Reducing Concrete Damage through Corrosion Resistant Reinforcing: an Overview of 40 years of Research and Practice

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October 30, 2012

Abstract

- *Over the past 40 years, substantial research has been conducted into reinforcing materials and coatings to reduce corrosion damage of concrete structures. This paper will present information on research and modifications to fusion-bonded epoxy-coated steel during this period and compare its performance in recently completed tests and extensive data analysis with that of other products.*

Epoxy Bar Use

- 2nd most common strategy to prevent reinforcement corrosion
  - Following increased concrete cover
- 850,000,000 ft^2 of decks
  - >70,000 bridges in the US alone
  - ~600,000 ton/yr or 10 - 15% of all rebar in NA
- USA, Canada, Middle East, Japan, and India

1970's use of deicing salts

- "The premature deterioration of concrete bridge deckings, in 5-10 years, has become a major problem during the past decade.
- ...caused by chloride ions from deicing materials.
- Use of deicing materials,...has increased substantially during the past decade."

1974 National Bureau of Standards

- Clifton, Beeghly, Mathey
- 47 coating materials (15 epoxies)
- *Epoxy coating should adequately protect steel reinforcing bars from corrosion with acceptable bond and creep characteristics*

NIST
National Institute of Standards and Technology
U.S. Department of Commerce

First Bridge 1973
Pennsylvania

1983 FHWA-non-specification epoxy-coated bars

- Horrible bars
  - 3-year-old bars
  - >25 holidays/ft
  - up to 0.8% damage
  - failed bent test
  - coating easy to peel
  - bars stored outdoors 2 year
  - 15lb/cy chloride in concrete
  - 1"cover, w/c 0.53
- Deemed "very effective",
  - Significantly reduced corrosion, esp. when used double mats.
  - 12 to 46 times less current than black bars

"if its green its good"

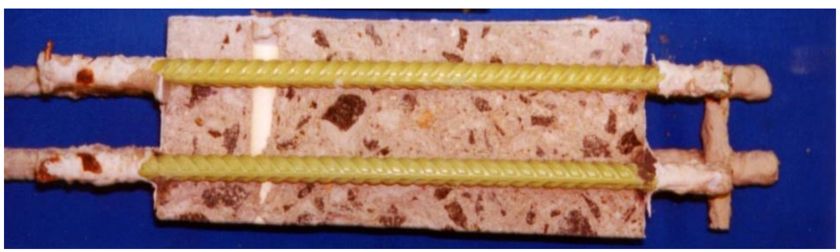
DEPARTMENT OF TRANSPORTATION UNITED STATES OF AMERICA

1988 KCC Research

- 3-year evaluation of bent and straight bars from 7 suppliers
  - Performed well during 1.35 years of southern exposure
  - During a subsequent 10.5 months water ponding, bars from two sources remained passive while many bars from other sources started to corrode
  - *The technology of epoxy-coated rebars, as practiced in North America, is flawed*

1991 WJE Evaluations

- Some provide high electrical resistance
- Some coatings are inferior and provide low electrical resistance



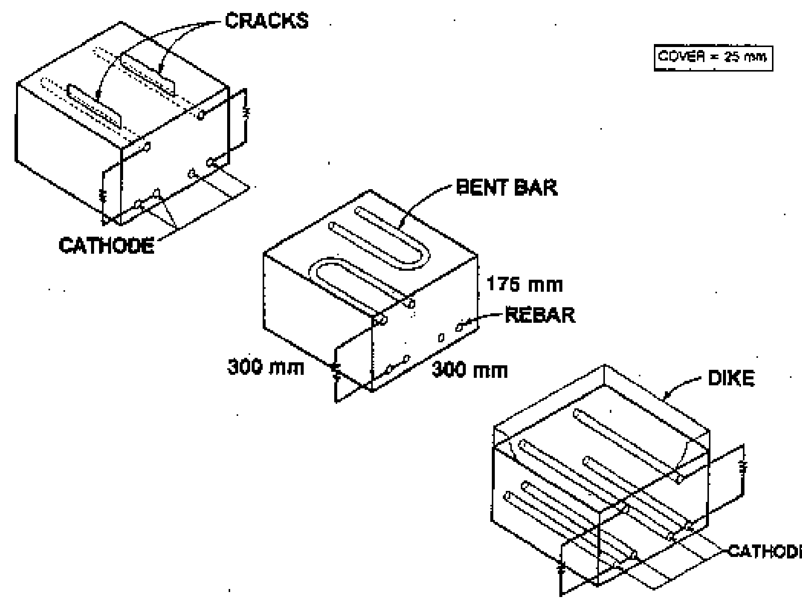
Epoxy performance depends on manufacture

1991 CRSI Voluntary Certification Program for manufacturing

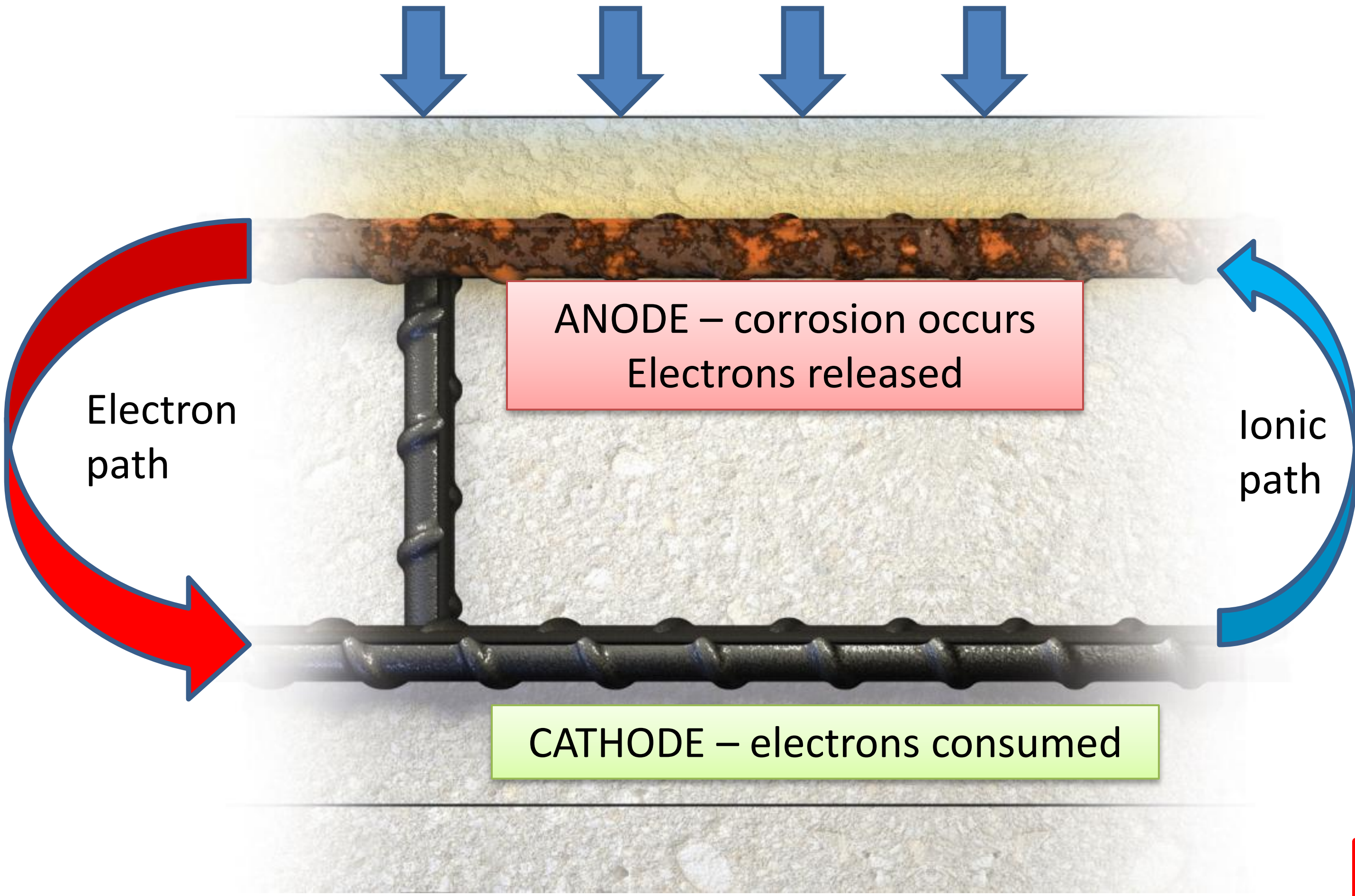
CELEBRATING 20 YEARS
EPOXY COATING PLANT CERTIFICATION
CRSI
1991-2011
CONCRETE REINFORCING STEEL INSTITUTE ™

