EPOXY INTEREST GROUP

Performance Of
WEST VIRGINIA BRIDGE DECKS

Constructed with Epoxy-Coated Reinforcing Bars

In 2009, the Epoxy Interest Group of CRSI (EIG) funded studies of bridge decks in West Virginia that contained epoxy-coated reinforcing steel. This investigation focused on 33 decks, built in the mid-1970's and surveyed by WVDOT in 1993. Evaluation of these structures is viewed as important as this study provided one of the few where side-by-side comparisons could be made between black and epoxy-coated bars. The black bar decks were overlaid or otherwise rehabilitated at ages from 18 to 21 years to address deterioration of the deck surface. By comparison none of the decks containing epoxy-coated reinforcing steel had been repaired due to corrosion-induced deterioration and these decks have reached ages of 33 to 35 years. Since the decks containing epoxy-coated reinforcing steel have shown little deterioration to date, the true service life extension is likely much greater.

The detailed report of this study is available at www.epoxyinterestgroup.org

INTRODUCTION

The life-extension provided through the use of epoxy-coated reinforcing bars to improve durability of concrete bridge structures has remained controversial, primarily due to the difficulty in extrapolating laboratory and field results. Few locations provide an opportunity to study the side-by-side performance of black and epoxy-coated bars.

In 1994, Kessler and Lipscomb reported on work for West Virginia Department of Transportation (WVDOT), where a total of 33 decks were inspected: 14 containing epoxy-coated reinforcing bars and 19 contained carbon steel (black) bars. While deterioration was observed on black bar decks (from 1% to as high as 29% of the deck areas were delaminated), deterioration of the decks reinforced with epoxy-coated reinforcing steel was identified on only three decks, where the amount of deterioration was limited (from 0% to 1% of the deck areas were delaminated). During the 2009 review, it was determined that ALL the decks constructed with black bar in Districts 1, 3 and 4 reported by WVDOT in 1993 had been rehabilitated with concrete overlays.

Removal of core samples.

Measuring concrete cover over reinforcing bars.

CURRENT STUDIES

In 2009, an investigation was initiated to assess the corrosion protection provided to concrete bridge decks by epoxy-coated reinforcing bars. This investigation consisted of:

- Follow-up survey of the condition of the decks containing both uncoated and coated bars originally examined by the WVDOT in 1993.
- A condition survey of six of the decks built with epoxy-coated reinforcing steel.

In September 2009, six bridges were studied and the condition of over 62,000 sq ft of deck was surveyed.

2009 FIELD EVALUATION

The field evaluation was conducted on six bridges by John Lawler and Paul Krauss from Wiss, Janney and Elstner Associates Inc, Northbrook Illinois. This evaluation consisted of:

- visual inspections
- crack mapping
- delamination survey
- continuity testing
- depth of cover measurements
- removal of core samples

In the laboratory, examination of extracted bar samples and chloride analysis of the concrete was conducted.

Three decks contained epoxy-coated bars in both top and bottom mats, whereas the other three decks contained black bars as their bottom mat reinforcing steel.

OBSERVATIONS AND MEASUREMENTS

BRIDGE NO. 2668 N – This bridge carries I-79 and consists of seven spans supported on steel girders. The bridge deck contains epoxy-coated reinforcing steel in both top and bottom mats and was topped with an anti-icing and anti-skid epoxy-based overlay in 2008.

Transverse cracking on underside of Bridge No. 2668N.

The delamination survey identified a few small delaminations away from the expansion joints totaling less than 10 sq ft in the 12444 sq ft that was surveyed. Examination of the deck from below revealed extensive transverse cracking. No corrosion-related deterioration was visible on the deck soffit. Electrical continuity testing was performed indicating that the bar segments are not electrically connected but that the overall resistance is somewhat lower than fully isolated bars.

Chloride values at the bar depth ranged from 0.009 to 0.117 percent by weight of concrete in uncracked cores. Visual inspection of bars found that one of the 11 extracted bars exhibited active corrosion, but this core was taken at a crack and only partially recovered; therefore chloride analysis was not performed. The epoxy coating thickness varied widely in this bridge. Most of the samples bars had a thickness of 9 to 15 mils; however, one bar had a coating thickness of only 3.5 mils. This bar was sampled at a lap and may represent an end of a bar.

