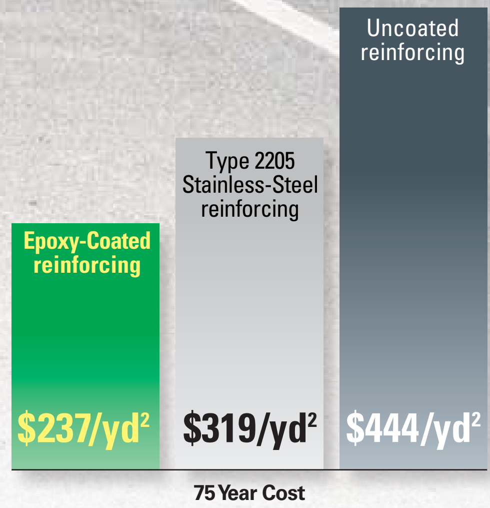
EPOXY INTEREST GROUP



COST-EFFECTIVE CORROSION PROTECTION SYSTEMS

For Reinforced Concrete

Owners of concrete structures are looking at ways of cost-effectively protecting new assets such as bridges and parking garages against corrosion. In order to conduct economic analyses for corrosion-induced damage, knowledge of chloride ingress, the amount of chloride to initiate corrosion, corrosion rates and the amount of corrosion to cause cracking are required. This document summarizes key findings relating to the cost and performance of concrete bridge decks containing various corrosion-protective systems.

OVERVIEW

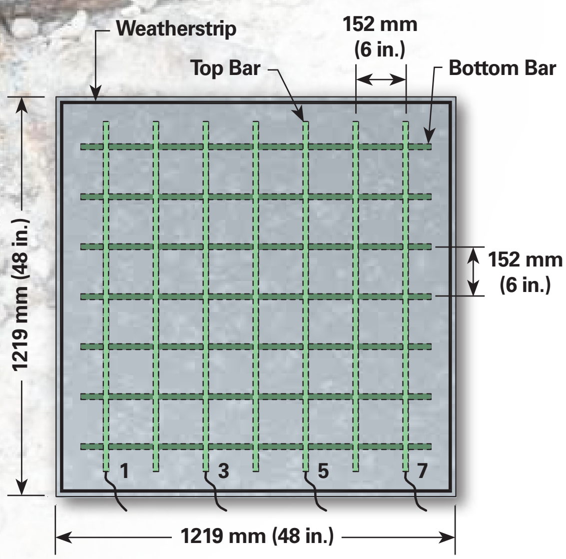
In 2011, the University of Kansas Center for Research published a report titled "Evaluation of Multiple Corrosion Protection Systems for Reinforced Concrete Bridge Decks." The Kansas Department of Transportation and the Federal Highway Administration provided the majority of the funding.

The report provides an in-depth evaluation of the performance of corrosion inhibitors, uncoated, epoxy-coated and stainless-steel reinforcing. It includes documentation of extensive laboratory and field research, an evaluation of the amount of corrosion to cause cracking and an economic analysis. The pertinent findings from the report are summarized as follows:

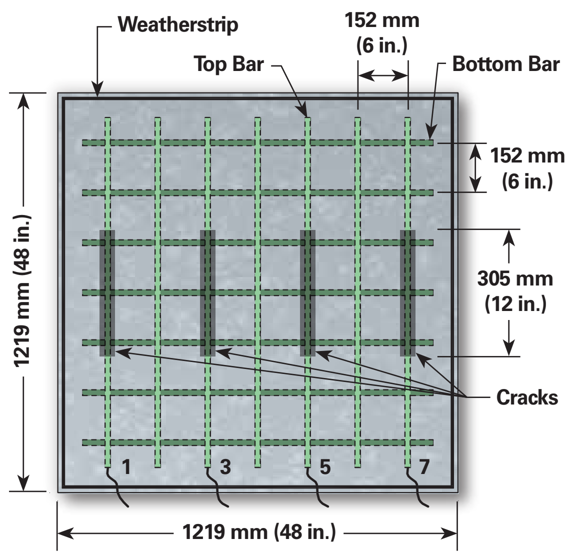
Uncoated Reinforcing Steel — A bridge deck containing uncoated reinforcing steel has the shortest design life of all systems tested and also the highest life-cycle cost.

