DO EPOXY-COATED BARS PROVIDE COST-EFFECTIVE CORROSION PROTECTION?

FHWA Highways for Life

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INTRODUCTION

Epoxy Bar Use

- Introduced in 1973
- 2nd most common strategy to prevent reinforcement corrosion
  - After increased cover
- USA, Canada, Middle East, Japan, and India
- 700,000,000 ft^2 of decks
  - 65,000 bridges in the US alone
  - ~600,000 ton/yr
  - 10 - 15% of all rebar

Maryland State Highway Administration

Woodrow Wilson Bridge, Virginia/Maryland

VDOT Virginia Department of Transportation

I-35 Minneapolis, Minnesota

Minnesota Department of Transportation

Bridge of Honor, Ohio

State of Ohio Department of Transportation

Biloxi Bay Bridge, Mississippi

MDOT Mississippi Department of Transportation

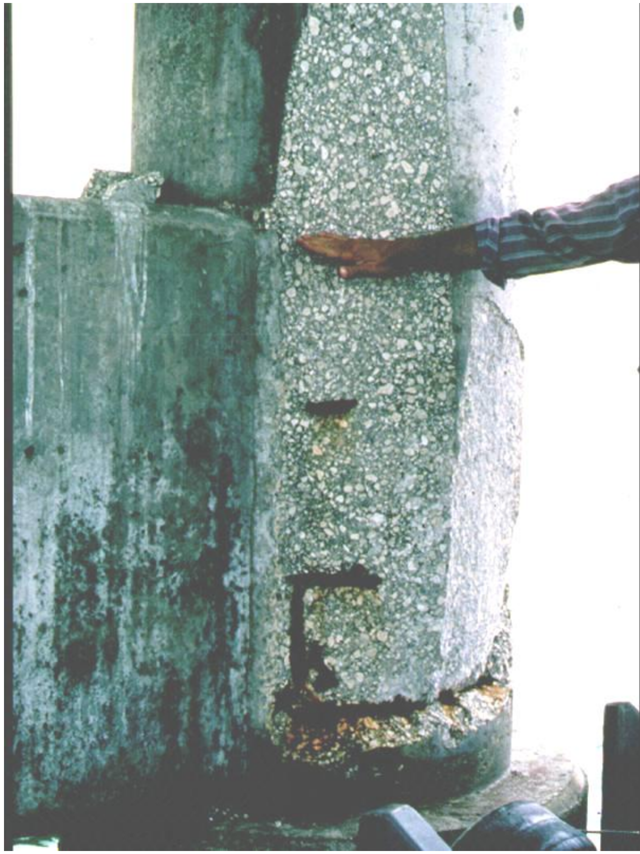
FIELD PERFORMANCE

Research and Performance

- Over 200 research papers

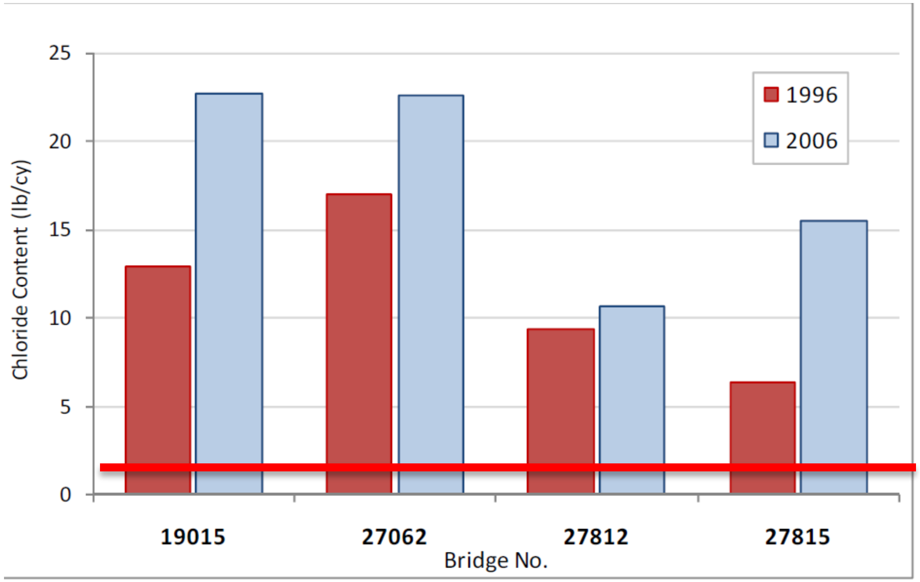
Poor concrete and poor bars

- 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



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



New York State Department of Transportation 2009

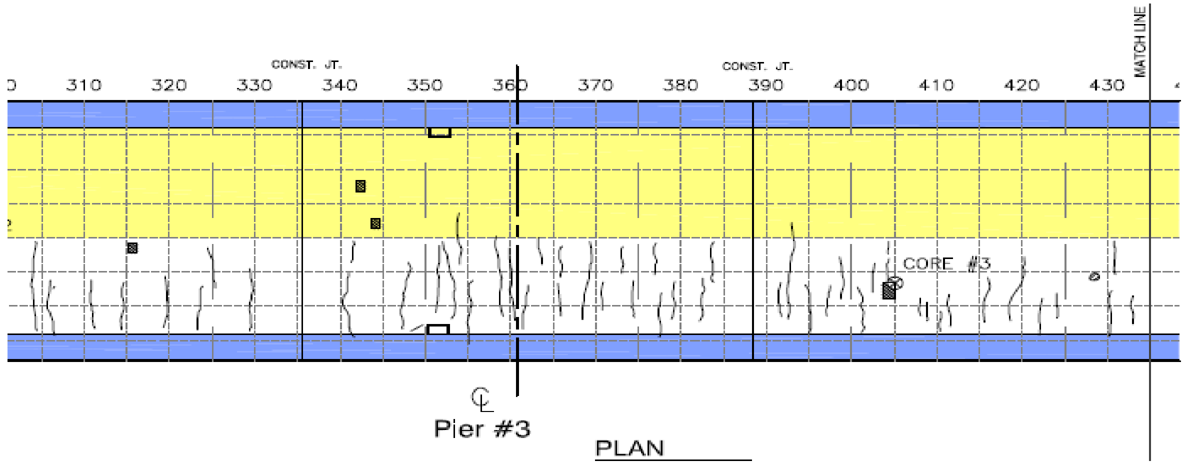
- Used extensive statistical analysis of all state bridge inspection data
- Pool of 17,000 structures
  - **“structural decks with epoxy-coated rebars perform significantly better than those with uncoated rebars, especially in the later years.”**

