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

EIG CRSI
EPOXY INTEREST GROUP

Epoxy Bar Use

- 2nd most common strategy to prevent reinforcement corrosion
- 700,000,000 ft^2 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

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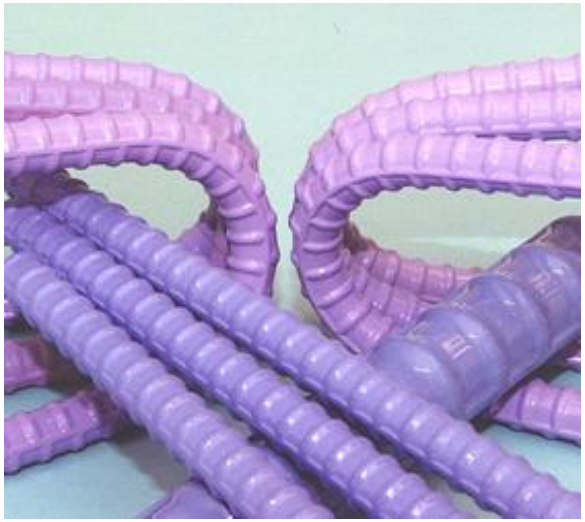
Research and Performance

- 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

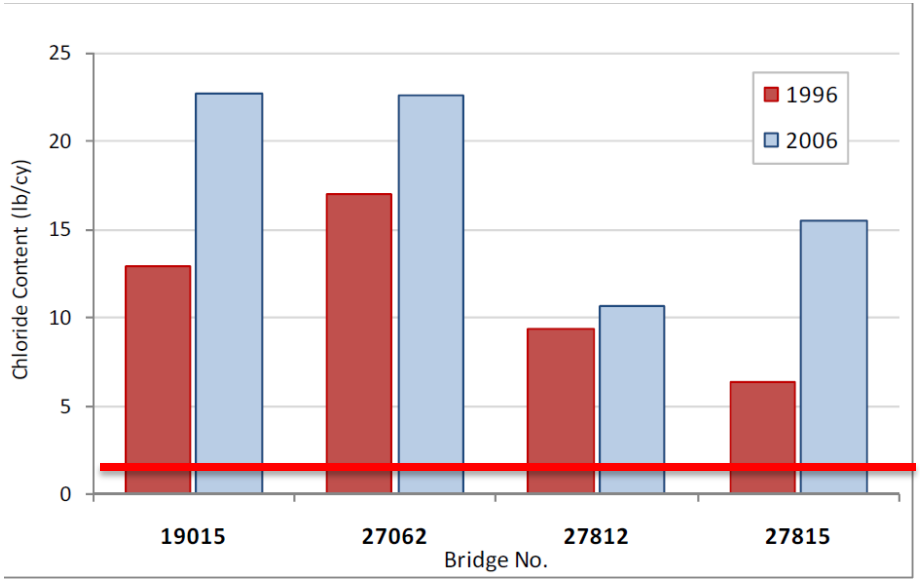
South Dakota Department of Transportation 2009

- 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.***

South Dakota DOT
Department of Transportation

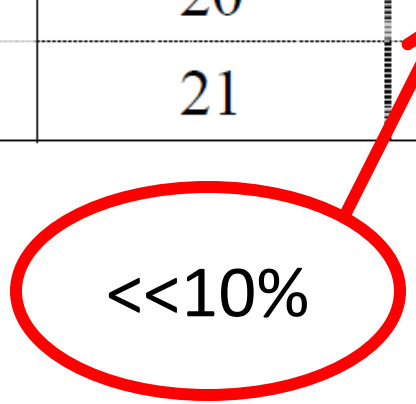
Minnesota Department of Transportation 2008