Epoxy-coated Reinforcing Steel — Epoxy coatings significantly reduce the corrosion rates of reinforcing steel. Epoxy-coated reinforcing steel maintains low initial and life-cycle costs over a 75-year life-cycle and use of epoxy-coated reinforcing steel was found to be substantially more cost-effective than either using uncoated reinforcing steel in concrete containing corrosion inhibitors or stainless-steel reinforcing.

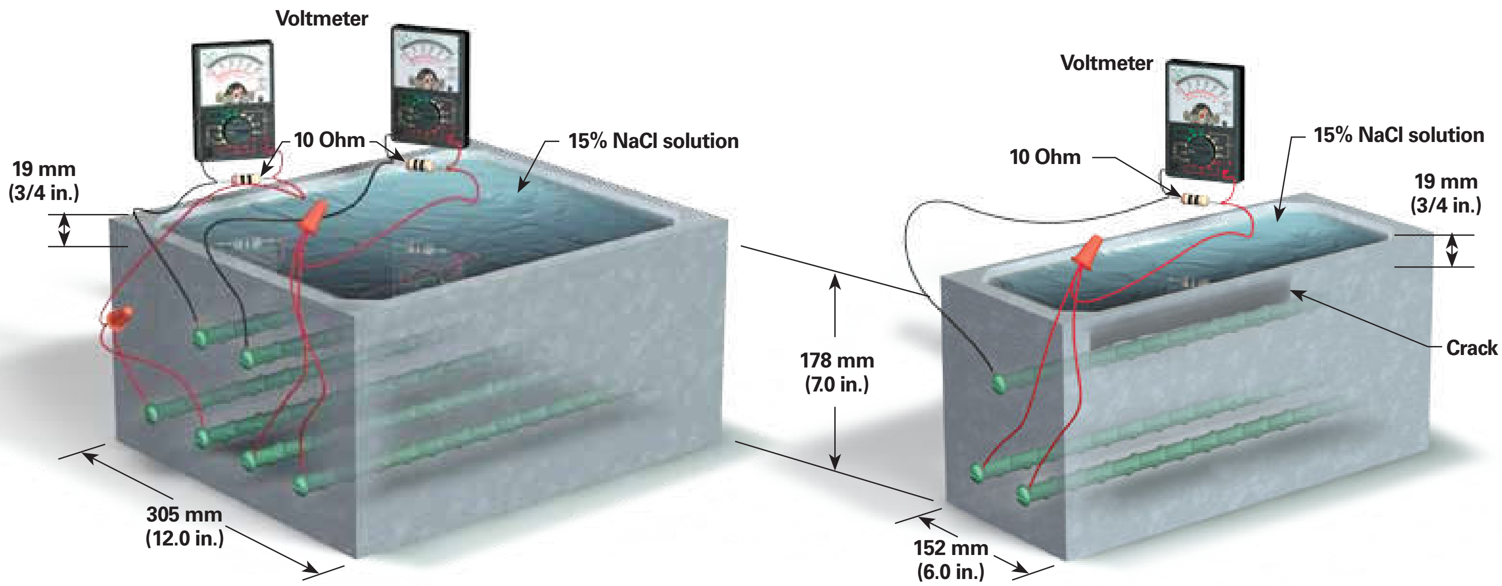
Stainless-Steel Reinforcing — Type 2205 stainless-steel reinforcing has an initial cost that increased the deck cost by approximately $130/yd^2 or 70 percent over the cost of uncoated reinforcing steel. The life-cycle cost of concrete with these bars was $82/yd^2 or 35% greater than that of epoxy-coated reinforcing steel.



Field Test Specimen Setup — Slab Without Cracks



Field Test Specimen Setup — Slab With Cracks



Southern Exposure (SE) Specimen **Cracked Beam (CB) Specimen**

TEST PROGRAM

An extensive test program was conducted on concrete containing corrosion inhibitors, uncoated, ASTM A775 epoxy-coated and Type 2205 stainless-steel reinforcing. The goal of the testing was to determine the performance of these materials that could then be used in an economic model. Tests included Southern Exposure, Cracked Beams and Corrosion Initiation specimens as well as Field Exposure slabs. Measurement included macrocell voltage, mat-to-mat resistance, corrosion potential and linear polarization resistance. The amount of chloride in the concrete during the testing was also determined.

