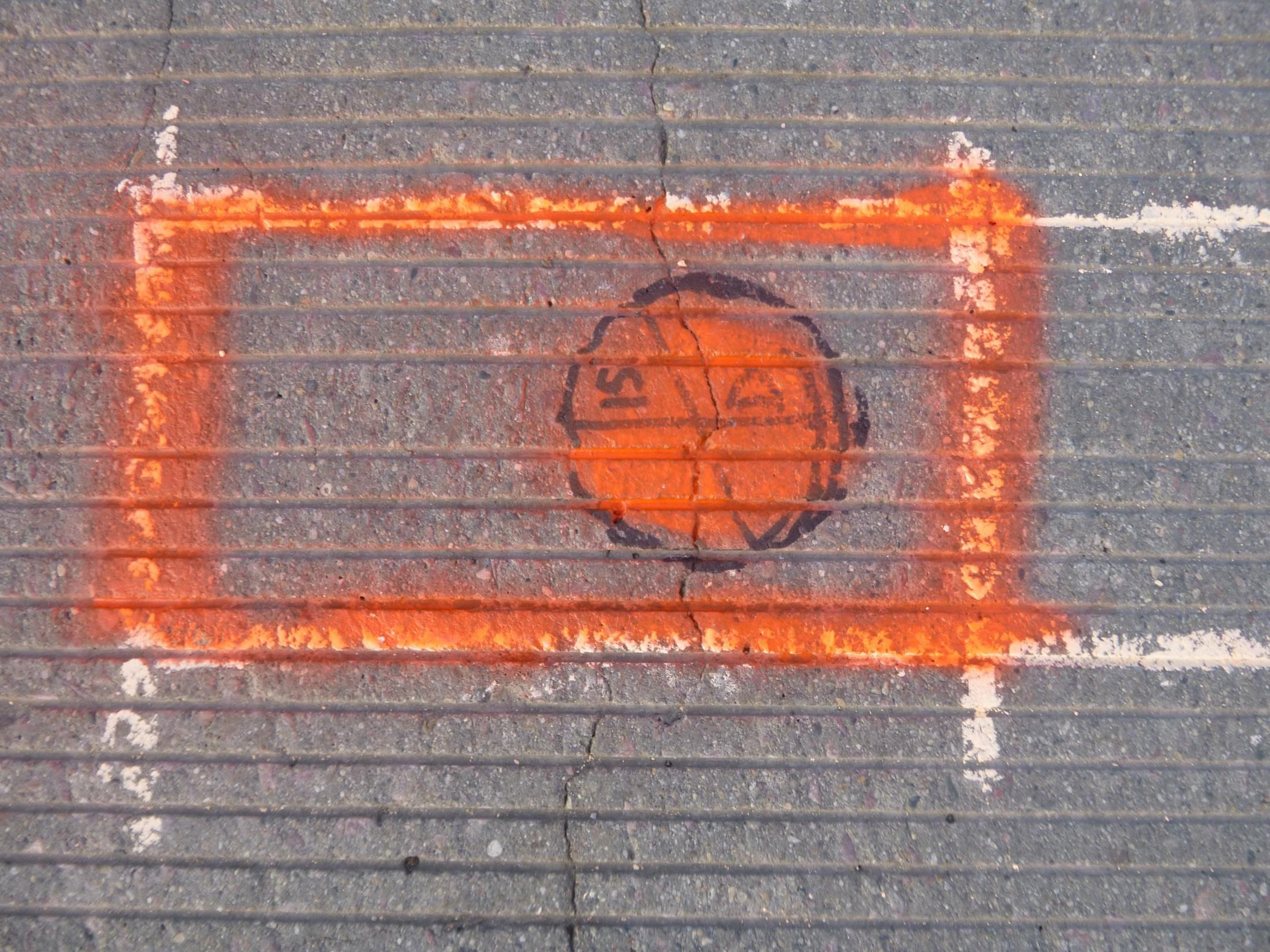

**Bridges built between 1969 to 2007**

# Preserving Bridges in 230-mile Highway Corridor

- US 18 and IA 9 - East-West Highways have hundreds of bridges in that corridor
- Need preservation program (doing the right thing at the right time for the right cost) to keep these bridges in good condition
- Preservation program required current condition and expected future condition

# Preserving Bridges in 230-mile Corridor

- Selected 6 bridge decks along US 18 and IA 9 for in-depth evaluation
- Selected 13 bridge decks for minimal sampling
- Goal is to identify preservation options to extend the lives of the decks by 50 years



# US-18 & IA-9 Bridges

| SCS # | Bridge NBI # | Bridge ID | IA 9: Feature Crossed | Year Built | No. of Spans | Deck Area sq. ft. | Bridge Length ft. | Deck Thick. in. | Const. Joint? | Deck GCR | Super GCR | Sub GCR | Top Rebar Type | Bottom Rebar Type | Deck Damage % | Total cores |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 28721 | 4520.2S009 | Drainage Ditch | 1976 | 3 | 3918 | 83 | 13.75 | Y | 6 | 6 | 7 | Epoxy | Bare | 2.6 | 4 |
| 2 | 28731 | 4525.1S009 | Crane Creek | 1976 | 3 | 6278 | 133 | 20.25 | Y | 6 | 6 | 7 | Epoxy | Bare | 5.4 | 13 |
| 3 | 36501 | 6693.5S009 | Rock Creek | 1992 | 1 | 3586 | 83 | 8 | Y | 7 | 8 | 7 | Epoxy | Epoxy | 0.0 | 4 |
| 4 | 36511 | 6697.3S009 | Cedar River | 1992 | 4 | 15984 | 370 | 8 | N | 7 | 7 | 7 | Epoxy | Epoxy | 0.0 | 17 |
| 5 | 36531 | 6607.2S009 | Little Cedar River | 1979 | 3 | 13272 | 280 | 8 | N | 7 | 7 | 7 | Epoxy | Epoxy | 0.2 | 4 |
| 6 | 36541 | 6609.3S009 | Soap Creek | 1978 | 3 | 5806 | 123 | 18.75 | N | 7 | 7 | 7 | Epoxy | Bare | 0.4 | 13 |
| 7 | 36561 | 6616.8S009 | Wapsipinicon River | 1979 | 3 | 8817 | 188 | 8 | N | 6 | 7 | 7 | Epoxy | Bare | 1.0 | 4 |
| 8 | 52590 | 9659.1S009 | Division Street | 1969 | 3 | 10497 | 163 | 7 | Y | 6 | 7 | 7 | Bare | Bare | 0.6 | 4 |
| 9 | 54021 | 9871.9S009 | Willow Creek | 2004 | 1 | 4437 | 94 | 8 | Y | 8 | 8 | 8 | Epoxy | Epoxy | 0.0 | 4 |
| 10 | 20291 | 2166.2S018 | Ocheyedan River Overflow | 1987 | 3 | 3586 | 83 | 15.25 | N | 7 | 7 | 8 | Epoxy | Bare | 0.1 | 13 |
| 11 | 20331 | 2181.0S018 | Little Sioux River | 2006 | 4 | 33553 | 459 | 8 | Y | 7 | 8 | 8 | Epoxy | Epoxy | 0.0 | 8 |
| 12 | 32821 | 5521.8S018 | Lotts Creek | 1993 | 1 | 5098 | 108 | 8 | N | 7 | 8 | 8 | Epoxy | Epoxy | 1.1 | 5 |
| 13 | 32831 | 5529.9S018 | Drainage Ditch | 1993 | 1 | 5506 | 93 | 8 | N | 7 | 8 | 8 | Epoxy | Epoxy | 0.1 | 4 |
| 14 | 32841 | 5530.3S018 | E Fork Des Moines River | 1984 | 4 | 18876 | 330 | 8 | Y* | 7 | 8 | 6 | Epoxy | Bare | 0.0 | 8 |
| 15 | 48211 | 8415.1S018 | Dry Run Creek | 2007 | 4 | 7344 | 170 | 20 | N | 7 | 7 | 7 | Epoxy | Epoxy | 0.0 | 4 |
| 16 | 48221 | 8416.3S018 | Rock River Overflow | 1989 | 3 | 8813 | 204 | 8 | Y | 7 | 7 | 7 | Epoxy | Epoxy | 0.0 | 13 |
| 17 | 48231 | 8416.6S018 | Rock River | 2002 | 4 | 18186 | 420 | 8 | N | 7 | 8 | 7 | Epoxy | Epoxy | 0.0 | 8 |
| 18 | 48281 | 8419.8S018 | Rogg Creek | 1985 | 3 | 6653 | 154 | 8 | N | 7 | 7 | 7 | Epoxy | Bare | 0.1 | 4 |
| 19 | 48351 | 8441.3S018 | Floyd River | 1992 | 3 | 9865 | 209 | 8 | N | 7 | 8 | 7 | Epoxy | Epoxy | 0.0 | 4 |

