Recent DOT Studies on the Long-Term Performance of Epoxy-coated Reinforcing Steel

ABCD - 24th ANNUAL BRIDGE CONFERENCE

David McDonald, Ph.D., P.E., FACI

November 9, 2012

EIG CRSI EPOXY INTEREST GROUP

Epoxy Bar Use

- 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

Woodrow Wilson Bridge, Virginia/Maryland

I-35 Minneapolis, Minnesota

Bridge of Honor, Ohio

Biloxi Bay Bridge, Mississippi

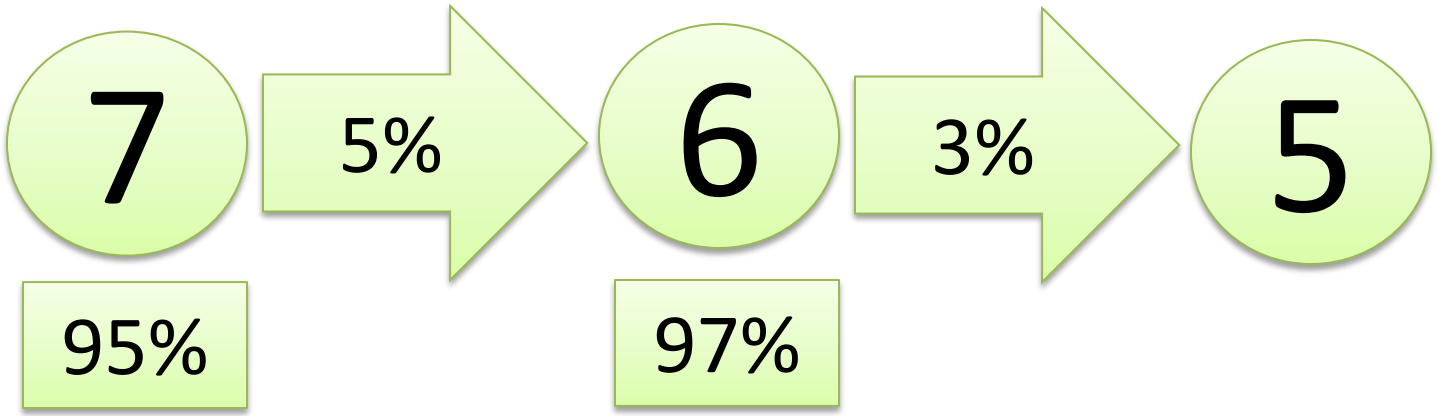
MICHIGAN DOT STUDY (2010)

Background

- Estimate the service life of bridge decks containing black reinforcing steel and epoxy-coated reinforcing steel
- Time to reach a poor condition.
  - Rating of 4 or less in the Bridge Safety Inspection Report

Markov analysis

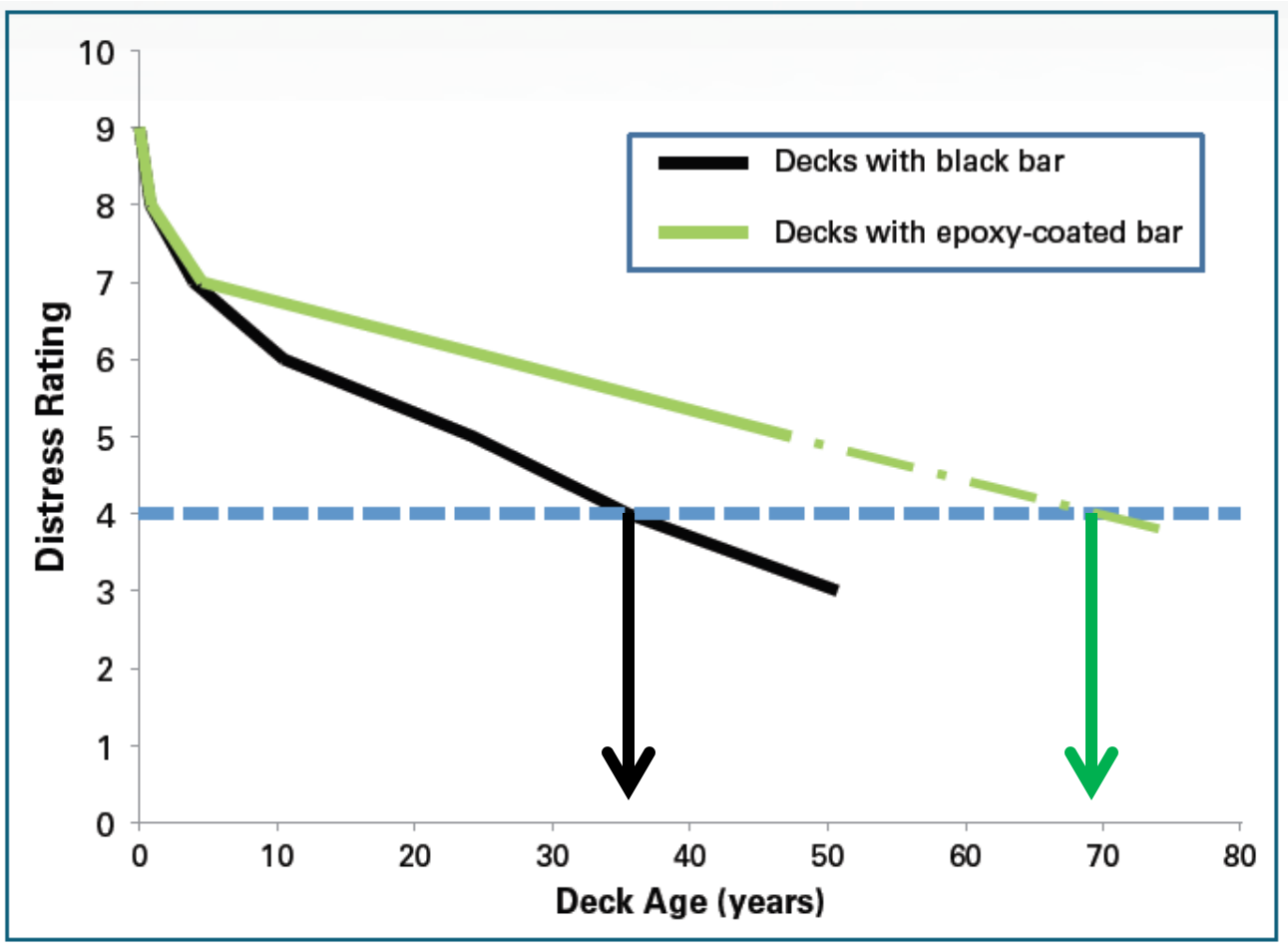
- Transition matrices
  - describe the probability that a bridge element will change to another condition state.
- Convert to a deterioration rate