BRIDGE NOS. 2672 N, 2672 S – The decks of Bridges 2672 N and 2672 S are similar in design and consist of three spans on concrete girders, carrying I-79. The bridge decks contain epoxy-coated reinforcing steel in the top mat and black bar in the bottom mat. Minor delaminations, 2 sq ft in size or less and some associated spalls and patching were identified in these decks and totaled less than 10 sq ft in the 8400 sq ft that was surveyed. The majority of these were associated with construction joints separating the deck placements over the piers. According to the design drawings, this joint was to be keyed and edged with $^1/_4$ in. edging tool then filled with a "hot-poured elastic-type construction joint sealer". Similar construction joint details are given for the other bridge decks that were investigated.

Transverse cracks were also present throughout the decks. Spalling at an uncoated bottom reinforcing bar in Bridge No. 2672 N was visible in one location and incipient spalling and staining related to corrosion of uncoated bottom bars was visible at a number locations on the soffit of both of these decks, particularly adjacent to the construction joints.

DC resistance between top bar segments indicated that the top bar segments measured were generally electrically discontinuous. Chloride values at the bar depth ranged from 0.009 to 0.039 percent by weight of concrete in uncracked cores and from 0.054 to 0.222 percent by weight of concrete in the cracked cores. Two of the 7 bars from Bridge No. 2672 N and one of the 7 bars from Bridge No. 2672 S were obtained with indications of active corrosion. The calculated chloride concentration at the bar depth for the corroding bars was 0.182, 0.132 and 0.222 percent by weight of concrete, respectively, or approximately 4 to $6^1/_2$ times higher than the chloride threshold for uncoated black steel (about 0.035 percent by weight of concrete). The coating thickness was less than 7 mils in all three cases, and a crack was present over each of these bars.

BRIDGE NO. 2673 – Bridge No. 2673 is an overpass over I-79 and sees significantly less traffic than other bridges included in this study. This bridge deck has five spans on steel girders and contains epoxy-coated reinforcing steel in the top and black uncoated bars in the bottom mat. Despite the lower traffic, the condition of the deck was similar in nature to the other decks. The largest delamination identified was approximately 5 sq ft in size and transverse cracking was present throughout and particularly concentrated in Span 4. A total of 5 sq ft of delamination was found in the 16,618 sq ft surveyed.

Relatively fewer cracks were observed on the deck soffit compared with other decks; however, signs of corrosion staining were visible at the construction joints. DC resistance between top bar segments varied depending on location and ranged significantly from 0.1 to 3600 Kohm.

Chloride values at the bar depth ranged from 0.079 to 0.165 percent by weight of concrete in uncracked cores and 0.204 percent by weight of concrete for the single cracked core. The bar segment at the cracked location was undergoing active corrosion. While no delamination was occurring at this bar, a delamination was present approximately 2 ft. away following the crack along the same bar.

Bridge No. 2668 N
Coated bars in top and bottom mat.

Bridge No. 2672 S
Coated bars in top mat only.

Bridge No. 2673
Coated bars in top mat only.

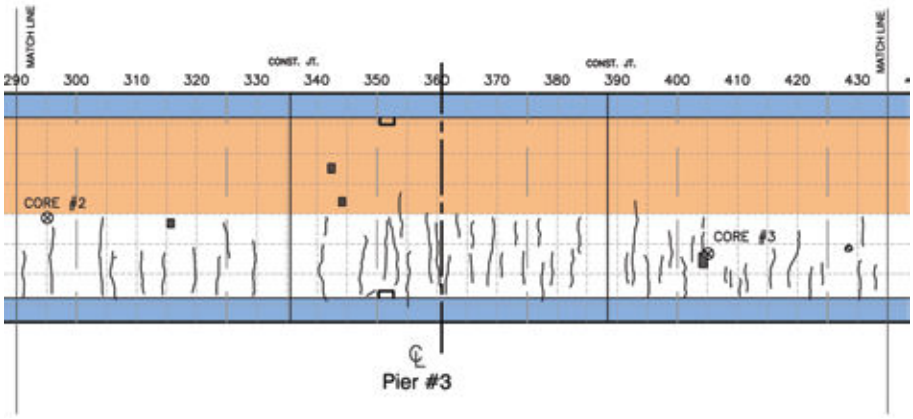
Repair of Span 5 of Bridge No. 2930 containing black bar.

BRIDGE NO. 2930 – Bridge No. 2930 is located in Clarksburg, WV. This deck consists of six spans on steel girders and is constructed differently on either side of Pier 4. It was originally believed that the entire bridge deck was reinforced with epoxy-coated reinforcing steel. However, it was learned through core sampling that Spans 5-6 contain uncoated black bar. The reinforcing in Spans 1-4 consists of epoxy-coated reinforcing steel in both top and bottom mats.