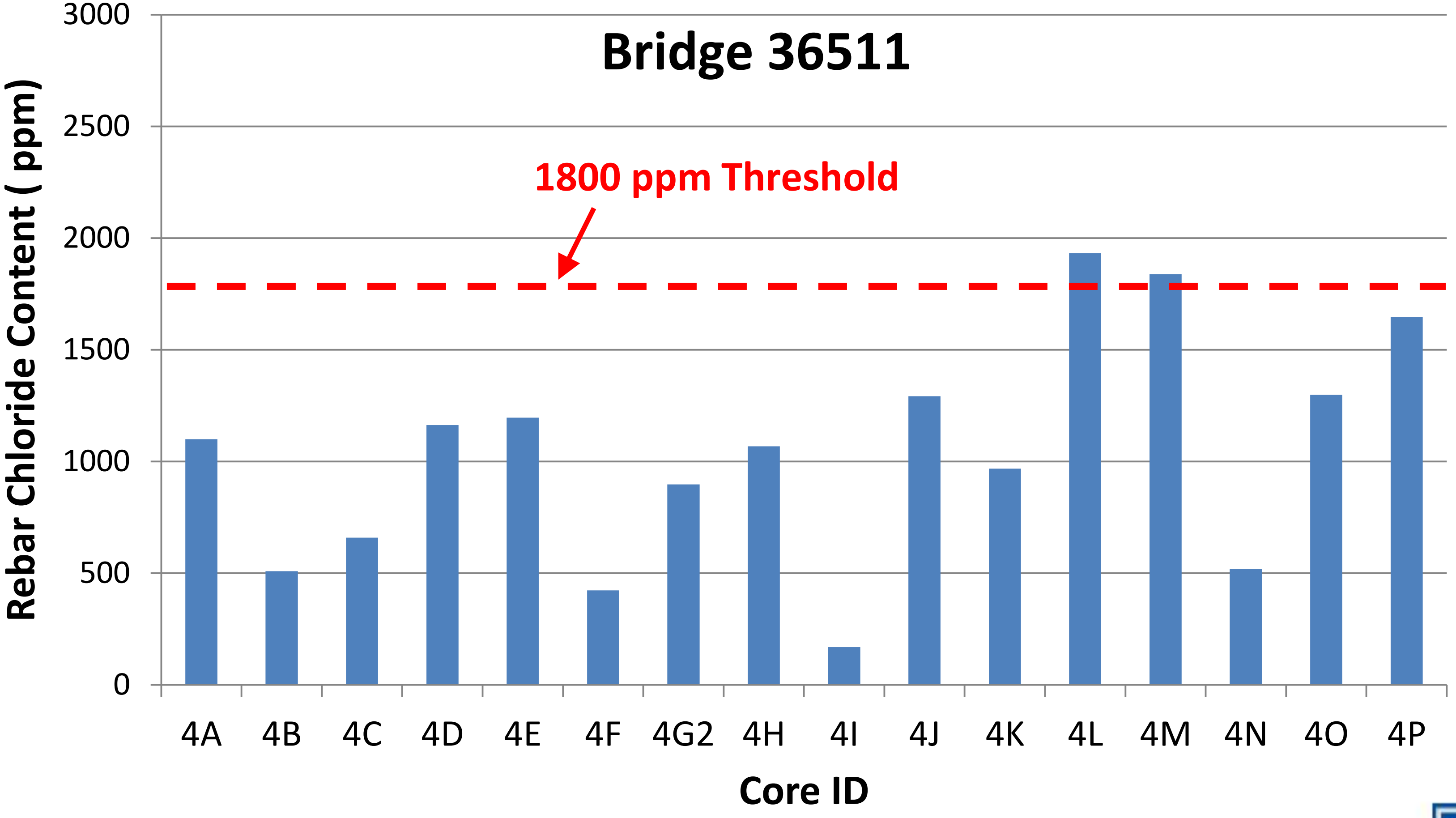
# SCS Methodology

- More comprehensive testing and analysis on in-depth service-life bridges (SLB)
  - allow accurate future concrete damage projections
  - life-cycle cost (LCC) analyses of repair options
  - select appropriate preservation option based on LCC
- Chloride and damage data for non-SLB compared to SLB in order to select effective preservation options for each deck

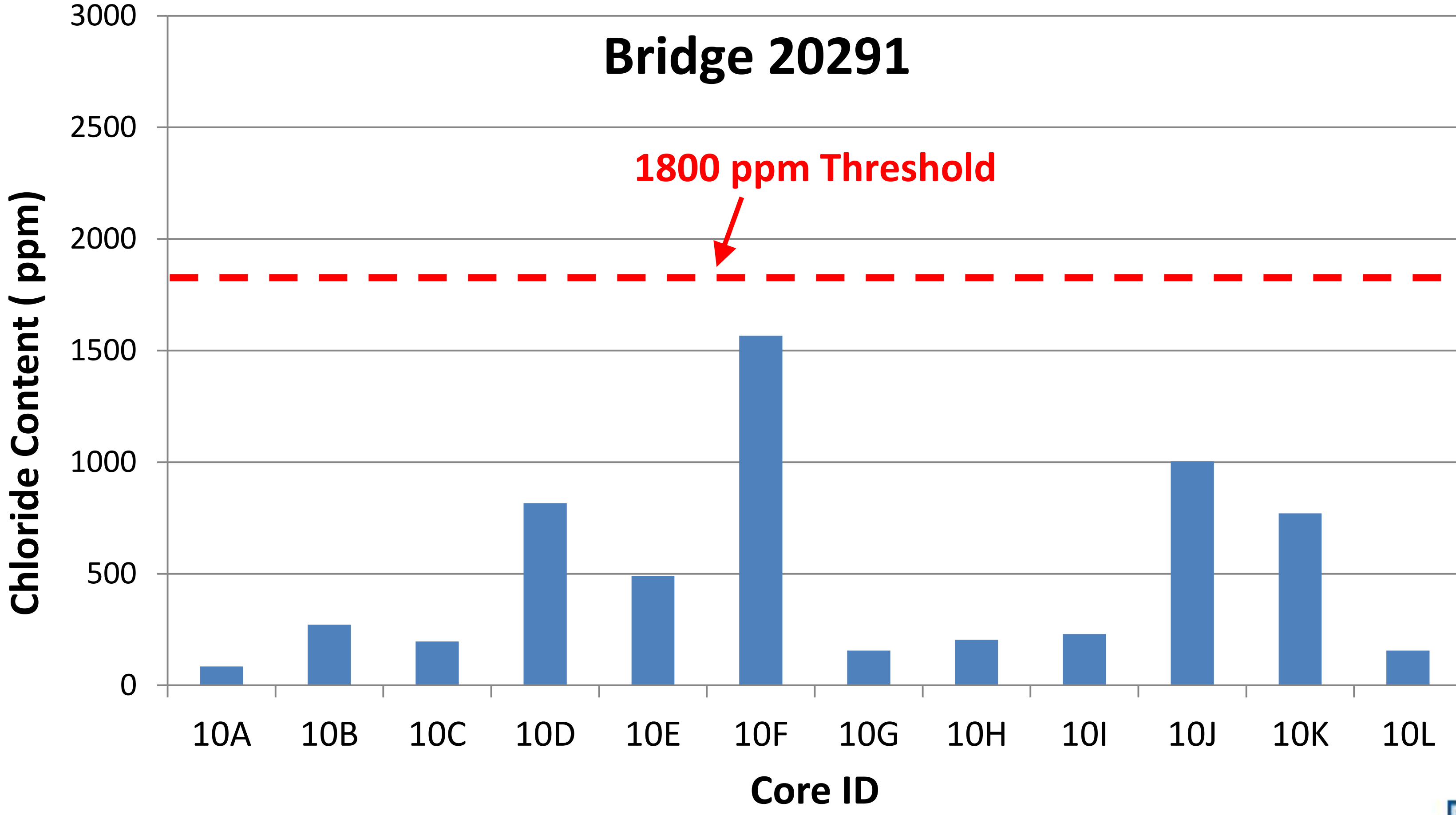
# In-Depth Evaluation of Service Life Bridges

- Delamination survey
- Cover survey
- 4 chloride cores per span; 1 petrographic core
  - Cores located using Ground Penetrating Radar
- Chloride profiling - testing at 8 depths
- Petrographic analysis to determine concrete quality
- Service life model (NCHRP 558)
- Identify effective preservation options
- Compare life cycle costs to select best option

