

What We Have Learned About the Use and Performance of Epoxy- Coating Reinforcing Bars

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What we have learnt

- Field
- Specifications
- Manufacturing



INTRODUCTION

Epoxy Bar Use

- 2nd most common strategy to prevent reinforcement corrosion
- 700,000,000 ft² of decks
 - 65,000 bridges in the US alone
 - ~600,000 ton/yr or 10 - 15% of all rebar in NA
- USA, Canada, Middle East, Japan, and India



FIELD PERFORMANCE

Research and Performance

- Over 200 research papers
- Widespread use continues by DOT's and Counties
- Approx 50% of all decks in 2008



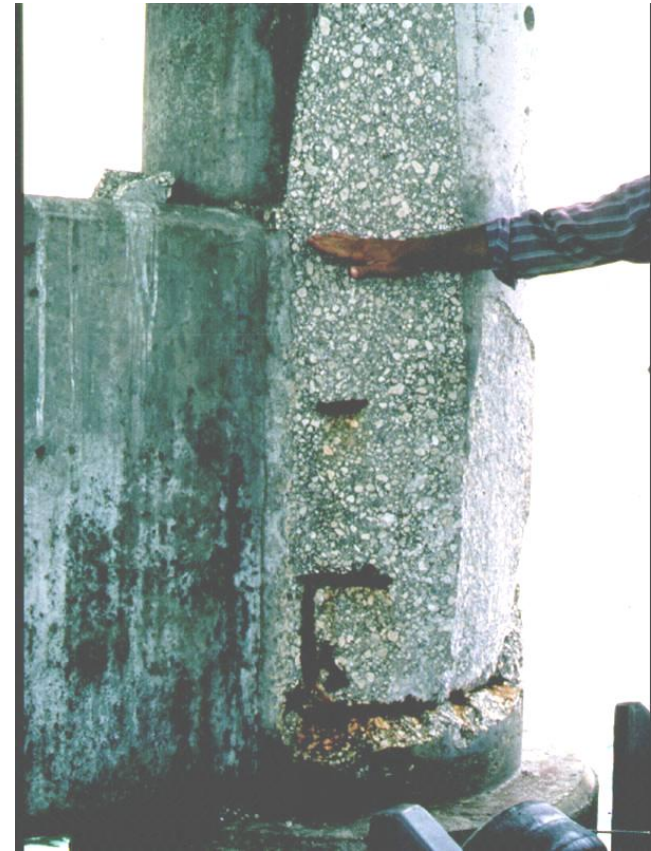
The big questions

- Do epoxy-coated bars perform better than black bars?
- Is using epoxy-coated bars better just reducing concrete permeability?
- What else could I do?
- Is it money well spent?



Poor concrete and poor bars

- 1986, spalls observed in Florida
 - Typically 1 x 1 ft spalls in tidal zone
- Poor concrete and poor bars
 - Bars left beside ocean
 - Highly salt contaminated concrete
 - Only 25 mm (1 in.) of cover.
 - Poor quality concrete
- 23 years later, 291 of the 300 structures using ECR in Florida do not exhibit corrosion



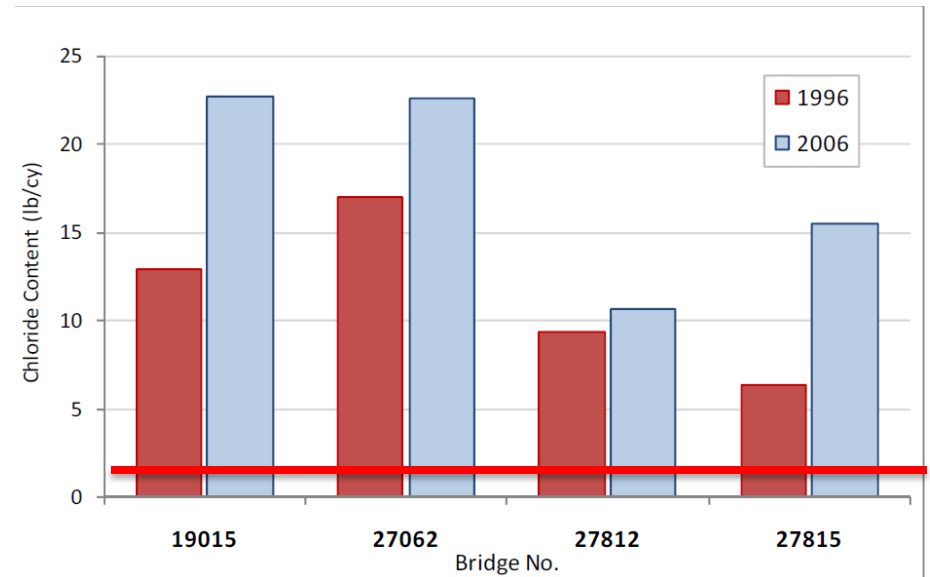
South Dakota Department of Transportation 2009

- Celebrated a 33-year career of Mr. Wilson from their Bridge Office.
 - 1,300 bridges were built.
 - Implemented the use of epoxy coated reinforcing steel in bridge decks
- ***To date, not one of those bridge decks has needed repairs or overlay due to rebar corrosion.***

Minnesota Department of Transportation 2008

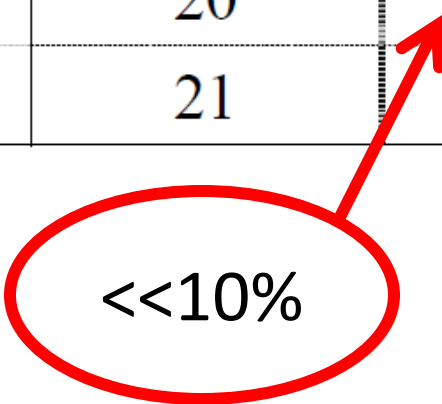


- Four bridges
 - 1973 to 1978
- Overall condition
 - good to very good, with no or modest levels of corrosion activity.
- Corrosion constrained joints over piers
- Amount of delamination in all decks is very low