2009 West Virginia Study

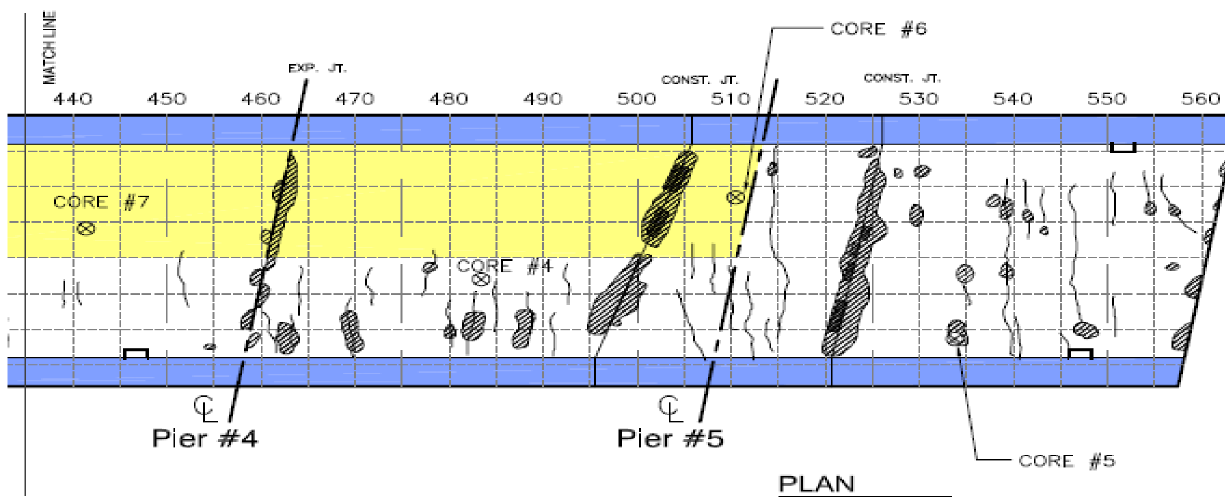
Lawler and Krauss

- 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

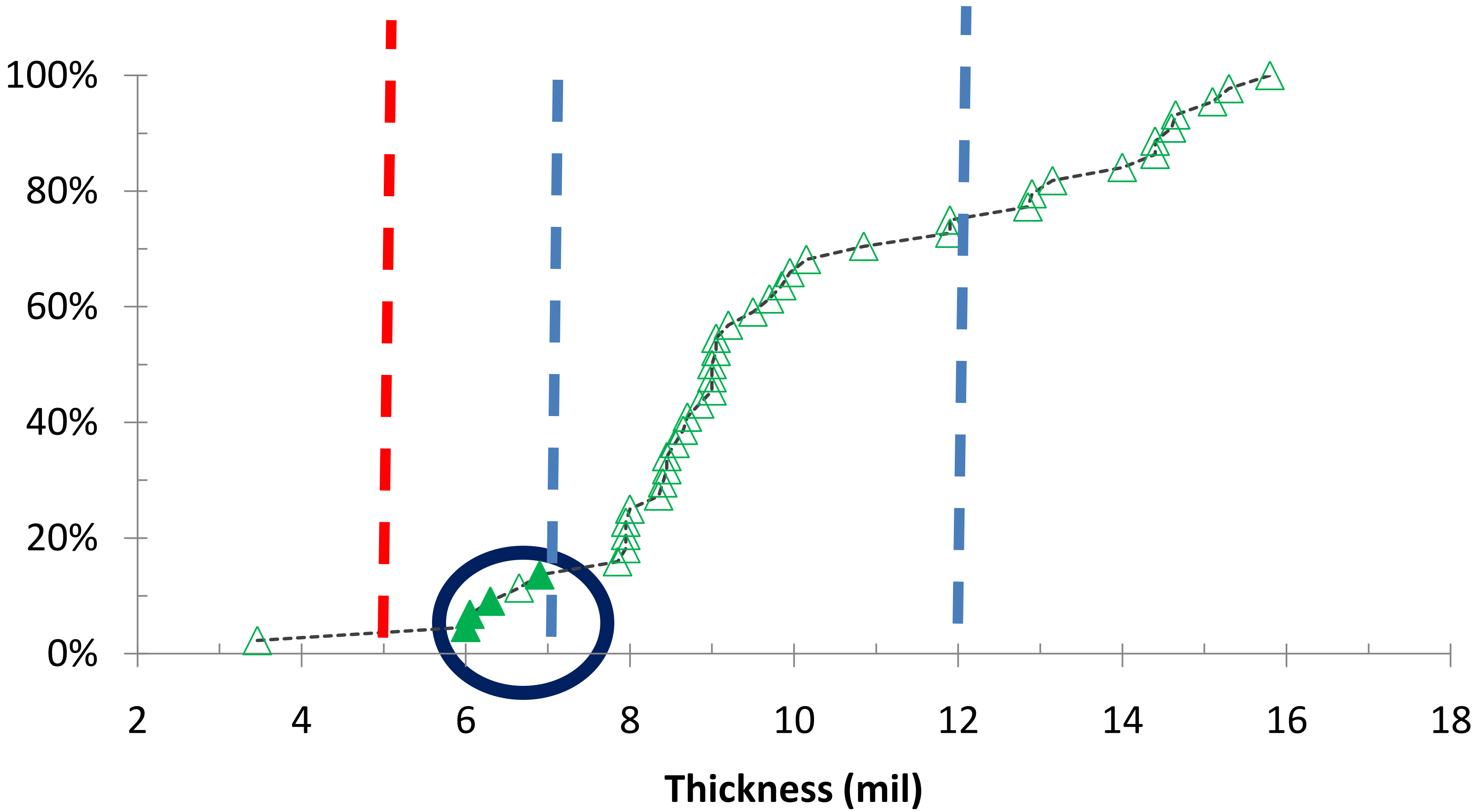


Epoxy-coated bars



Black Bars

Effect of coating thickness

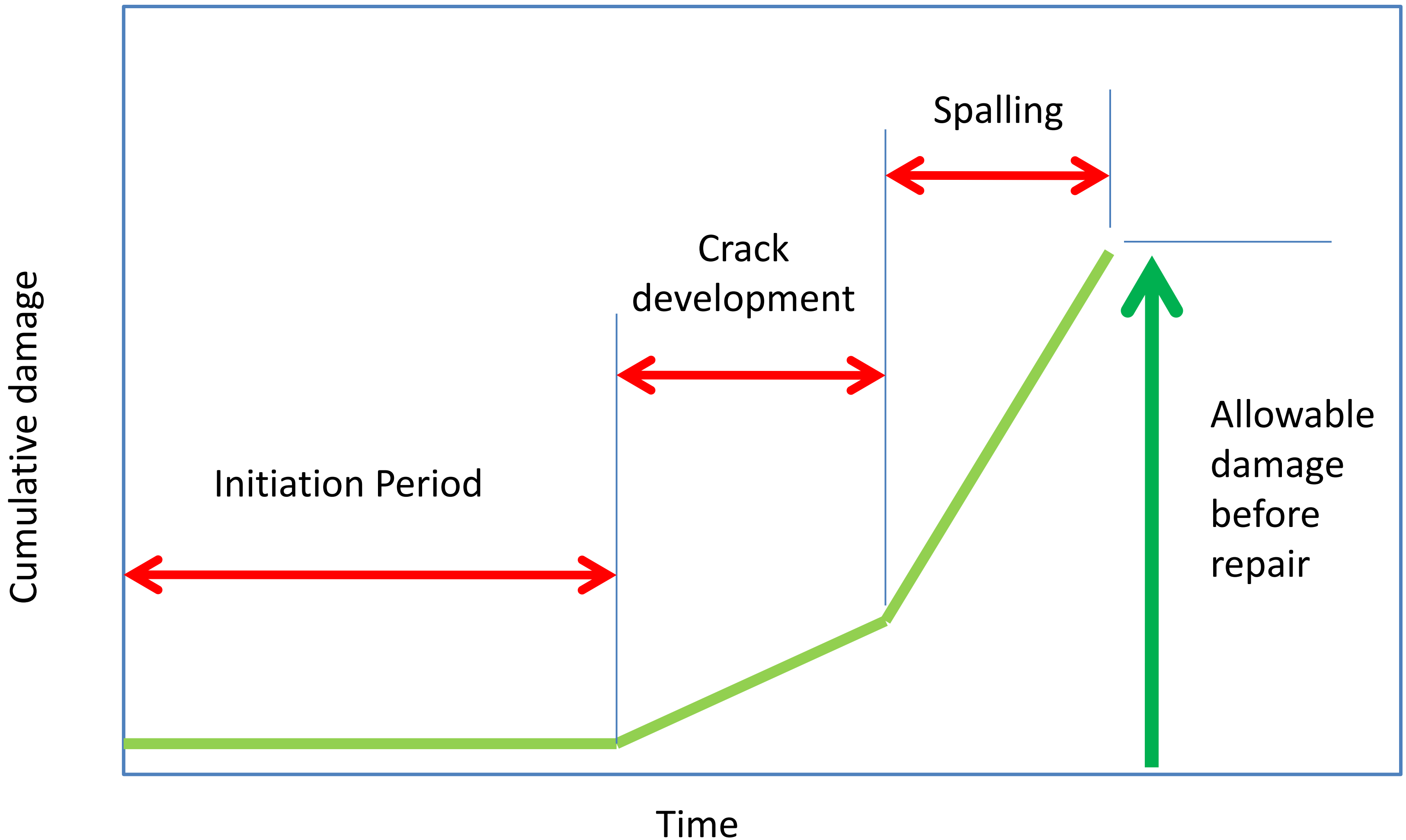


DESIGN LIFE PREDICTION

Life modeling

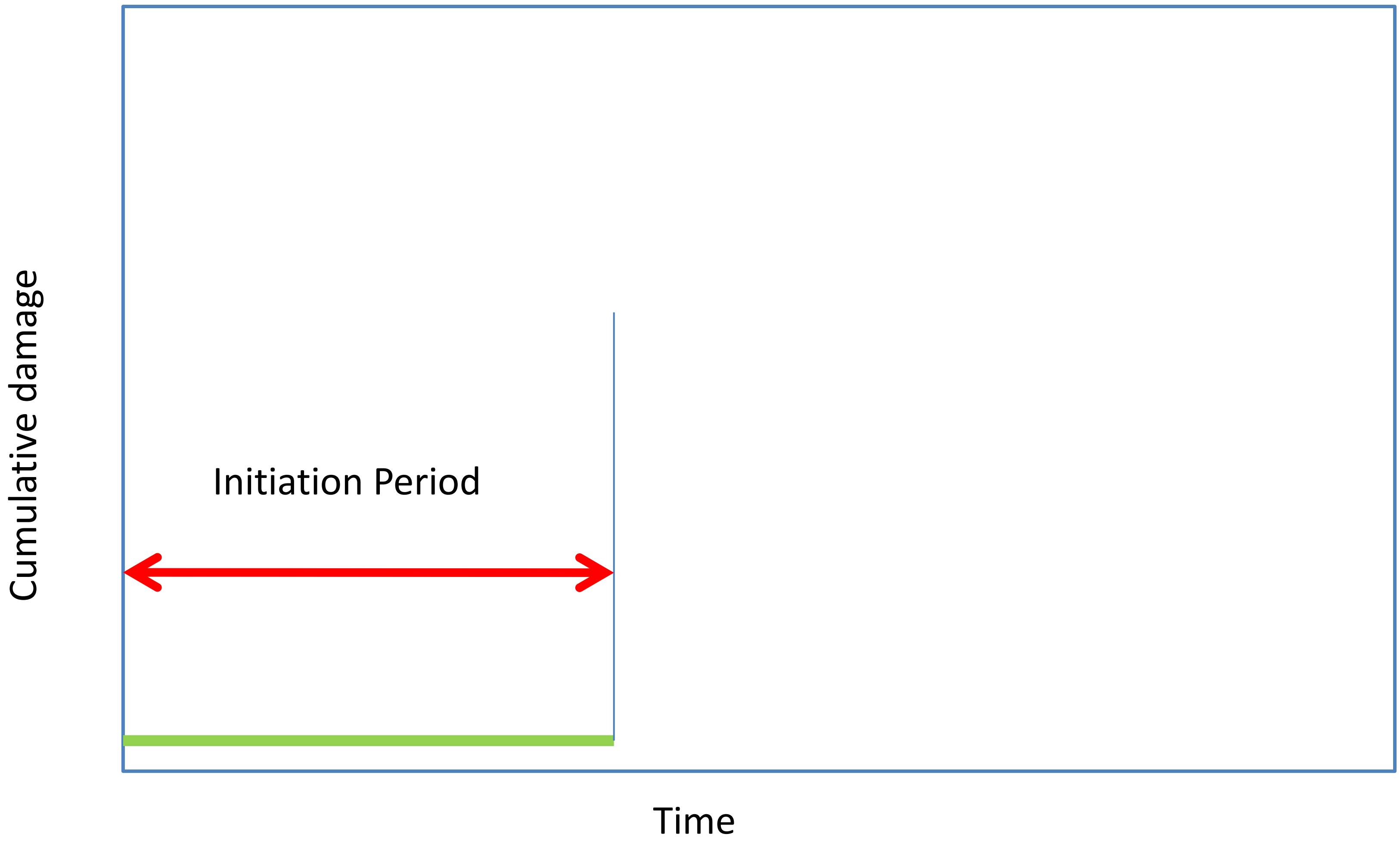
- Environment
- Materials
- Repair
- Design

Tuuti Model


Spalling
Crack
