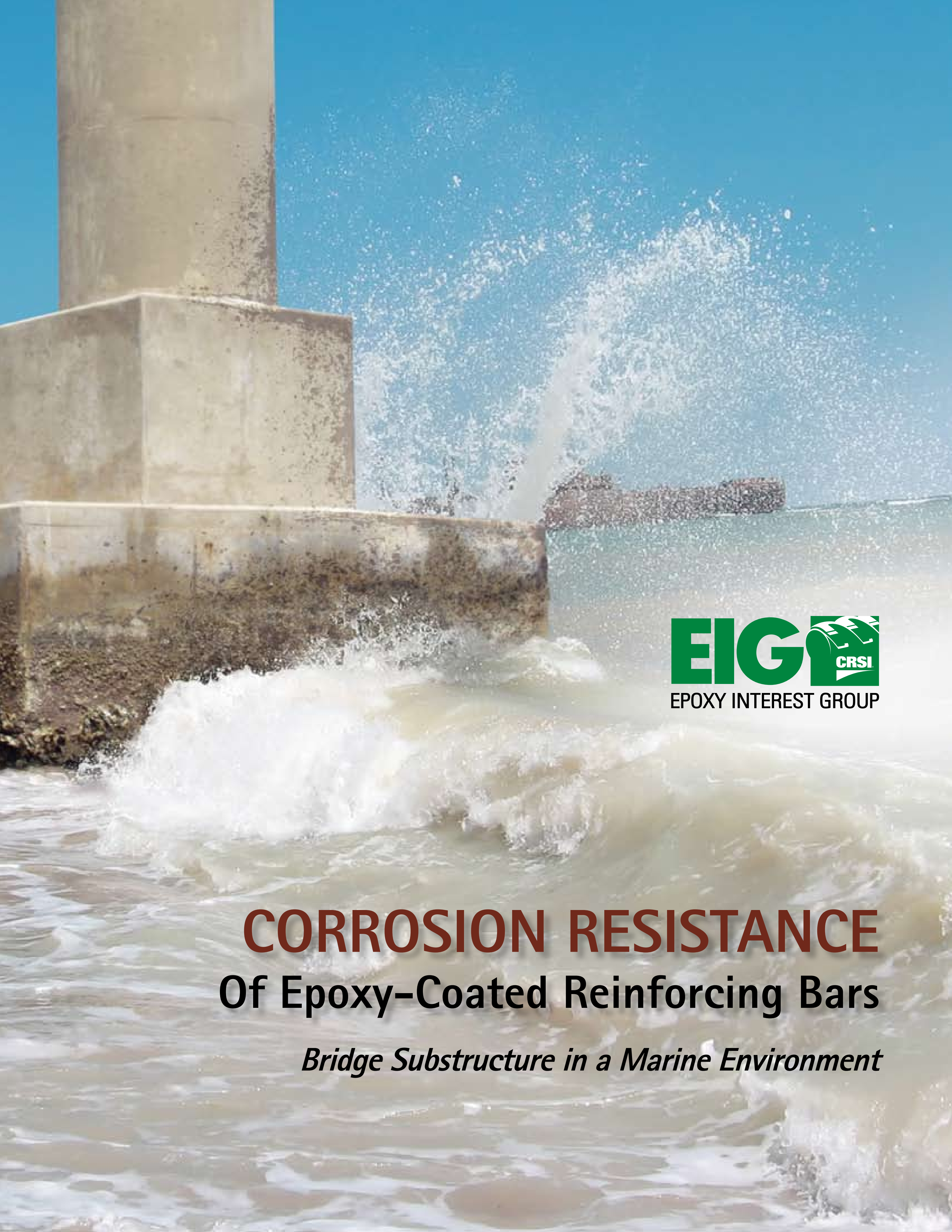

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CORROSION RESISTANCE

Of Epoxy-Coated Reinforcing Bars

Bridge Substructure in a Marine Environment

In 2006, detailed field and laboratory evaluations were conducted by Wiss, Janney, Elstner Associates, Inc. for four concrete bridges in Georgia and North Carolina that contained epoxy-coated steel reinforcing bars. No concrete distress induced by corrosion of epoxy-coated bars was observed. It was further found that coating adhesion was a poor indicator of bar performance. Despite poor adhesion, a number of epoxy-coated bar segments were found to resist high chloride concentrations (up to five times the threshold normally assumed for uncoated bars). Modeling calculations suggested that the most critical areas of these bridges would have developed significant concrete damage if uncoated bars had been used. The use of epoxy-coated reinforcing steel provides extended service life even though most bars examined from these bridges had greater coating damage and lower coating thickness than admissible by current standards.

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

INTRODUCTION

Epoxy-coated steel reinforcing bars have been used to improve the life in numerous marine bridges, many of which have been in service for more than 35 years.