Delaminations in 1996 and 2006

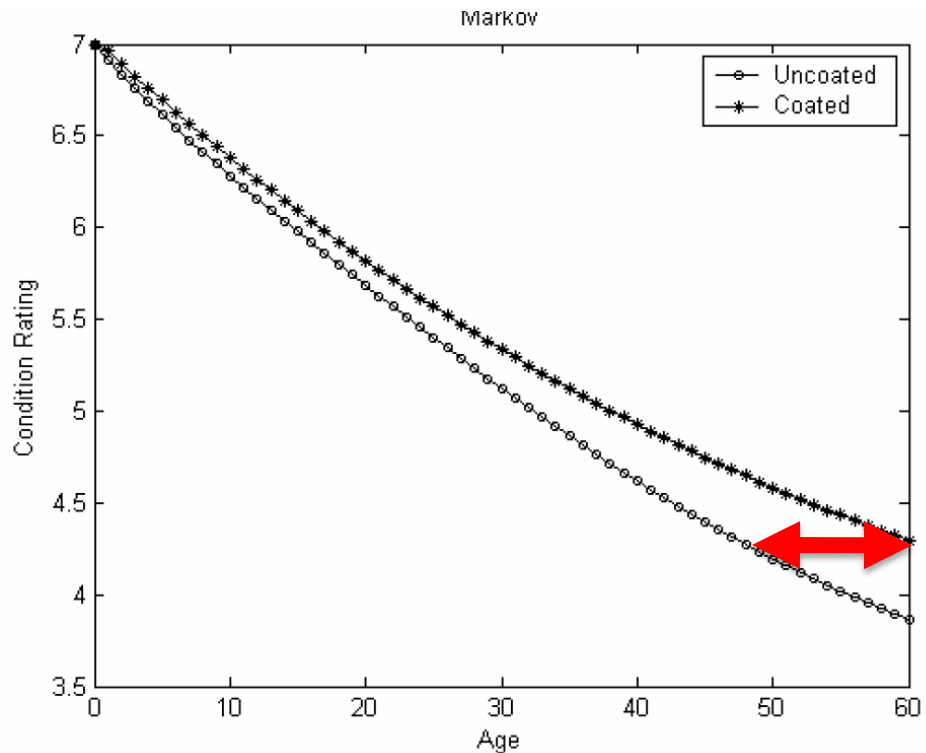
Bridge	Total Delaminated Area 1996		Total Delaminated Area 2006	
	(ft ²)	(%)	(ft ²)	(%)
19015	0	0.0%	39	1.1%
27062	2	0.0%	84	1.1%
27812	0	0.0%	20	0.3%
27815	0	0.0%	21	0.4%



<<10%

New York State Department of Transportation 2009

- Used extensive statistical analysis of all state bridge inspection data
- Pool of 17,000 structures
 - **“structural decks with epoxy-coated rebars perform significantly better than those with uncoated rebars, especially in the later years.”**





2009 West Virginia Study

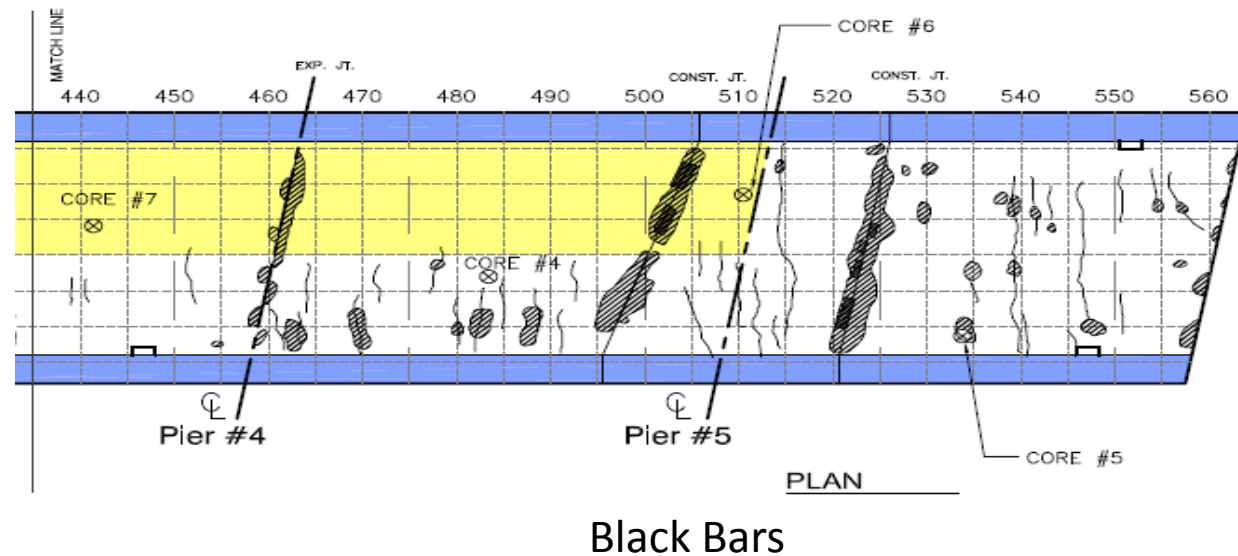
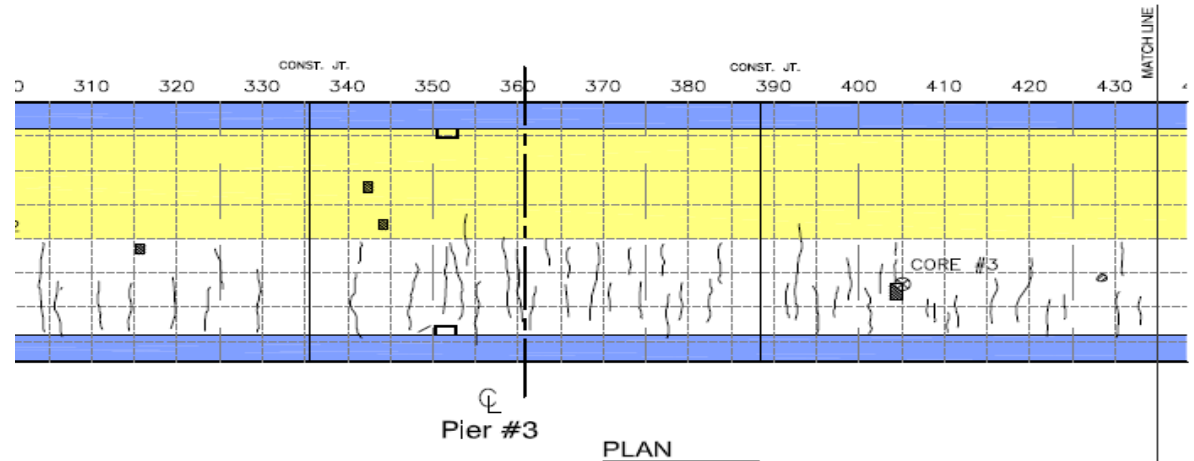
Lawler and Krauss

- Detailed study of six bridges built 1974 – 1976
 - Deck area: 62,000 sq ft
- After 34 -36 years
 - Total delamination: 22.7 sq ft
 - Chloride levels above threshold
- Black Bar performance
 - Repaired in 1993 with overlays