1998 New Breeds of Reinforcing Bars

- McDonald, Sherman, Pfeifer
- Screening test: 33 organic coated, 14 ceramic, inorganic and metallic coated, 10 solid types
- Concrete test: 10 type of bars
  - Epoxy coated bars
  - Galvanized
  - Zinc-alloy clad
  - Copper clad
  - Type 304 SS
  - Type 316 SS

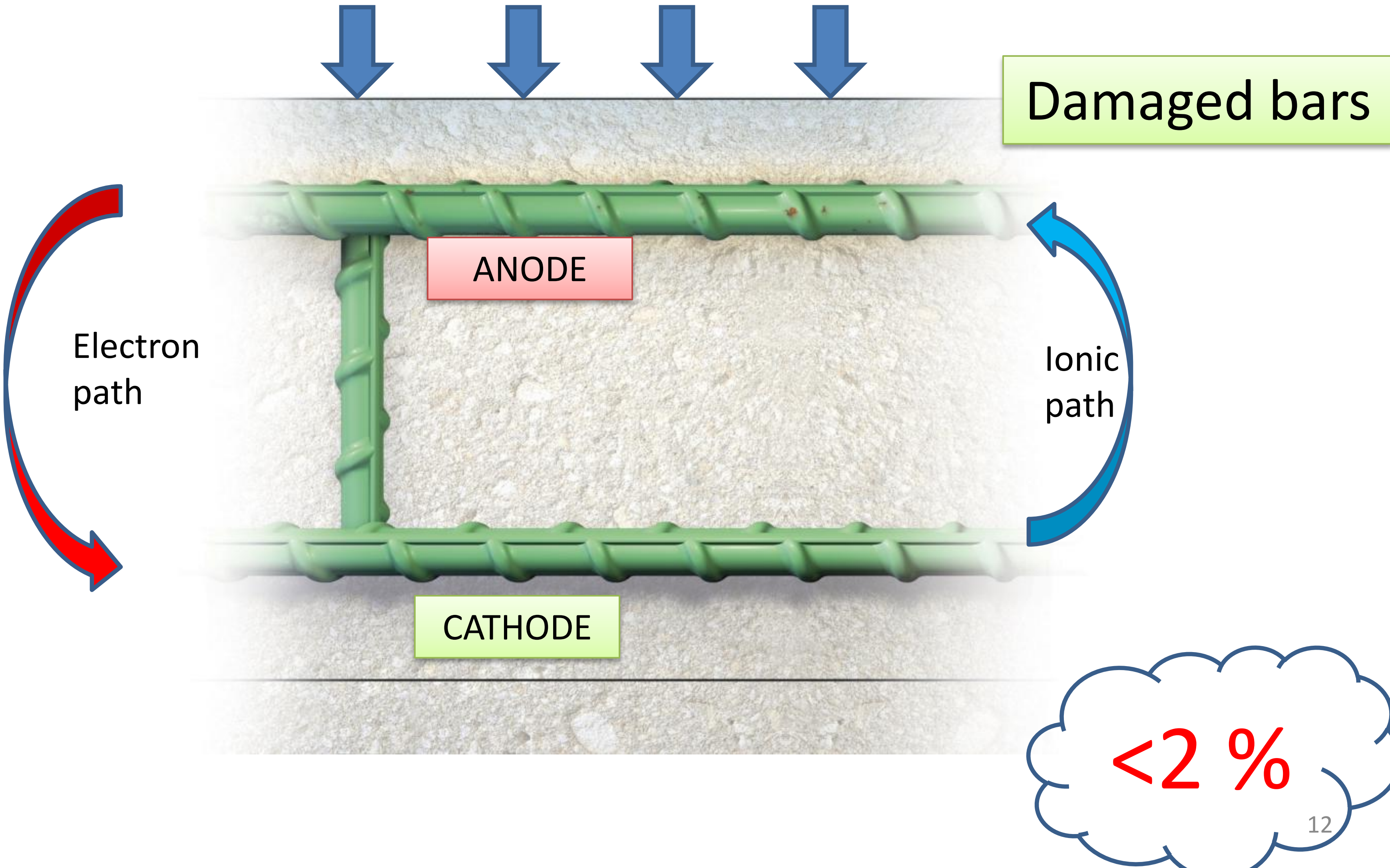


Black Bars in Bridge Deck



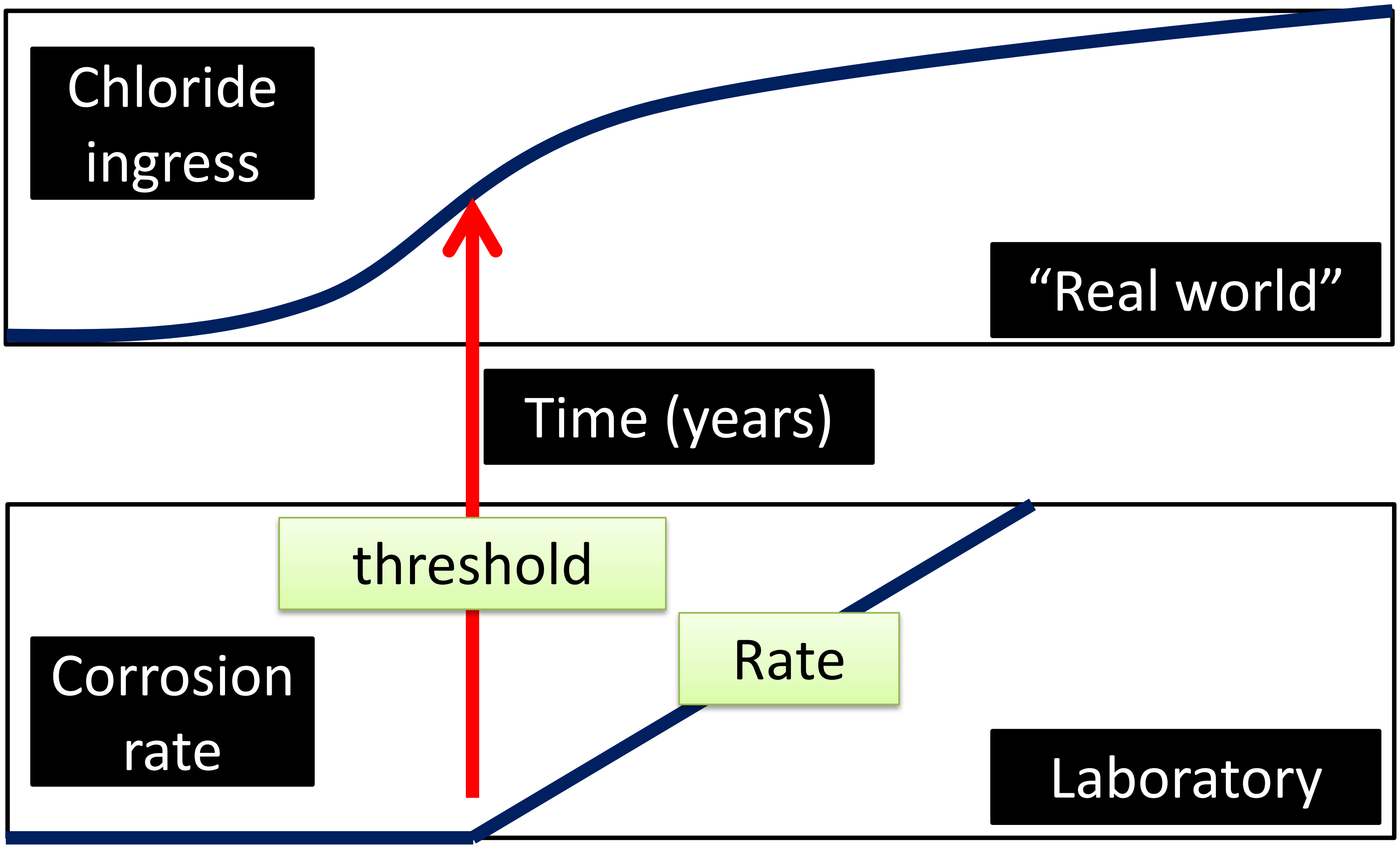
100%

Epoxy-coated bars



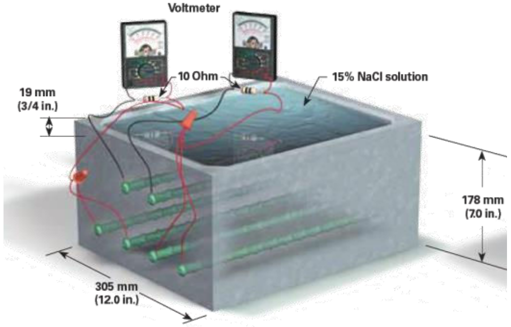
UNIVERSITY OF KANSAS STUDIES

2010 – University of Kansas

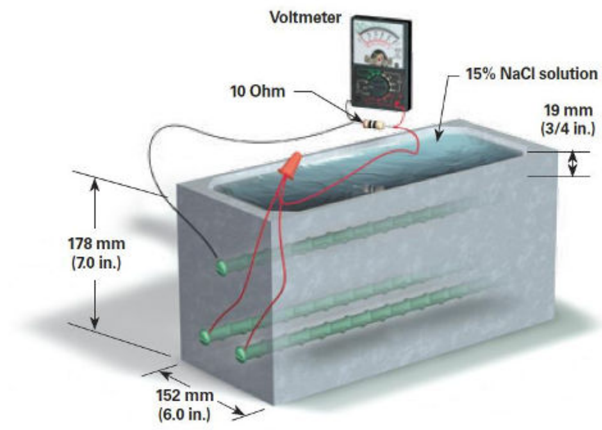


2010 – University of Kansas

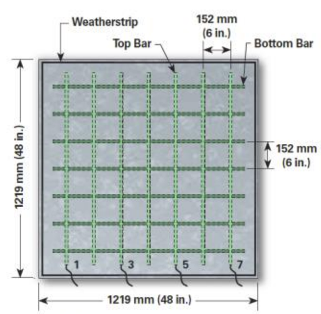
- Cracked and uncracked concrete
- Long term testing