Data

- Deck surface ratings from 2004 to 2010
- 1,790 bridge decks
  - 766 contained epoxy-coated reinforcing steel
  - 1,024 contained black reinforcing steel.

Predicted distress



Estimated time to reach rating of 4

Black	Epoxy-coated
35 years	70 years

Performance of epoxy-coated bars showing substantial improvement over uncoated bars

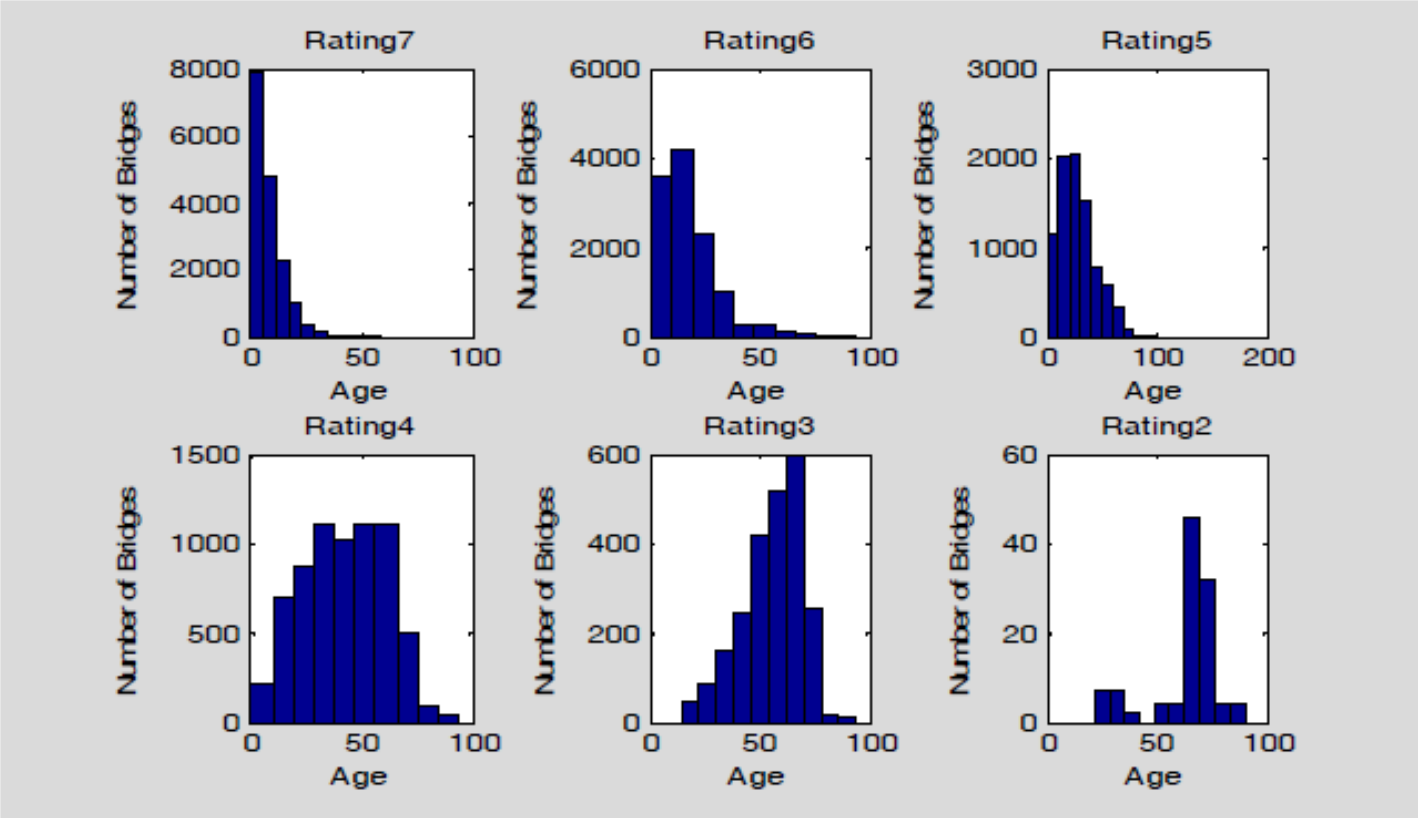
NYDOT STUDY (2009)