Chloride Threshold — The amount of chloride required to initiate corrosion in uncoated reinforcing steel was 1.58 lb/yd^3. **The amount of chloride required to initiate corrosion in the epoxy-coated reinforcing steel was found to be 7.28 lb/yd^3 or 4.6 times that of the uncoated reinforcing steel.** This was substantially greater than that required for concrete with uncoated reinforcing steel and corrosion inhibitors, where values of 0.83 to 3.05 lb/yd^3 were determined. When epoxy-coated reinforcing steel and corrosion inhibitors, chloride amounts of 1.69 to 9.85 lb/yd^3 were required to initiate corrosion. A chloride threshold of 26.4 lb/yd^3 was determined for the Type 2205 stainless-steel reinforcing.

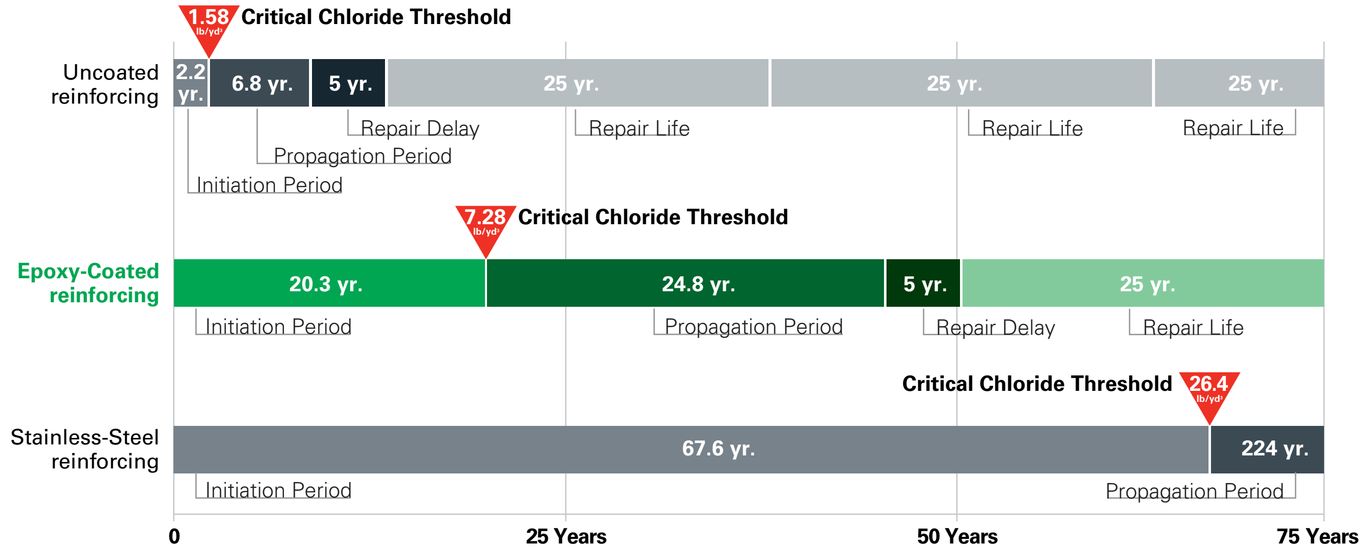
Corrosion Rates — After corrosion initiation, the corrosion rates of the bars were measured. The uncoated reinforcing steel exhibited the highest corrosion rates among the systems studied. **Epoxy coated reinforcing steel was found to have a significantly lower corrosion rate compared to the systems containing uncoated reinforcing steel.** Use of corrosion inhibitors in the concrete together with either uncoated or epoxy-coated reinforcing steel reduced observed corrosion rates.

Corrosion to Cause Cracking — The amount of corrosion to cause cracking was extensively studied using experimental and finite element analyses. An equation was developed for the amount of corrosion to cause cracking, based upon the concrete cover, bar diameter and the fractional length and area of the bar that is corroding. For uncoated reinforcing steel, the corrosion losses required to crack concrete are directly proportional to the clear concrete cover. For isolated corrosion sites, such as occurs at damage sites on epoxy-coated steel reinforcing, the relationship changes to one that is directly proportional to the square of the concrete cover.