- 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



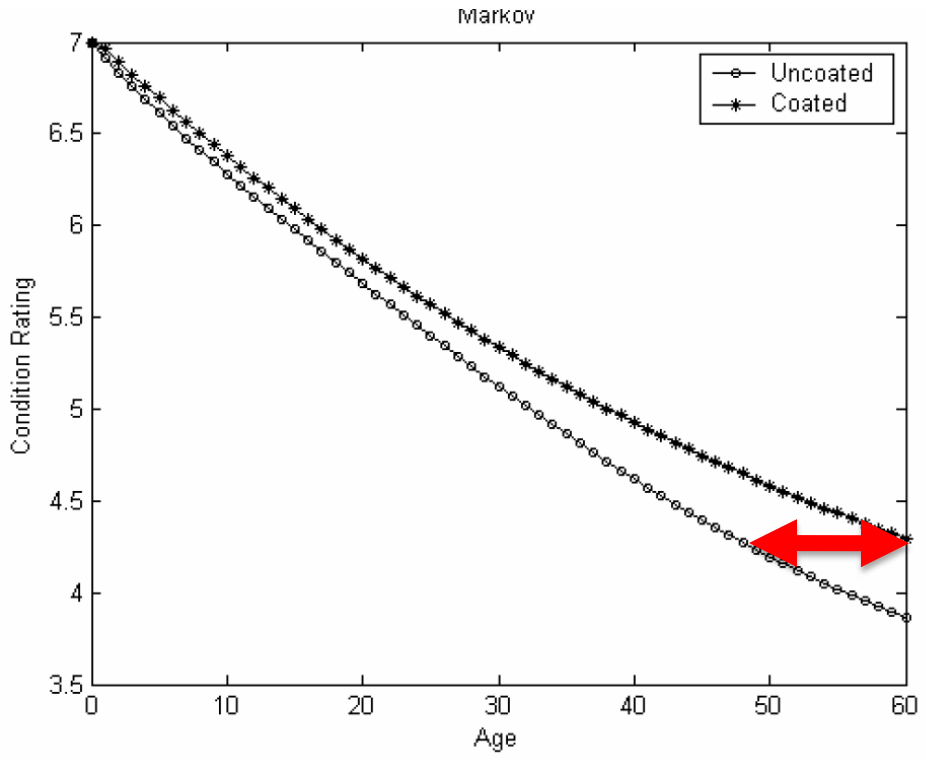
Delaminations in 1996 and 2006

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%



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.”**

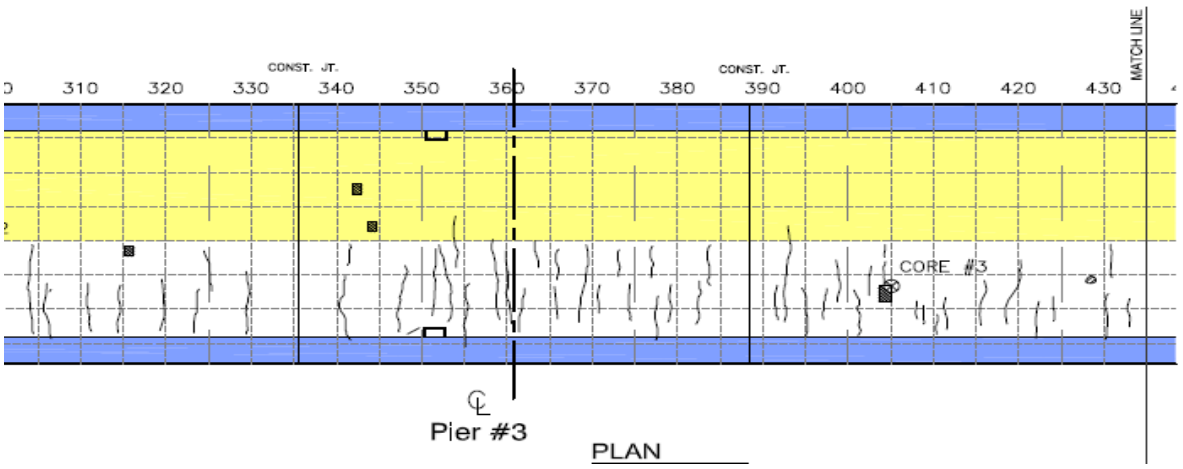