2009 Bridge Element Deterioration Rates

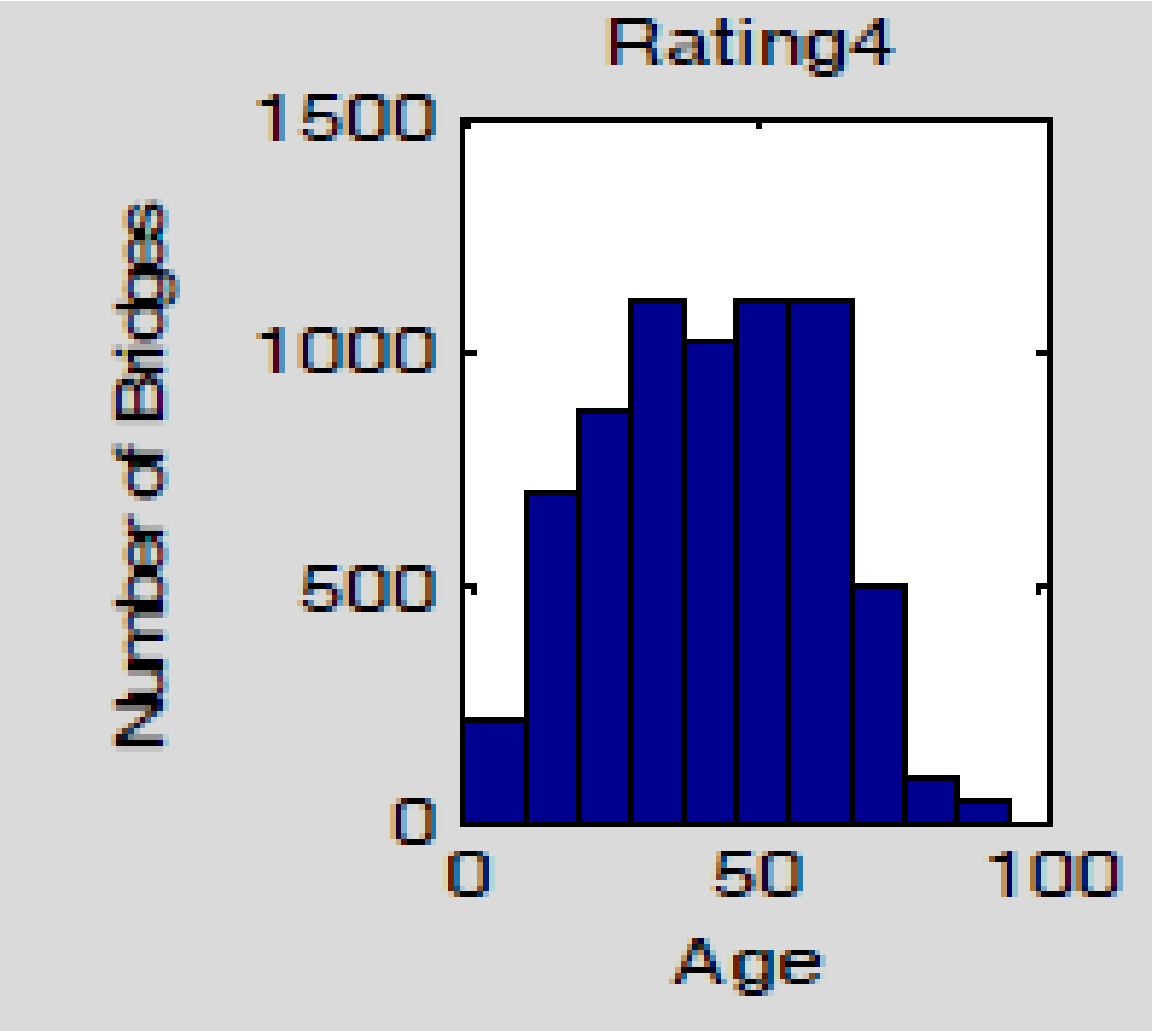
- Statistical analysis of 17,000 structures
  - NYSDOT bridge inspection database
- Markov chains and Weibull-based approaches
- Data going back to 1981

Weibul Analysis

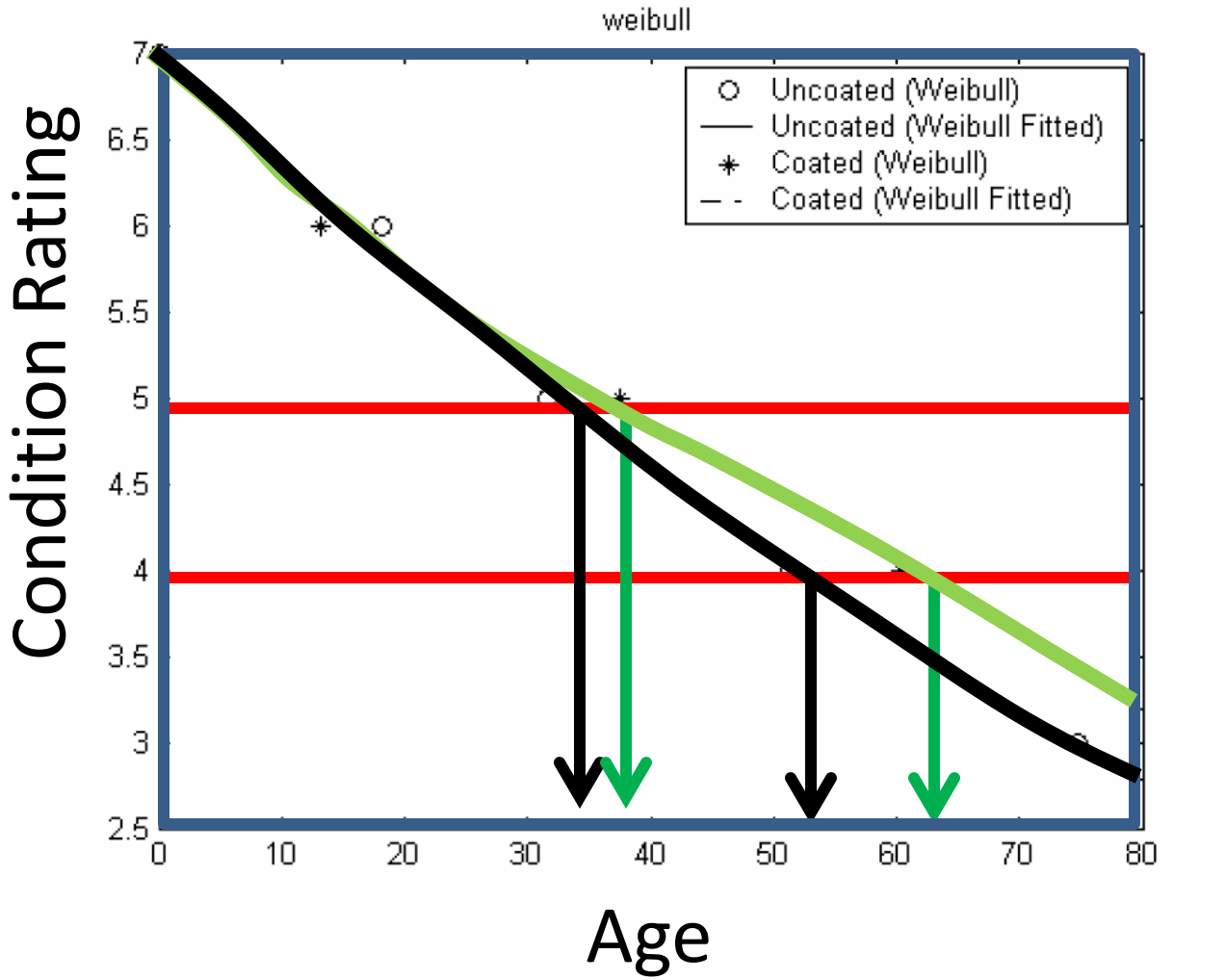
- Uses statistical distribution of rating vs bridge age



