Cost-Effective Methods for Improving the Corrosion Resistance of Concrete

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Constraints

- Available resources
  - Don’t have unlimited funds
  - Don’t wish to continually repair

Chloride

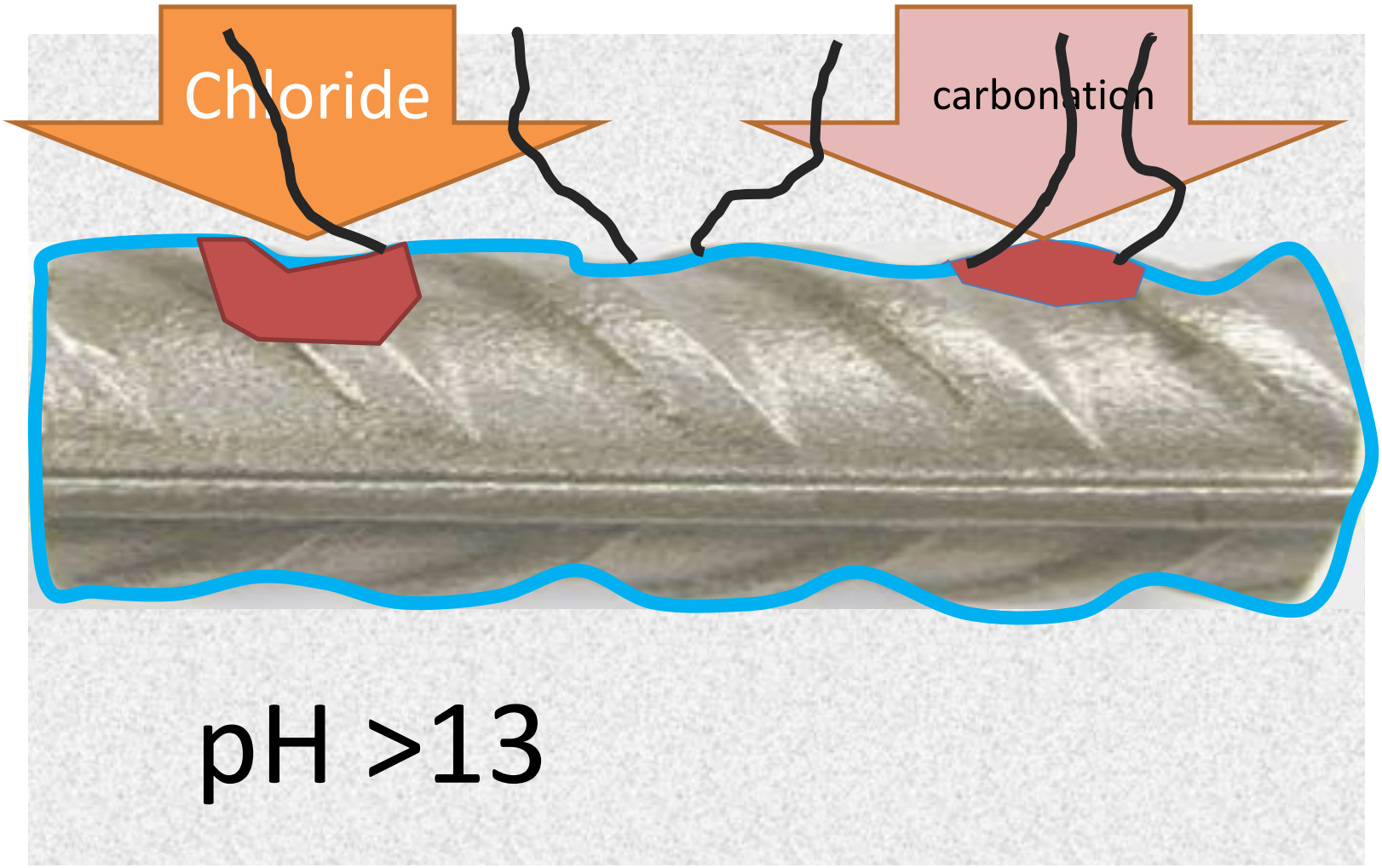
- Deicing salts
- Marine waters

- Mechanism
  - iron chloro-complex (green rust)
  - expansion

Courtesy W.R. Meadows

Carbonation
CO_2 reacts with cement

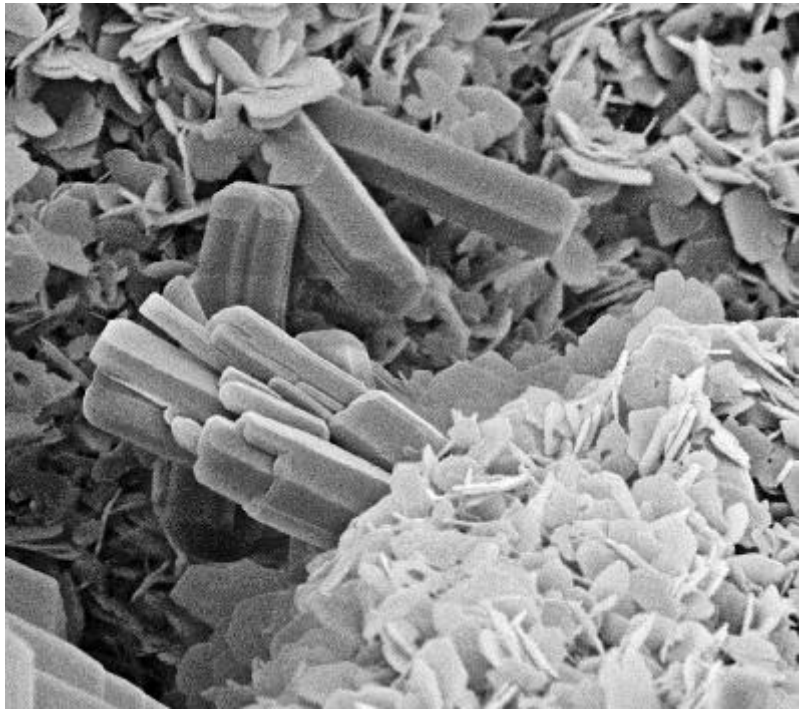
Reinforcing Steel in Concrete



CONCRETE MODIFICATION

Concrete Modification

- Reduce permeability
- w/cm (<0.40)
- Pozzolans
  - silica fume (< 5%)
  - fly ash (< 30%)
  - slag cement (< 50%)