- Damaged bars



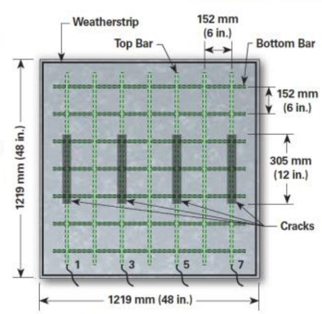
Southern Exposure (SE) Specimen



Corrosion-Initiation Beam (CI) Specimen



Field Test Specimen Setup – Slab Without Cracks

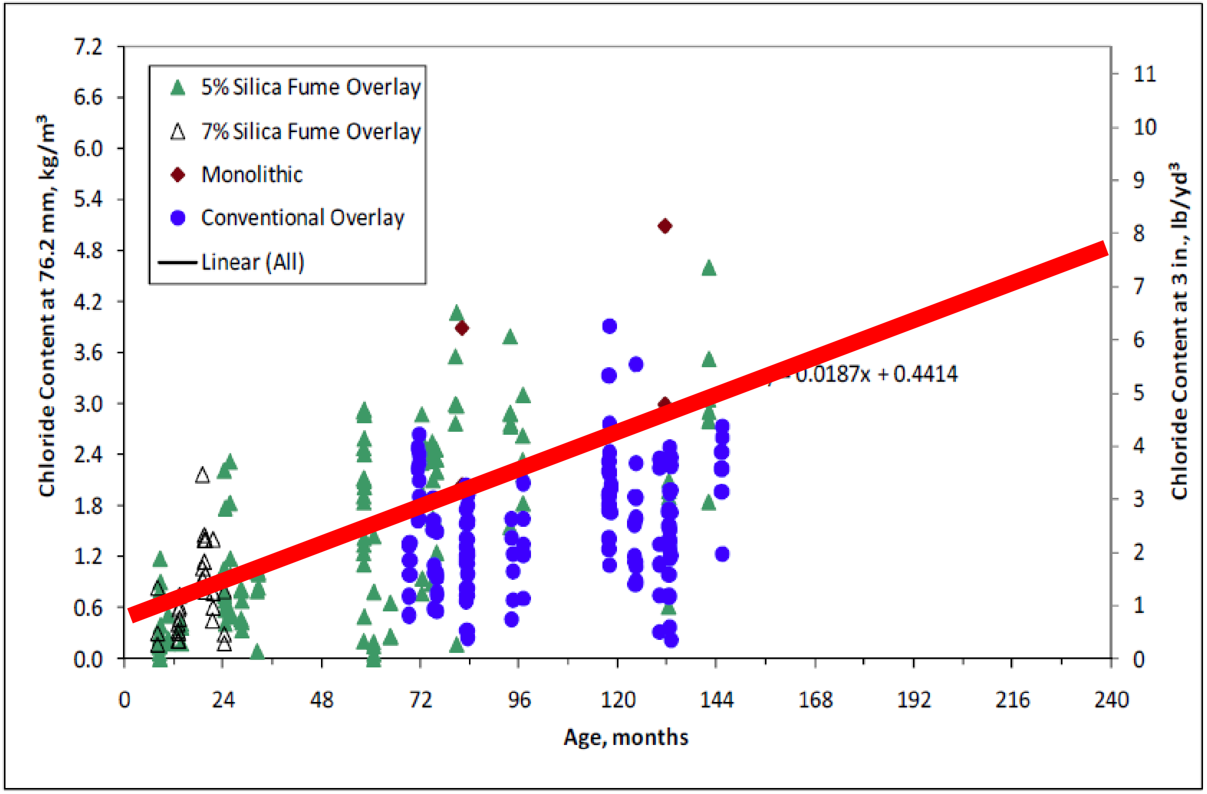


Field Test Specimen Setup – Slab With Cracks

Measured Corrosion Thresholds

System	Threshold (lb/yd^3)	Relative threshold
Uncoated	1.58	1
Epoxy Coated	7.28	4.6
Type 2205	26.4	16.7

Chloride Data at cracks
3 in. depth, AADT > 7500



$$C(t) = 0.0316.t + 0.746$$

Where t = time (months)

C(t) = chloride content (lb/yd^3)

Estimated performance – cracked concrete

	Initiation (years)
Uncoated reinforcing	2
Epoxy-coated reinforcing	20
Type 2205 stainless-steel	68