Distribution of rating 4 vs age



Weibul – coated vs uncoated



Life prediction

Rating	Black		Epoxy	
Analysis	Markov	Weibull	Markov	Weibull
7 to 5	32	31.5	38	37.6
7 to 4	49	43	62	60

Conclusions

- *Structural decks with epoxy-coated reinforcement perform significantly better than those with uncoated reinforcement, especially in the later years.*

KU STUDIES FOR KDOT

Draper, Darwin, Browning, Locke, Evaluation of Multiple Corrosion Protection Systems for Reinforced Concrete Bridge Deck

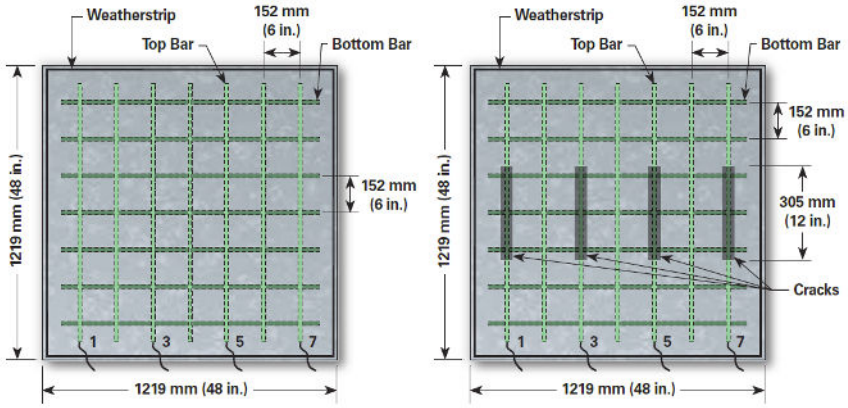
Program

- Chloride to cause corrosion (threshold)
- Rate of corrosion
- Field chloride levels

- Materials
  - Uncoated steel
    - With and without corrosion inhibitors
  - Epoxy-coated steel
    - With and without corrosion inhibitors
  - Type 2205 stainless steel