2009 West Virginia Study

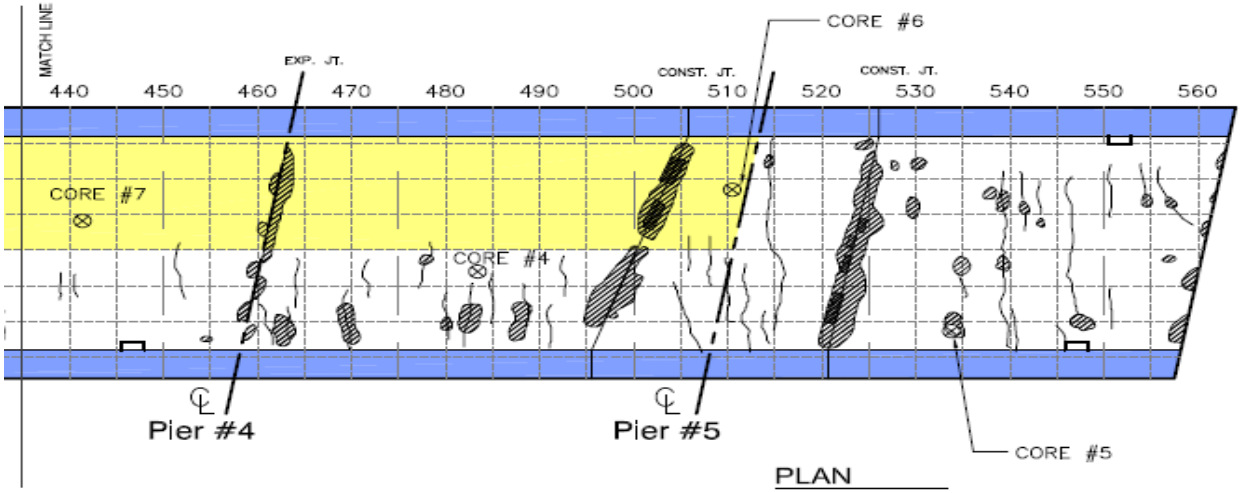
Lawler and Krauss

- 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

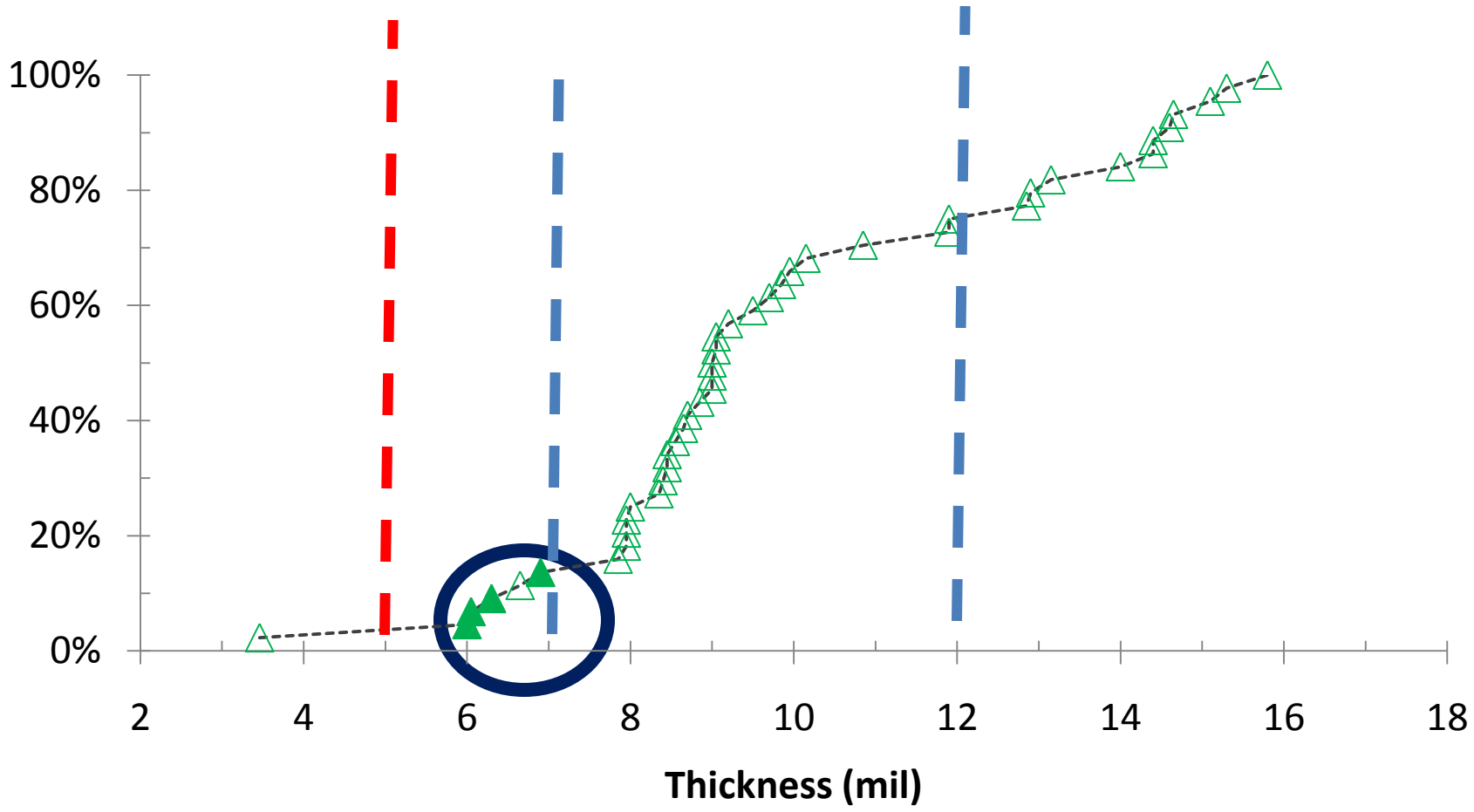


Epoxy-coated bars

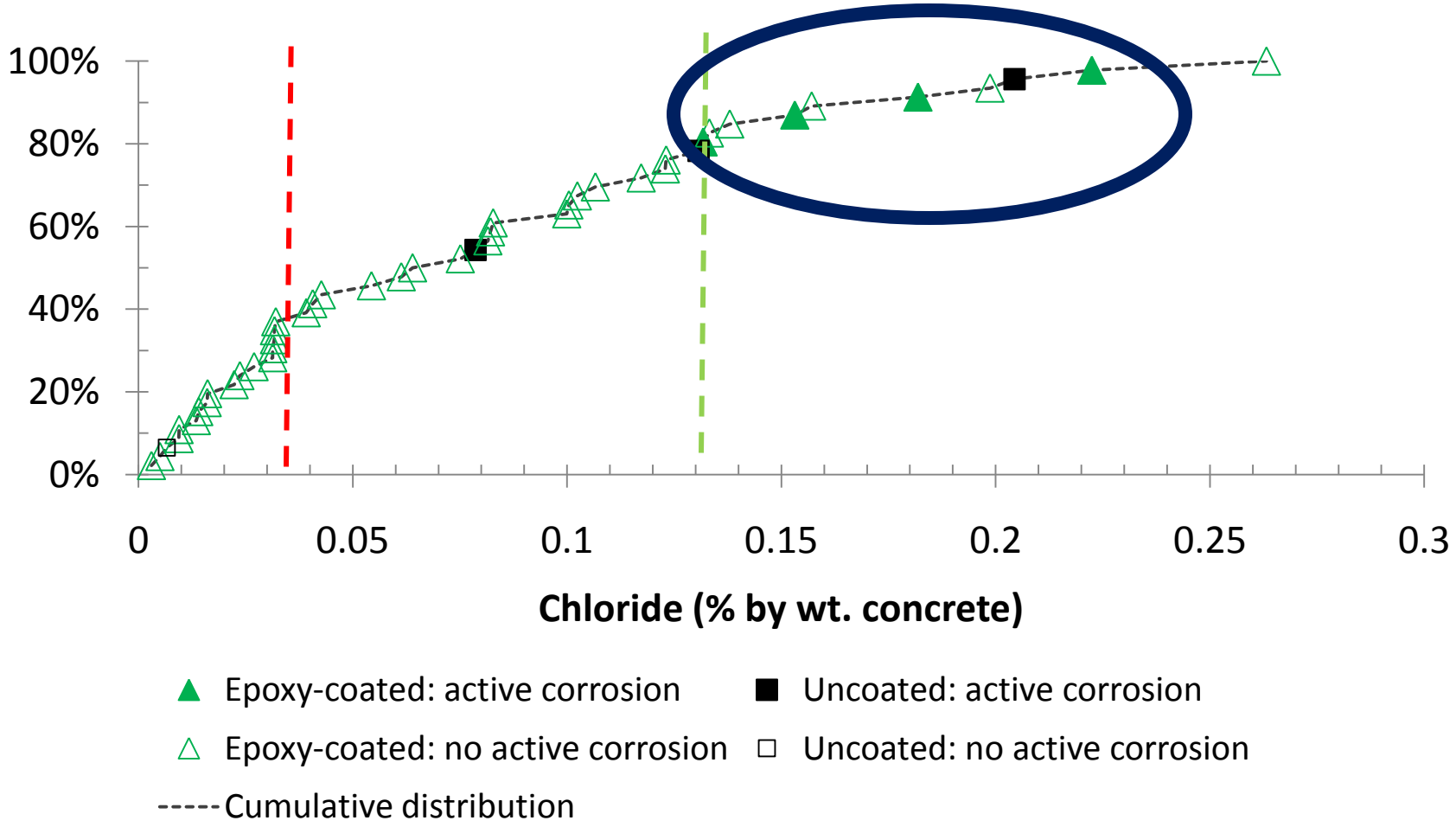


Black Bars