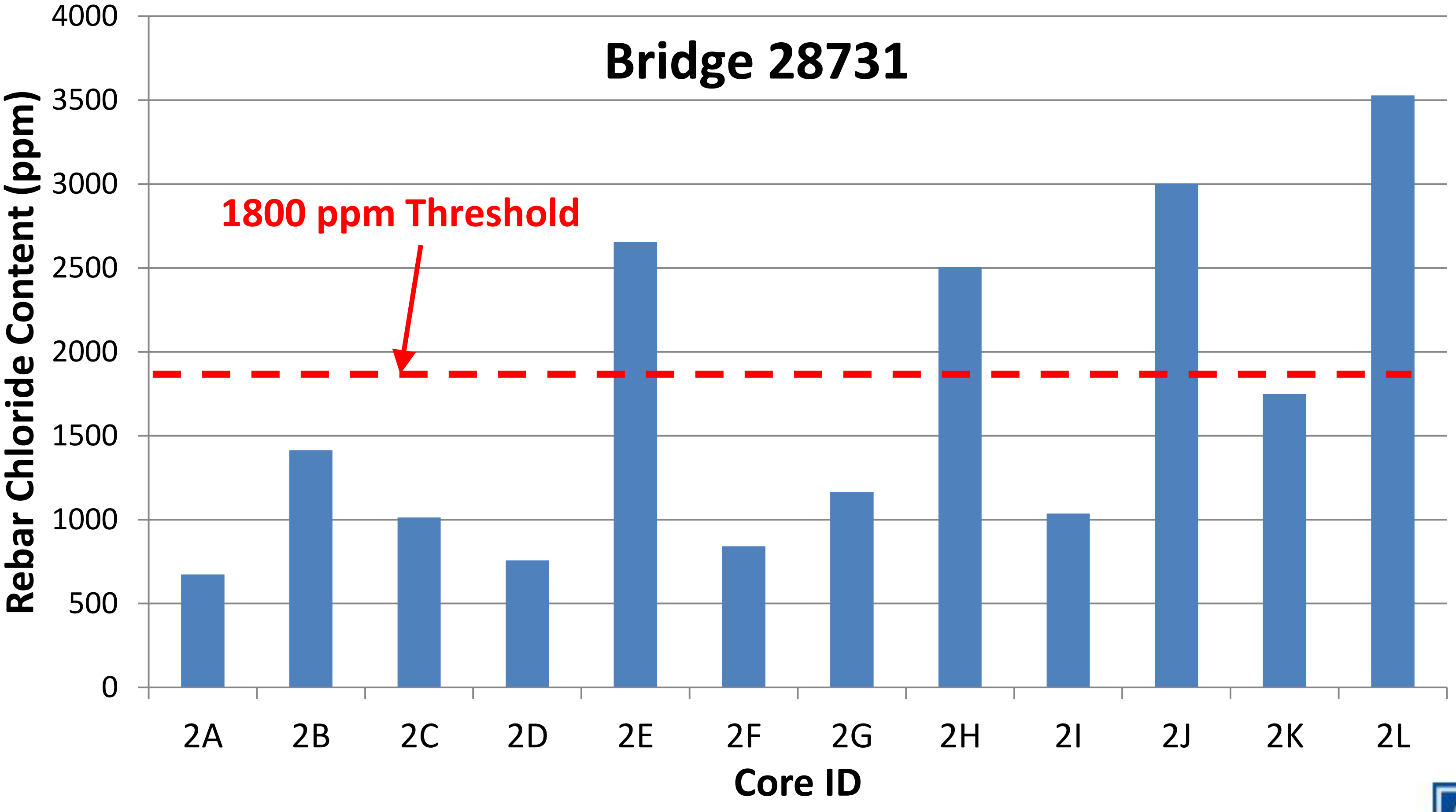
# SLB: Example 1 – Bridge 36511 (Chlorides at Threshold)