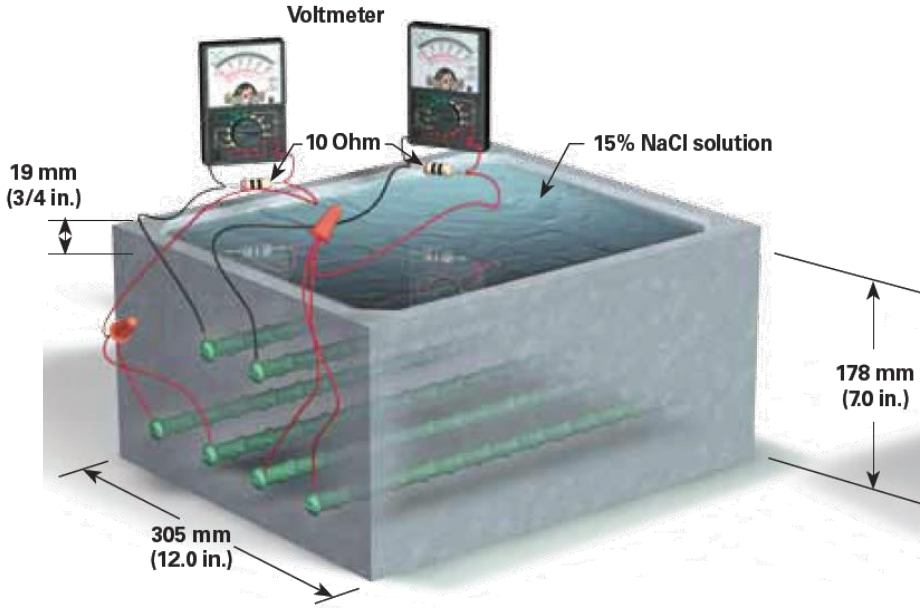
Test specimen types

96 week period, using two test cycles.
15 percent sodium chloride salt solution

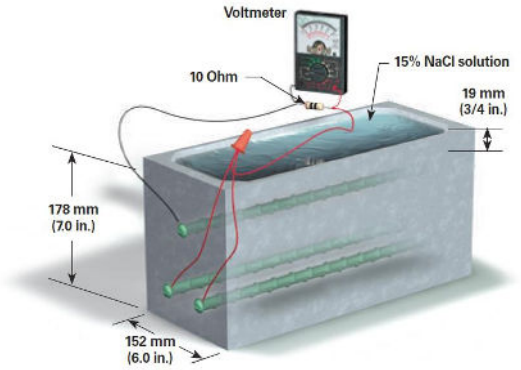


Field Test Specimen Setup — Slab Without Cracks

Field Test Specimen Setup — Slab With Cracks



Soutl



Corrosion-Initiation Beam (CI) Specimen

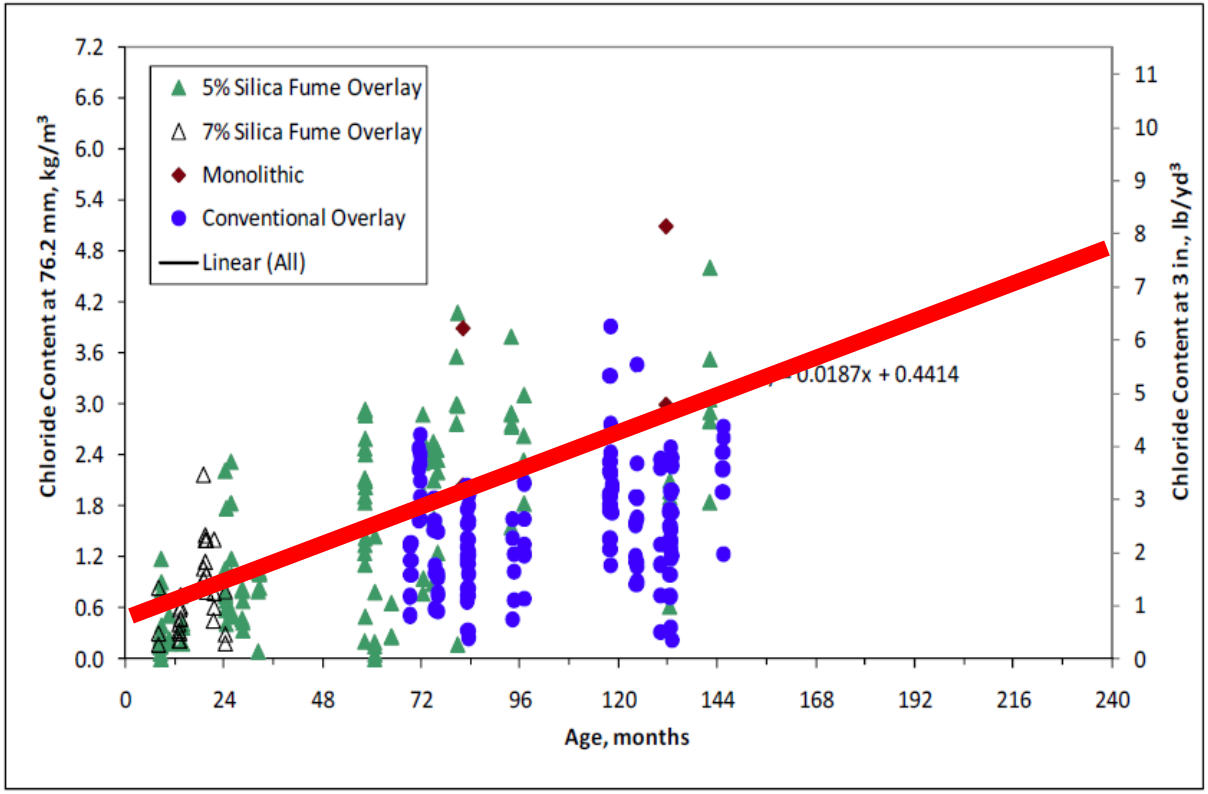
Measured Corrosion Thresholds

System	Threshold (lb/yd^3)	Relative threshold
Uncoated	1.58	1
Epoxy Coated	7.28	4.6
Inhibitors	0.83 - 3.05	0.52 – 1.9
Inhibitors and ECR	1.69 - 9.85	1.1 – 6.2
Type 2205	26.4	16.7

Rate
Cracked Concrete Specimens

	Propagation (years)	Relative rate
Uncoated reinforcing	7	1
Epoxy-coated reinforcing	25	3.6
Corrosion inhibitor	7 - 27	1 – 3.9
Corrosion inhibitor & epoxy-coated reinforcing	25 - 46	3.9 – 6.6
Type 2205 stainless-steel	359	51

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/yd³)

Estimated performance – cracked concrete

	Initiation (years)
Uncoated reinforcing	2
Epoxy-coated reinforcing	20
Corrosion inhibitor	1 - 4
Corrosion inhibitor & epoxy-coated reinforcing	3 - 24
Type 2205 stainless-steel	68

Estimated performance – cracked concrete

	Initiation (years)	Propagation (years)
Uncoated reinforcing	2	7
Epoxy-coated reinforcing	20	25
Corrosion inhibitor	1 - 4	7 - 27
Corrosion inhibitor & epoxy-coated reinforcing	3 - 24	25 - 46
Type 2205 stainless-steel	68	359