Estimated performance – cracked concrete

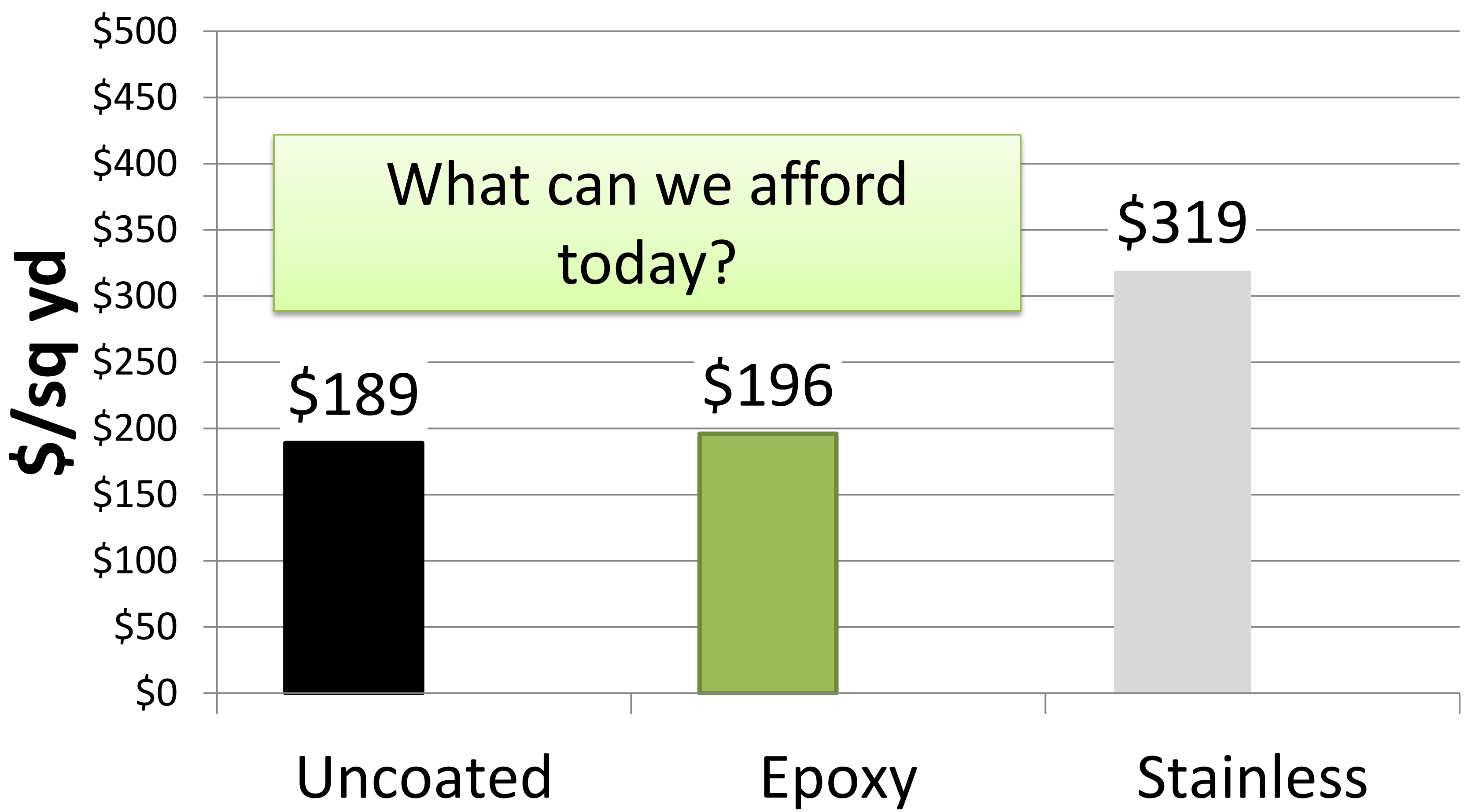
	Initiation (years)	Propagation (years)
Uncoated reinforcing	2	7
Epoxy-coated reinforcing	20	25
Type 2205 stainless-steel	68	359

Estimated performance cracked concrete

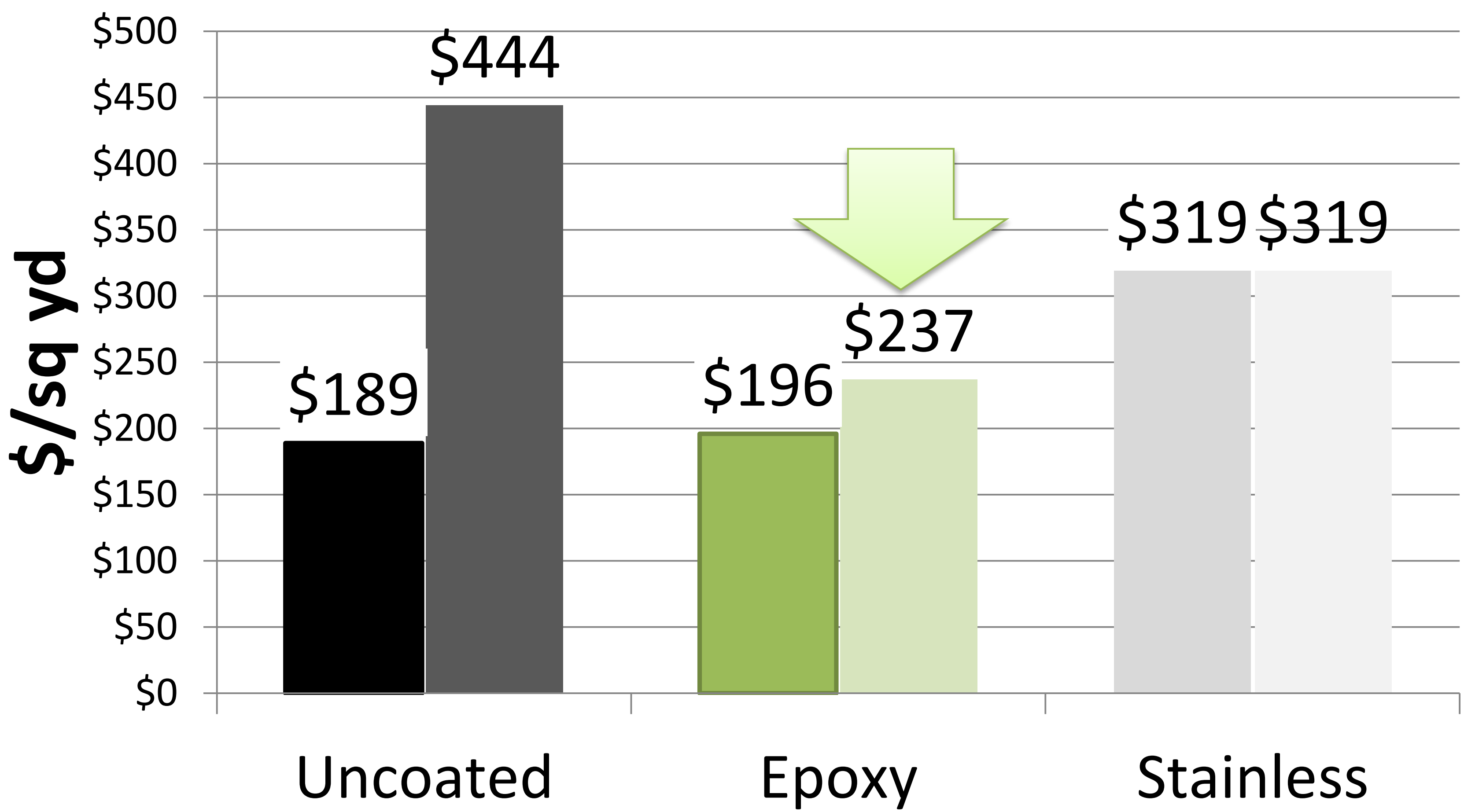
	Initiation (years)	Propagation (years)	Time to first repair (years)
Uncoated reinforcing	2	7	14
Epoxy-coated reinforcing	20	25	50
Type 2205 stainless-steel	68	359	432