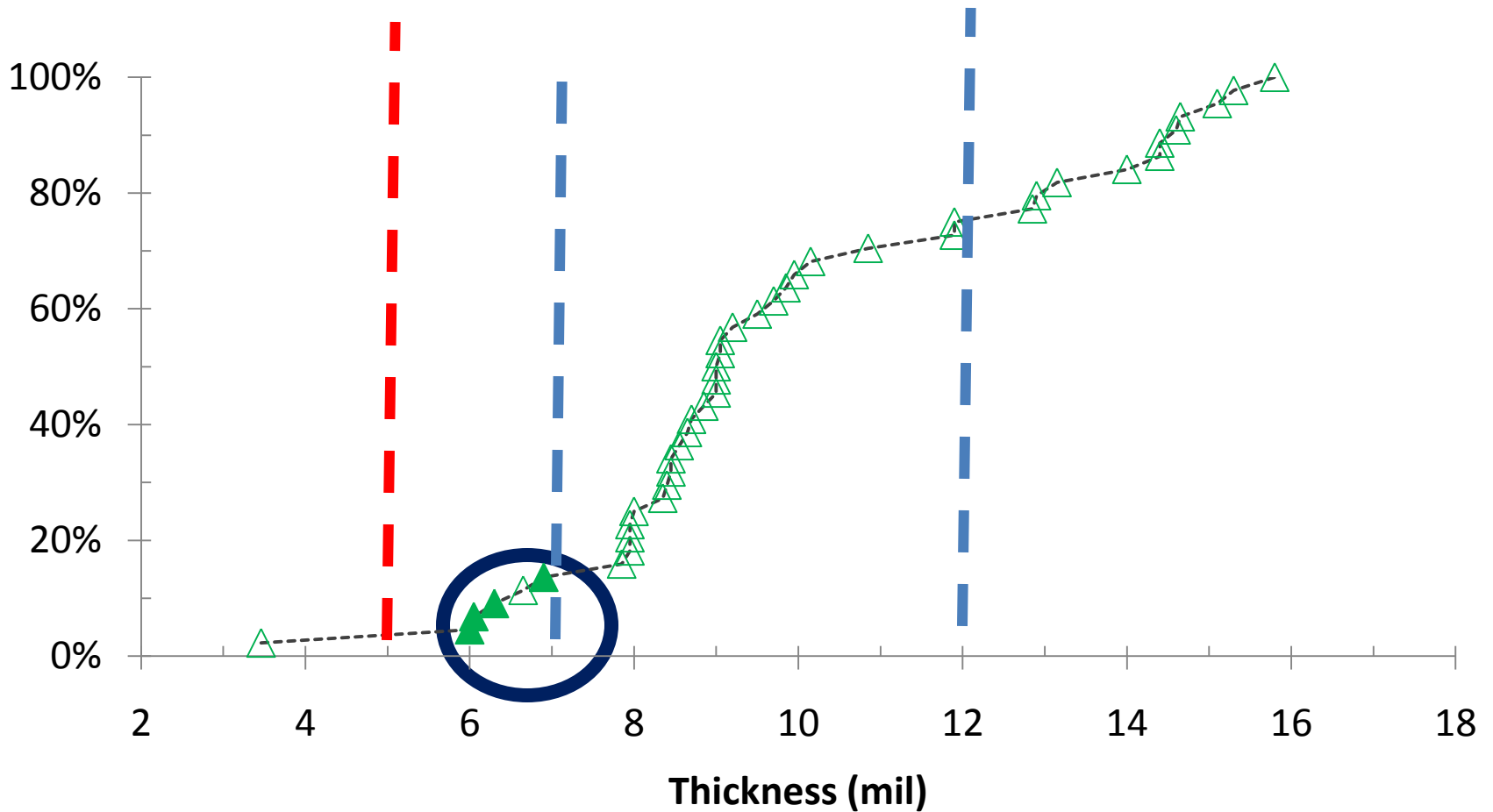


Bridge 2930, West Virginia



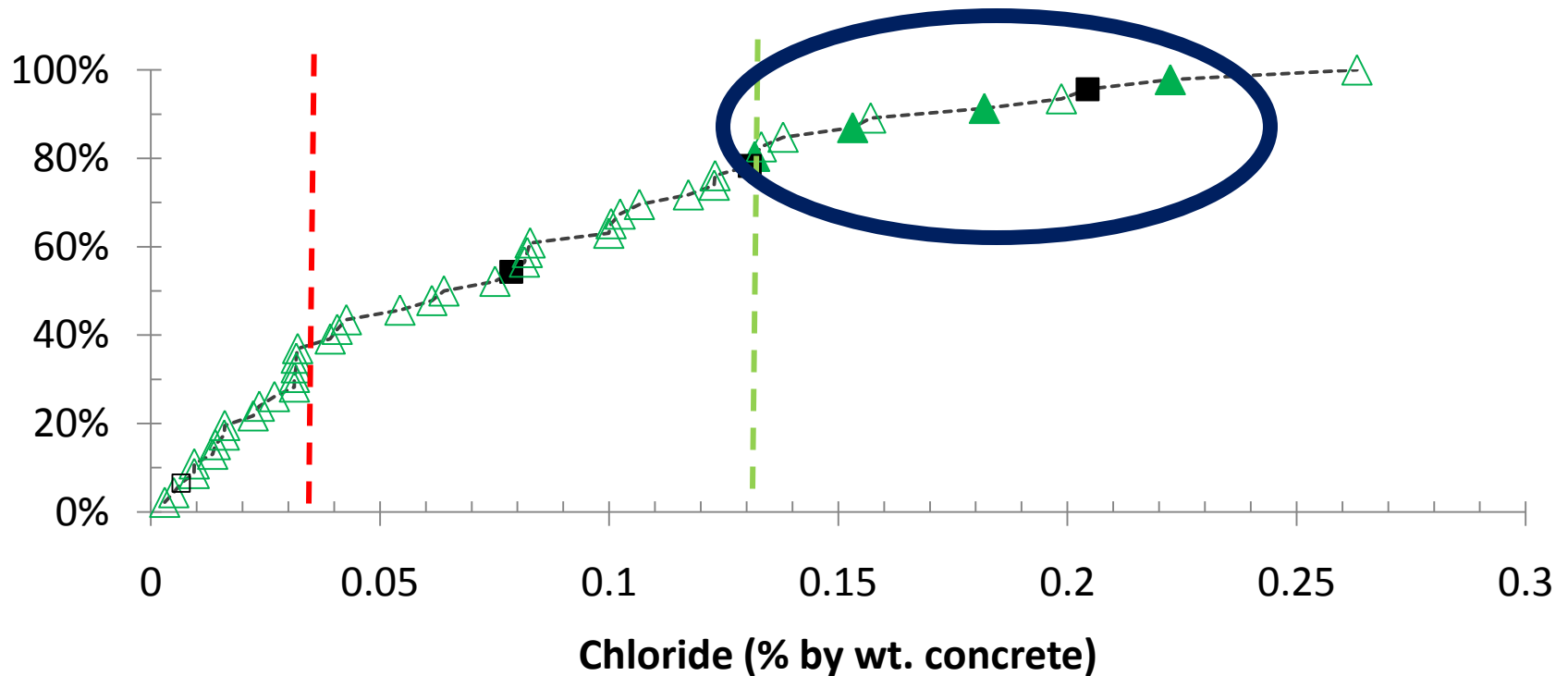


Effect of coating thickness





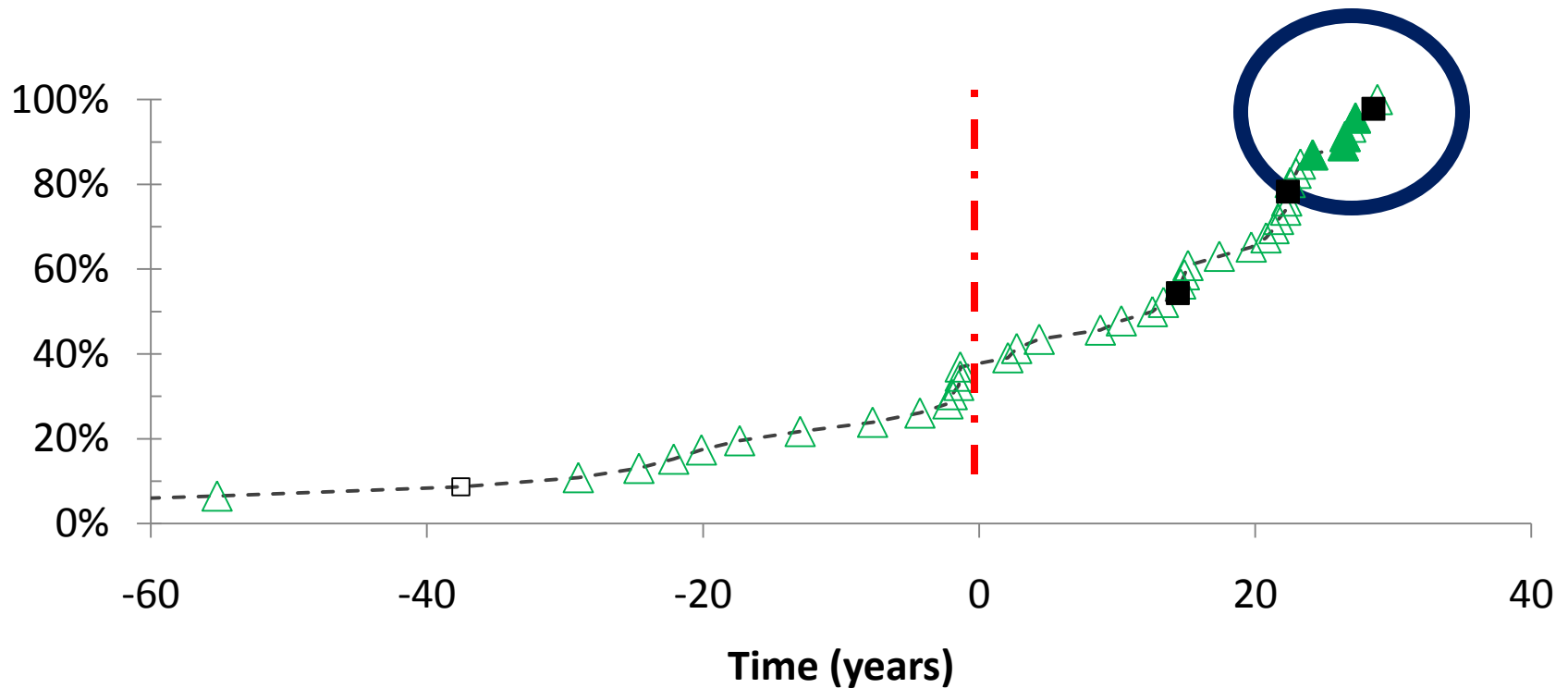
Effect of chloride level



- ▲ Epoxy-coated: active corrosion
- Uncoated: active corrosion
- △ Epoxy-coated: no active corrosion
- Uncoated: no active corrosion
- Cumulative distribution



Effect of time



△ Epoxy-coated: no active corrosion ▲ Epoxy-coated: active corrosion

□ Uncoated: no active corrosion ■ Uncoated: active corrosion

- - - Cumulative distribution



Conclusions from WV bridges 33 – 35 years old

- Good to excellent condition (33 – 35 years)
- Black bar decks were overlaid or otherwise rehabilitated at 18 to 21 years
- No delaminations where both mats epoxy-coated reinforcing steel
 - High chloride contents in the concrete
- Factors:
 - high chloride
 - low coating thickness
 - extended exposure to chloride concentrations above the black bar chloride threshold

2008 Laboratory study, Darwin et al.

- Short-term tests
 - the epoxy-coatings evaluated provide superior corrosion protection to the reinforcing steel.
- Reduced water-cement ratio improves the corrosion performance in uncracked concrete but has little effect in cracked concrete.