development
Allowable
damage
before
repair
Initiation Period
Cumulative damage
Time

INITIATION PERIOD

Tuuti Model



Fick's Model

- 2nd law of diffusion $$\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial x^2}$$

- C = concentration, D = diffusion coefficient, t = time, x = distance

$$C(x,t) = C_s - \left[\left(C_s - C_0\right)\cdot erf\left(\frac{x}{2\sqrt{Dt}}\right)\right]$$

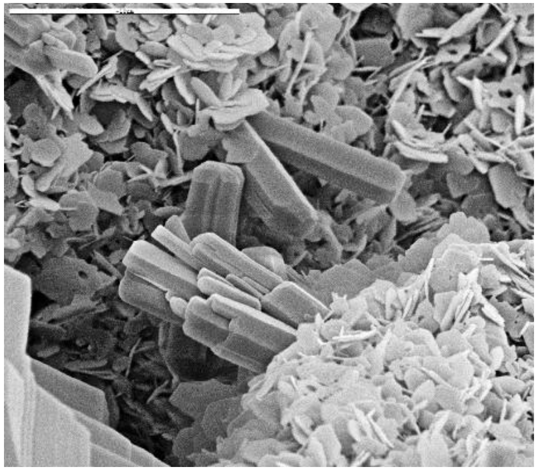
Chloride exposure

State	tons/lane mile			times /year		
	Max	Min	Avg	Max	Min	Avg
Illinois	15	2.4	6.5	93	12	50
New Jersey	6.5	2.75	4.5	44	30	37
Pennsylvania	6.25	0.75	3.5	50	10	30
Utah	9	0.1	2.5	60	2	25
Wisconsin	30	8	12	205	50	85

Concrete permeability

- Pore structure
  - chemistry of the cement and additives
  - water-cement ratio
  - types and quantities of aggregates.

- For w/c of 0.42
  - Lawler and Krauss ~ 0.15 in^2/yr,
  - Life-365 ~ 0.43 in^2/yr [16].