Time to repair = initiation + propagation + 5 years

Initial Cost



Life-cycle cost

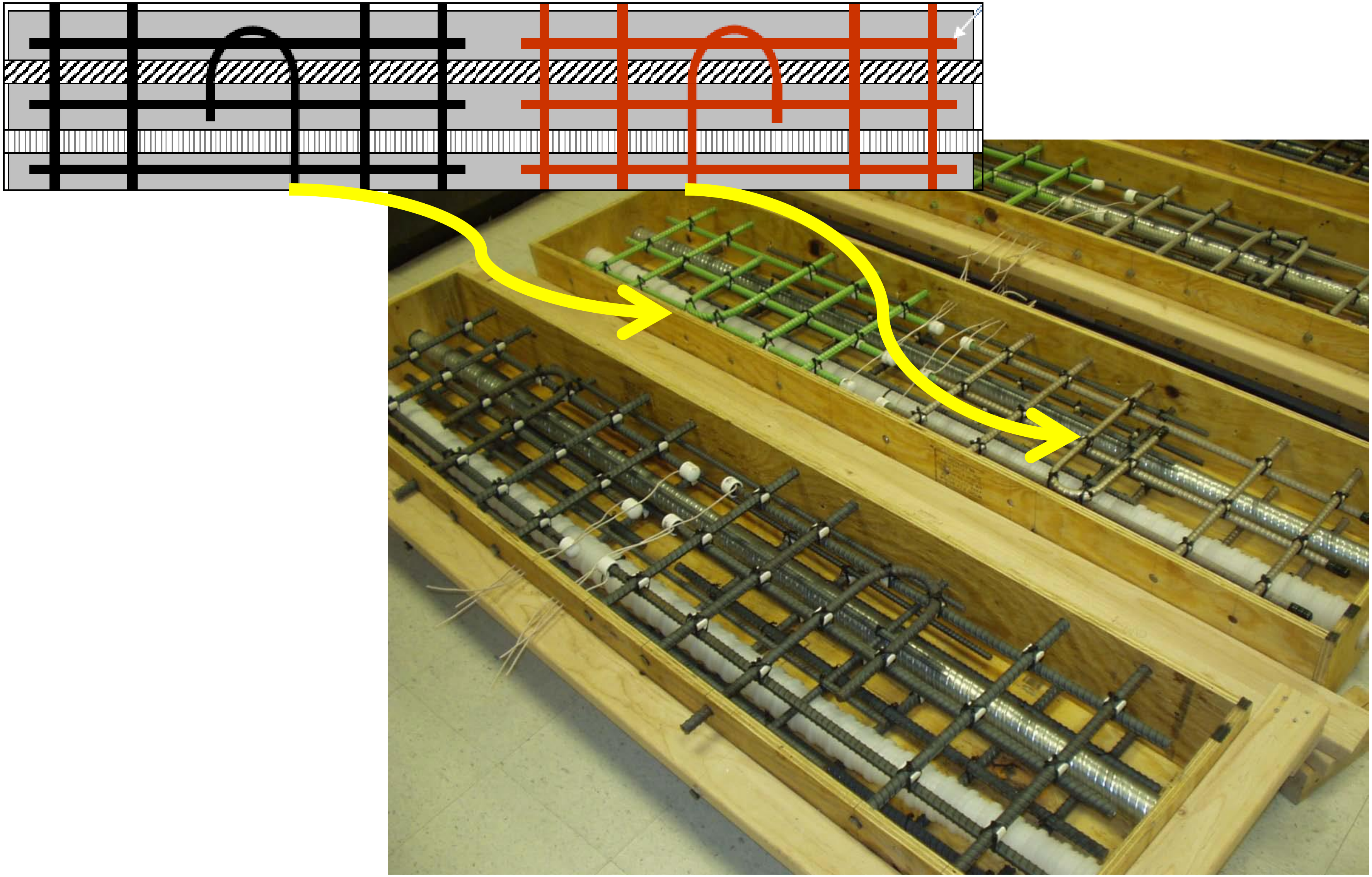


FHWA TURNER FAIRBANKS

2012 – FHWA/Lee study

- 12 different bar types from 11 sources
  - Epoxy-coated*
  - Dual-clad*
  - Galvanized*
  - Low carbon chromium
  - Steel alloys
  - Stainless clad
  - 2205 Stainless steel

Defects added
0.15, 0.5, 1.0%



Preliminary Findings

- Use of fusion-bonded coated bars (epoxy, and dual coated) in both mats offered the best corrosion resistance
  - Due to large electrical resistance
- Alloyed bars did not provide adequate corrosion resistance
  - A1035 low carbon-chrome
  - Duracorr
  - 3CR12

Preliminary Findings (con't)

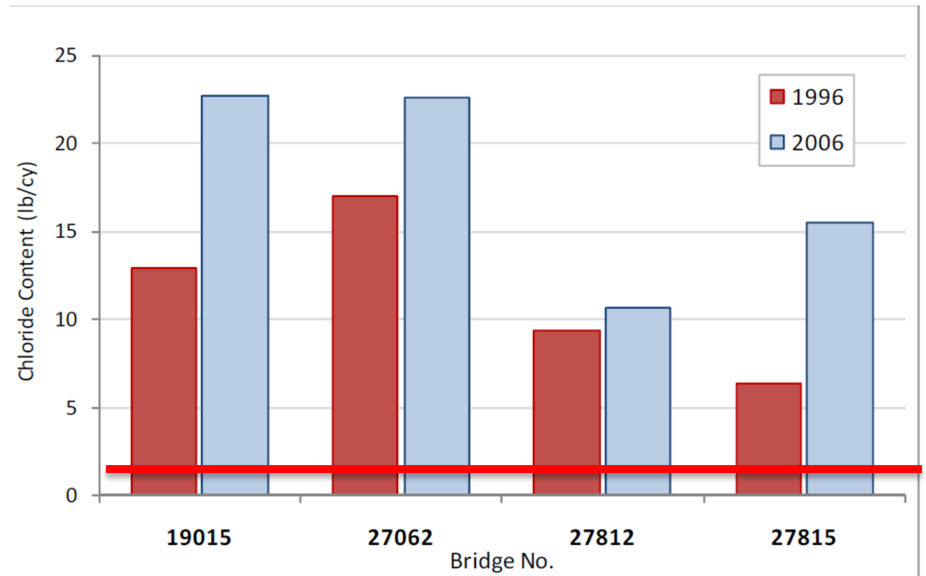
- Solid stainless and stainless clad bars exhibited very good corrosion performance
  - Enduramet 32?
- Galvanized bars may be used in moderately corrosive environments

Final report due 2013?

FIELD STUDIES

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



Chloride threshold greater than black

New York State Department of Transportation 2009

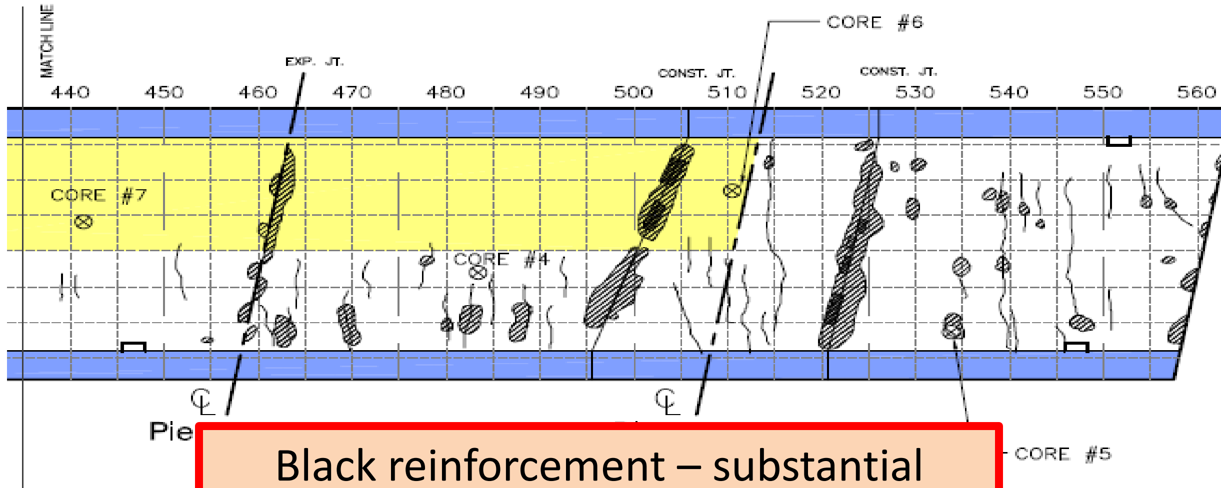
- Statistical analysis of 17,000 structures
- *Structural decks with epoxy-coated reinforcement perform significantly better than those with uncoated reinforcement, especially in the later years.*

West Virginia Bridges

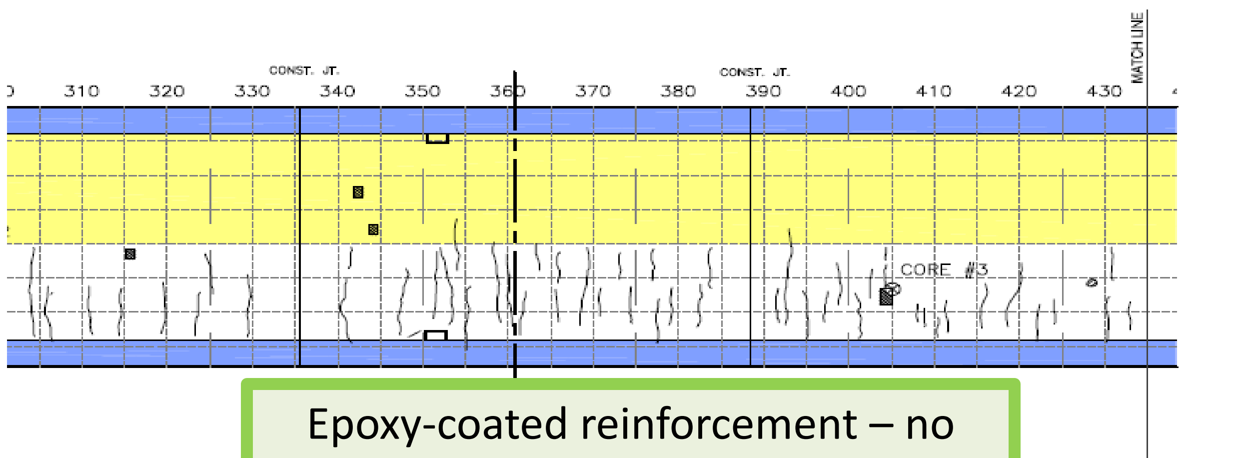
- WVDOT survey in 1993
  - Built mid 1970's
  - 33 decks
- 2009 Studies
  - All decks with black bars had been overlaid