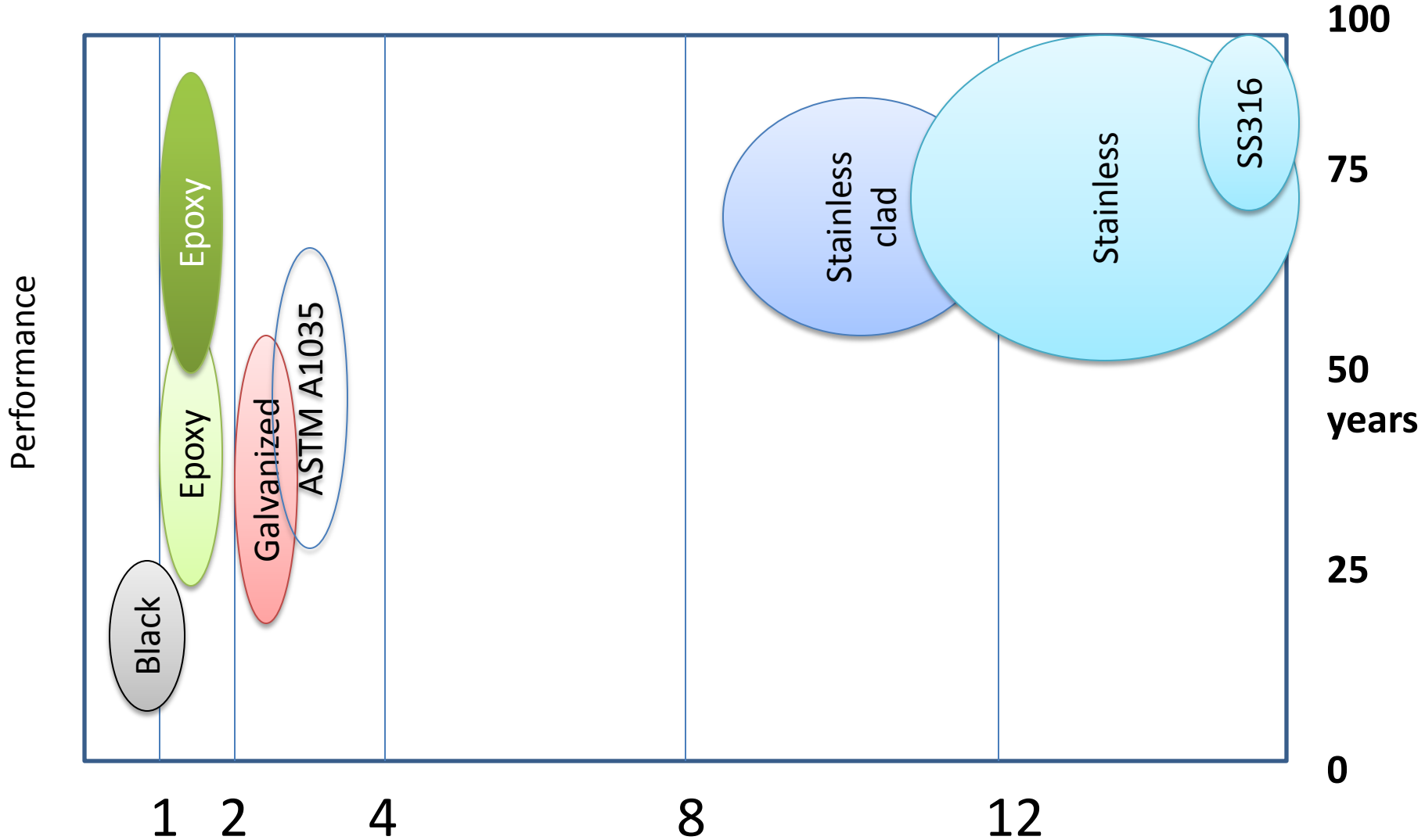
PROTECTION STRATEGIES

Questions

- What is the appropriate design life?
- Can I repair the structure?
- What can I afford?



Performance vs. Cost



EXAMPLES OF RECENT USE



Maryland 
State Highway Administration

Woodrow Wilson Bridge,
Virginia/Maryland



I-35 Minneapolis, Minnesota



Bridge of Honor, Ohio



Biloxi Bay Bridge, Mississippi



CHANGES TO SPECIFICATIONS

ASTM A775

Manufacturing specifications



Criteria	1980's	2007
Bar anchor profile	-	1.5-4 mil
Coating delay after blasting	< 8 hours	< 3 hours
Coating thickness	90 percent within 5-12 mil	7-12 mil (Nos. 3-5) 7-16 mil (Nos. 6-18)
Coating continuity	< 2 holidays per foot	< 1 holiday per foot
Coating flexibility	120 degree bend	180 degree bend
Cathodic disbondment test	-	Yes

D3963 Field Handling



Criteria	1980's	2007
Permissible damage	No patch for damage $< 0.1 \text{ in}^2$ Maximum damage level 2 percent	All damages must be patched Maximum damage level 1 percent
External storage protection	-	Yes, if > 2 months