http://www.fugro-robertson.com/images/content/sem_aa_chlorite_cement.jpg

Effect of cracks

- Most models do not consider the effect of cracks

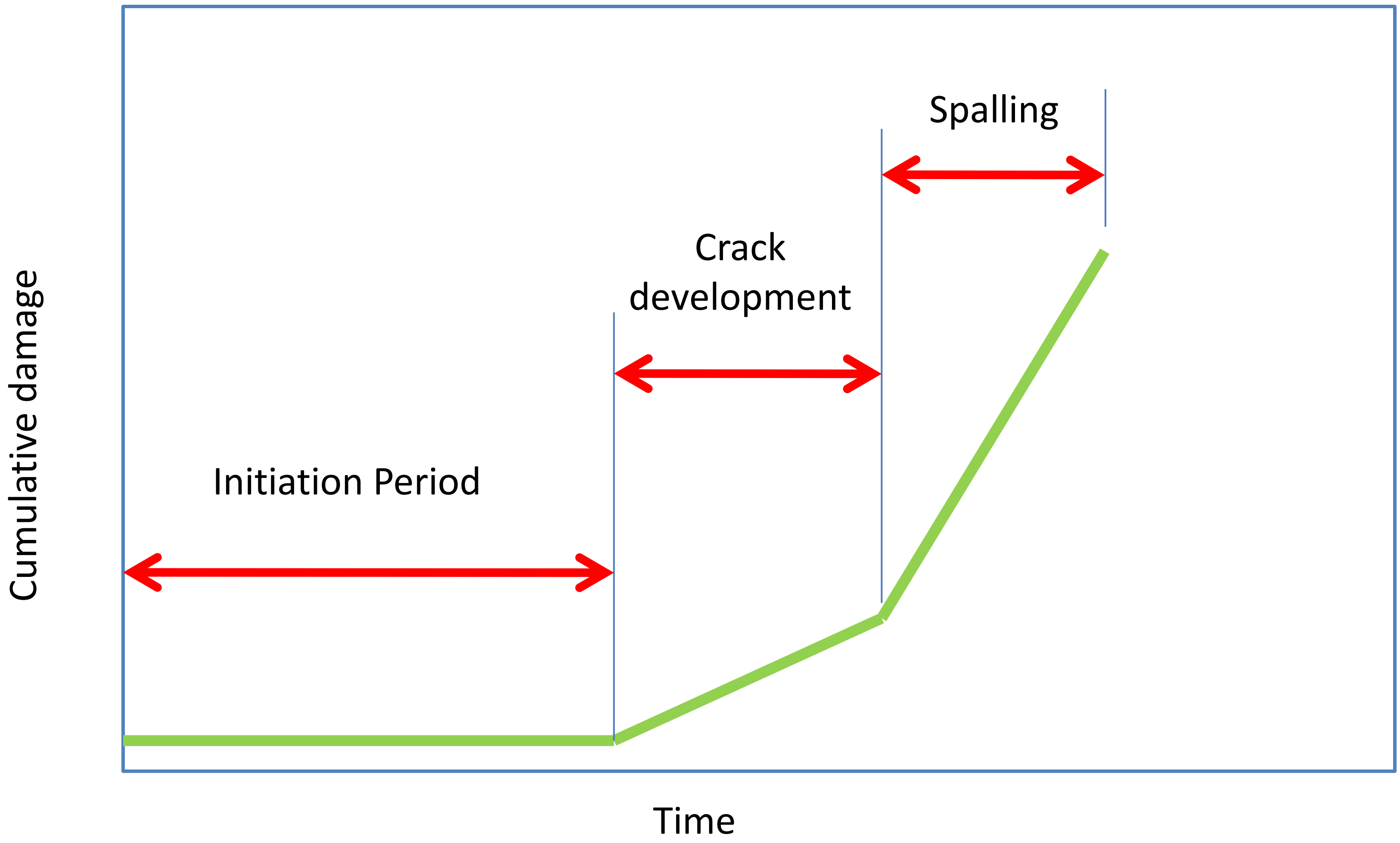
Corrosion threshold

- Typical 1.2 lb/yd^3
- Azad 1.0 to 2.1 lb/yd^3 chloride ion by weight of concrete.

Effect of variability

Parameter	Assumption 1	Assumption 2
Cover (in.)	2.8	3.2
Permeability (in.in/year)	0.15	0.075
Surface chloride (lb/cu yd)	10	7.5
Assumed threshold (lb/cu yd)	1.2	1.5
Calculated time to corrosion initiation (years)	11	42