New materials, such as polycarboxylate help improve concrete

Corrosion Inhibitors

- Materials
  - calcium nitrite
  - amine carboxylate
  - amine-ester
  - alkenyl carboxylate
- Improves chloride threshold
  - Dependent on the dosage
- 212.3R-10: Report on Chemical Admixtures for Concrete

BAR MATERIALS

Types

- Epoxy-coated
  - ASTM A775, A934
- Galvanized
  - ASTM A767
- Stainless Steel
  - ASTM A955
- Others
  - A1035 – Low carbon, chrome
  - A1055 – Dual Clad
  - Glass Fiber

Epoxy-coated Reinforcing Steel

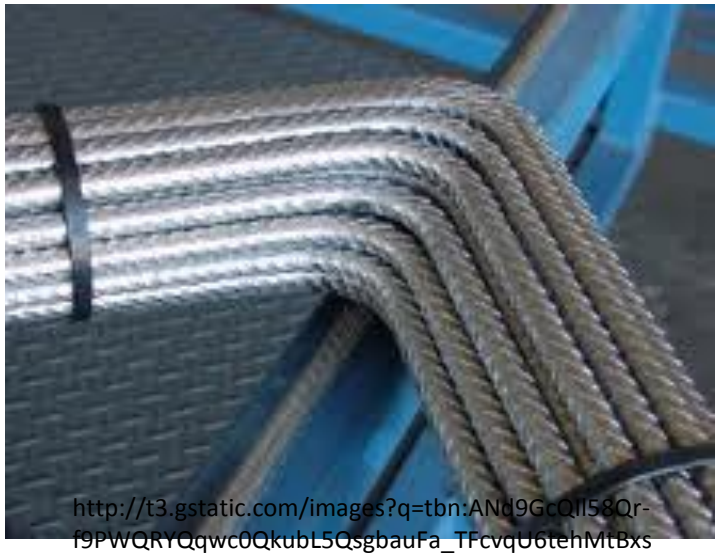
- A775: Green
- A934: Purple or Grey
- Most widely used and researched material
- Significant material improvements over 37 years
- Over 70,000 bridges
  - ~ 2500 per year

Galvanized Reinforcing

- ASTM A767
- Develop oxide layer for protection
  - Dependant on cement and zinc chemistry
  - Microstructure may significantly affect performance
- Only 1050 bridges
  - ~ 40 per year

Stainless Steel Reinforcing

- ASTM A955
- Chemistry/microstructure
  - Excellent: 316, 2205, 2304
  - Fair: 2201, 3Cr12
- “Stainless steel isn’t”
  - Roper 1986
- ?? bridges



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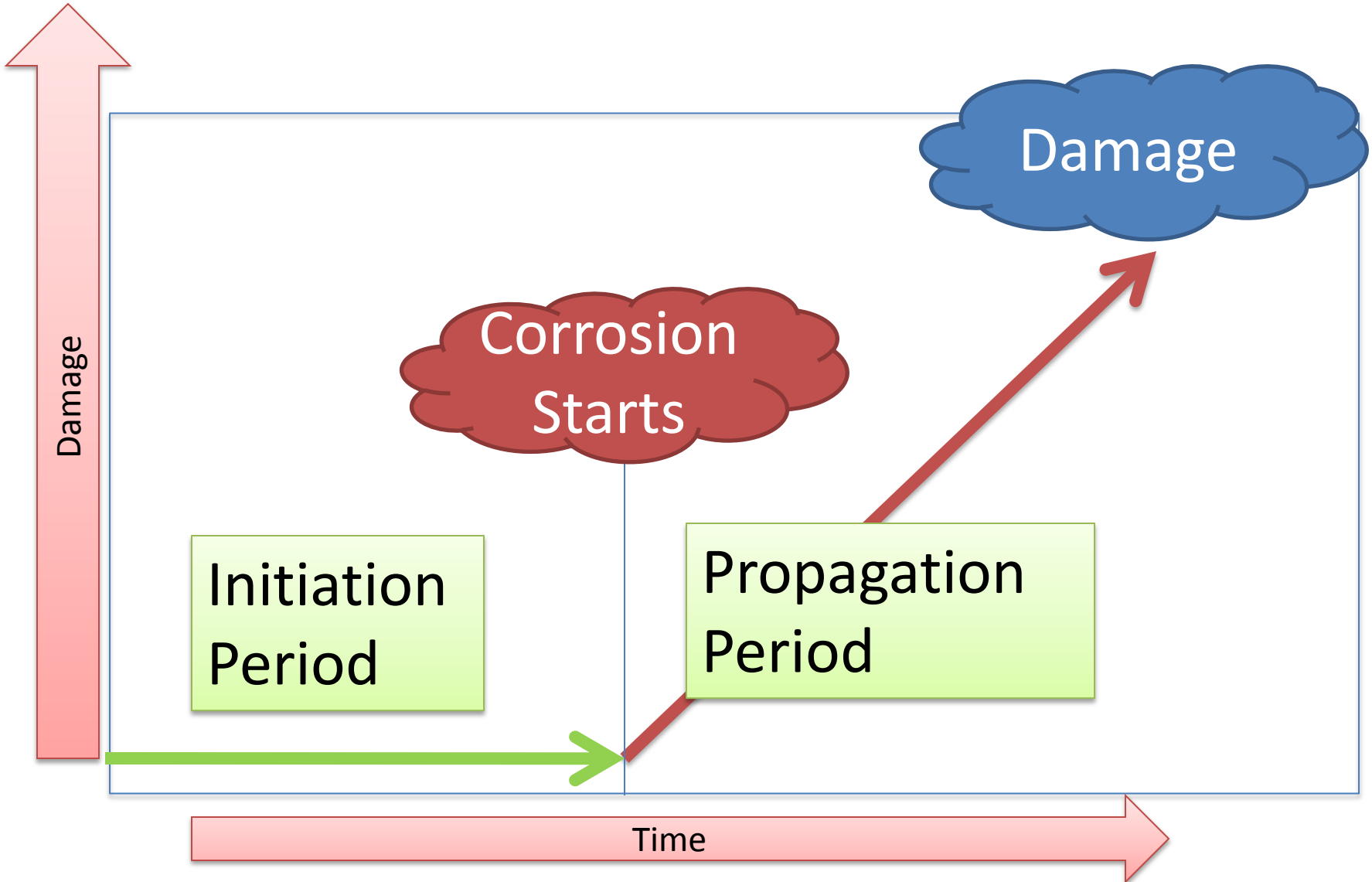
Other Materials