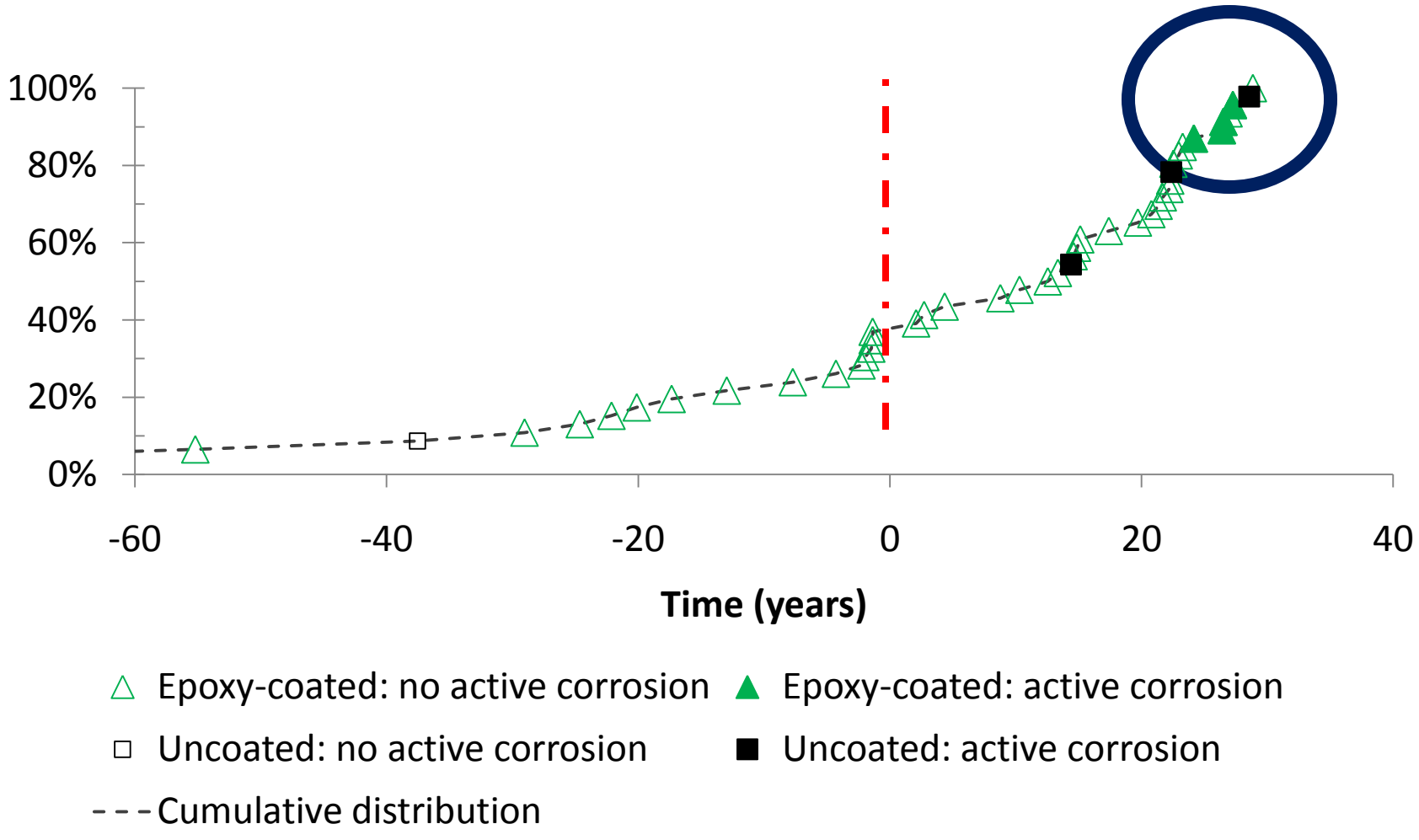
Effect of coating thickness



Effect of chloride level



Effect of time



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

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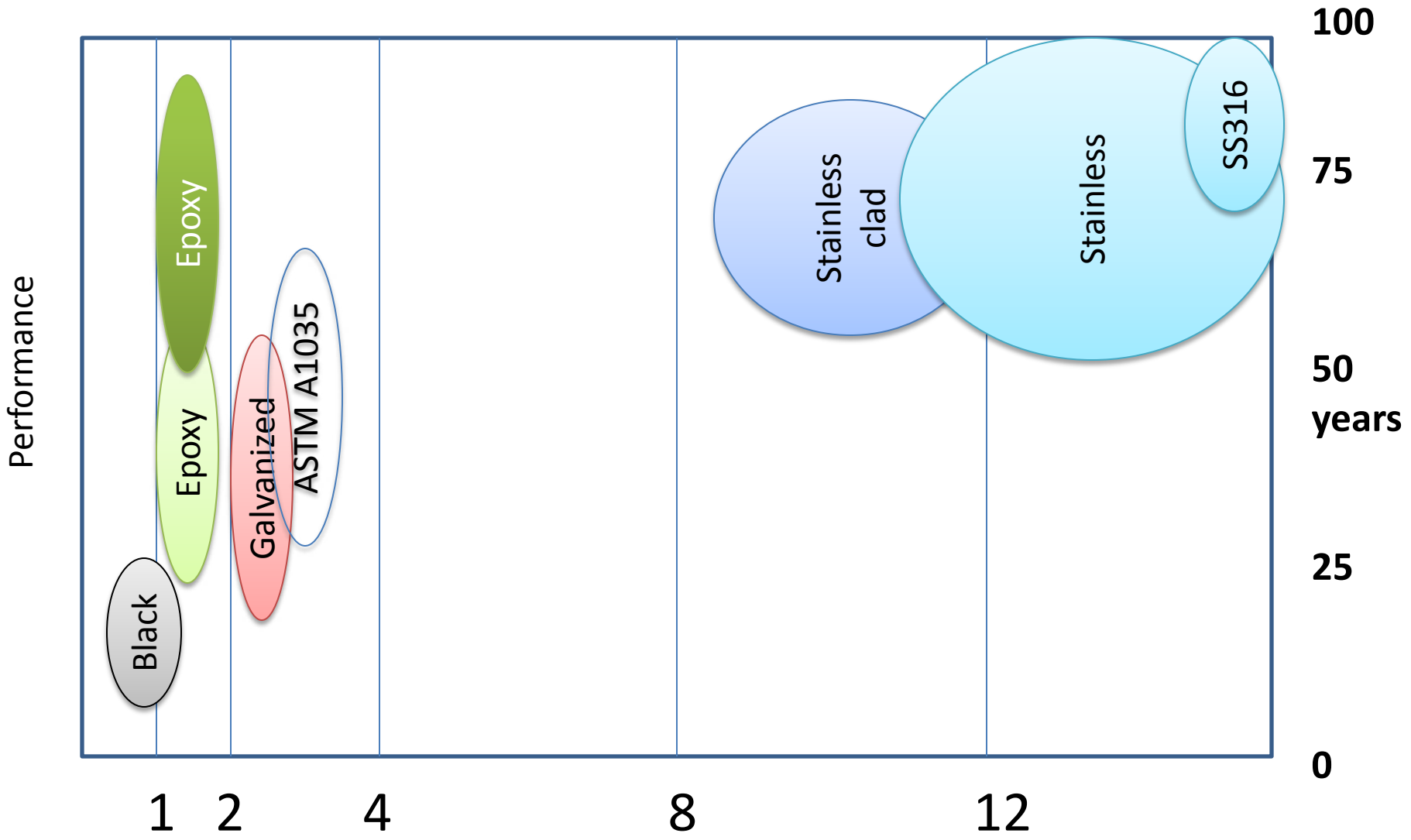
EPOXY INTEREST GROUP