Tuuti Model

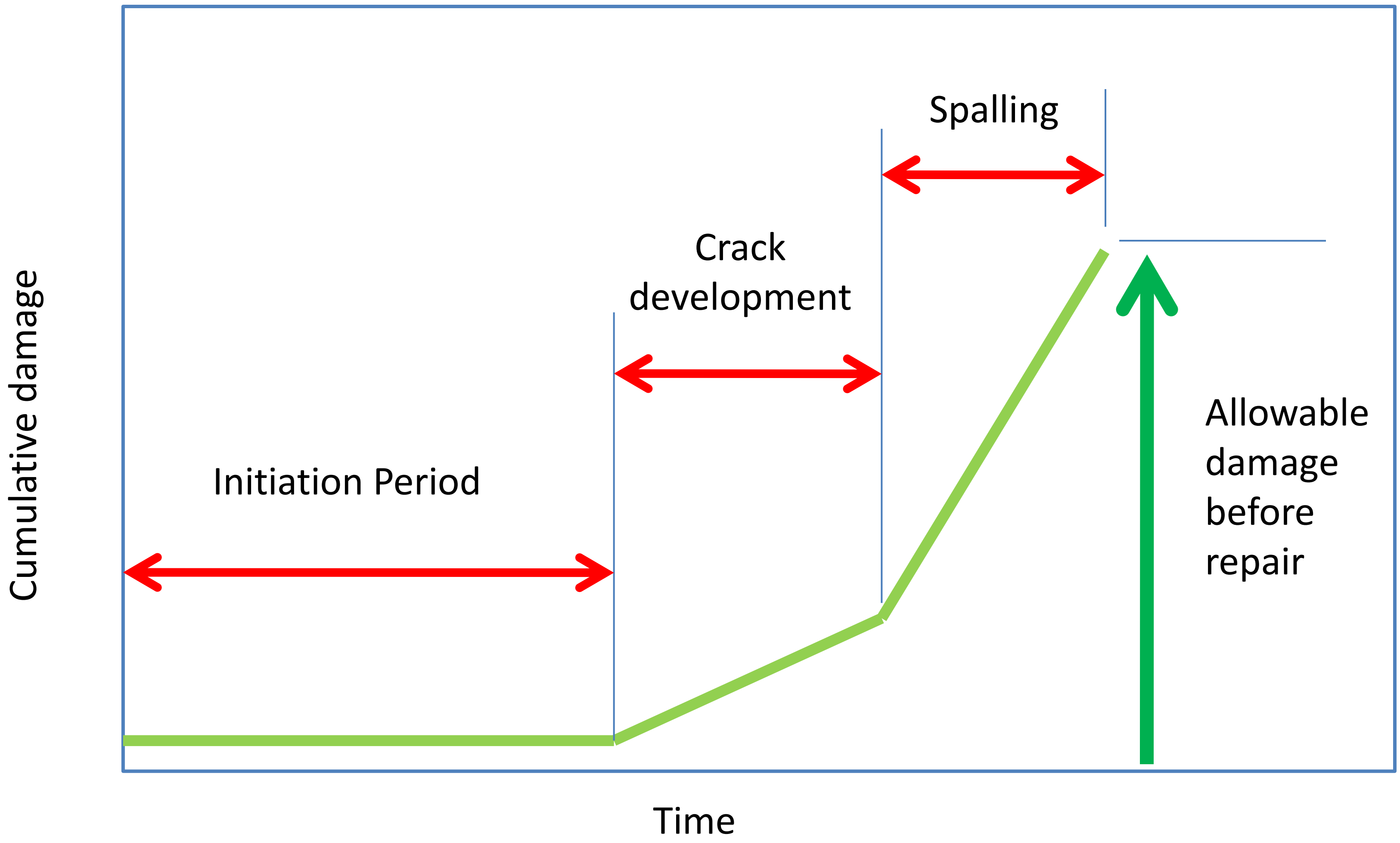


Spalling
Crack
development
Initiation Period
Cumulative damage
Time

Propagation period

- Dependant on:
  - temperature
  - oxygen availability
  - cathode areas
  - concrete resistivity
- Black bars
  - standard 5-year
- Epoxy-coated bars
  - Standard 20 years
  - significantly influenced by the availability of cathodic areas
  - very conservative

Tuuti Model


Spalling
Crack development
Initiation Period
Allowable damage before repair
Cumulative damage
Time

Repair timing

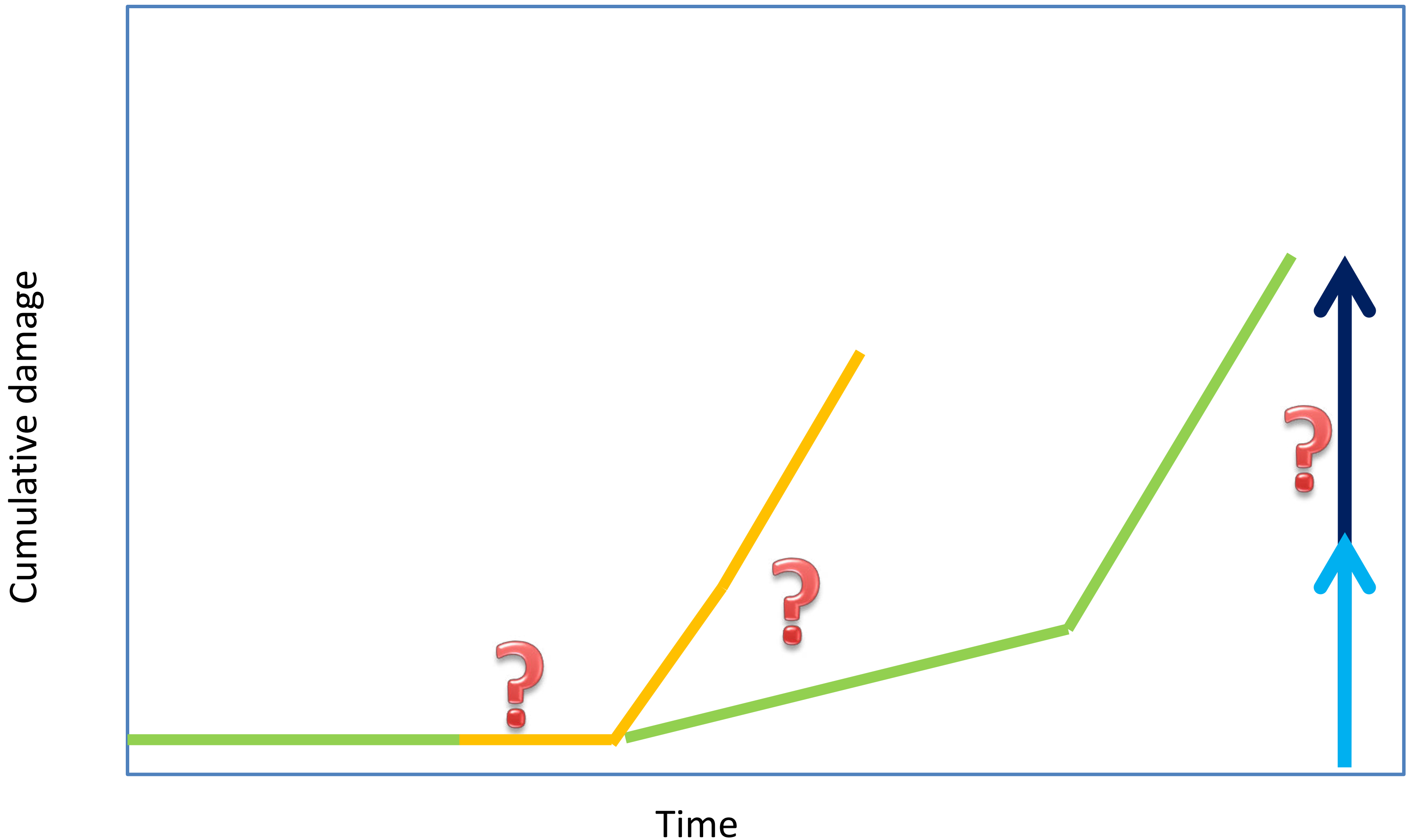
- Amount of deterioration
- Funding and labor
- Condition of the superstructure
- Volume of traffic
- Rate of physical deterioration