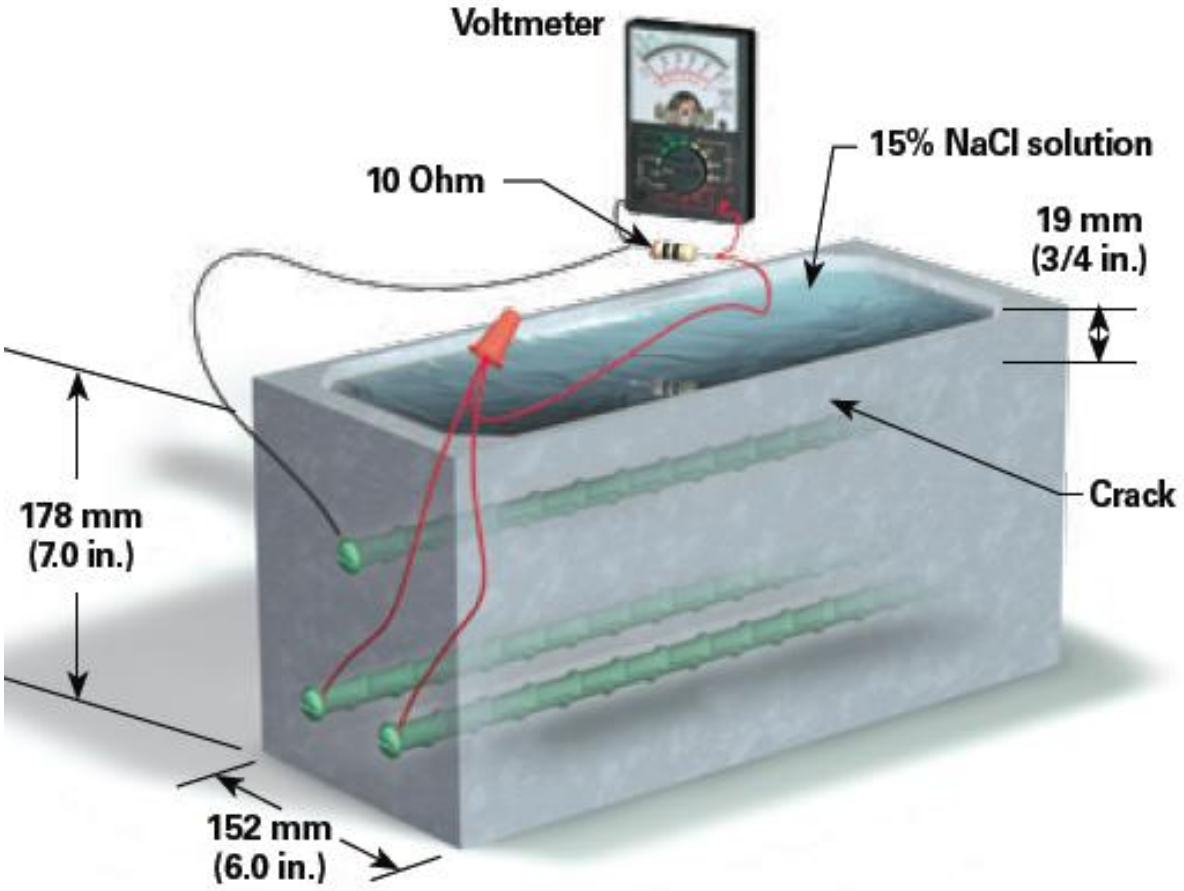
- Single source or proprietary
  - ASTM A1035/3CR12
    - Low grade stainless steels
  - ASTM A1055
    - Epoxy and zinc layers
  - Glass and Basalt fiber bars

PERFORMANCE

Tutti Model


Damage
Damage
Corrosion Starts
Initiation Period
Propagation Period
Time

Laboratory Tests



Cracked Beam (CB) Specimen

Corrosion Thresholds

- Kansas University Study for KDOT and FHWA

• Black reinforcing	1.6 (lb/yd^3)
• Corrosion inhibitors	0.8 – 3.0
• Galvanized	2.6
• Epoxy-coated reinforcing	7.3
• Stainless 2205 reinforcing	26.4

Propagation Period

- Cracked Concrete

• Black bars	14 years
• Corrosion inhibitor	33
• Epoxy-coated bars	50
• ECR + Corrosion inhibitors	63
• Stainless steel	> 100