Questions

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

Performance vs. Cost



EXAMPLES OF RECENT USE

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Woodrow Wilson Bridge,
Virginia/Maryland

I-35 Minneapolis, Minnesota

Bridge of Honor, Ohio

Biloxi Bay Bridge, Mississippi

CHANGES TO SPECIFICATIONS

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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 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

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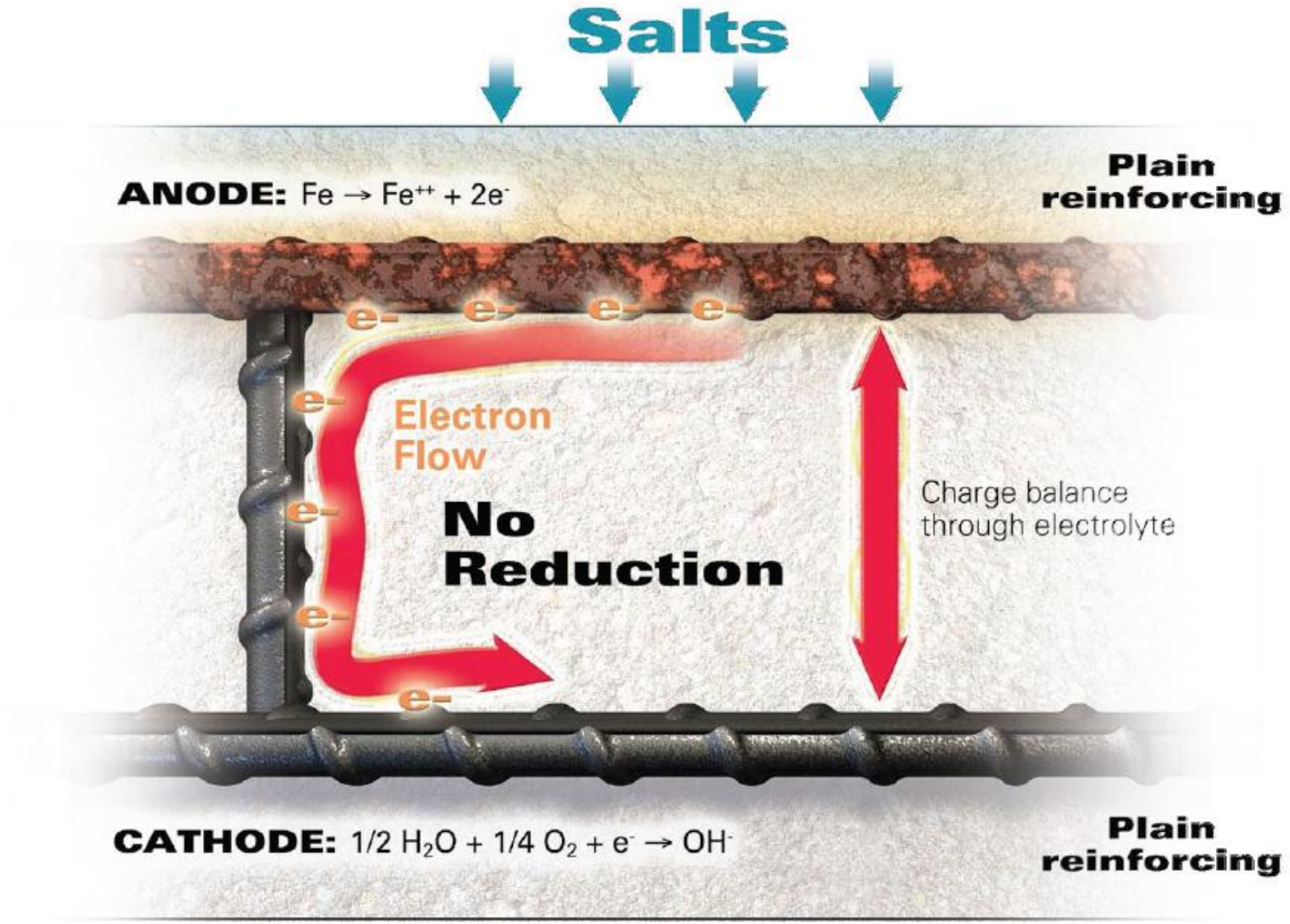
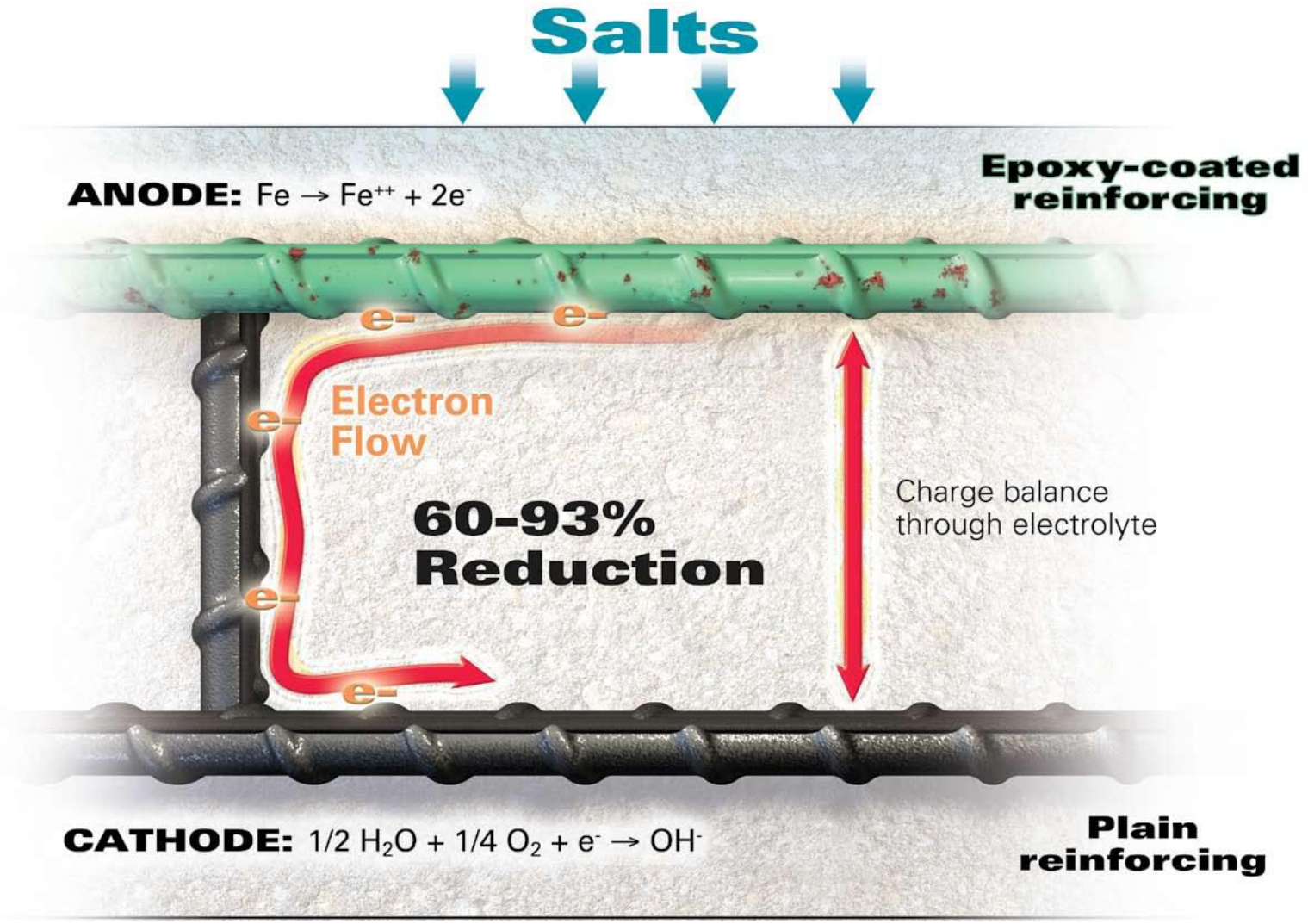
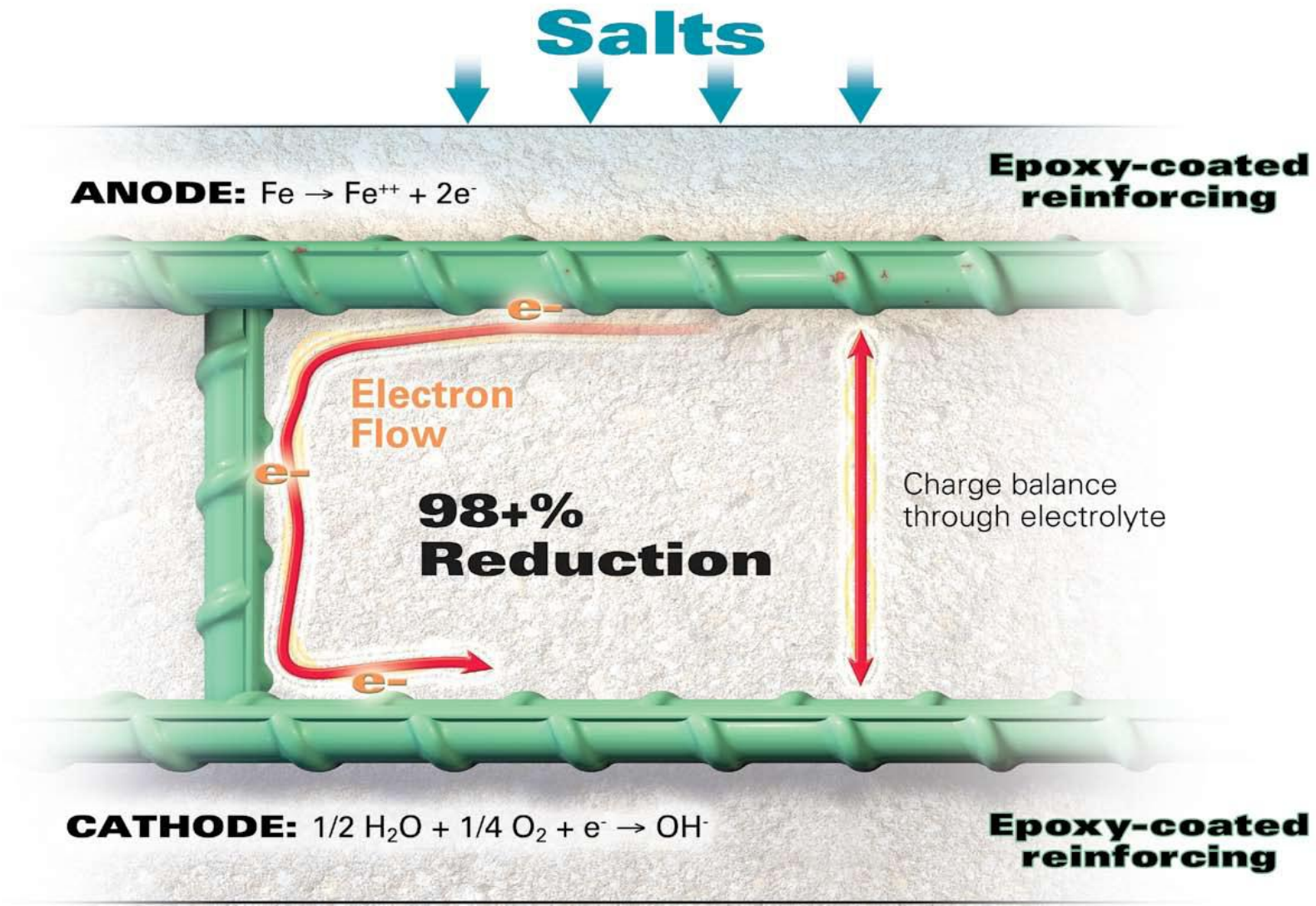
Black bars


Salts
ANODE: Fe → Fe++ + 2e-
Plain reinforcing
e-
e-
e-
e-
e-
e-
e-
e-
Electron Flow
No Reduction
Charge balance through electrolyte
CATHODE: 1/2 H2O + 1/4 O2 + e- → 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