- 18 structures in Kansas
  - damage 1.0 to 29.8 percent of the deck surface

Durability of Repairs

- Need to develop durability databases
  - Significantly influence models
    - 10 year period for patch repairs
    - 20 years for an overlay

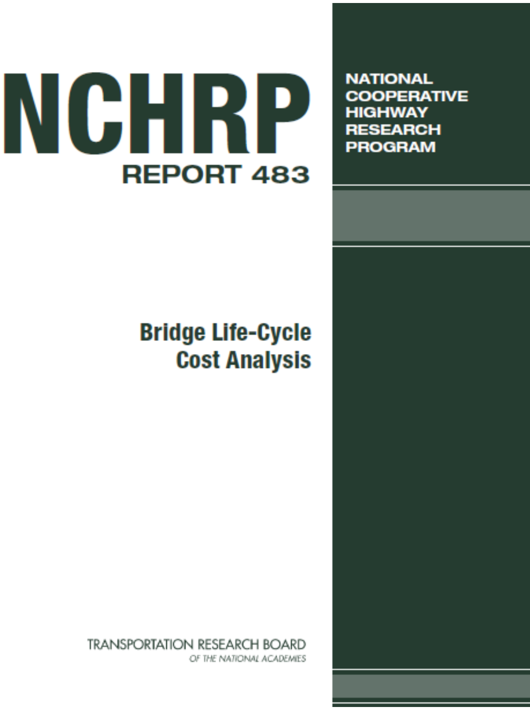
Tuuti Model



LIFE CYCLE ANALYSIS

LIFE CYCLE COST ANALYSES

- *Not a straightforward procedure.*
  - *economic principles*
  - *bridge repair techniques, costs, and effectiveness*
  - *good costing database*
  - *most likely alternatives*
  - *good knowledge of how a bridge behaves over the long term.*
- ***Poor decisions can result if the user applies the wrong assumptions.***



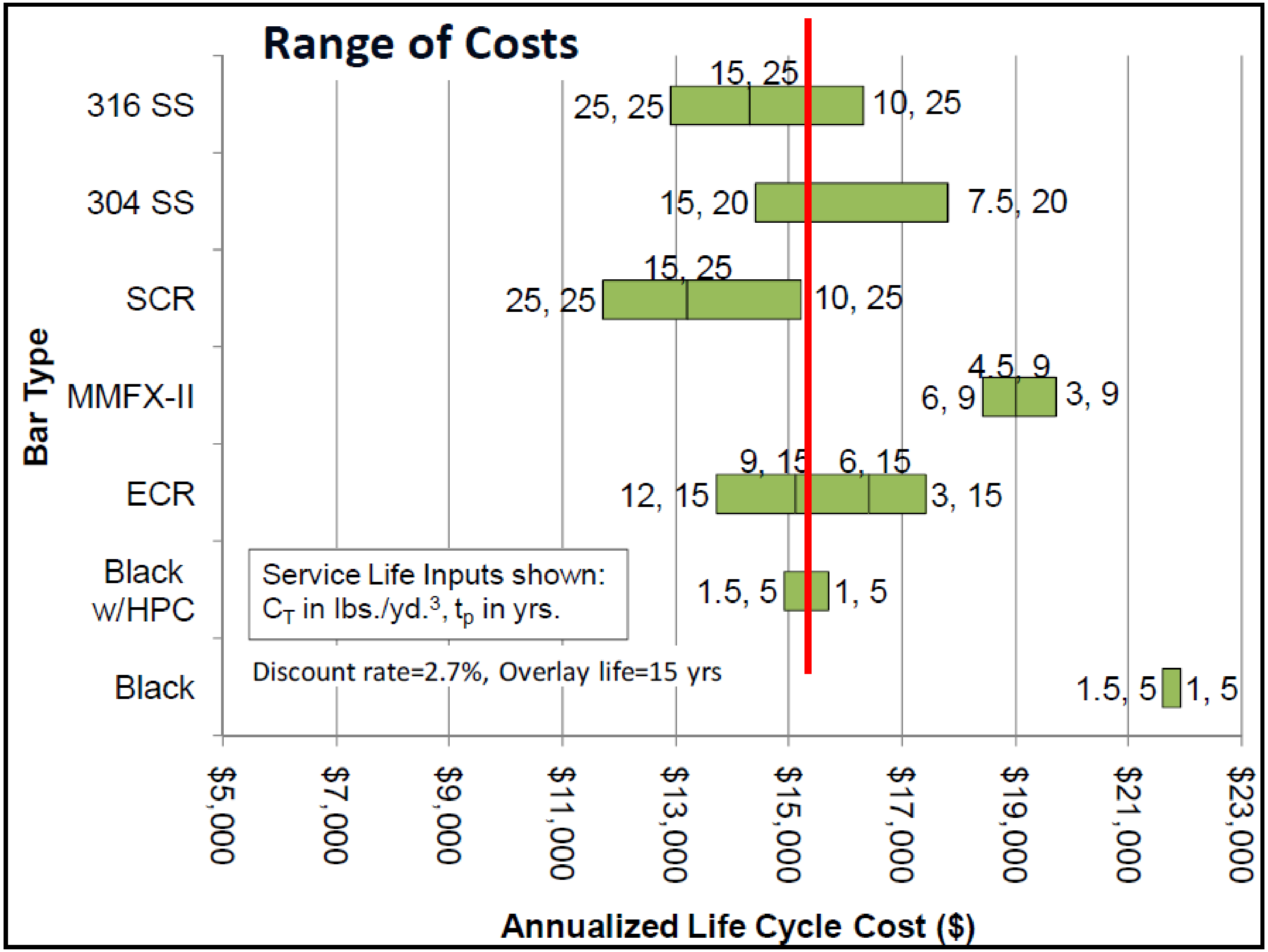
Cost of repair

- Significant portion of the total cost comes from incidental costs
  - mobilization
  - traffic control
  - repairs and improvements to other parts of the bridge
- Kansas
  - Averaged $12/sf
    - minimum of $3/sf
    - maximum of $26/sf