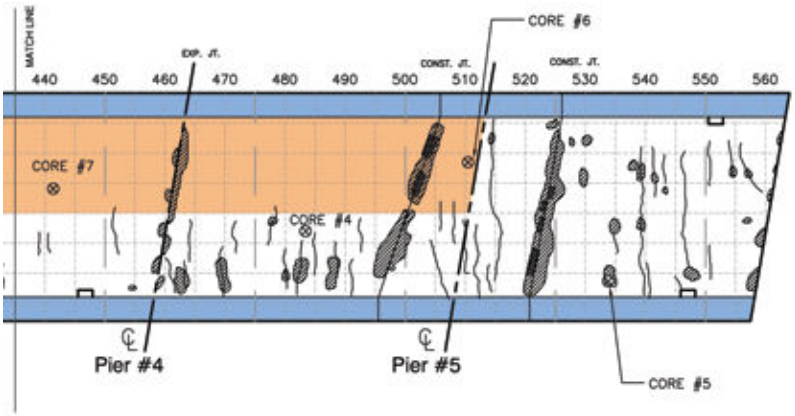
According to WV DOT, some repairs were performed on this deck in 1998. These repairs took one of two forms. The first consisted of conventional patches, which are most prevalent at spalls concentrated in Span 5-6. In addition, a number of small (less than 1 sq ft), uniform, isolated, essentially square repairs were observed throughout the spans. The reason for these smaller isolated repairs is uncertain, though given their size they do not appear to be related to reinforcing corrosion.

The frequency of transverse cracking was higher in this bridge than any of the other decks examined. However, despite the presence of these cracks throughout the bridge, essentially no reinforcing corrosion-related deterioration was observed in Spans 1-4, which are reinforced with epoxy-coated reinforcing steel. All the deterioration that was detected on this bridge occurred in Spans 5-6, with more than 5% of the surface area of Spans 5-6 exhibiting repairs, spalling or delaminations.

For the epoxy-coated bar spans, none of the exposed bar segments were electrically continuous with any other cut segment. Chloride values at the bar depth ranged from 0.041 to 0.165 percent by weight of concrete in uncracked concrete. No cracks were found in the spans containing epoxy-coated bars. The measured coating thickness on all bars taken from Spans 1-4 ranged from 8–15.8 mil and none of these epoxy-coated reinforcing steel segments exhibited evidence of corrosion.



Map of deck of Bridge 2930 containing epoxy-coated bars showing cracks.



Map of deck of bridge 2930 containing black bars showing delaminations & cracks.

BRIDGE NO. 2953 – Bridge No. 2953 is an urban bridge in Clarksburg, WV. This deck is three spans on steel girders and stay-in-place forms. This bridge deck contains epoxy-coated reinforcing steel in both the top and bottom mats. No corrosion related deterioration was observed in this deck.

The DC electrical resistance between epoxy-coated reinforcing steel bar samples cut during coring was typically very high on this bridge, which indicated that the bars in this bridge are essentially electrically isolated by the reinforcing coating.

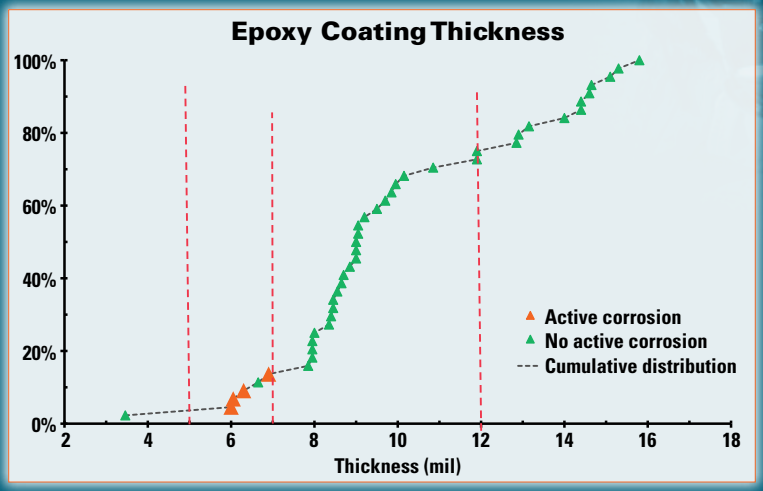
Chloride values at the bar depth ranged from 0.082 to 0.165 percent by weight of concrete in uncracked cores and 0.263 percent by weight of concrete in the cracked cores. The coating thicknesses on these bar segments ranged from 8.0 to 11.9 mil and none of these epoxy-coated reinforcing steel segments exhibited evidence of corrosion.