Time to Repair — The time to repair is determined by adding the initiation period to the propagation period. An additional five-year period was provided within the report to account for time from the first crack to the repair of the deck. The report explains that a five-year delay between first cracking and repair is assumed for all corrosion protection systems.

Corrosion rates from cracked concrete only were used in this study as "…bridge decks inevitably develop cracks over the reinforcement; the comparisons using the corrosion rates in cracked concrete likely provide the more accurate representation of corrosion in bridge decks."

For uncoated reinforcing steel in cracked concrete, repair would be required after 14 years, whereas for epoxy-coated reinforcing steel in cracked concrete, repair would be required after 50 years. The systems with Type 2205 stainless-steel reinforcing did not require repair during the 75-year analysis period.



Initiation, propogation and repair.

INITIAL COSTS

Initial cost analyses were conducted using costs of a typical bridge deck. Initial costs of $0.35, $0.45 and $2.35 per lb, were used for uncoated, epoxy-coated and Type 2205 stainless-steel reinforcing, respectively. Placement costs were estimated at $0.52 per lb. The amount of reinforcing steel in a deck was approximately 275 lb/yd^3 and the in-place cost of normal concrete used in the analyses was $562/yd^3.

For uncoated reinforcing steel, the initial deck cost was determined to be $189/yd^2. The use of epoxy-coated reinforcing steel increased the deck costs by only 3.7% to $196/yd^2. When stainless-steel reinforcing was used, deck cost increased by $130/yd^2 or approximately 70% to $319/yd^2.

REFERENCES

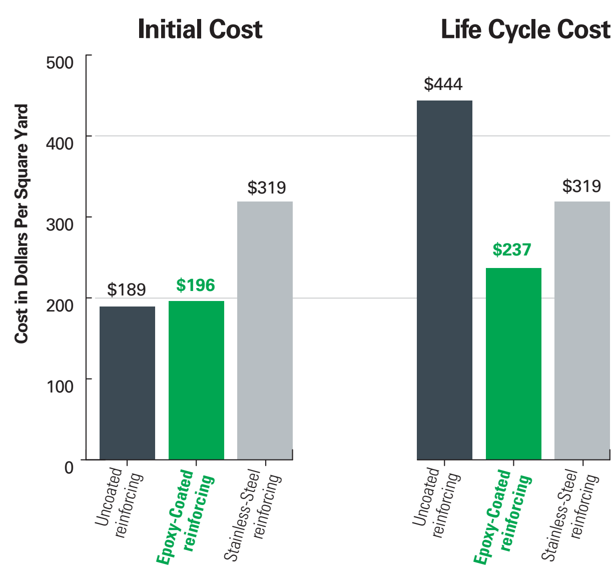
1. O'Reilly, M.; Darwin, D.; Browning, J.; Carl E. Locke, J. "**Evaluation of Multiple Corrosion Protection Systems for Reinforced Concrete Bridge Decks"**; The University of Kansas Research Inc., Lawrence, KS, 2011.

The full summary report titled *Evaluation of Multiple Corrosion Protection Systems For Reinforced Concrete Bridge Decks*[1] is available from the Epoxy Interest Group of CRSI.

LIFE-CYCLE COST

Life-cycle costs are determined by considering the net present value of all the costs during the life of a structure. Based on using an appropriate discount rate of 4%, the initial and repair costs were considered during a 75-year period. Repairs were assumed to last 25 years before an additional similar repair would be required, and repair costs were assumed to be $283/yd^2.

For uncoated reinforcing steel, the life-cycle cost for a bridge deck was estimated to be $444/yd^2, which was approximately 2.3 times the initial deck cost. **The life-cycle cost of a deck using epoxy-coated reinforcing steel was only $237/yd^2, almost half that of the deck containing uncoated reinforcing steel.** When Type 2205 stainless-steel reinforcing was used, the life-cycle cost of the system was $319/yd^2, however, this cost was almost $82/yd^2 greater than that of epoxy-coated reinforcing steel.



Initial and 75 Life-cycle Costs using a discount rate of 4 percent.

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