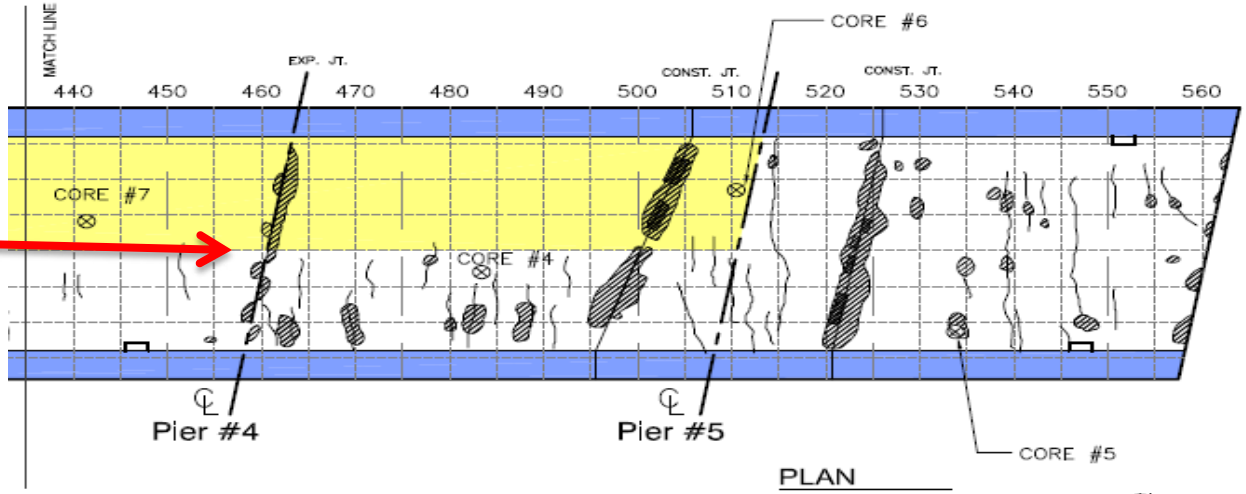
PERFORMANCE

West Virginia 2009

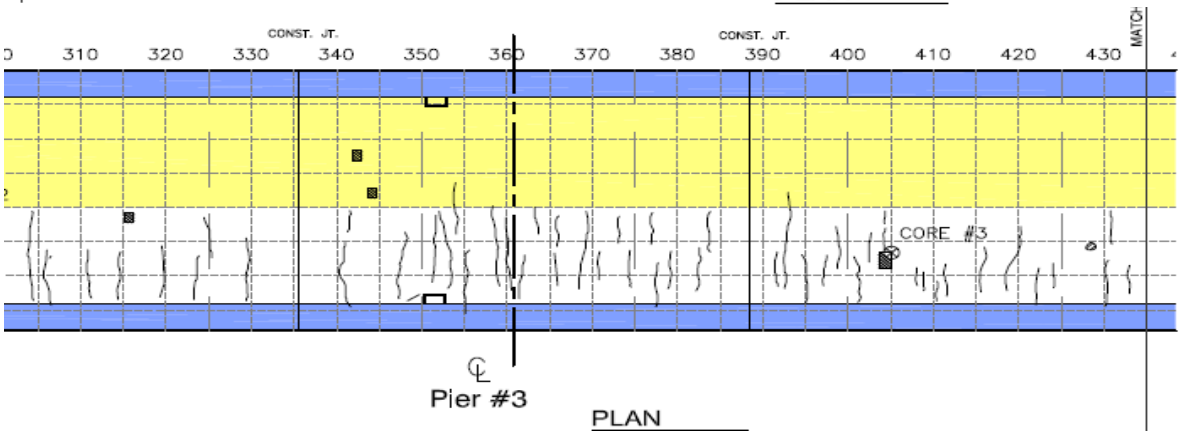
Deck with both epoxy and black bar sections