Bridge No. 2930, Spans 1-4
Coated bars in top and bottom mat.

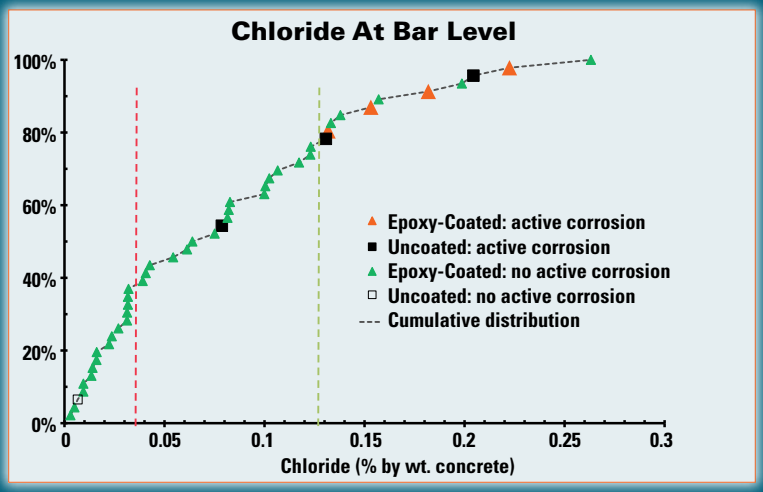
Bridge No. 2930, Spans 5-6
Black bar in top and bottom mat.

Bridge No. 2953
Coated bars in top and bottom mat.

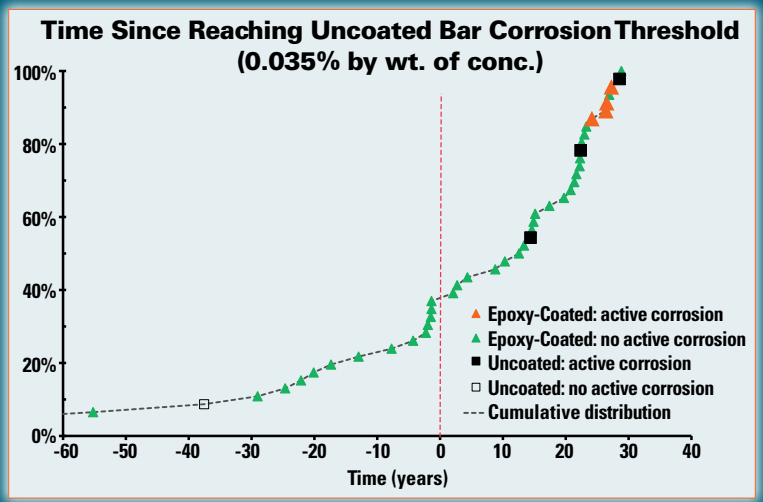
Epoxy-coating thickness test.



Distribution plot of epoxy coating thickness on bars in cores sampled from all bridges.



Distribution plot of chloride concentration at bar depth from all bridges.



Distribution of time since reaching black bar corrosion threshold (0.035 percent by weight of concrete).

ANALYSIS OF BAR CONDITIONS

To further explore the performance of epoxy-coated reinforcing steel in these decks, analysis of the statistical distributions of the properties and exposure conditions of the bars was performed relative to the presence of corrosion.

The analysis evaluated:

- Cover
- Coating adhesion and backside cleanliness
- Coating thickness
- Chloride concentration at bar depth
- Time since chloride concentration exceeded black bar threshold

Coating thickness strongly correlated to corrosion, with all four bar segments judged to be experiencing active corrosion having a coating thickness of less than 7 mils, which would be unacceptable or marginally acceptable by current standards.

The distribution of chloride values for both the epoxy-coated reinforcing steel segments was evaluated. The only segment of black bar not undergoing active corrosion is at a location where the chloride concentration is less than the commenly issued black bar threshold of 0.035 percent by weight of concrete. For the coated bars, 22 epoxy-coated reinforcing steel segments without active corrosion had a chloride concentration of greater than this threshold. The chloride concentrations at the four actively corroding epoxy-coated reinforcing steel segments are greater than 0.13 percent by weight of concrete or about 4 times the black bar threshold. Furthermore, five other epoxy-coated reinforcing steel segments exposed to chloride concentrations greater than 0.13 percent by weight of concrete were not actively corroding, with the greatest at 0.263 percent by weight of concrete. This suggests that the epoxy coating provides a significant level of protection to chloride-induced corrosion of the reinforcing steel.