Estimated performance cracked concrete

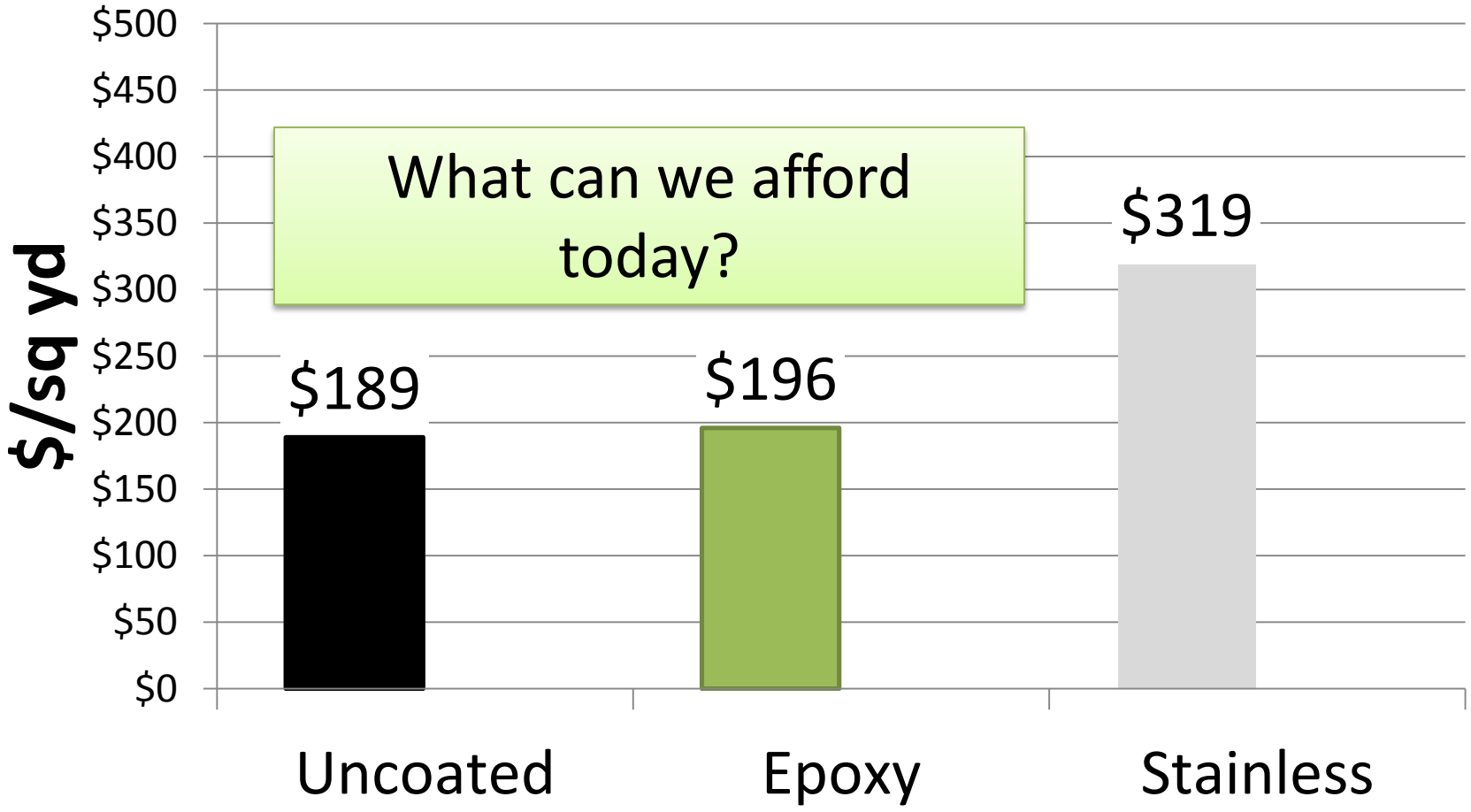
	Initiation (years)	Propagation (years)	Time to first repair (years)
Uncoated reinforcing	2	7	14
Epoxy-coated reinforcing	20	25	50
Corrosion inhibitor	1 - 4	7 - 27	16 - 33
Corrosion inhibitor & epoxy-coated reinforcing	3 - 24	25 - 46	50 - 63
Type 2205 stainless-steel	68	359	432

Time to repair = initiation + propagation + 5 years

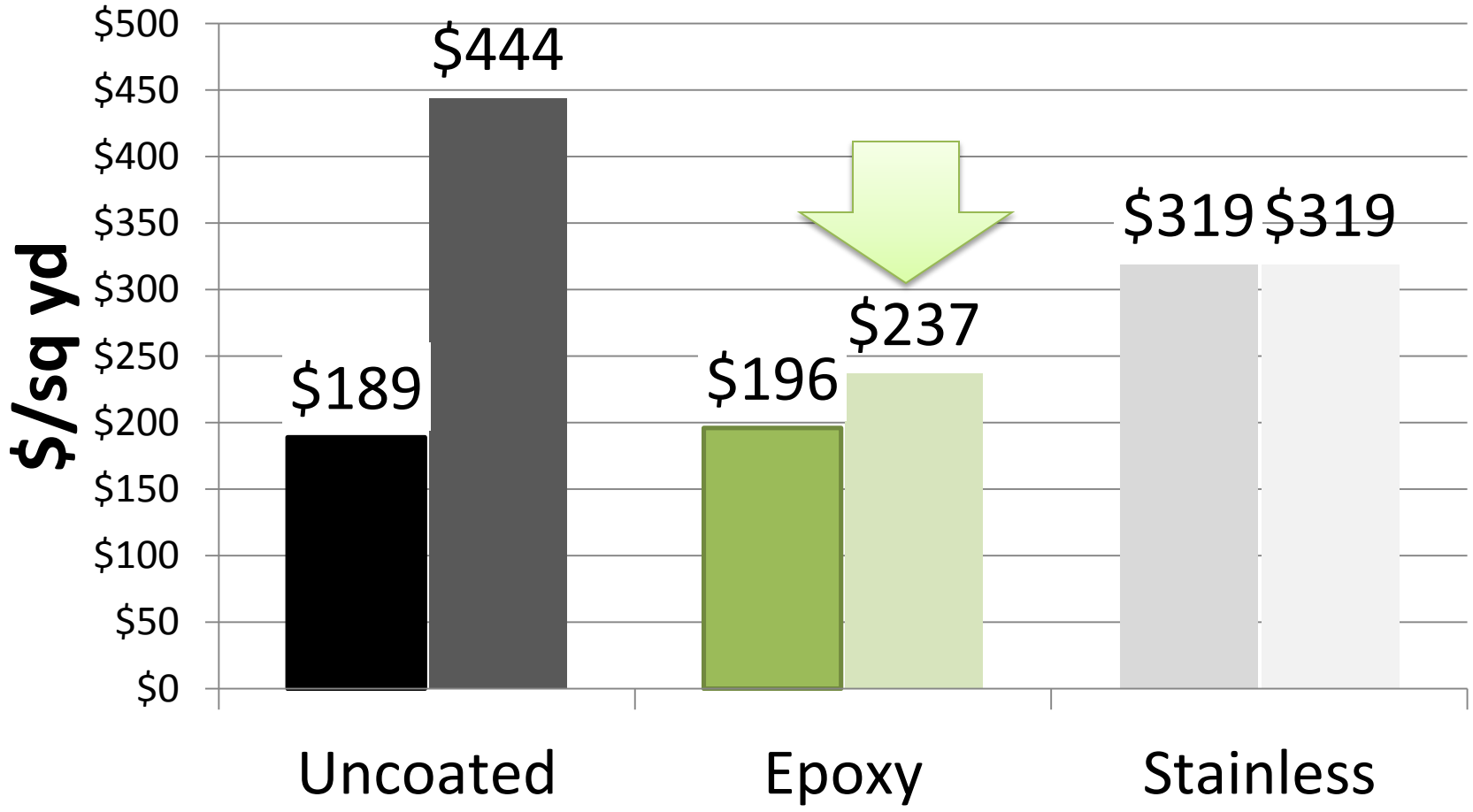
Economic Analysis

- Net present value (NPV)
  - Concrete and reinforcing costs
  - Repair costs and repair life
  - Discount rate (4%)
    - High discount rates reduce long term costs