# SLB: Example 2 – Bridge 20291 (Chloride below Threshold)



# SLB: Example 3 – Bridge 28731 (Chloride above Threshold)

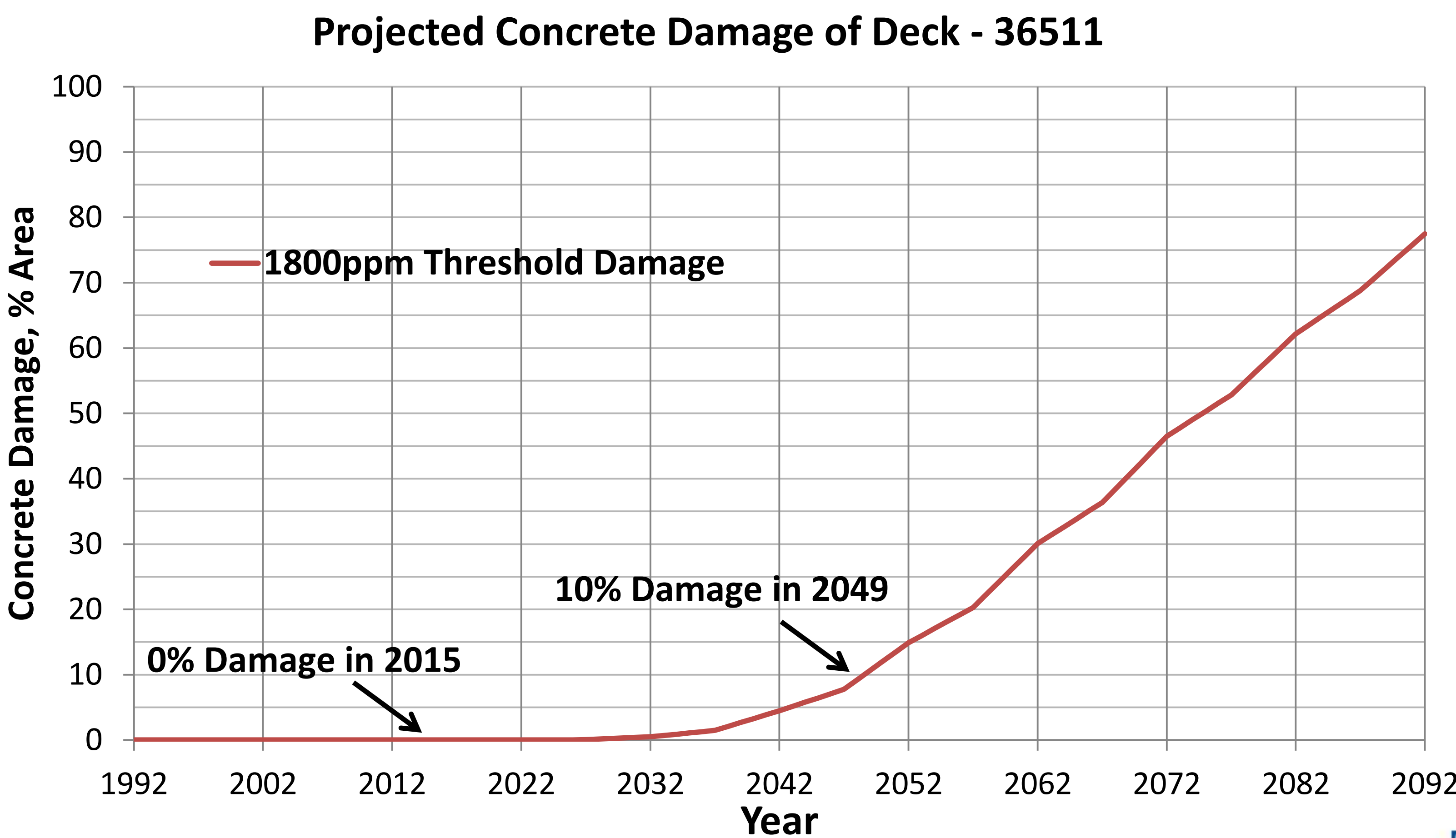


# SLB Data Summary

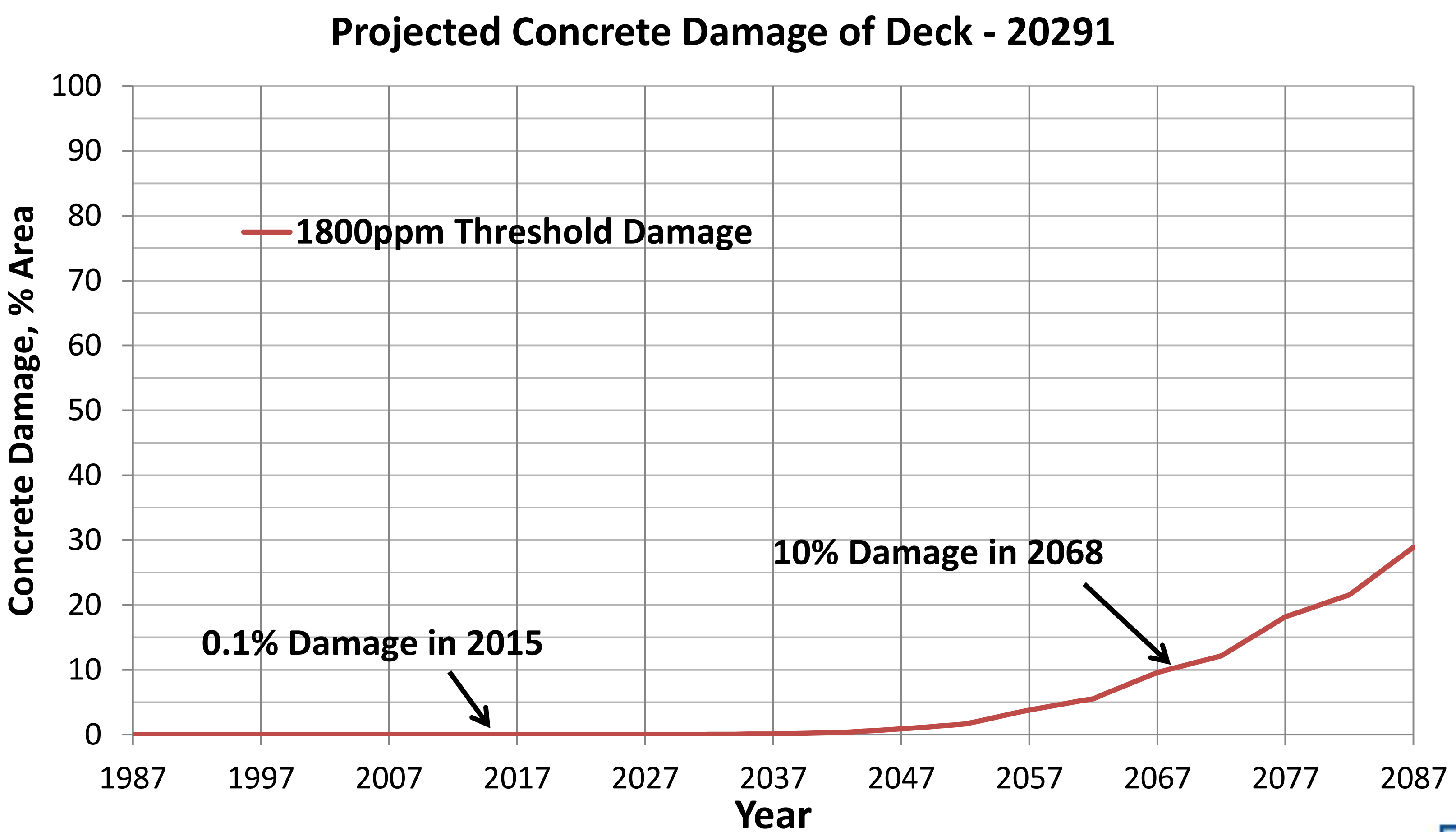
| Bridge | Facility Crossed | Year Built | Element | % Damage | Avg. Cover (in) | 95% Cover (in) | Avg. Diffusion Coeff. (in$^2$/yr) | Cl% over 1800 ppm | Cl% over 350 ppm | |
|---|---|---|---|---|---|---|---|---|---|---|
| **IA9 Bridges** | | | | | | | | | | |
| 28721 | Drainage Ditch | 1976 | Deck | 2.6% | 2.61 | 1.80 | 0.053 | 25.0% | 75.0% | |
| 28731 | Crane Creek | 1976 | Deck | 5.4% | 2.82 | 2.02 | 0.056 | 33.3% | 100.0% | above |
| 36501 | Rock Creek | 1992 | Deck | 0.0% | 2.73 | 2.29 | 0.084 | 0.0% | 75.0% | |
| 36511 | Cedar River | 1992 | Deck | 0.0% | 2.74 | 2.32 | 0.061 | 12.5% | 93.8% | at |
| 36531 | Little Cedar River | 1979 | Deck | 0.2% | 2.35 | 1.96 | 0.021 | 0.0% | 25.0% | |
| 36541 | Soap Creek | 1978 | Deck | 0.4% | 2.84 | 1.86 | 0.045 | 25.0% | 91.7% | |
| 36561 | Wapsipinicon River | 1979 | Deck | 1.0% | 2.35 | 2.05 | 0.051 | 25.0% | 100.0% | |
| 52590 | *Division Street | 1969 | Deck | 0.6% | 2.22 | 1.72 | 0.010 | 0.0% | 0.0% | |
| 54021 | Willow Creek | 2004 | Deck | 0.0% | 2.80 | 2.39 | 0.089 | 0.0% | 75.0% | |
| **US18 Bridges** | | | | | | | | | | |
| 20291 | Ocheyedan River Overflow | 1987 | Deck | 0.1% | 3.38 | 2.58 | 0.052 | 0.0% | 41.7% | below |
| 20331 | Little Sioux River | 2006 | Deck | 0.0% | 2.65 | 2.16 | 0.123 | 0.0% | 25.0% | |
| 32821 | Lotts Creek | 1993 | Deck | 1.1% | 2.53 | 1.83 | 0.080 | 75.0% | 100.0% | |
| 32831 | Drainage Ditch | 1993 | Deck | 0.1% | 2.49 | 1.89 | 0.071 | 25.0% | 50.0% | |
| 32841 | E Fork Des Moines River | 1984 | Deck | 0.0% | 3.03 | 2.56 | 0.072 | 12.5% | 75.0% | |
| 48211 | Dry Run Creek | 2007 | Deck | 0.0% | 3.36 | 2.63 | 0.177 | 0.0% | 0.0% | |
| 48221 | Rock River Overflow | 1989 | Deck | 0.0% | 2.74 | 2.33 | 0.017 | 0.0% | 16.7% | |
| 48231 | Rock River | 2002 | Deck | 0.0% | 2.47 | 1.93 | 0.058 | 0.0% | 12.5% | |
| 48281 | Rogg Creek | 1985 | Deck | 0.1% | 2.49 | 1.83 | 0.066 | 0.0% | 25.0% | |
| 48351 | Floyd River | 1992 | Deck | 0.0% | 2.78 | 2.32 | 0.085 | 0.0% | 100.0% | |

*Black Bar Deck

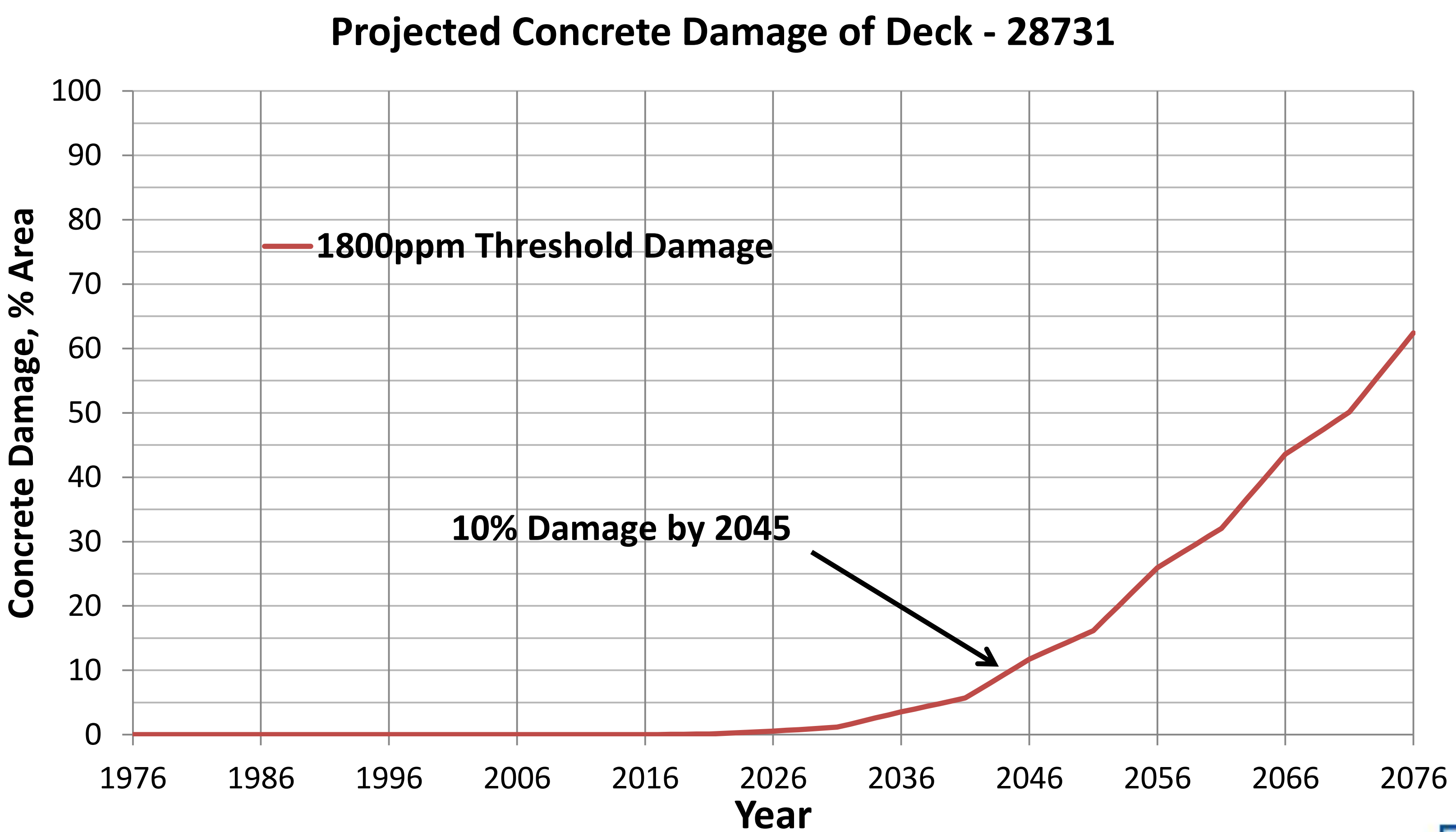
# Service Life Model (Future Damage): Example 1 – Bridge 36511- Cl @ threshold