WHAT WE HAVE LEARNT ABOUT CORROSION MECHANISMS

Black bars

Salts



ANODE: $\text{Fe} \rightarrow \text{Fe}^{++} + 2\text{e}^-$

Plain reinforcing

e^- e^- e^- e^-

e^-

**Electron
Flow**

e^-

e^-

e^-

e^-

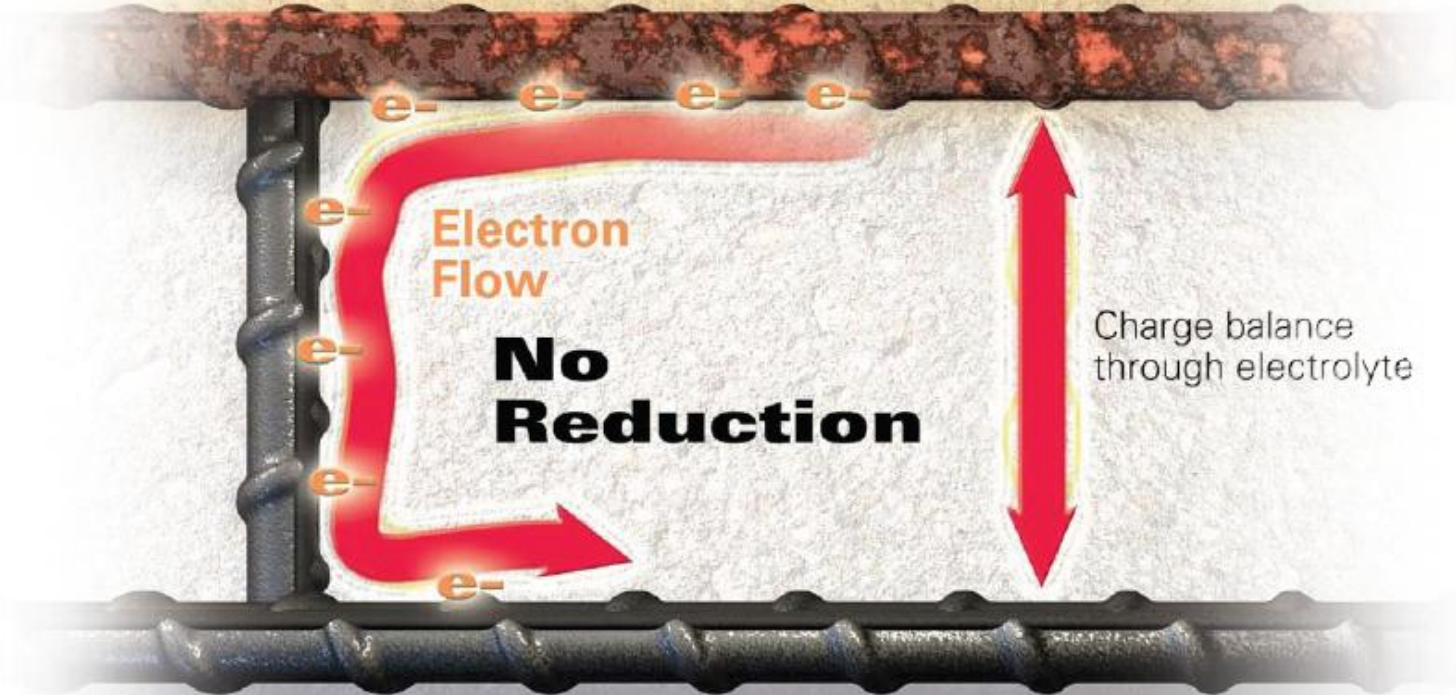
**No
Reduction**

Charge balance
through electrolyte

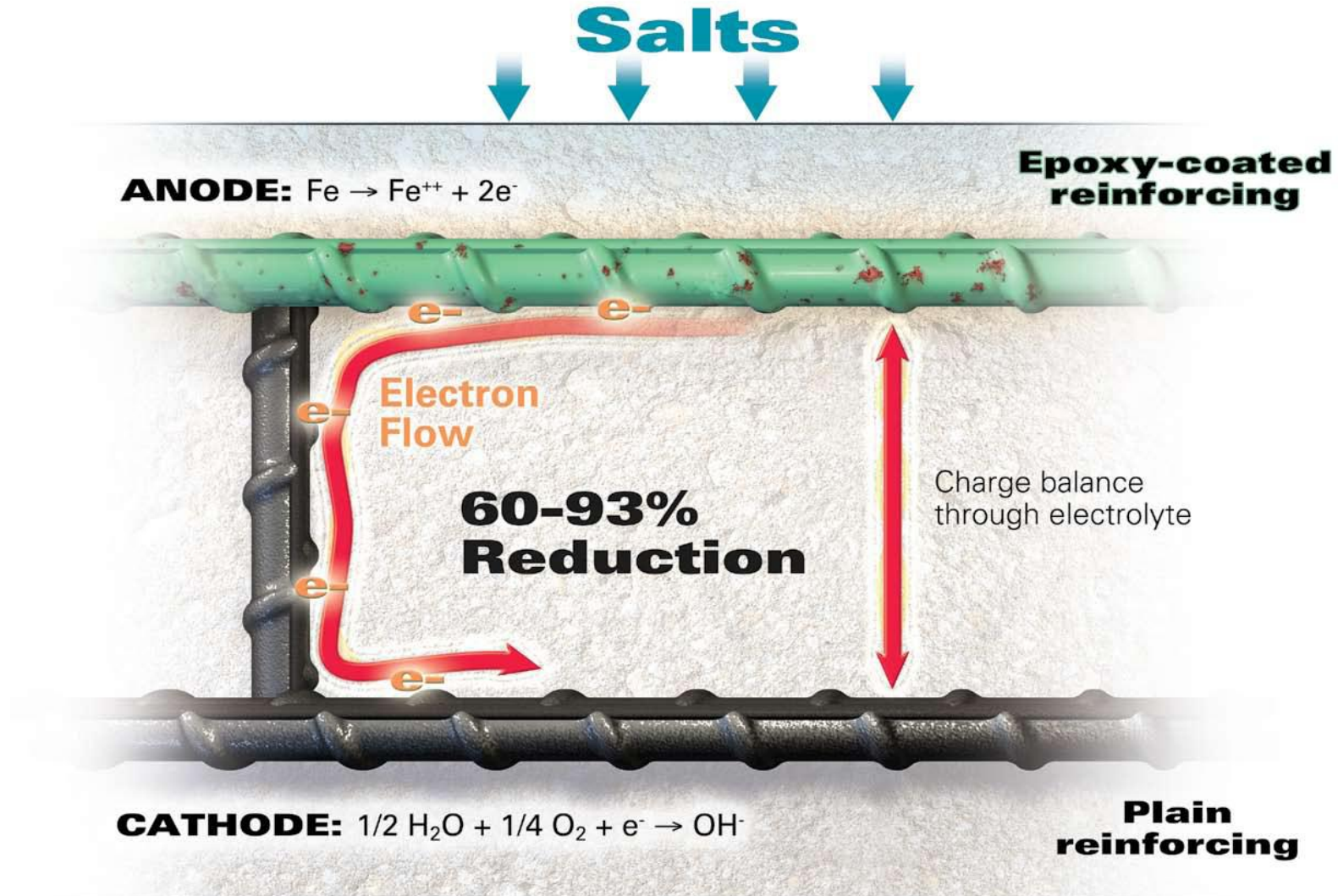


CATHODE: $\frac{1}{2} \text{H}_2\text{O} + \frac{1}{4} \text{O}_2 + \text{e}^- \rightarrow \text{OH}^-$