West Virginia 2009

Black - Delaminated concrete after 17 years



Epoxy - No delaminations after 34 years

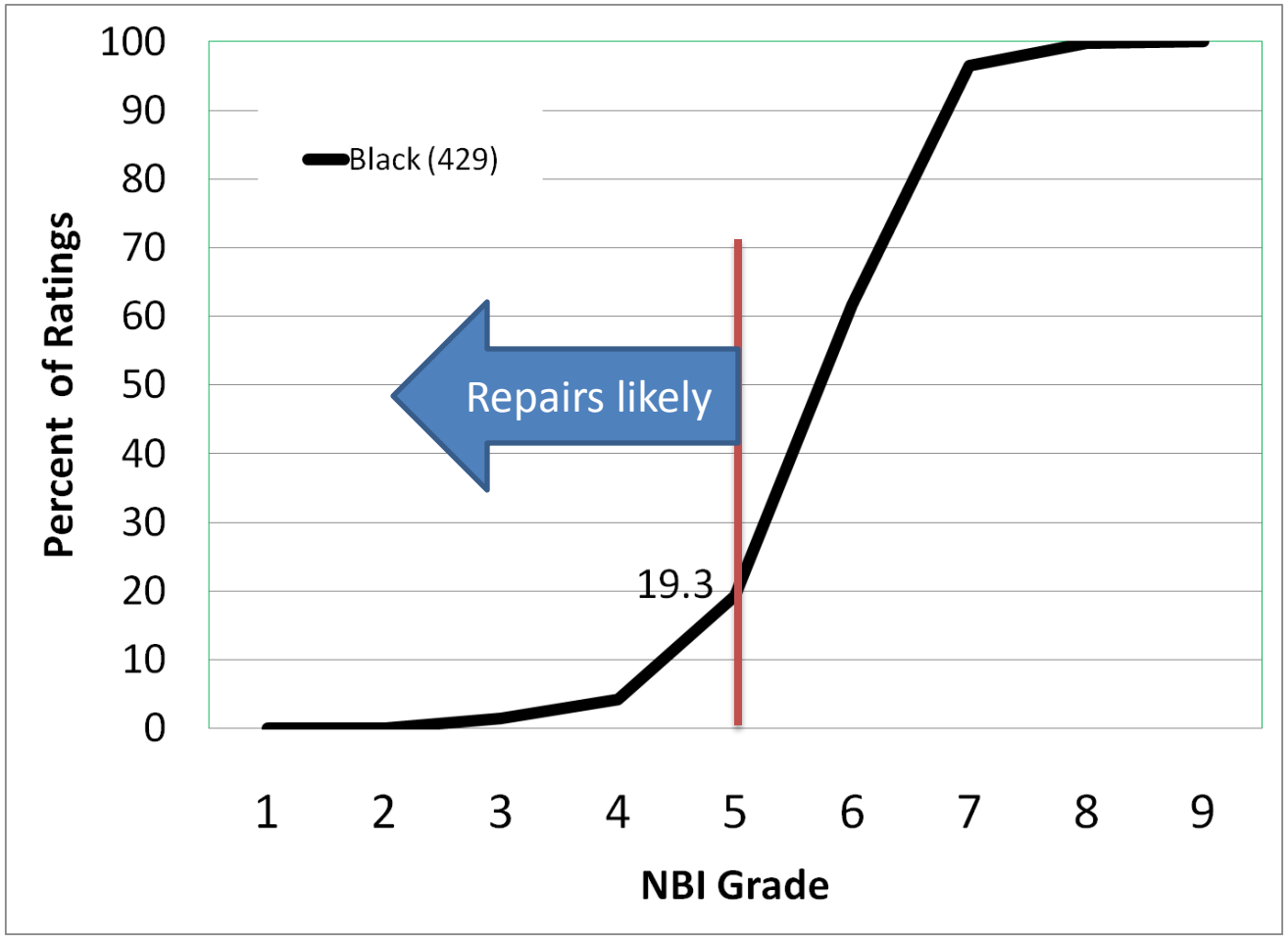


Deck with both epoxy and black bar sections

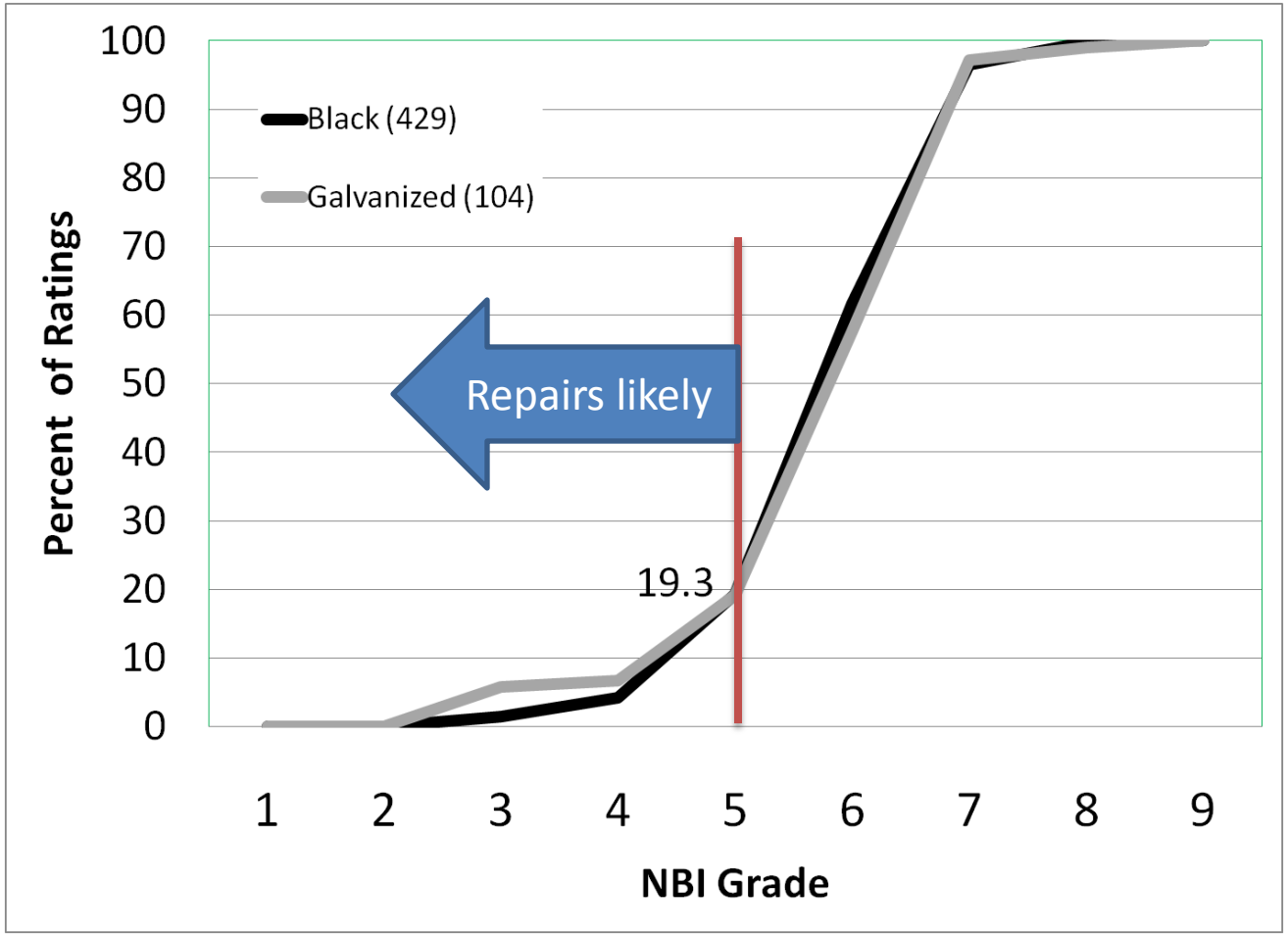
New York State Department of Transportation 2009

- 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.