# Service Life Model (Future Damage): Example 2 – Bridge 20291-Cl below Threshold



# Service Life Model (Future Damage): Example 3 – Bridge 28731-Cl above Threshold



# SLB Life Cycle Cost Comparison

## Bridge 36511: Example 1 – Chlorides at Threshold

| | Deck Repair Options | Repair Life, years | Initial Cost | Life Repair, Present Value | Life Repair MOT, Present Value | Life Cycle Cost of Repair Options |
|---|---|---|---|---|---|---|
| 1 | Patch Repairs Only | 5 | $ - | $ 103,600 | $ 66,054 | $ 169,654 |
| 2 | Thin Epoxy Overlay | 15 | $ 122,440 | $ 326,651 | $ 26,524 | $ 353,175 |
| 3 | LSHD Overlay | 20 | $ - | $ 175,845 | $ 21,785 | $ 197,630 |

## Bridge 20291: Example 2 – Chlorides below Threshold

| | Deck Repair Options | Repair Life, years | Initial Cost | Life Repair, Present Value | Life Repair MOT, Present Value | Life Cycle Cost of Repair Options |
|---|---|---|---|---|---|---|
| 1 | Patch Repairs Only | 5 | $ 1,870 | $ 5,159 | $ 24,444 | $ 29,603 |
| 2 | Thin Epoxy Overlay | 15 | $ 33,019 | $ 58,111 | $ 15,674 | $ 73,785 |
| 3 | LSHD Overlay | 20 | $ 1,870 | $ 14,811 | $ 16,820 | $ 31,631 |

## Bridge 28731: Example 3 – Chlorides above Threshold

| | Deck Repair Options | Repair Life, years | Initial Cost | Life Repair, Present Value | Life Repair MOT, Present Value | Life Cycle Cost of Repair Options |
|---|---|---|---|---|---|---|
| 1 | LSHD Overlay | 20 | $ 83,360 | $ 144,001 | $ 35,897 | $ 179,898 |
| 2 | Overlay + GCP | 20 | $ 294,034 | $ 500,570 | $ 25,280 | $ 525,850 |
| 3 | Overlay + ICCP | 50 | $ 185,252 | $ 308,063 | $ 24,500 | $ 332,563 |

# SLB Recommendations

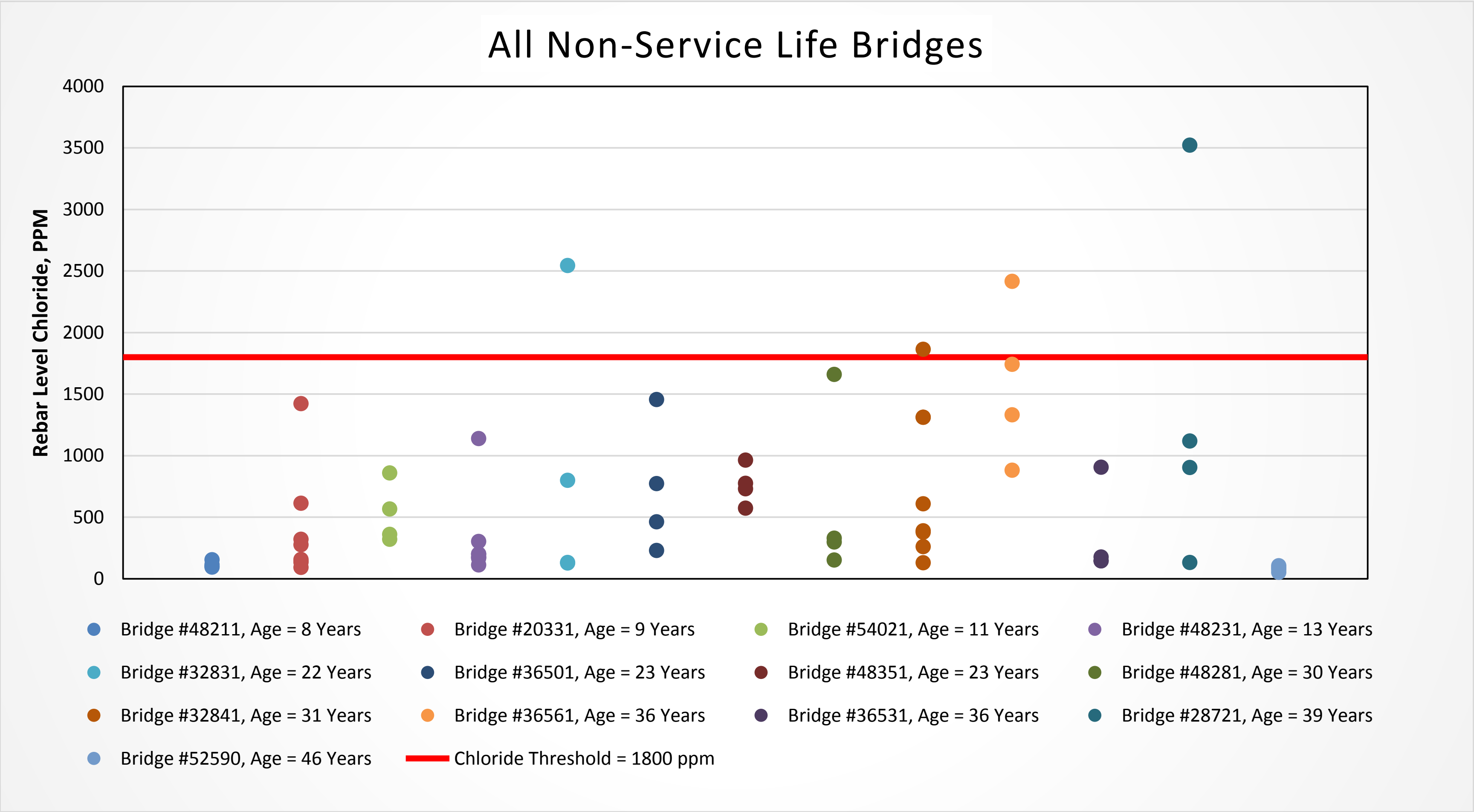
| Bridge | Facility Crossed | Year Built | % Damage | Cl% over 1800 ppm | Recommendation Cost | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **IA9 Bridges** | | | | | **Patch Only** | **Thin Overlay** | **LSHD** | **GCP** | **ICCP** |
| 28721 | Drainage Ditch | 1976 | 2.6% | 25.0% | | | | | |
| 28731 | Crane Creek | 1976 | 5.4% | 33.3% | - | - | $179,898 | $525,850 | $332,563 |
| 36501 | Rock Creek | 1992 | 0.0% | 0.0% | | | | | |
| 36511 | Cedar River | 1992 | 0.0% | 12.5% | $169,654 | $353,175 | $197,630 | - | - |
| 36531 | Little Cedar River | 1979 | 0.2% | 0.0% | | | | | |
| 36541 | Soap Creek | 1978 | 0.4% | 25.0% | $123,179 | $141,595 | $127,355 | - | - |
| 36561 | Wapsipinicon River | 1979 | 1.0% | 25.0% | | | | | |
| 52590 | *Division Street | 1969 | 0.6% | 0.0% | | | | | |
| 54021 | Willow Creek | 2004 | 0.0% | 0.0% | | | | | |
| **US18 Bridges** | | | | | | | | | |
| 20291 | Ocheyedan River Overflow | 1987 | 0.1% | 0.0% | $29,603 | $73,785 | $31,631 | - | - |
| 20331 | Little Sioux River | 2006 | 0.0% | 0.0% | | | | | |
| 32821 | Lotts Creek | 1993 | 1.1% | 75.0% | - | - | $155,741 | $425,228 | $295,813 |
| 32831 | Drainage Ditch | 1993 | 0.1% | 25.0% | | | | | |
| 32841 | E Fork Des Moines River | 1984 | 0.0% | 12.5% | | | | | |
| 48211 | Dry Run Creek | 2007 | 0.0% | 0.0% | | | | | |
| 48221 | Rock River Overflow | 1989 | 0.0% | 0.0% | $5,058 | $158,314 | $39,700 | - | - |
| 48231 | Rock River | 2002 | 0.0% | 0.0% | | | | | |
| 48281 | Rogg Creek | 1985 | 0.1% | 0.0% | | | | | |
| 48351 | Floyd River | 1992 | 0.0% | 0.0% | | | | | |