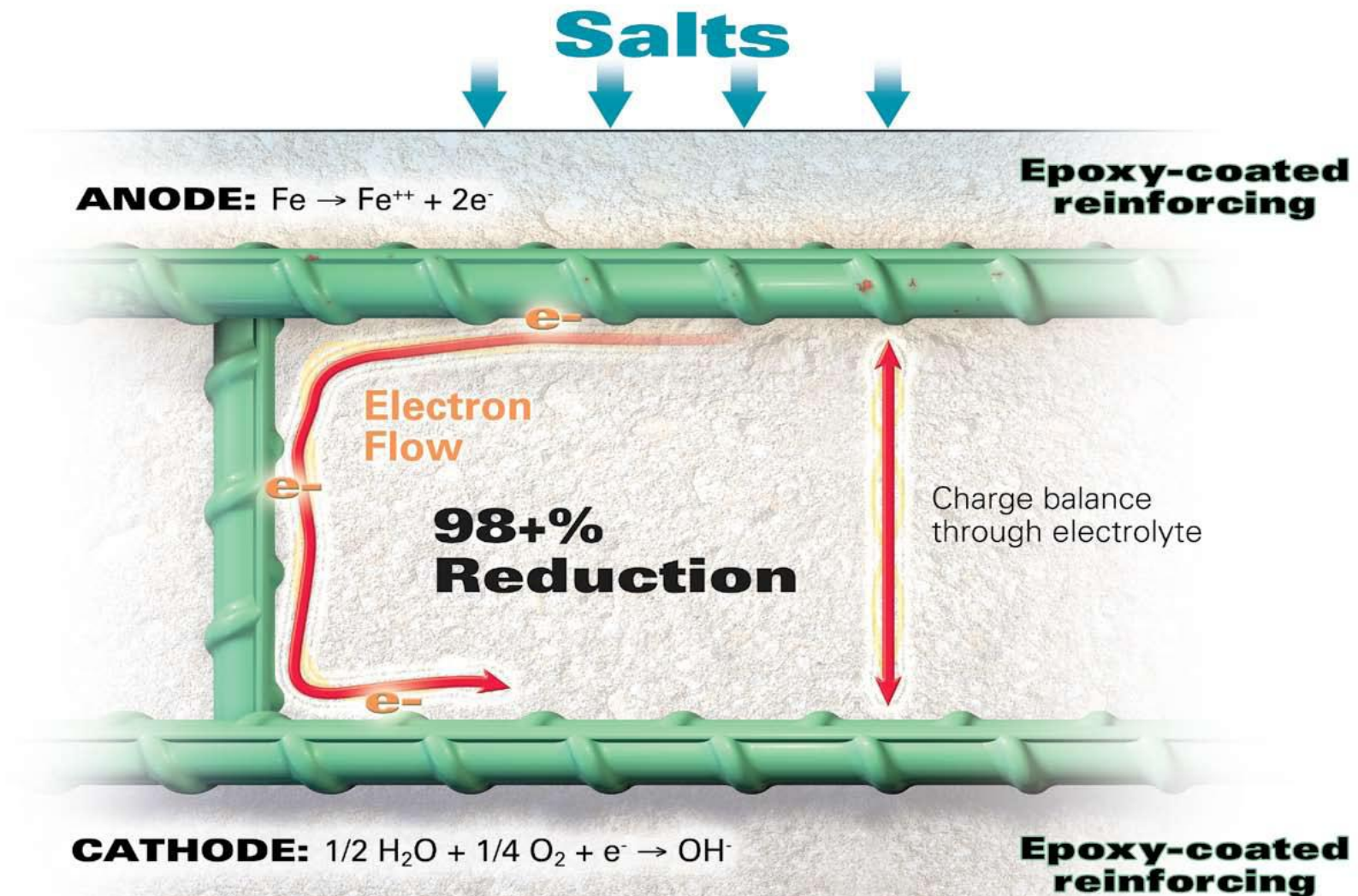
**Plain
reinforcing**



Epoxy-Coated Bars - Top mat only with deliberate damage



Epoxy-Coated Bars - Both mats with deliberate damage



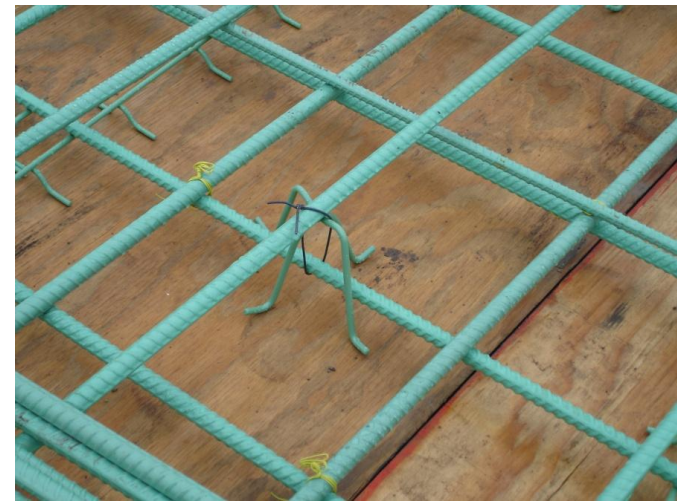
What has been learnt

- The cathodic reaction is important
 - Use ECR on both top and bottom mats coated to reduce cathodic area
 - Most agencies are now doing this
 - But some are not...
- Even damaged bars perform considerably better than black bars

MANUFACTURING AND QC PROCESS

Plant Certification Program

- CRSI in 1991
- *...capable of producing epoxy-coated steel reinforcing bars in accordance with industry standards and recommendations.*
- Almost all plants are certified
- Required by 21 DOT's

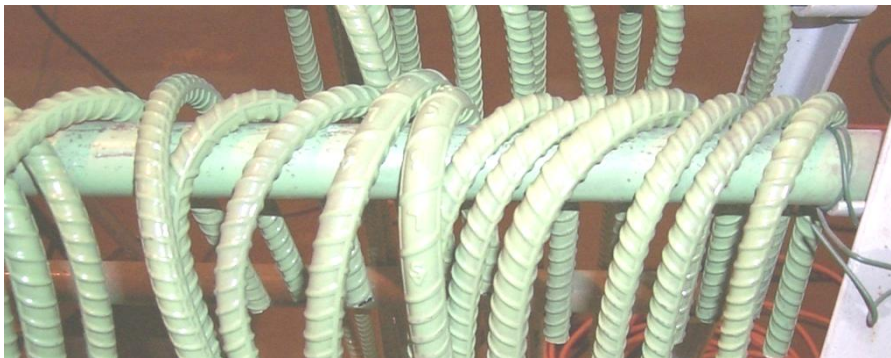
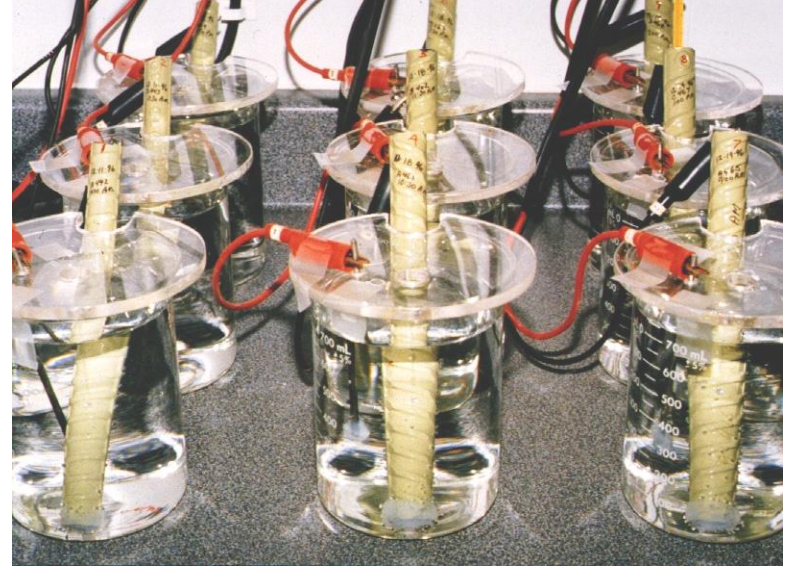
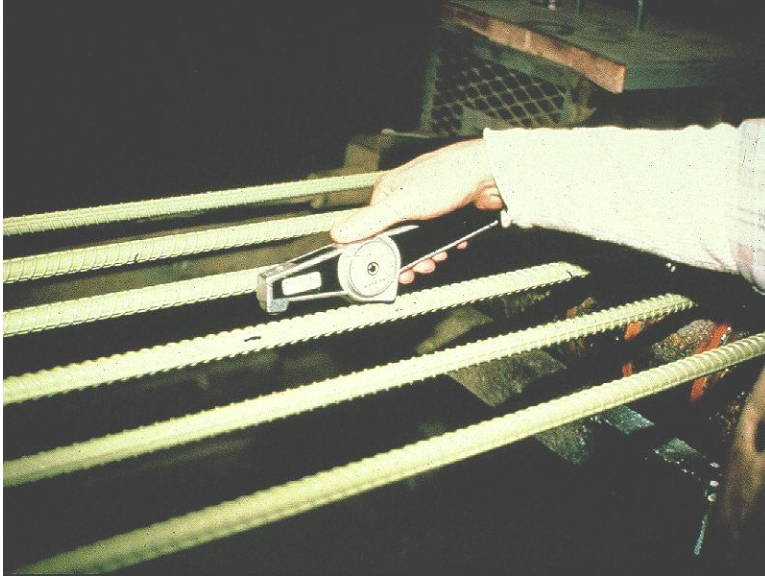