Side-by-side analysis of black vs epoxy

West Virginia 2009 – 34 yo deck



Black reinforcement – substantial corrosion damage



Epoxy-coated reinforcement – no corrosion damage

2010 Boatman/Michigan DOT

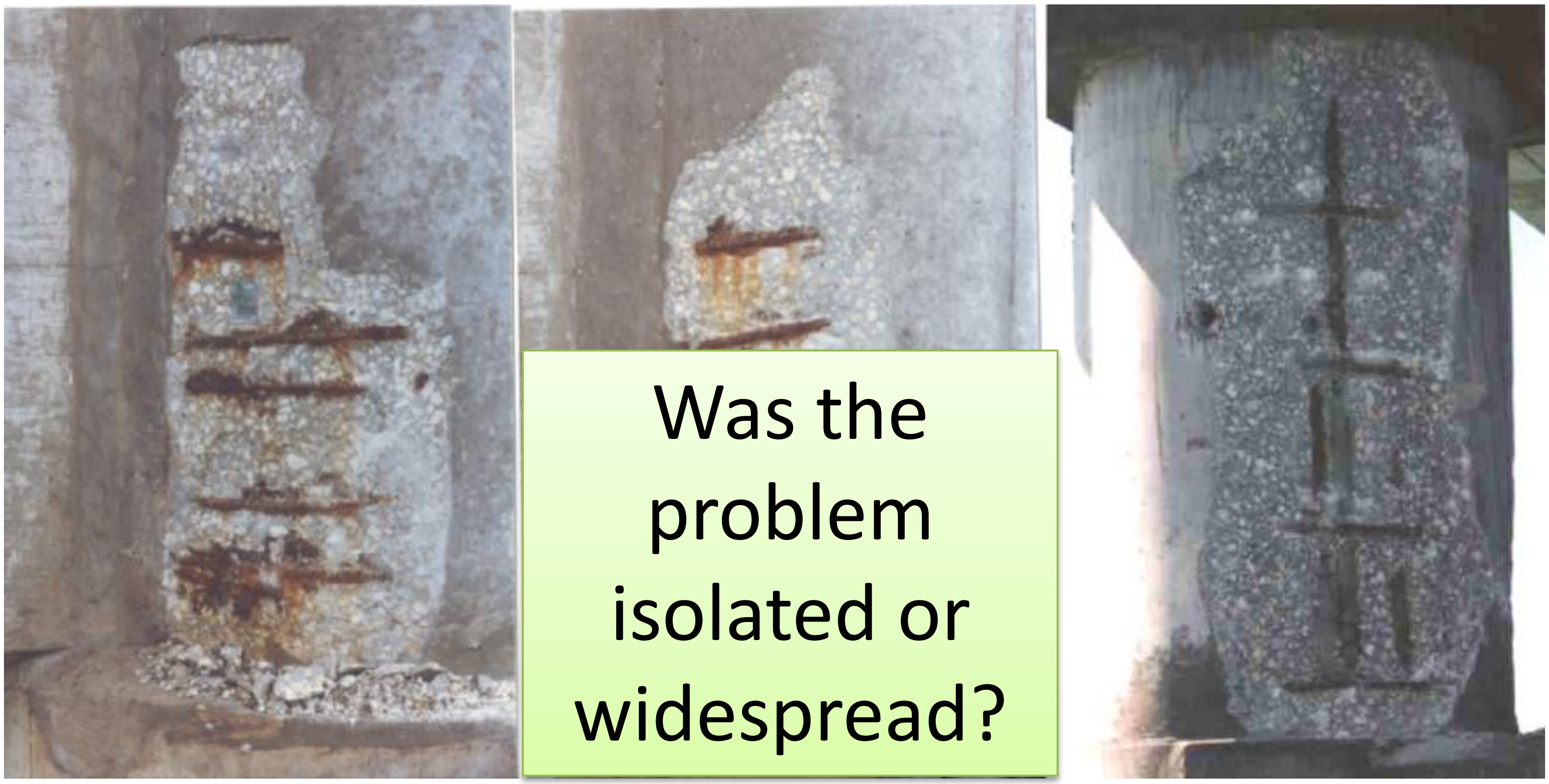
- The service life of a black rebar bridge deck is estimated to be 35 years.
- The service life of an ECR bridge deck is estimated to be approximately 70 years.

2012 Hatami and Morcous

- Rating of 5 as minimum acceptable
  - Black bar – 40 years
  - Epoxy bar – 68 years
- Rating of 4 as minimum acceptable
  - Black bar – 60 years
  - Epoxy Bar – 90 years

NDOR
Nebraska Department of Roads

1986 Florida Bridges

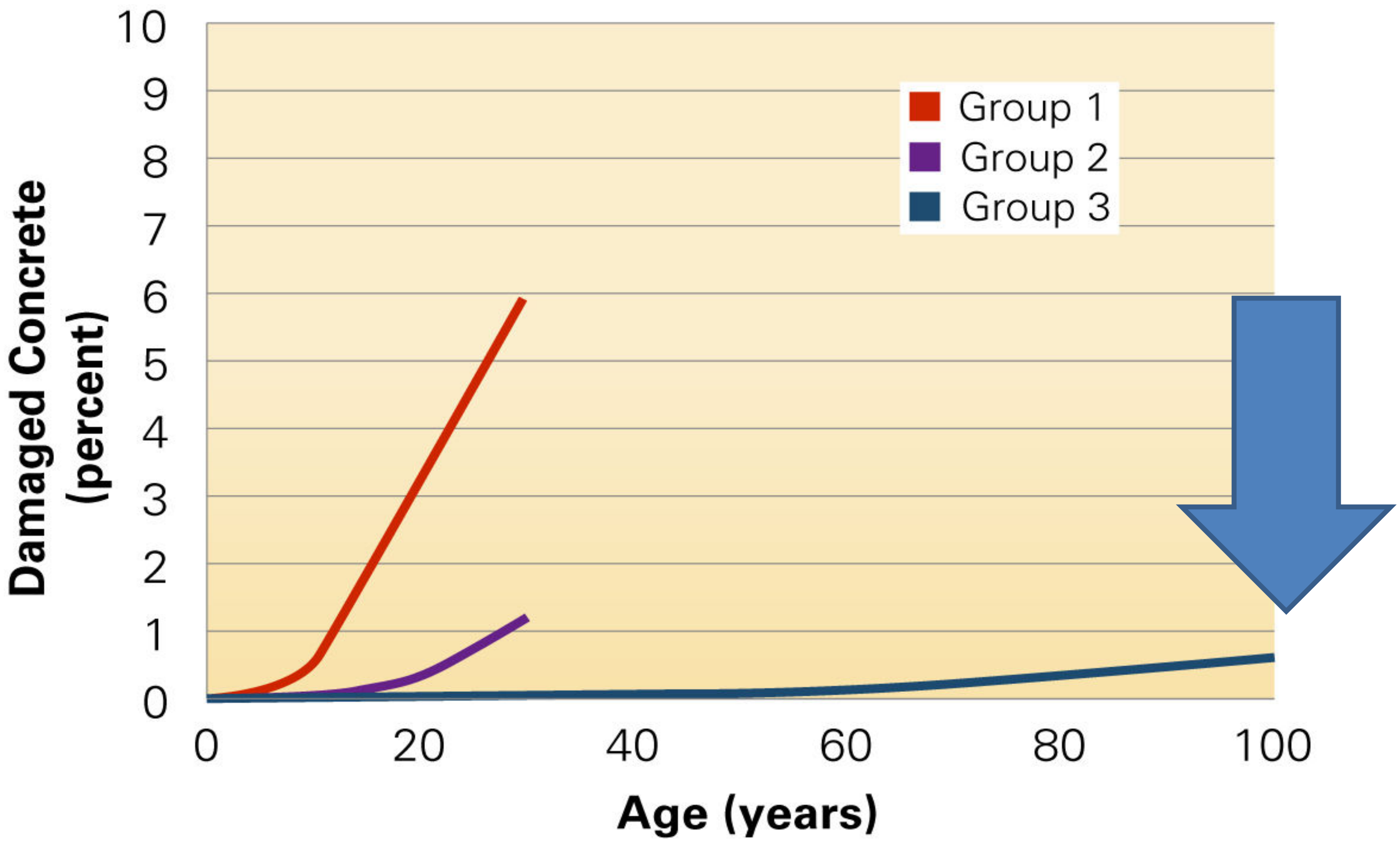


Was the problem isolated or widespread?