To determine what level of corrosion protection is currently being provided by the epoxy coating in aged marine bridges substructures, an investigation was performed on four coastal bridges that were constructed in the mid-1980s:

- **MacKay River Bridge** near Brunswick, Georgia; (1984)
- **Ocean Isle Bridge** in Ocean Isle, North Carolina; (1985)
- **Holden Beach Bridge** in Holden Beach, North Carolina; (1985)
- **Atlantic Beach Bridge** in Atlantic Beach, North Carolina. (1985)

METHOD

The investigation included a field survey, concrete and steel sampling, and laboratory analyses. An established statistical model considering distributions of concrete cover over the steel and chloride concentrations within the concrete was adapted to estimate the remaining service life of these structures.

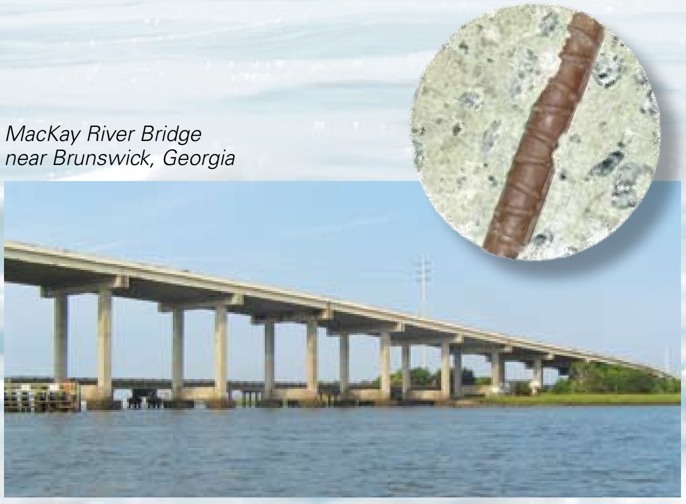
The goals of this investigation were to obtain long-term corrosion performance data for epoxy-coated bars and to determine the service life of epoxy-coated bars in marine applications based on up-to-date data obtained from in-service structures.

OBSERVATIONS

The field investigation did not reveal any epoxy-coated bar corrosion-induced distress on any of these four bridges after 21 years of service. Three of the four bridges were found to have limited early-age thermal or shrinkage cracking. Core sampling at the cracked areas revealed no corrosion of the epoxy-coated reinforcing steel.

Approximately twelve cores were extracted from each bridge. The effective diffusion coefficient, D, and surface chloride content, C_s, were calculated based on the chloride concentrations measured at various depths from these cores. Based on the chloride profiles, the chloride concentration at the depth of the steel was estimated. Both the effective diffusion coefficient and the surface chloride content typically decreased with increasing elevation and can be grouped into two zones: tidal zone (between low and high tide) and splash zone (0 to 5 ft. above high tide).

MacKay River Bridge
near Brunswick, Georgia



Ocean Isle Bridge
Ocean Isle, North Carolina

The portions of reinforcing steel bar in the cores were extracted to allow evaluation of damage and corrosion, and for adhesion testing and coating thickness measurement. Coating damage varied, but the average amount of damage present was under 2% for each bridge. Many bar segments, especially those from the MacKay River Bridge, exhibited poor coating adhesion. Nevertheless, a number of epoxy-coated bar segments (14 unique bars) were found to have resisted high chloride concentrations (up to 0.156 wt%, or five times the 0.030 wt% threshold normally assumed for uncoated bars). This indicates that coating adhesion is not a good indicator of epoxy-coated bar corrosion performance.

Active corrosion was observed on three epoxy-coated bar segments (one from the MacKay River Bridge and two from the Ocean Isle Bridge) that had significant coating damage (2 to 5%). This coating damage appears to have been present since construction. These bars were all located in the tidal zone and exposed to chloride concentrations (0.183 to 0.251 wt%)

Typical condition of corrosion-free epoxy-coated bar extracted from the Ocean Isle Bridge: 10 in. below high tide. Bar-level chloride concentration is 0.056 wt%. Undercoating steel often has a dark color but is corrosion-free.

well above the threshold for uncoated bar (0.030 wt%). Using corrosion modeling, it was calculated that corrosion of uncoated bars would have initiated around 1989. As their was no observed concrete distress in 2006, it was concluded that the propagation time for damaged epoxy-coated bar in the tidal zone is greater than 17 years.

Most bars examined from these bridges had greater coating damage and lower coating thickness than admissible by current standards governing the use of epoxy-coated reinforcing steel. The coating used in the MacKay River Bridge was an old generation of epoxy coating and this product demonstrated particularly poor performance in terms of adhesion and thickness. Modern epoxy-coated bars, which are required to have thicker coatings, should exhibit greater corrosion resistance than was observed in these four bridges.