Discount Rate

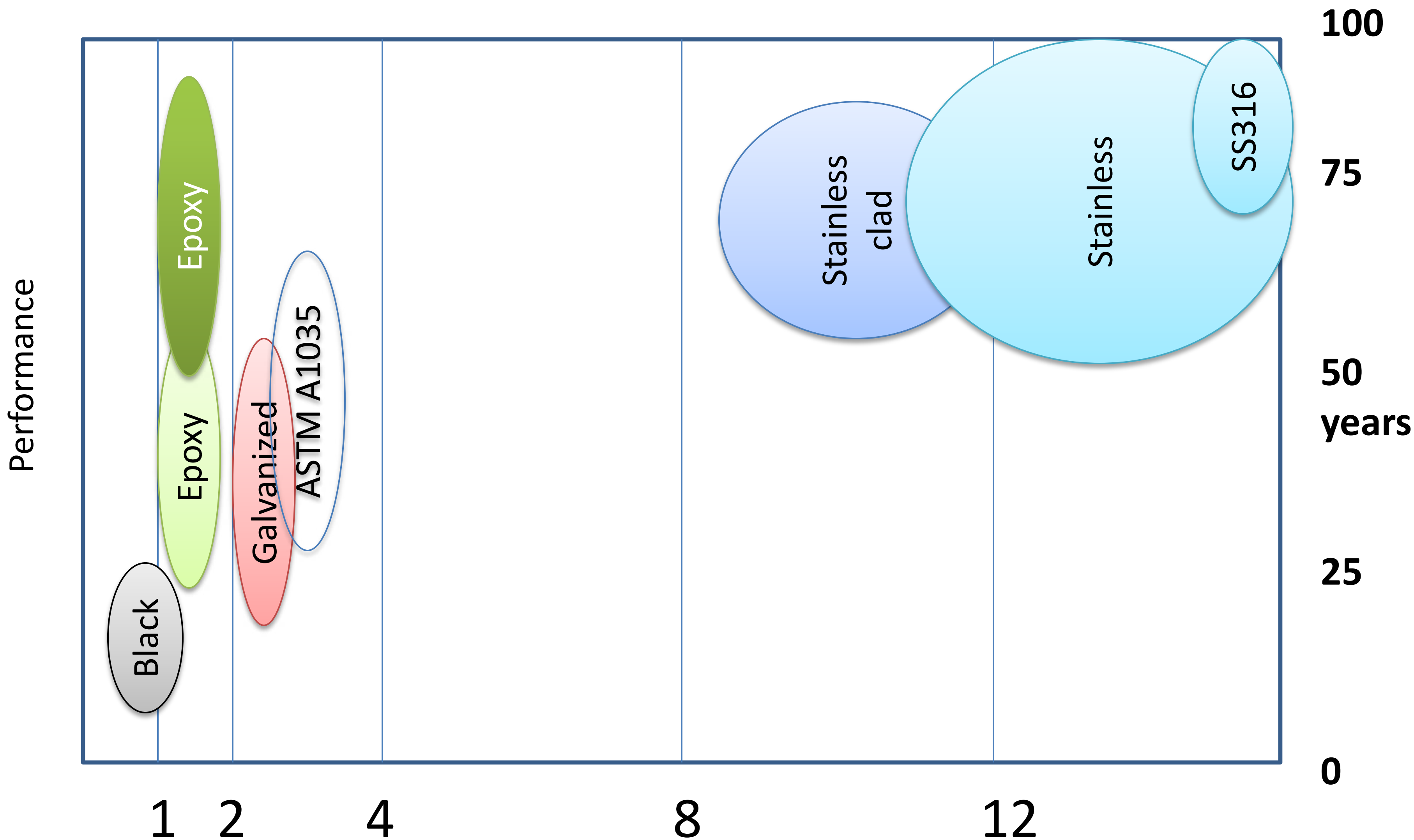
- Office of Management and Budget (OMB)
  - 2010: 2.8% for a 30 year program
  - 1982: 7.9%
- Low discount rates favor materials with high durability requiring little or no maintenance
- Present value of a $100 repair in 60 years, the present values will be $19 or $1, respectively

Which one to choose?



INITIAL COSTS

Performance vs. Cost



CONCLUSIONS

Selection Factors

- Experience
  - 700,000 bridges already in existence in North America.
- Initial cost.
  - Corrosion can go away – at a premium
  - Epoxy-coated bars have already provided 40 year design life in 1970s concrete for minimal cost

Dealing with uncertainty

- *Everything is vague to a degree you do not realize till you have tried to make it precise*
- Any product can be made cost effective, dependent on the assumptions.
  - Black reinforcing bars become cost effective if the discount rate is high.

Conclusions

- Designers and specifiers should consider the experience gained from 65,000 structures containing epoxy-coated bars over the past 37 years.
- Epoxy-coated bars have already demonstrated almost a 40-year design life in 1970s concrete
- Epoxy-coated bars provide cost-effective corrosion protection.