Initial Cost



Life-cycle cost



Conclusions from Kansas Study

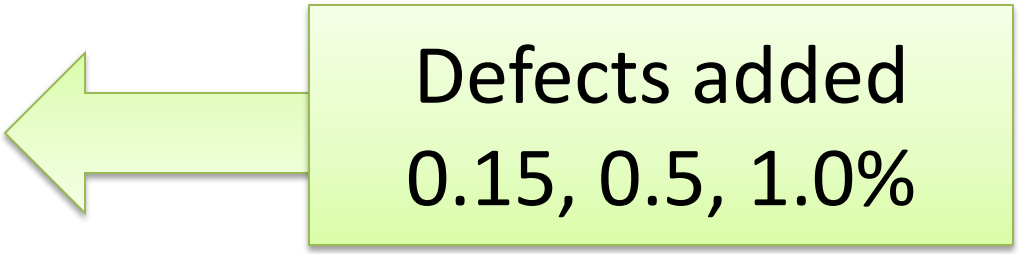
- Uncoated reinforcement exhibits the highest corrosion rates
- Epoxy coated bars have higher corrosion threshold and lower corrosion rate than uncoated bars
- LCA shows Type 2205 stainless steel is $82/sq yd than epoxy-coated reinforcement

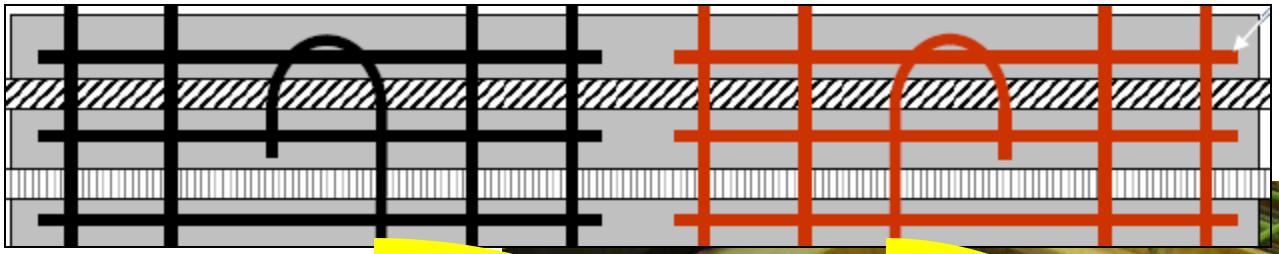
FHWA Research

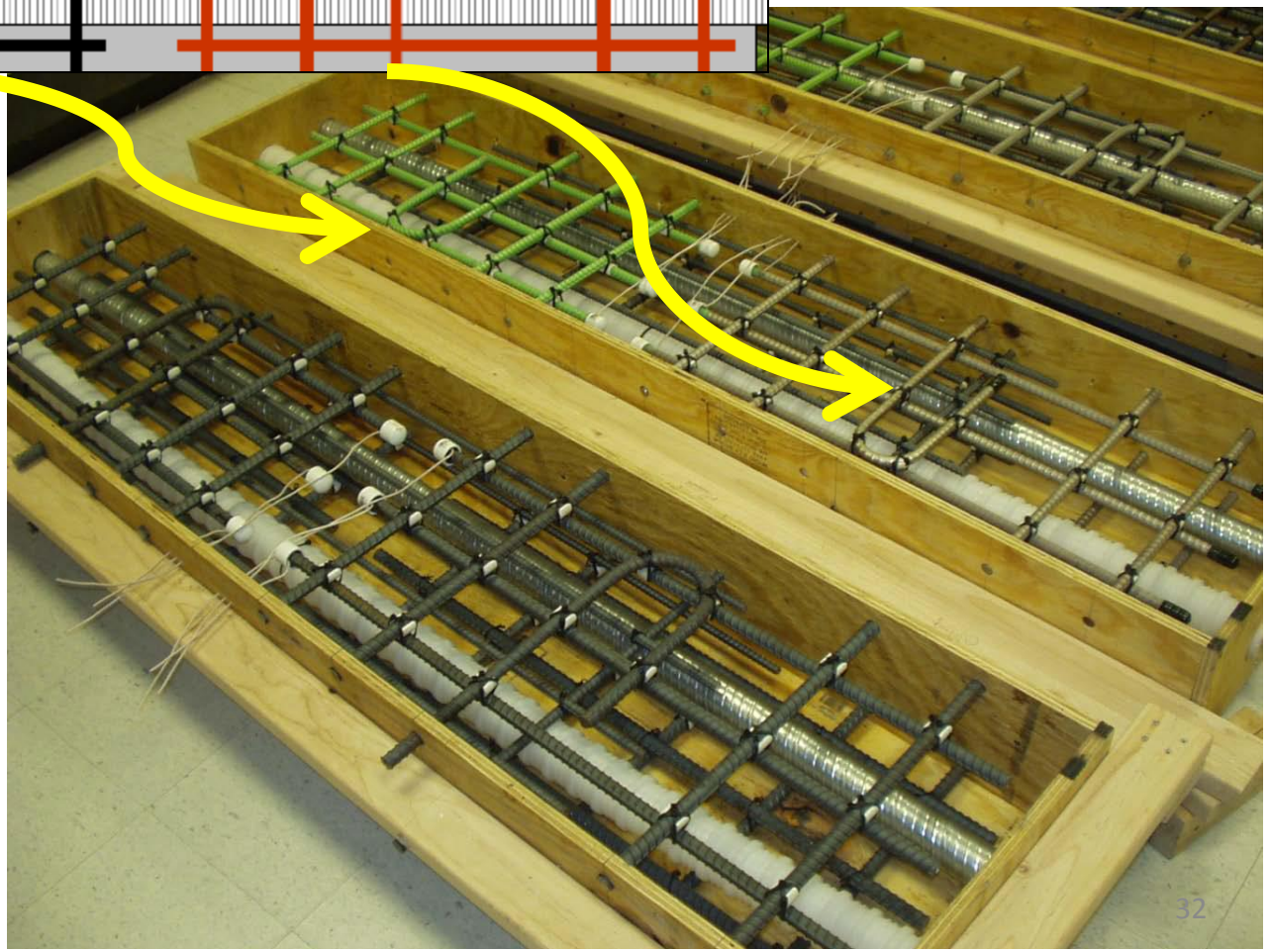
FHWA TURNER-FAIRBANKS LABORATORY

Laboratory

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







Preliminary Findings

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

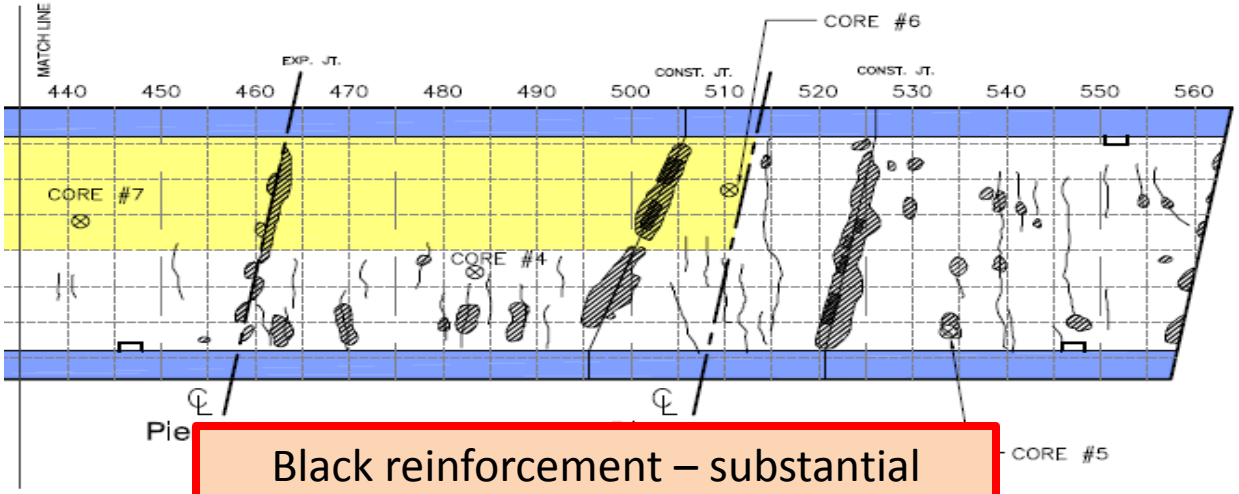
Preliminary Findings (con't)