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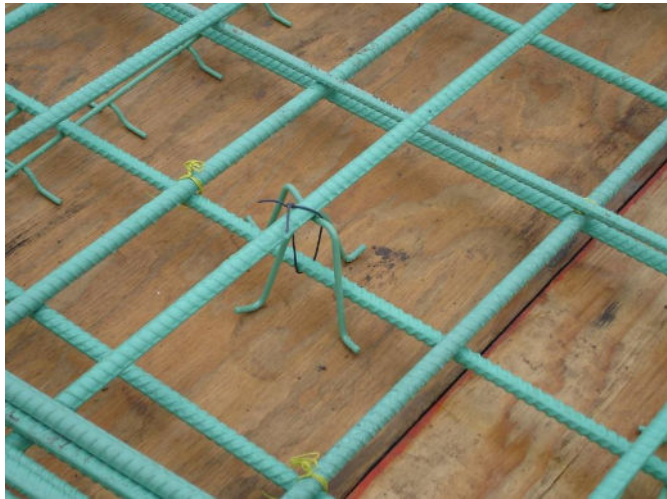
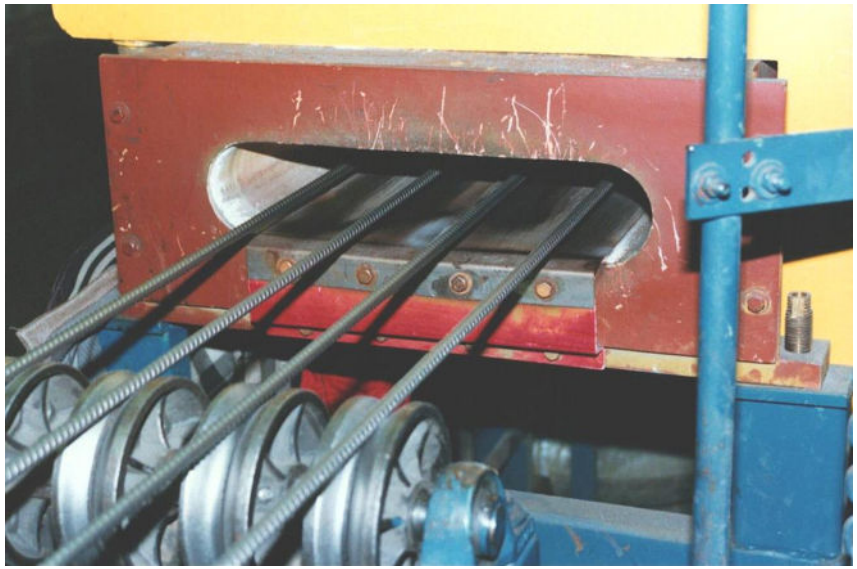
Plant Certification Program

- 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



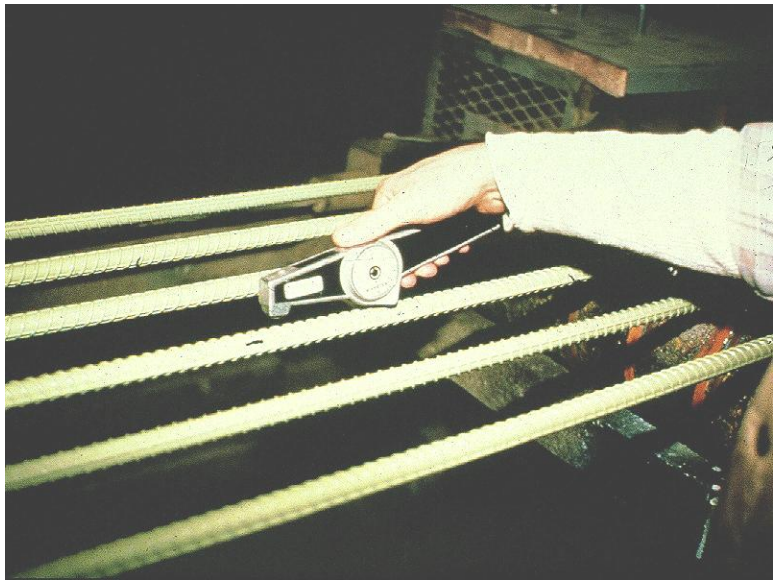
Program activities

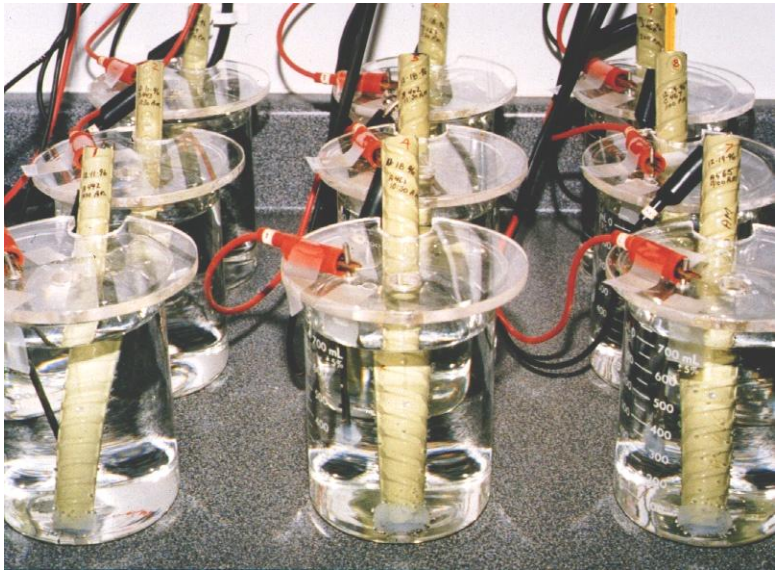
- QC inspector
- QC equipment
- Equipment
- Cleaning
- Coating
- Handling
- Testing
- Records