Program activities

- QC inspector
 - QC equipment
 - Equipment
 - Cleaning
 - Coating
 - Handling
 - Testing
 - Records
-
- Unannounced inspections
 - QC competence



Thickness, cathodic disbondment, flexibility, storage



FIELD HANDLING

Understand the material

- Improper handling on ANY MATERIAL may reduce its performance
- Any material can be misused or misapplied





Proper loading



Good lifting practices



Appropriate Storage



Covering to protect from UV



Repair ALL damage



Use non-metallic vibrator heads

Improper handling

- Dragging
- Lifting using chains
- Flexing bundles while lifting
- Using non-approved patching material
- Leaving uncovered in storage for more than 30 days
- Using uncoated bar supports
- Using uncoated tie wire
- Flame cutting
- Using unprotected concrete vibrator



SUMMARY AND CONCLUSIONS

Conclusions

- ECR used in 65,000 bridge structures
 - Still excellent performance
- 2nd most common strategy to prevent reinforcement corrosion
- Many favorable field and laboratory studies
 - Even Gen 1 product provided substantial increases in design life
- Cost/performance better than other materials

Materials have changed

- Improved manufacturing specifications
 - ASTM A775
- Improved manufacturing
 - CRSI certification
- Improved field handling
 - ASTM D3963
- Improved concrete technology
- Improved design
 - Both mats using epoxy-coated bars



EPOXY INTEREST GROUP

www.epoxyinterestgroup.org

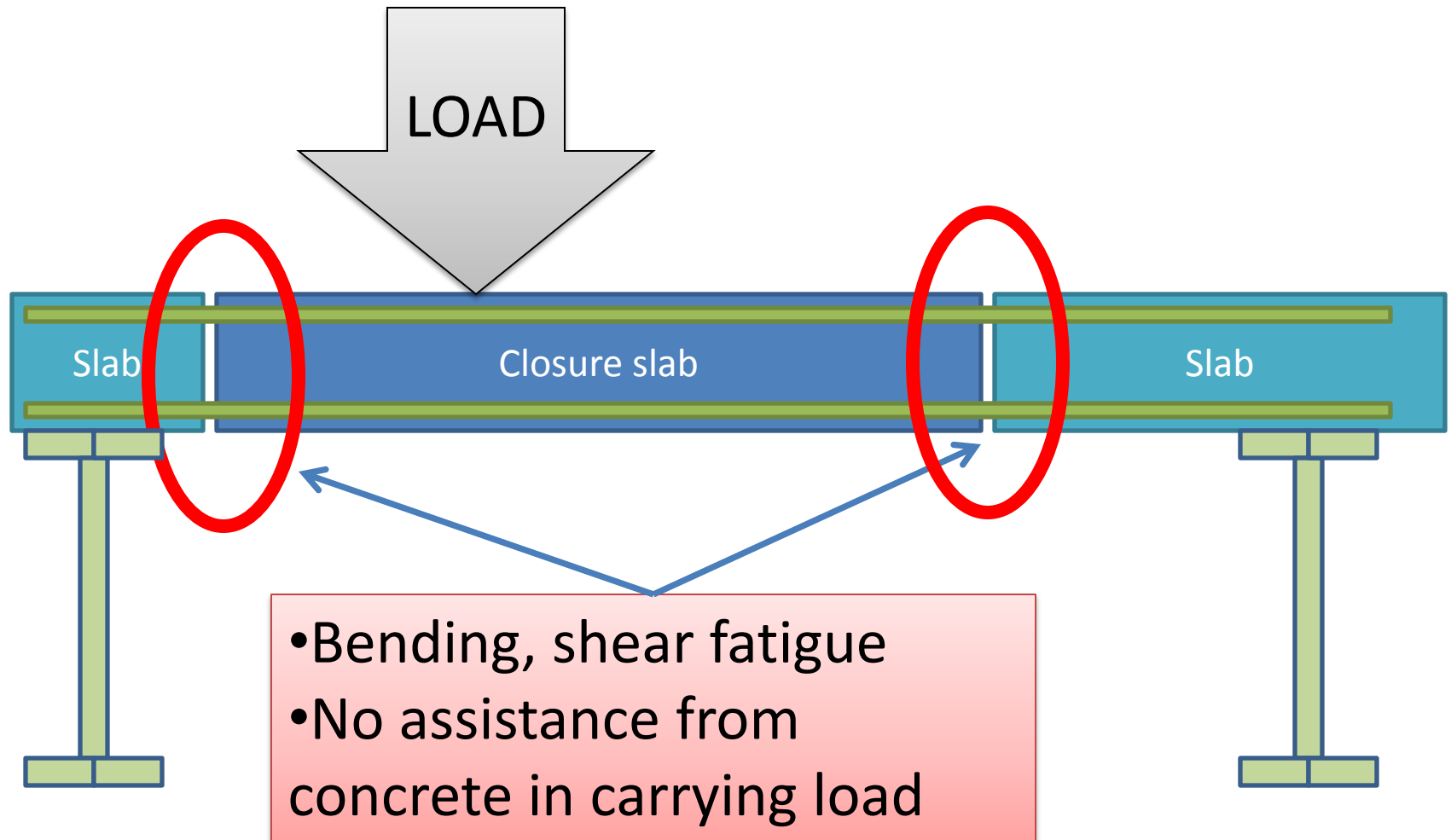
THOUGHTS ON I-81

2009, I-81 Weyers et al.

- What else may have gone wrong?
 - Coating thickness
 - Damage at jobsite
 - Onsite bending
 - Steel performance
 - Steel cracking
 - fatigue



Loads on Closure Pour





EPOXY INTEREST GROUP

Comparison with Galvanized

- Outperformed by ECR in almost every corrosion test
- Only used in 950 decks
- Not available from certified plants
- 40 ft lengths or less
- Quality depends on the steel chemistry
- Bars may become brittle
 - May need to consider prebending

Comparison with Stainless Steel

- Performance depends on steel chemistry
- Up to five times the cost of black bars
 - Increase total structural cost by 10% or more.
- Price volatility
- Uses limited mined materials
- Limited supply
- Need to ensure that they don't become contaminated with black bars
- May require pickling
- No recognized handling specifications

Comparison with ASTM A1035

- No long-term performance data
- Outperformed by ECR in almost every corrosion test
- Single source, proprietary supply
- Not ductile
- Substantially more expensive



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