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

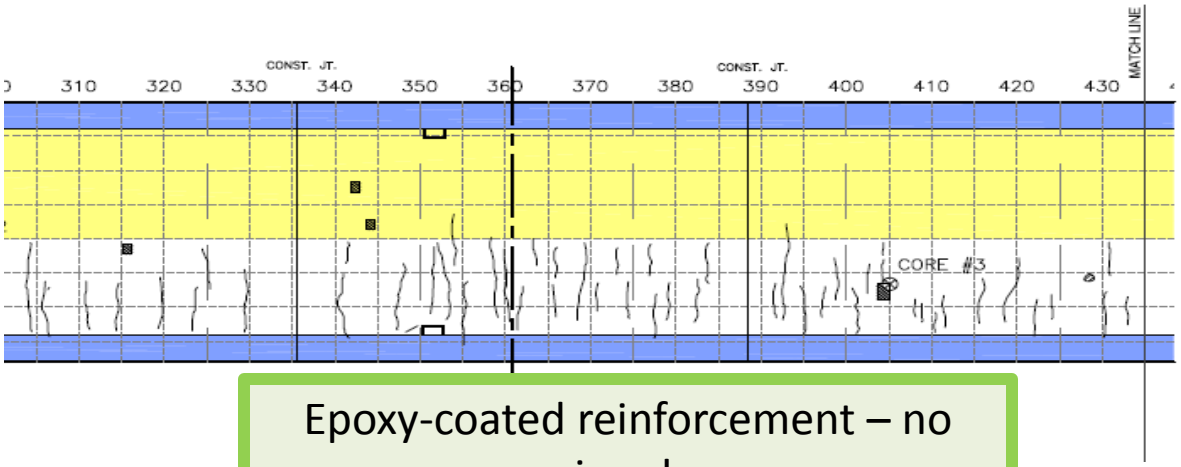
Final report due 2013?

WV STUDIES

West Virginia 2009 – 34 yo deck



Black reinforcement – substantial corrosion damage



Epoxy-coated reinforcement – no corrosion damage

SUMMARY

Conclusions

- Field research (NY, MI, WV) shows long lives of decks with epoxy-coated reinforcing steel
- Laboratory data (KU, FHWA) showing epoxy and stainless performing well
- Cost analysis shows epoxy-coated reinforcing provides lowest lifecycle costs (KU)

Celebrating 40 years of improved materials and manufacturing of epoxy-coated reinforcing steel

www.epoxyinterestgroup.org

EIG CRSI
EPOXY INTEREST GROUP

Celebrate 40 YEARS
EPOXY-COATED REINFORCING STEEL