PA deck condition 2010
1973 - 1983



PA deck condition 2010
1973 - 1983



PA deck condition 2010
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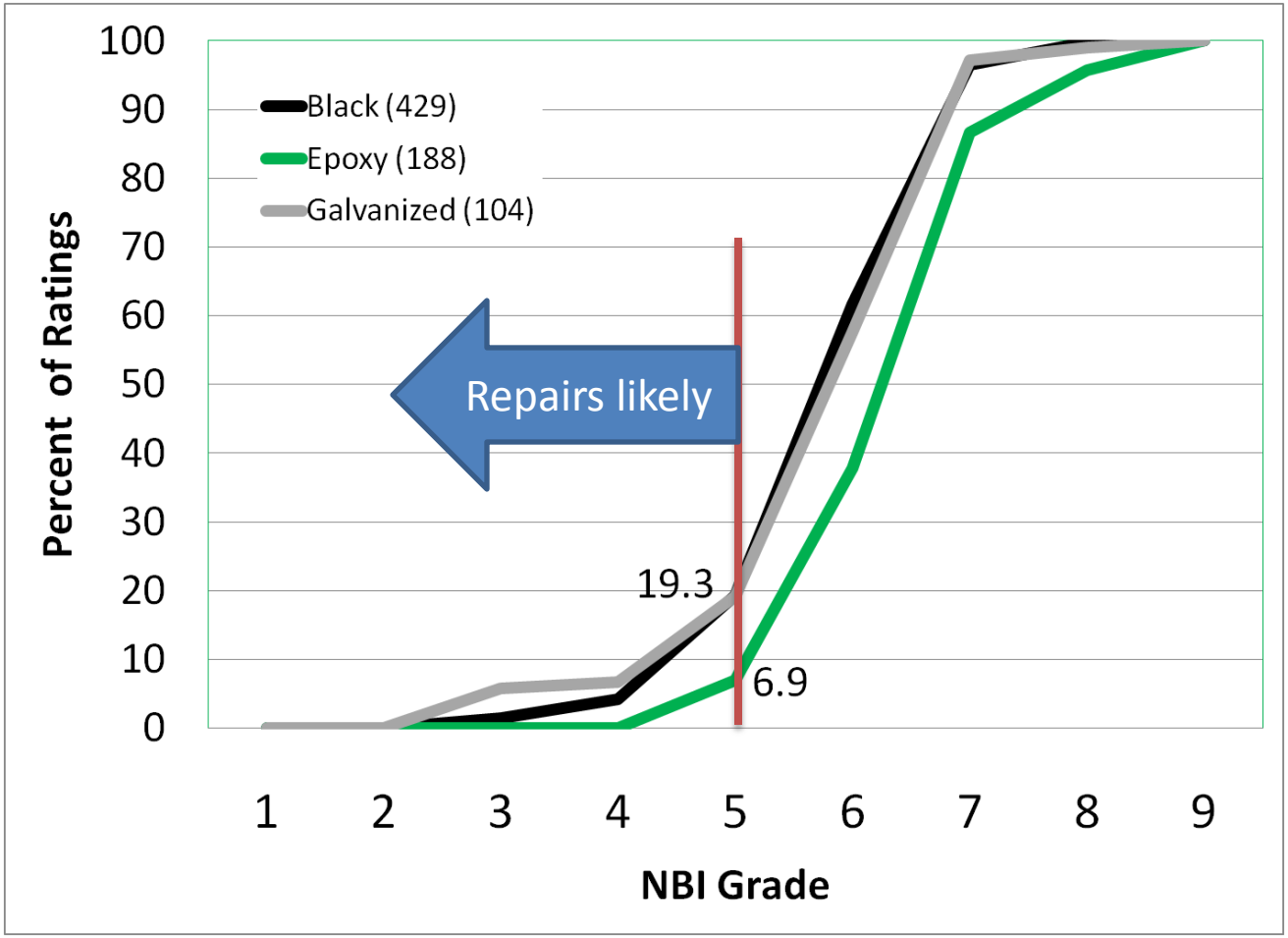
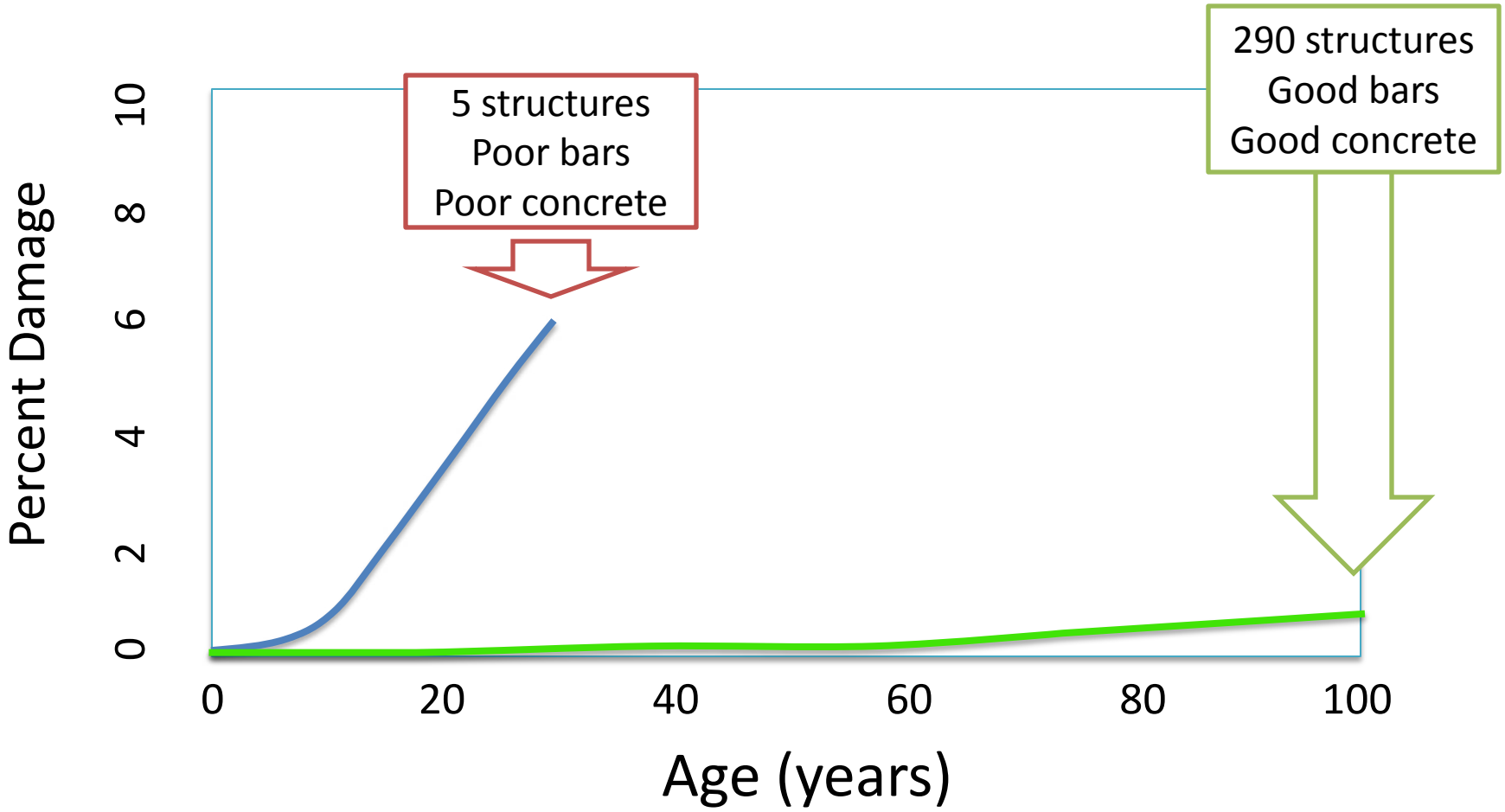


Epoxy – 3x less likely to exhibit low deck ratings

Florida Bridges with ECR



After Sagues et al.