*Black Bar Deck

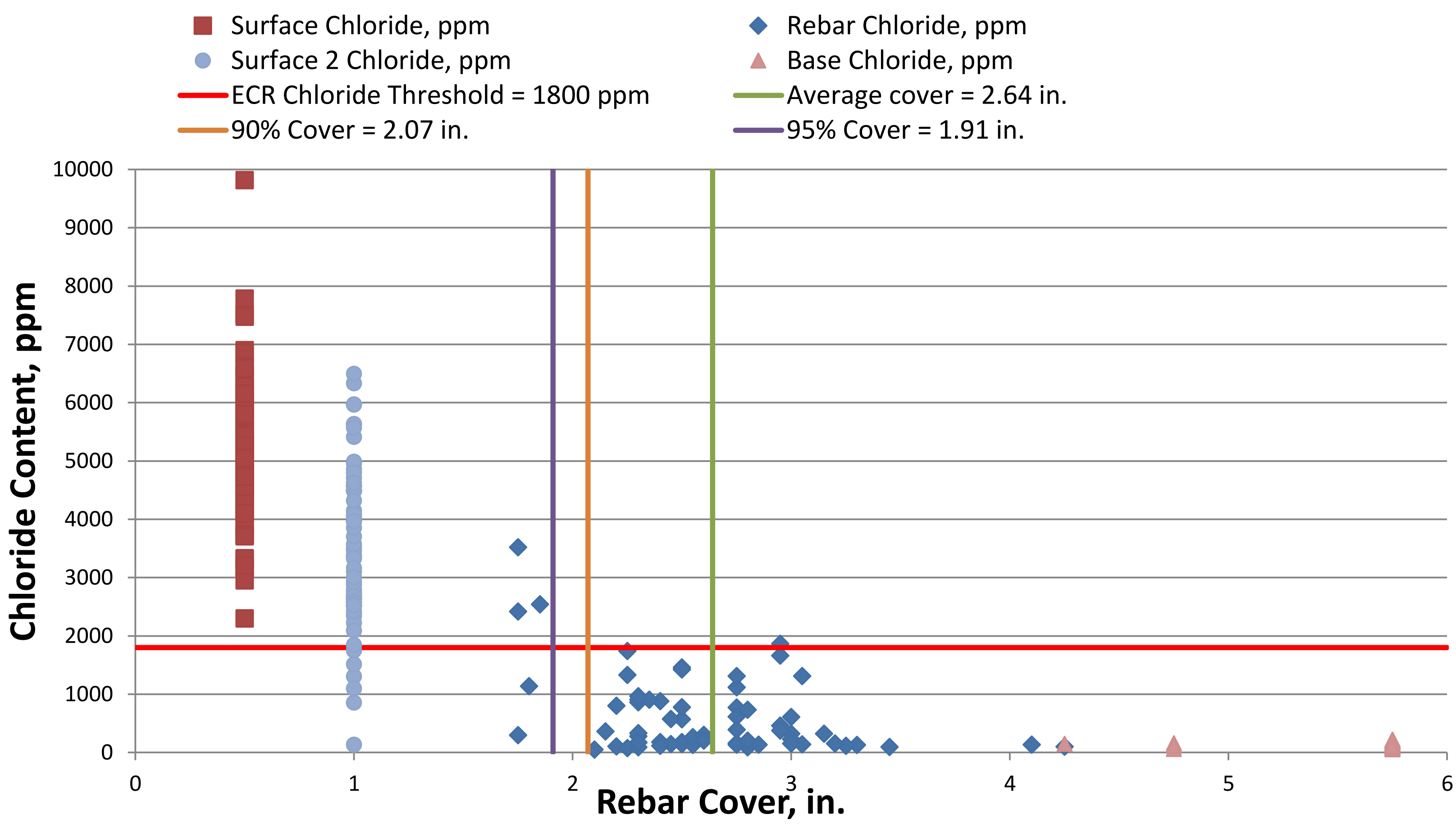
# Non-Service Life Scope of Work

- Delamination survey
- Limited cover survey
- 4 to 8 chloride cores total
  - Cores located using Ground Penetrating Radar
- Chloride testing along 4 depths
- Identify effective preservation options
- Compare to preservation options identified for service-life bridges

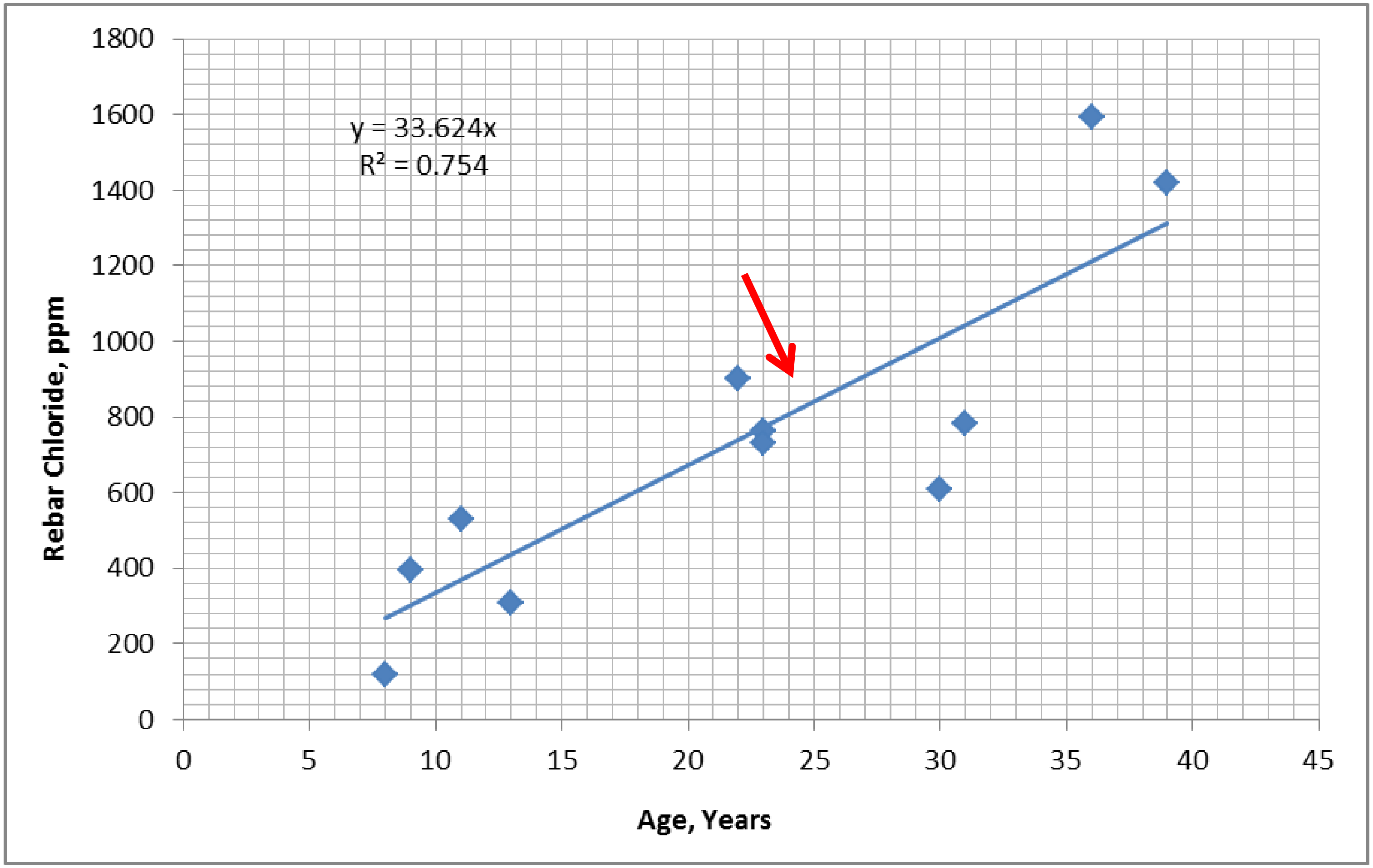
# Non-SLB Chloride Analysis



# Non-SLB Chloride Analysis



# Non-SLB Chloride Analysis



# Time for Chloride Sampling

- 1800 ppm chloride threshold for epoxy-coated rebar decks
- Using 50% of chloride threshold, time to 900 ppm = 900/33.624 ≈ 25 years
- SCS suggest collecting cores and testing for chloride profile at 25 years of age