It was further found that the epoxy-coated reinforcing steel segments exhibiting active corrosion are among those bar segments that have been exposed to chloride concentrations above the black bar threshold for the longest period of time, exceeding 20 years in all four cases. Some epoxy-coated reinforcing steel segments have been exposed to chloride concentrations longer than 20 years without active corrosion.

DISCUSSION

The age of the six bridge decks that were inspected ranged from 33 to 35 years. In general, with the exception of the southern two spans of Bridge No. 2930 that contained black bar, the bridge decks that were investigated are in good to excellent condition. Five of these decks are heavily exposed to deicing salts and aggressive environmental conditions, while one, although exposed to similar environmental conditions, appears to have been salted less frequently. The spans reinforced with epoxy-coated reinforcing steel in two decks exhibited no corrosion-induced deterioration, while the other four decks showed such deterioration over less than 0.15 percent of the deck areas surveyed. The only portions of the six decks that were inspected showing widespread deterioration were the two spans reinforced with uncoated black bars.

It is notable that both decks with no deterioration were constructed with both top and bottom mats of epoxy-coated reinforcing steel. For the other structures, most of the observed deterioration was concentrated around the construction joints, which were built based on a similar design requiring $^1/_4$ in. open tooled joints in the deck. These joints have provided a path for rapid ingress of chloride into the deck and promoted corrosion in their vicinity.

Analysis of the chloride profiles in the core samples indicated that many of the epoxy-coated reinforcing steel segments have been exposed to chloride levels higher than the typical threshold for black bars (0.035 percent by weight of concrete) for many years. The lowest chloride concentration at which active corrosion of an epoxy-coated reinforcing steel segment was observed was 0.132 percent by weight of concrete, though chloride concentrations surrounding epoxy-coated reinforcing steel as high as 0.263 percent by weight of concrete were observed without active corrosion. Therefore, the epoxy coating obviously provides a significant level of protection to the reinforcing steel from the corrosion promoting effects of chloride contamination.

Active corrosion was observed on only four of the 45 of epoxy-coated reinforcing steel segments extracted from the bridge decks. The occurrence of corrosion was correlated to three factors in this limited sample: high chloride concentrations, low coating thickness (all actively corroding bars had coating thickness less than 7 mils), and extended exposure to chloride concentrations above the black bar chloride threshold. While it cannot be determined conclusively based on this limited sampling whether these factors contributed to the development of corrosion, it is known that greater coating thicknesses reduce the likelihood of coating defects. Therefore, bars with thin coating may have more defects present that permitted the corrosion to initiate on those bars.

CONCLUSIONS

Conclusions reached based upon studies of 33–35 year old decks in West Virginia containing epoxy-coated reinforcing steel are summarized as follows:

- The spans of the six bridge decks inspected during this study were in generally good to excellent condition.
- In contrast to the good condition of the decks containing epoxy-coated bars, the black bar decks were overlaid or otherwise rehabilitated at ages from 18 to 21 years to address deterioration of the deck surface.
- No delaminations were observed in decks containing both upper and lower mats of epoxy-coated reinforcing steel, despite high chloride contents in the concrete.
- Deterioration that was observed in the epoxy-coated reinforcing steel decks is concentrated at cracks and at the construction joints.
- One deck contained epoxy-coated reinforcing steel and black bars in separate spans. The epoxy-coated reinforcing steel sections of this deck exhibited no delamination, compared with more than 5 percent corrosion-induced deterioration in these two black bar spans.
- Active corrosion in the epoxy-coated bars correlated to three factors: high chloride concentration, low coating thickness and extended exposure to chloride concentrations above the black bar chloride threshold.
- Approximately 85 percent (22 of 26) of the epoxy-coated reinforcing steel segments that were exposed to chloride concentrations in excess of the level expected to corrode uncoated reinforcement did not exhibit active corrosion.

Given the lack of deterioration observed in the 33–35 year old epoxy-coated reinforcing steel decks inspected during this study, many more years of service life are expected.

Thanks are extended to West Virginia Department of Transportation for allowing access to these structures.

The full report titled *"Condition Survey Of Older West Virginia Bridge Decks Constructed With Epoxy-coated Reinforcing Bars"* is available from www.epoxyinterestgroup.org.

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