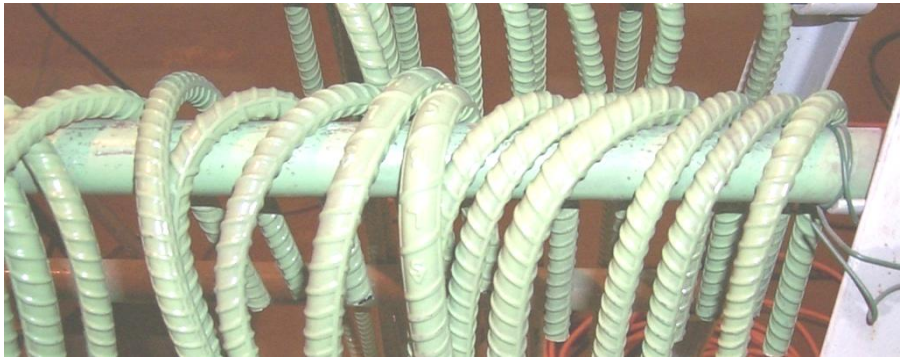


- Unannounced inspections
- QC competence

Thickness, cathodic disbondment, flexibility, storage







FIELD HANDLING

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Understand the material

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

Proper loading

Epoxy-Coated Bar
DO'S

Good lifting practices

Epoxy-Coated Bar
DO'S

Appropriate Storage

Epoxy-Coated Bar
DO'S

Covering to protect from UV

Epoxy-Coated Bar
DO'S

Repair ALL damage

Epoxy-Coated Bar
DO'S

Use non-metallic vibrator heads

Epoxy-Coated Bar
DO'S

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

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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

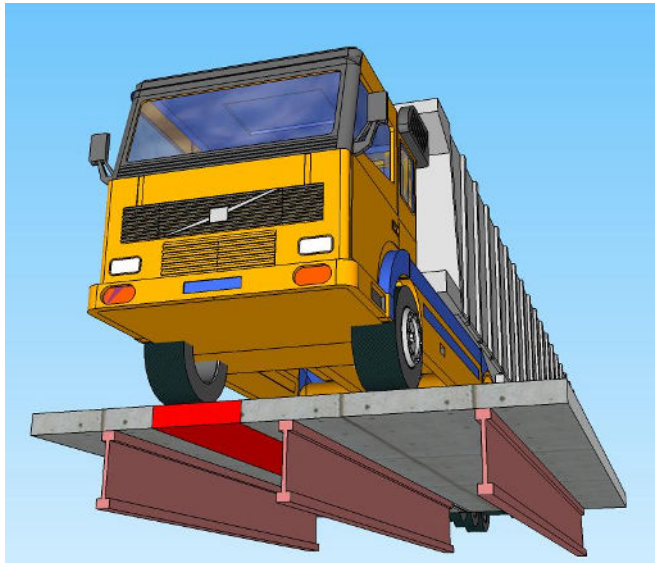
EPOXY INTEREST GROUP

www.epoxyinterestgroup.org

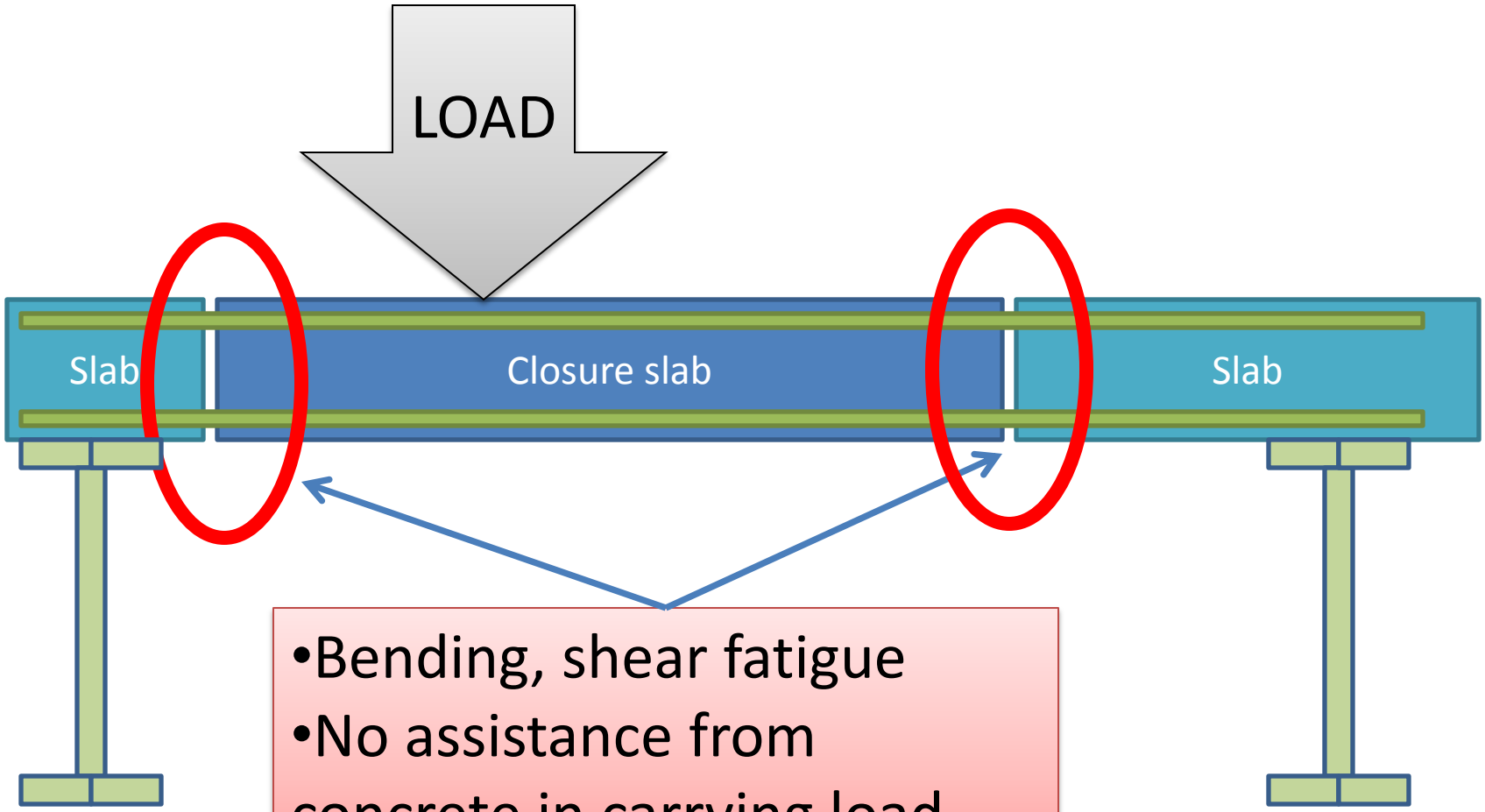
THOUGHTS ON I-81

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



- Bending, shear fatigue
- No assistance from concrete in carrying load

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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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