# Non-SLB Recommendations

| Bridge | Facility Crossed | Year Built | Element | % Damage | Avg. Cover (in) | 95% Cover (in) | Removal Depth (in) | Patch+LSHD Initial Cost |
|---|---|---|---|---|---|---|---|---|
| **IA9 Bridges** | | | | | | | | |
| 28721 | Drainage Ditch | 1976 | Deck | 2.6% | 2.61 | 1.80 | 1.75 | $52,680 |
| 28731 | Crane Creek | 1976 | Deck | 5.4% | 2.82 | 2.02 | - | - |
| 36501 | Rock Creek | 1992 | Deck | 0.0% | 2.73 | 2.29 | 2.00 | $46,360 |
| 36511 | Cedar River | 1992 | Deck | 0.0% | 2.74 | 2.32 | - | - |
| 36531 | Little Cedar River | 1979 | Deck | 0.2% | 2.35 | 1.96 | 1.75 | $144,090 |
| 36541 | Soap Creek | 1978 | Deck | 0.4% | 2.84 | 1.86 | - | - |
| 36561 | Wapsipinicon River | 1979 | Deck | 1.0% | 2.35 | 2.05 | 2.00 | $101,340 |
| 52590 | *Division Street | 1969 | Deck | 0.6% | 2.22 | 1.72 | 1.75 | $117,360 |
| 54021 | Willow Creek | 2004 | Deck | 0.0% | 2.80 | 2.39 | 2.00 | $54,870 |
| **US18 Bridges** | | | | | | | | |
| 20291 | Ocheyedan River Overflow | 1987 | Deck | 0.1% | 3.38 | 2.58 | - | - |
| 20331 | Little Sioux River | 2006 | Deck | 0.0% | 2.65 | 2.16 | 2.00 | $346,090 |
| 32821 | Lotts Creek | 1993 | Deck | 1.1% | 2.53 | 1.83 | - | - |
| 32831 | Drainage Ditch | 1993 | Deck | 0.1% | 2.49 | 1.89 | 1.75 | $65,680 |
| 32841 | E Fork Des Moines River | 1984 | Deck | 0.0% | 3.03 | 2.56 | 2.25 | $199,350 |
| 48211 | Dry Run Creek | 2007 | Deck | 0.0% | 3.36 | 2.63 | 2.00 | $83,940 |
| 48221 | Rock River Overflow | 1989 | Deck | 0.0% | 2.74 | 2.33 | - | - |
| 48231 | Rock River | 2002 | Deck | 0.0% | 2.47 | 1.93 | 1.75 | $192,360 |
| 48281 | Rogg Creek | 1985 | Deck | 0.1% | 2.49 | 1.83 | 1.75 | $77,180 |
| 48351 | Floyd River | 1992 | Deck | 0.0% | 2.78 | 2.32 | 2.00 | $109,150 |

*Black Bar Deck

# Recommendations

- Specific recommendation for each SLB
- For non-SLB, sample concrete for chloride profiling at 25 years
- Decide on preservation action based on chloride depth and concrete cover

# Benefits to the Owners

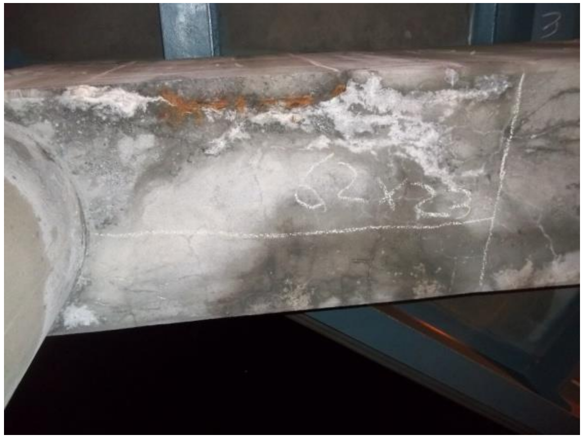
- SCS was able to cost-effectively evaluate a small number of bridge decks in the 230-mile corridor and develop data-driven preservation solutions
- This inspection methodology may be applied to other ECR bridge decks in Iowa and other states and cost effectively develop bridge preservation schedule

# Case Study 1
# I -581 over Williamson Road, Roanoke, VA

# Bridge Information

- Built: 1968
- Regular reinforced concrete
- 5 Spans, 4 piers, 2 abutments
- Previous condition rating:  5 (fair) in the 2014 NBI inspection

# Visual Conditions



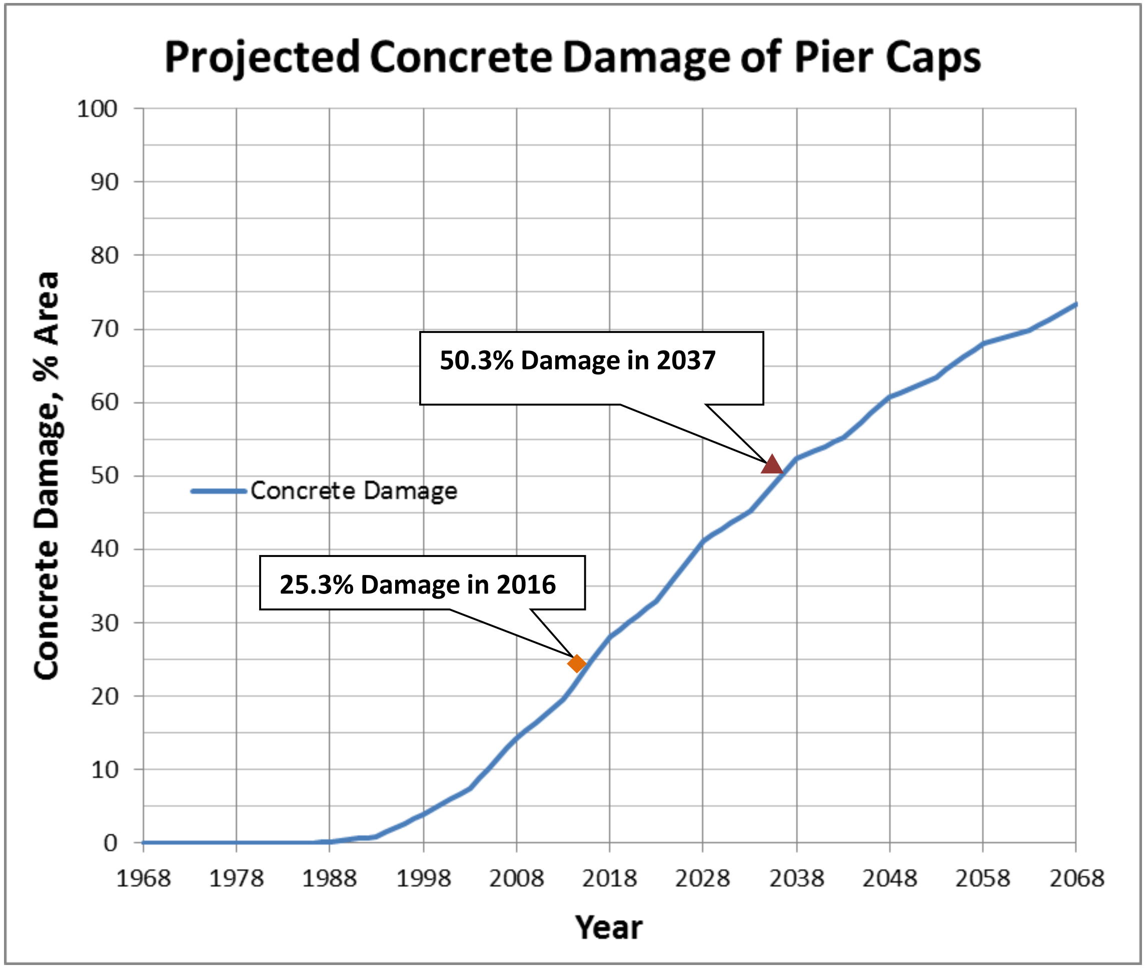
# SCS Approaches

- Visual survey
- Delamination survey
- Concrete cover
- Chloride profile analysis
- Carbonation
- Petrographic analysis
- Service life modeling