- Concrete spalling within 6 years of placement
- Cover = 1 in.
- Extremely high chloride (23 lb/cy)

After Sagues et al.

2011 Florida Predictions (Sagues et al)



Most bridges in Florida with epoxy-coated bars are predicted to last 100 years with minimal corrosion damage

CURRENT KNOWLEDGE

Epoxy-coated reinforcing steel

- A775: Green
  - Bent after coating
  - Most widely used and researched material
  - Significant material improvements over 37 years
  - Over 70,000 bridges
    - ~ 2500 per year
- A934: Purple or Grey
  - Bent before coating

How do you do to ensure your paint is durable?

- Preparation
- Material
- Application

Quality changes since 1990

- Increased coating thickness
- Required roughness
- Clean substrate (backside contamination)
- No cracking allowed during bending
- Improved storage and handling

The 2012 product is greatly improved

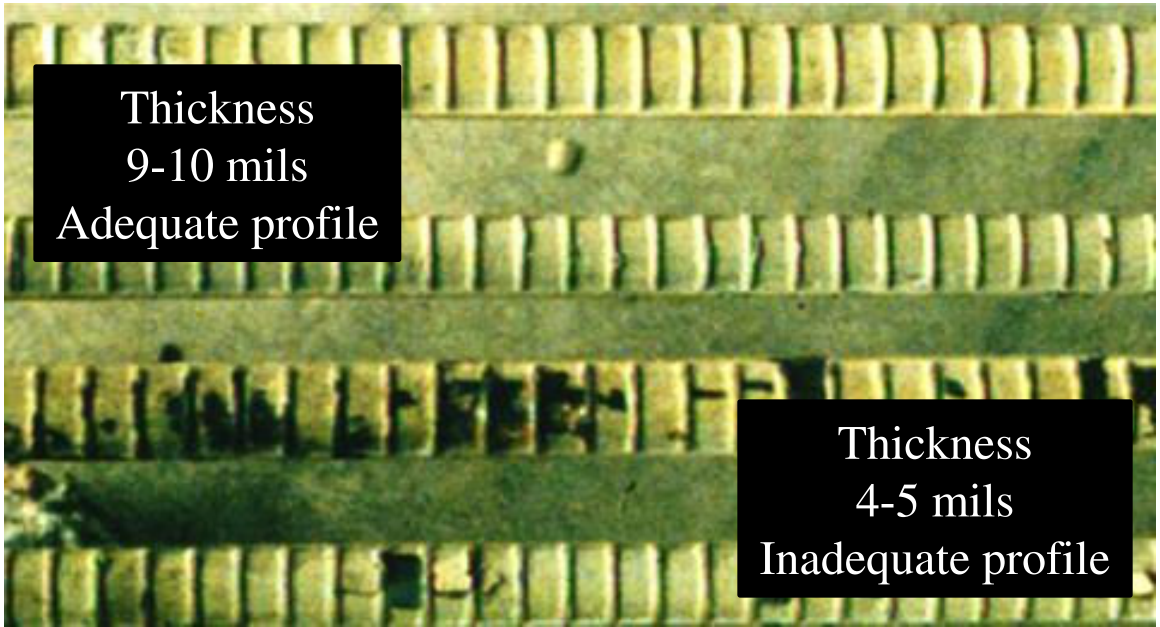
Coating thickness

1980s

- 7 +/- 2 mil

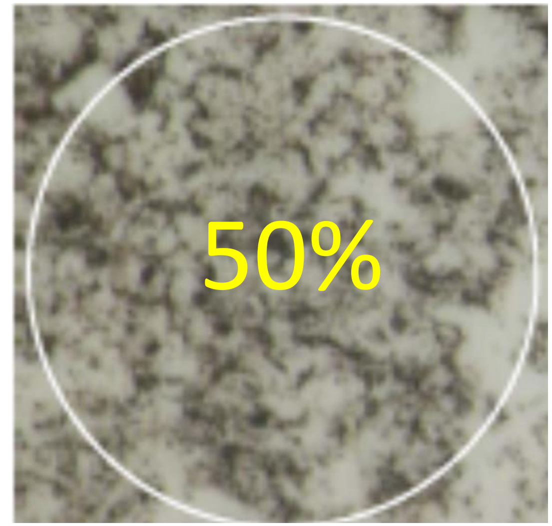
2010

- 7 – 12 mil
  - For #3, #4 and #5
- 7 – 16 mil
  - For #6 and greater

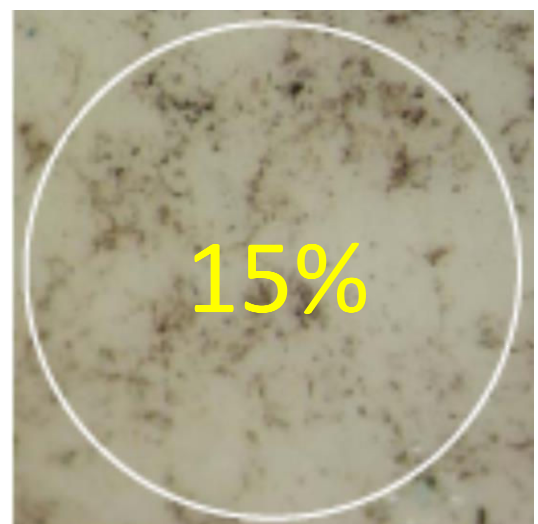


Backside contamination

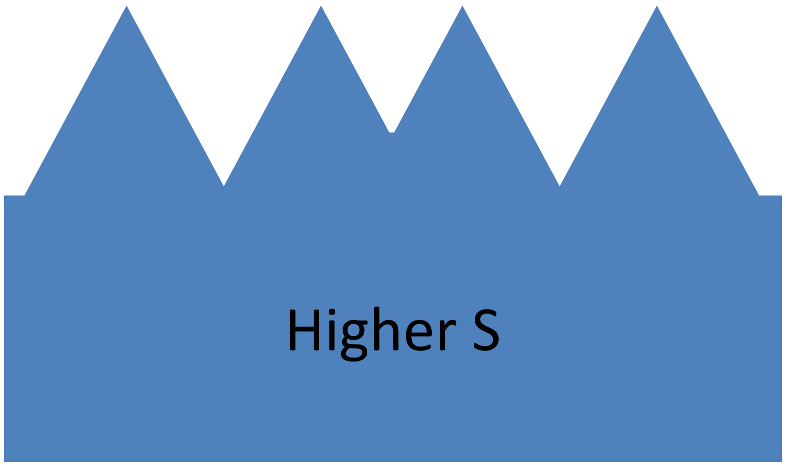
- 1992: Median contamination was 25%...from 10 to 70%



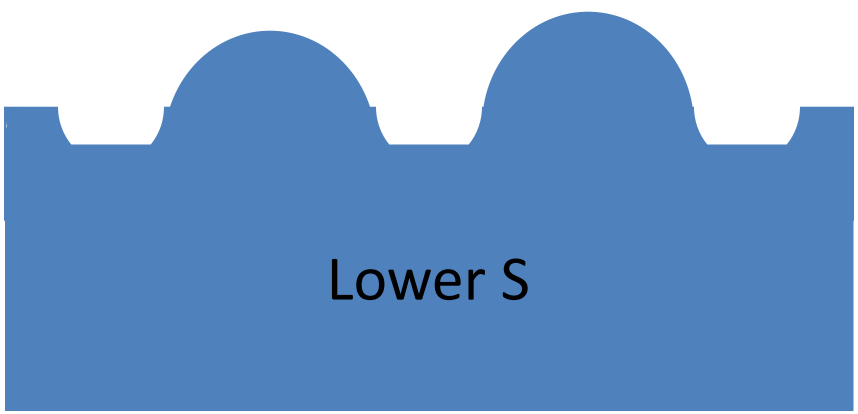
- 2011: Average contamination less than 15%