Modeling calculations using values of D and C_s suggested that the most critical areas of these bridges would have developed significant concrete damage if uncoated bars had been used. The

Two bars from the Ocean Isle Bridge show light corrosion: a) a horizontal No. 6 bar with a cover of 4.75 in. and bar-level chloride concentration of 0.199 wt%; b) a vertical No. 8 bar with a cover of 5.1 in. and bar-level chloride concentration of 0.183 wt%.

Characterization Of Coating

		MacKay River	Ocean Isle	Holden Beach	Atlantic Beach
Average thickness (mils)		6.2	8.0	8.5	7.7
Percentage of thickness measurements less than 5 mils		18	7	0	5
Percentage of thickness measurements less than 5.6 mils[1]		36	14	0	21
Adhesion Rating[2]	Tidal zone	5.0	5.0	4.3	n/a
	Splash zone	4.8	4.4	3.4	3.2

[1] The thickness criterion specified in ASTM A775-06. A coating with a single measurement under this value is considered to fail the thickness requirement

[2] Rating scaled defined such that "1" corresponds to excellent and "5" corresponds to poor adhesion.

Holden Beach Bridge
Holden Beach, North Carolina

Atlantic Beach Bridge
Atlantic Beach, North Carolina

concrete cover and diffusion were demonstrated to have a large effect on the projected service life and the service life extension provided by epoxy-coated reinforcement. This finding emphasizes the importance of sufficient concrete cover, highlights the additional benefits of epoxy coating, and may explain why relatively poor performance of epoxy-coated bars in tidal zones of marine sub-structures with low quality concrete and concrete cover has been observed in the past.

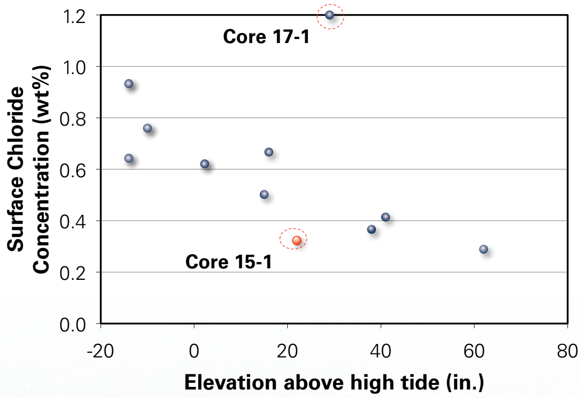
Poor adhesion of coating to steel for bar obtained from the MacKay River Bridge (tidal zone, bar-level chloride concentration is 0.251 wt%).

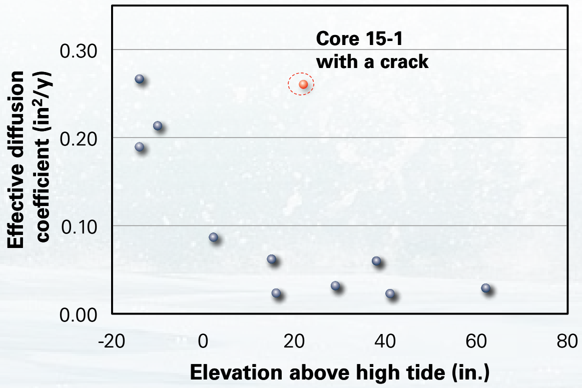
CONCLUSIONS

Based on this investigation, the following conclusions were drawn:

1. No epoxy-coated steel bar corrosion-induced concrete distress in well consolidated concrete was observed.
2. A considerable number of the epoxy-coated bars were found to have resisted up to 0.156 wt% chloride.
3. Corrosion of epoxy-coated steel bars was observed on three epoxy-coated steel bars that had significant coating damage (2-5%). All bars were from the tidal zone and exposed to very high chloride concentration (0.183-0.251 wt% or 6-8½ times the threshold for black bar).
4. Coating damage varied; however, the average value for the bars sections sampled was under 1%.
5. The bar coating used in the MacKay River Bridge did not meet the ASTM A775-81 requirement for coating thickness and had poor adhesion performance. Modern epoxy coatings produced under strict quality control and good field practice would be expected to provide greater protection to reinforcing steel than was observed in this bridge.
6. Coating adhesion is not a good indicator of epoxy-coated steel bars performance. Many coatings had lost adhesion completely.
7. Bars with no coating damage were consistently in a corrosion-free condition despite the presence of high chloride concentrations that were well-above the threshold for uncoated bars.
8. Modeling calculations indicate that the most critical areas of these bridges would have developed more than 10% damage by 2006, if uncoated bars were used. Therefore, the use of epoxy-coated steel bars is likely responsible for the observed lack of deterioration of these structures.

The full report titled *"Condition Survey And Service Life Prediction Of Four Marine Bridge Substructures containing Epoxy-Coated Reinforcing Bars"* is available from www.epoxyinterestgroup.org





Calculated surface chloride C_s and effective diffusion coefficient D for the MacKay River Bridge.

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