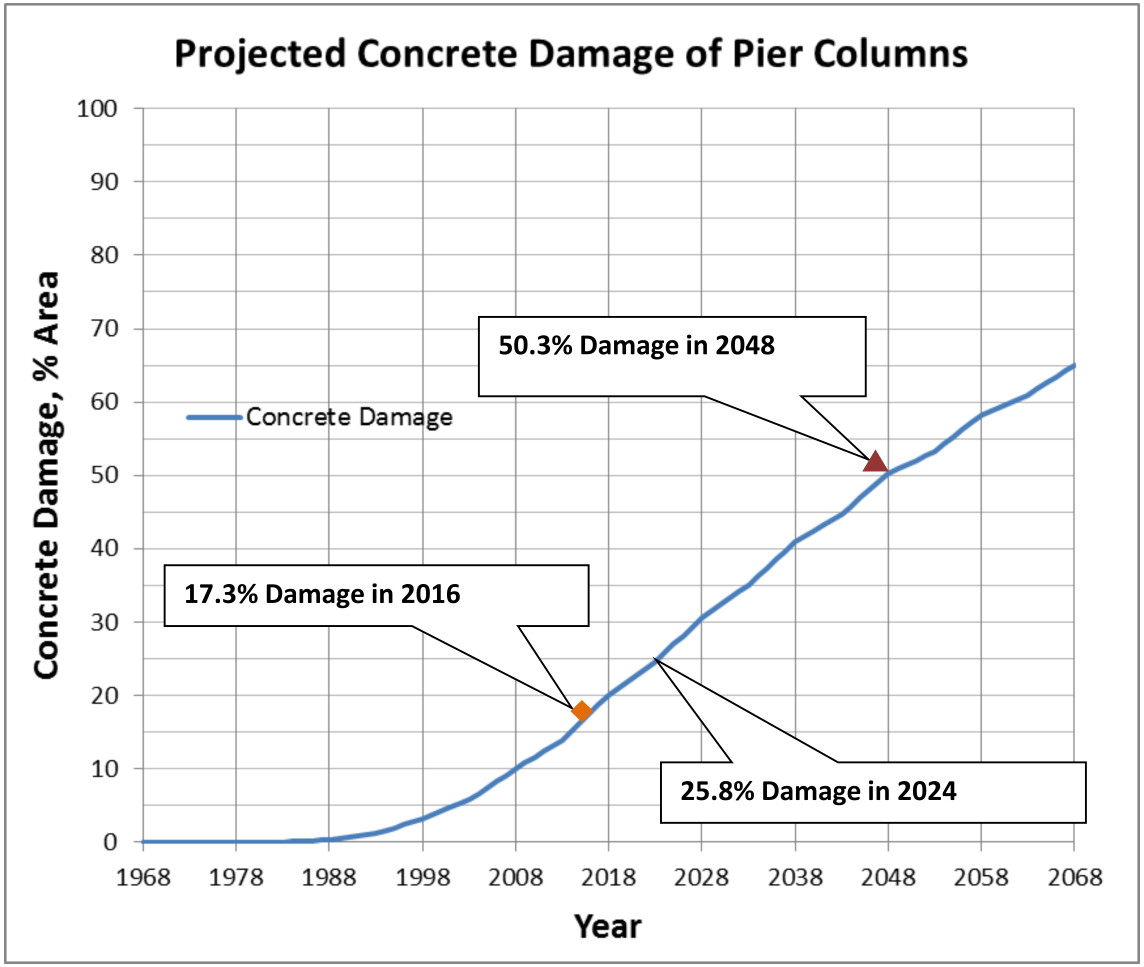
# Inspection Findings

| Element | % Damage | Avg. Cover (in) | 95% Cover (in) | Cl% over 1000 ppm | Cl% over 500 ppm | Avg. Diffusion Coeff. ($in^2/yr$) | Carbonation Depth (in) | Petro. Analysis |
|---|---|---|---|---|---|---|---|---|
| **Pier Caps** | 25.3 | 2.06 | 1.01 | 60% | 60% | 0.070 | 0.50 | Generally good quality concrete |
| **Pier Columns** | 17.3 | 2.50 | 1.48 | 17% | 17% | 0.018 | 1.15 | |
| **Abutments** | 4.2 | 2.67 | 1.15 | 25% | 25% | 0.039 | 0.64 | |

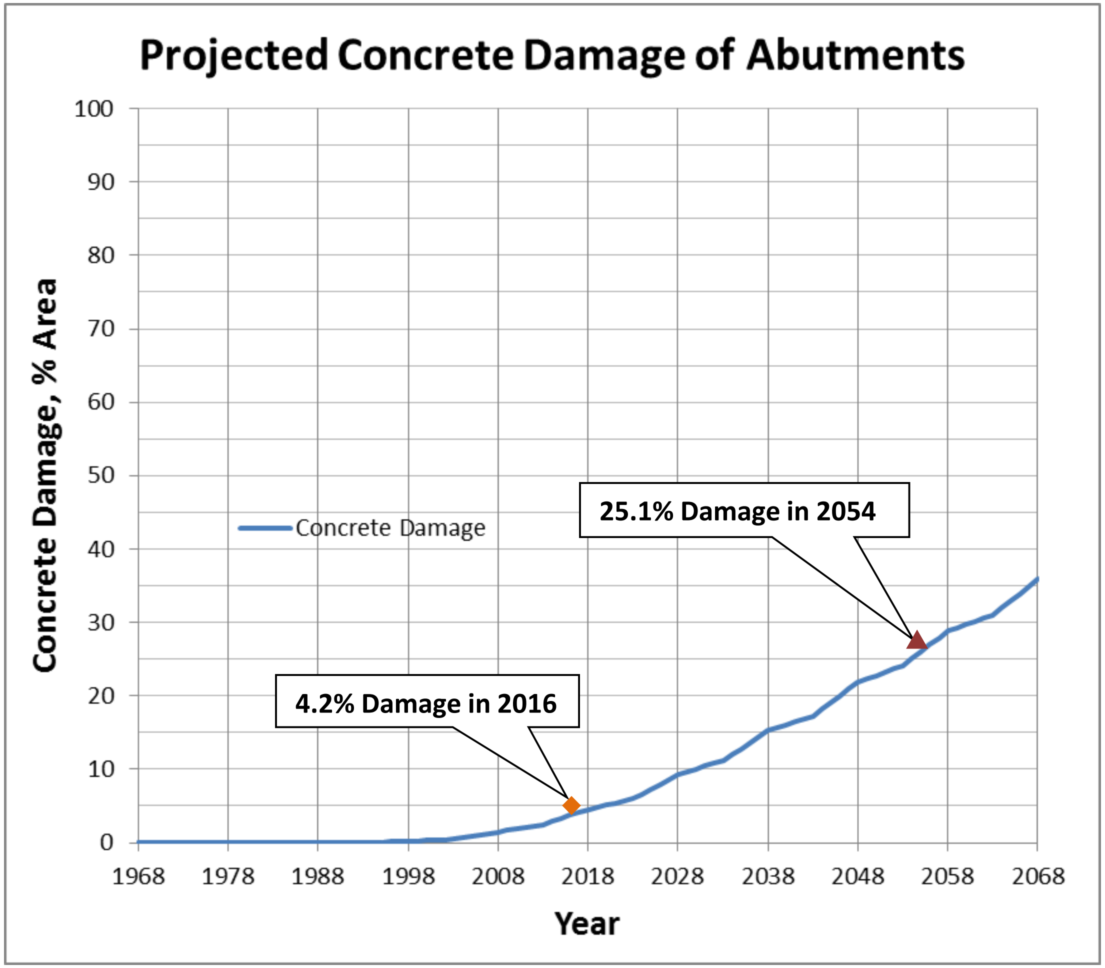
# Service Life Processing – Pier Caps



# Service Life Processing – Pier Columns



# Service Life Processing - Abutments



# Conclusions and Viable Options - Piers

- Viable repair options:
  - A. Patch repairs + Impressed Current Cathodic Protection (ICCP)
  - B. Patch repairs + Electrochemical Chloride Extraction (ECE) + a breathable sealer, or
  - C. Patch repairs + sprayed Galvanic Cathodic Protection (GCP) system

# Conclusions and Viable Options - Abuts

- The viable repair options:
  - A. Patch repairs + discrete GCP anodes + seal
  - B. Patch repairs + thermal sprayed GCP, or
  - C. Patch repairs + ECE + a breathable sealer

# Life Cycle Cost Estimate

| Bridge Element | Description | Initial Cost | Additional Repair Cost (50 years) | Additional MOT Cost (50 years) | Total |
|---|---|---|---|---|---|
| | | | | | |
| Pier Caps | Patch + ECE | $784,849 | $147,311 | $0 | $932,160 |
| Pier Columns | Patch + ECE + Seal | $231,000 | $85,633 | $18,206 | $334,839 |
| | ~~Patch + ICCP~~ | ~~$229,032~~ | ~~$147,311~~ | ~~$0~~ | ~~$376,343~~ |
| Abutments | Patch + Anodes + Seal | $12,589 | $49,250 | $0 | $61,840 |
| **Subtotals** | | **$1,028,438** | **$282,194** | **$18,206** | **$1, 328,839** |

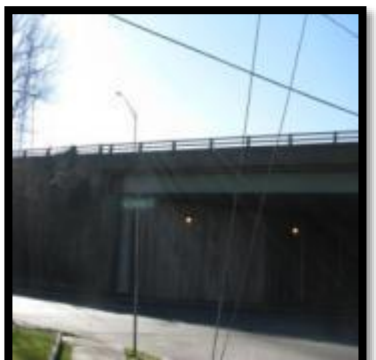
# SCS Recommendations

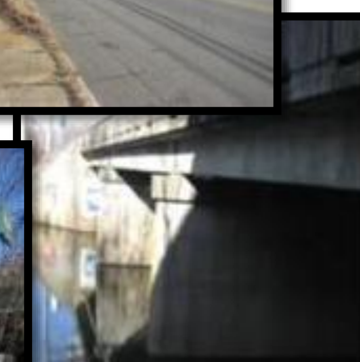
- Pier Caps – Patch + ECE + Seal
- Pier columns – Patch + ECE + Seal
- Abutments – Patch + Discrete Anode + Seal

# ECE ON 11 BRIDGES IN RICHMOND, VA








# ECE on Pier – 11 Bridges

# ECE on Pier – 11 Bridges