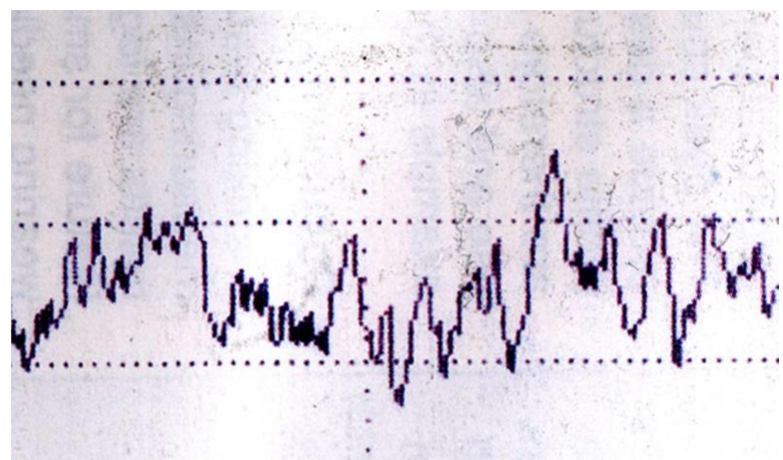


Anchor profile - roughness



Preferred Profile



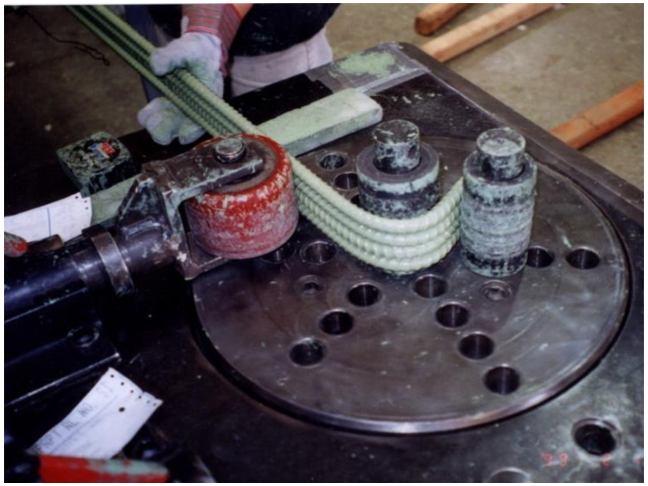


Profile not measured in 1980s

Bending

- 1992: …zero to 32 cracks at the bends
  - Bending to 120°

- 2011: Cracks in coating not allowed
  - Bending to 180°



Design

- Increase lap length
  - Follow code recommendations
- Use in both mats to provide long life

FIELD OPERATIONS

Optimum performance

- Like all materials
- Appropriate handling
  - Damaged bars have lower performance than undamaged bars

Damaged bars still perform well

Field specifications

- Individual agency specifications
- ACI 301 Specifications for Structural Concrete
- ASTM A775 ~~(AASHTO M284)~~ Annex
- ASTM A934 Annex
- ASTM D3963 (AASHTO M317)

Pick up

- Spreader bar or strong-back with multiple pickup points
  - minimize sag

Carrying

DO NOT DRAG!

Slings

- Use nylon or padded slings
- No bare chains or cables

Storage

- Store bundles on timber cribbing
  - Do not store directly on the ground

Placement

- Oil forms prior to bar placement
- Use coated supports
  - epoxy or plastic
- Tie using coated tie wire

Cutting

- Cut using power shears or chop saws
- Do not flame cut

Jobsite bending

- Only bend with the permission of the engineer
  - Bend at ambient temperatures
  - Use CRSI Bending diameters

Rejection

- > 2% area damaged in any 1 ft section

- < 5% of patching material in any 1 ft section
  - Does not include sheared or cut ends

Coating repair

- Wire brush
  - Remove rust or other contaminants
- Two-part epoxy
  - No spray cans
  - Approved by the coating manufacturer
  - Mixed according to the manufacturer's direction
  - Used within the specified pot life
- Provided cure time prior to concrete

Pre-Pour inspection

- Bar spacing, size and type
- Lap lengths
- Bar supports
- Mechanical splices
- Coated tie wire

Pre-Pour inspection

- Repairs
  - Sufficient time for coatings to dry
  - Use a two-part epoxy, not spray can
- Clear concrete cover
  - If force is used do not damage bars

Traffic and welds

- Minimize traffic over the epoxy-coated steel
- Weld only with the permission of the engineer
  - Cleaned and patched with repair materials
- Stands or rails used for concrete placement machines should not be welded to the epoxy-coated steel

Concrete hose

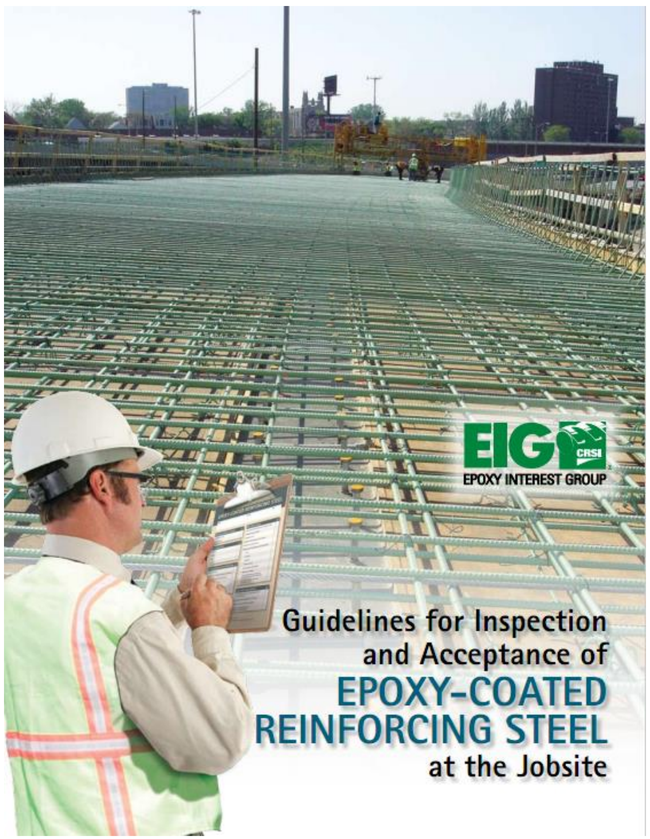
- Fit concrete pumps with an "S" bend
- Protect bar against hose couplers

Vibration

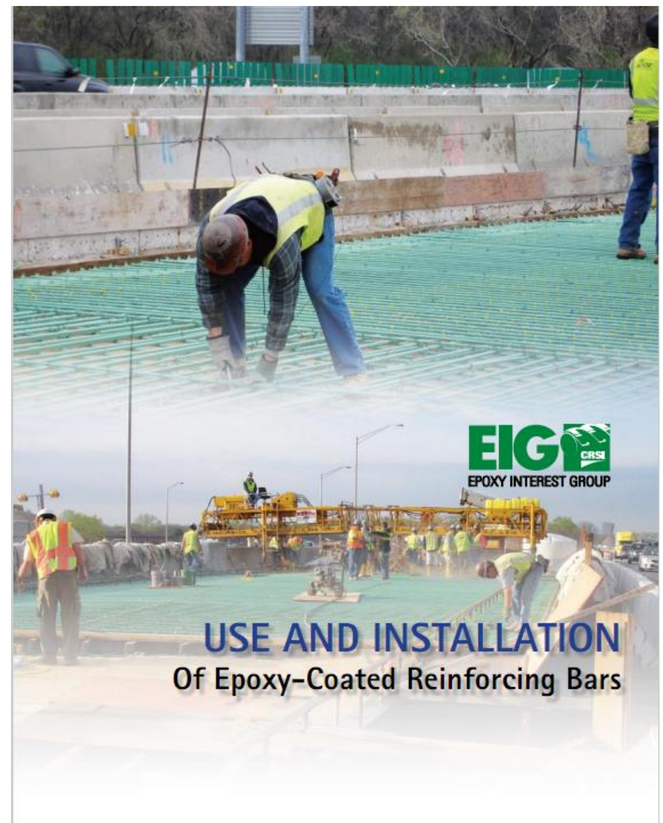
- Use plastic headed vibrators

Additional information

Inspectors



Field Crews



Woodrow Wilson Bridge, Virginia/Maryland

I-35 Minneapolis, Minnesota

Bridge of Honor, Ohio

Biloxi Bay Bridge, Mississippi

World Trade Center, NY

Georgia Aquarium

Aqua Building Chicago

Crystal Bridges Museum of American Art - Bentonville, Arkansas

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