Stainless in Marine (1)

- Progreso Pier (1940)
- Generally good performance

- "serious laminated corrosion on the visible reinforcement and the reinforcement area was reduced to approximately 60 – 70%."

Stainless in Marine (2)

- Magnetic Silencing Facility, Point Loma

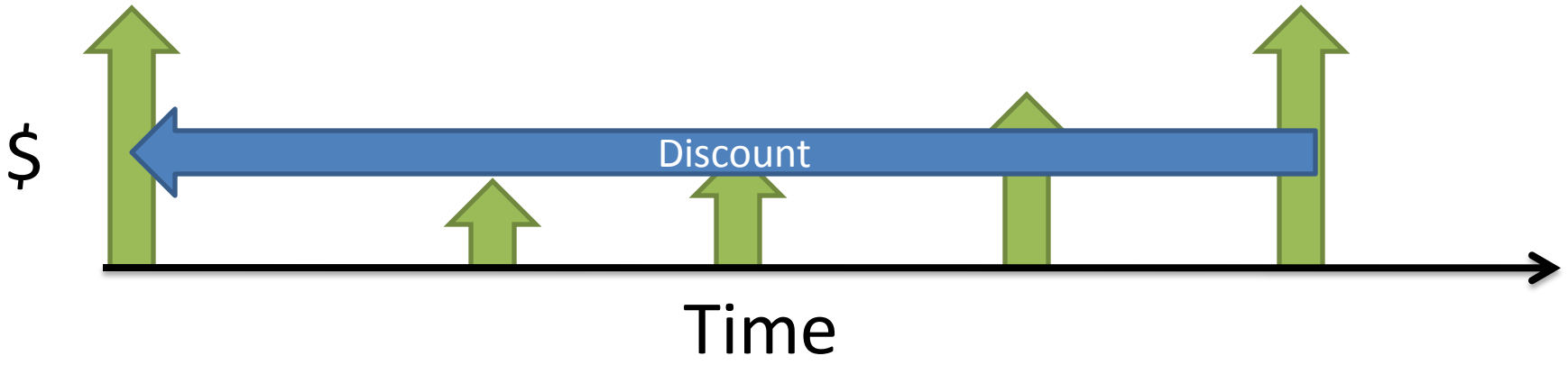
http://farm3.static.flickr.com/2718/4389549311_eb08812cb4.jpg

- Losses of stainless steel cross-section exceeded 50 percent
- *The reinforcement is inadequate for its environment*
  - *despite being of stainless steel composition, which has generally been considered superior in marine concrete*

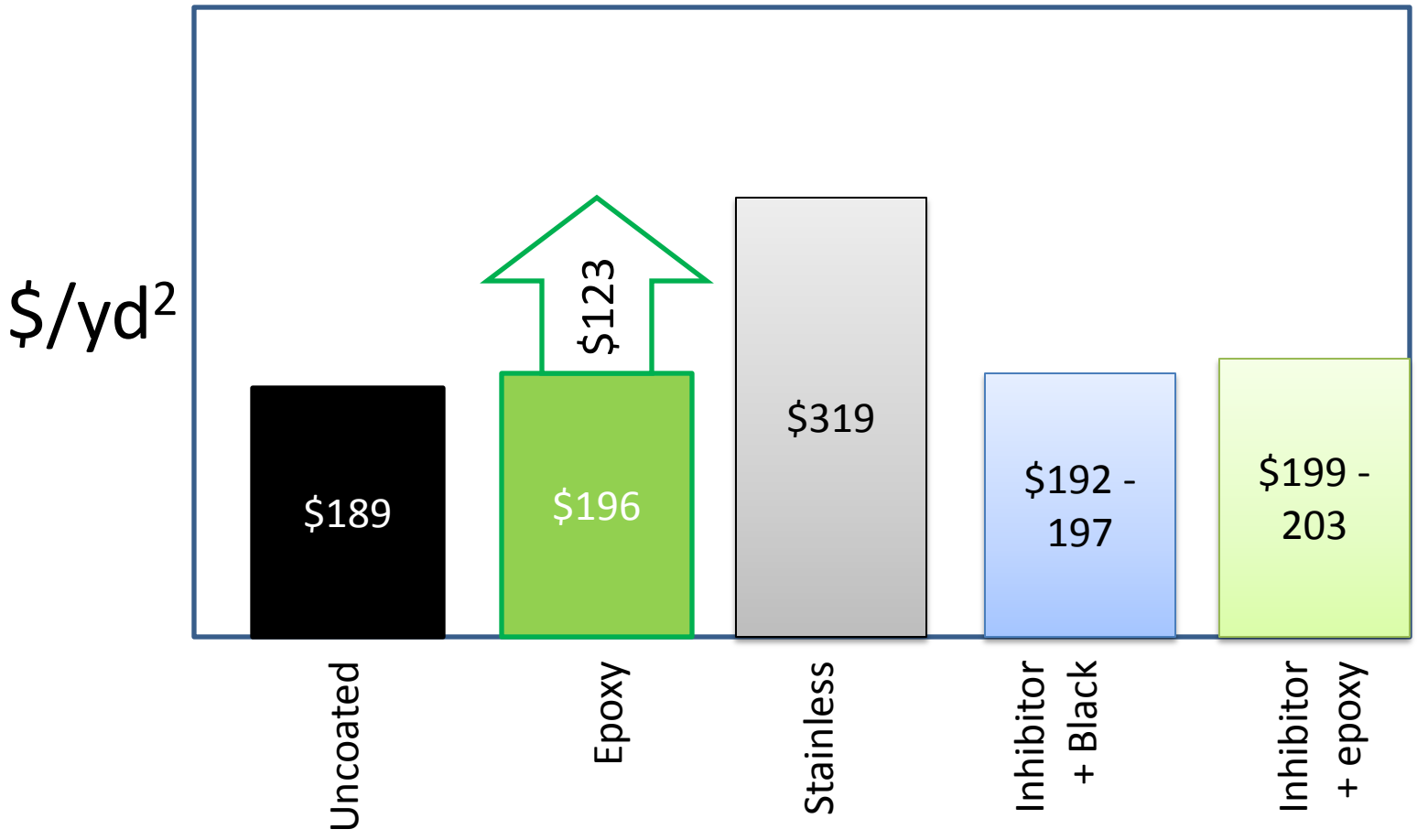
COST EFFECTIVENESS

Life-Cycle Cost Analysis (LCCA)

- Calculate net present value
  - Determine initial and repair costs
  - Timing of repairs
  - Discount rate
    - No consensus as to the appropriate value
    - 3 to 5 percent are commonly recommended

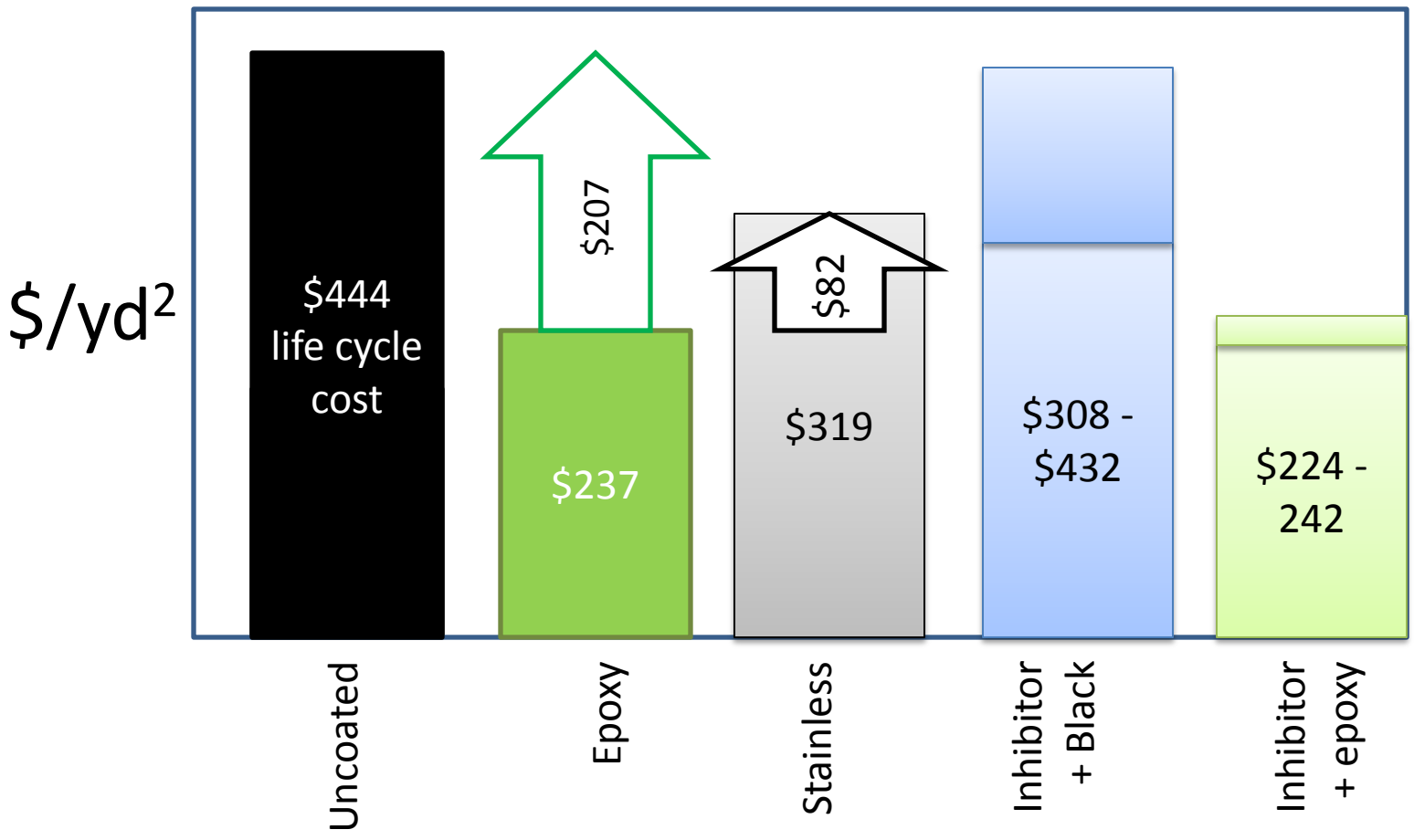


Initial Cost



Is stainless in the budget?

Life Cycle Cost



ECR provides lowest life cycle cost

OTHER FACTORS

Sustainability

- Pozzolans
  - reduce carbon footprint
  - post-industrial waste
- Recycled Content
  - Epoxy-coated and galvanized bars >95%
  - Stainless Steel >75%
- Processing Energy
  - Stainless steel > epoxy-coated or galvanized bars

Availability

- Pozzolans
  - East of Mississippi
- Galvanizing
  - Experience
  - Bar lengths (40 ft)
  - Chromate treatment
- Epoxy-coated
  - Bar lengths (60 ft)
  - Widely available
- Stainless steel reinforcing
  - limited manufacturers
  - substantial lead times
  - Identification/theft
- Other Products
  - Proprietary
  - Lead times
  - Bent bars

CONCLUSIONS

Summary And Conclusions

- Wide choice in the selection of materials for corrosion protection
- Low water-cement ratio
- Pozzolans
  - Cracks should be repaired
- Epoxy-coated bars
  - Proven protection over 40 years
- Stainless
  - Cost, performance

- Overall performance is not the only criteria
  - Sustainability
  - Initial and life-cycle cost
  - Availability

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