EPOXY INTEREST GROUP

Review of Papers –

CORROSION RESISTANCE
Of Epoxy-Coated Reinforcing Bars in Florida Bridges

During the past 30 years, many papers have been published regarding the performance of epoxy-coated reinforcing bars in Florida. Several researchers have used these structures as a reason to not specify epoxy-coated reinforcing in marine environments. In 2010, two papers were published by the University of South Florida and the Florida Department of Transportation which demonstrate that in appropriate concrete, epoxy-coated reinforcing bars can be used for a 100-year design life. This document summarizes that work.

INTRODUCTION

In 2010, two papers[1, 2] were presented that reviewed work conducted during the past 30 years on the performance of epoxy-coated reinforcing bars in Florida. Epoxy-coated reinforcing steel was used in approximately 300 Florida bridges to control corrosion of the substructure in the splash-evaporation zone of marine bridges. In 1986, severe corrosion of the substructure of five major bridges along US 1 in the Florida Keys was observed, prompting significant review of the use of epoxy-coated reinforcing bars in marine environments.

BRIDGE CLASSIFICATION

The five bridges that exhibited early age distress were classified in the two papers as Group 1. When spalls were found, they were of the order of 3 sq ft. Typical spalls are shown in **Figure 1**.

These bridges were built with permeable concrete that enabled rapid ingress of chloride ions. Substantial deviations from design concrete cover were also observed.

Significant repairs have been conducted to the piers of these structures. Appropriate questions were raised during the 1990s as to the durability of other structures containing epoxy-coated reinforcing bars in a marine environment.

Bridges that did not exhibit distress in the 1990s but also had highly permeable concrete, similar to those of Group 1, were classified as Group 2. These bridges tended to have increased cover compared with those of Group 1.

Bridges in Group 3 were constructed using very low to moderate permeability concrete, while bridges in Group 4 were similar to those of Group 3, except that the piers were painted. To date, none of the bridges in Group 3 or 4 have exhibited distress.

REFERENCES:

[1] Sagüés, A. A., Lau, K., Powers, R. G., and Kessler, R. J. (2010). "Corrosion of Epoxy-Coated Rebar in Marine Bridges — Part 1: A 30-Year Perspective." Corrosion, 66(6), 065001.

[2] Lau, K., Sagüés, A. A., and Powers, R. G. (2010). "Corrosion of Epoxy-Coated Rebar in Marine Bridges — Part 2: Corrosion in Cracked Concrete." Corrosion, 66(6), 065002.

Figure 1: Typical spalls observed in bridge piers[1].

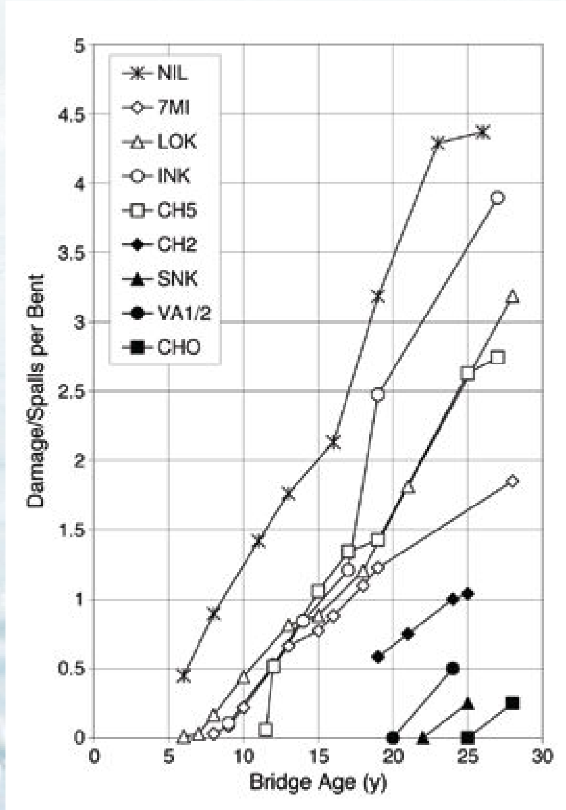

Figure 2: Count of spalls observed per bent[1].

FIELD INSPECTIONS

During field inspections, the number of spalls on the piers was counted. **Figure 2** shows the count of spalls per bent, plotted against the bridge age for the nine structures that exhibited spalling. As of 2010, only nine bridges of the 300 containing epoxy-coated bars have exhibited any visible corrosion-induced distress.

Concrete cores were removed for chloride analysis and this data was used to establish chloride diffusion models. Corrosion on extracted bars was documented and the coating adhesion to the reinforcing steel determined.

CORROSION AND SPALLING

The authors report that the observed corrosion was a result of: ...*allowable production imperfections, which were then aggravated by fabrication, handling and a severe construction yard environment. This was followed by placing the rebars in moist, warm, eventually high chloride-level substructure service that was conducive to severe corrosion, aggrevated by extended macrocell formation.*

COATING ADHESION

After cores were removed the coating adhesion was determined using knife adhesion tests. Many of the tests found complete coating disbondment on the surface of the epoxy-coated bars. Despite disbondment, no evidence of significant corrosion was observed, even at crack locations. No correlation was found between the presence or position of the crack and the extent or location of vestigial rusting or coating disbondment in the coated bar segments.

PREDICTION OF PERFORMANCE

Prediction models were developed by Sagüés et al. to predict the long-term performance of Florida bridges. These models divided the substructure surface into discrete elements. For each element, a corrosion initiation (t_i) and corrosion propagation state (t_p) was calculated.

The models assume that the area of splash zone was 215 sq ft and a typical spall affects 3 sq ft. Diffusion, surface chloride and threshold values are shown in **Table 1.** As shown in **Figure 2**, the growth of concrete damage appeared to linearly increase with time. For Group 1, this assumption is consistent with a relatively small fraction of the rebar assembly causing much of the damage in the first decade or two, with that fraction representing areas where the rebar had experienced the most distress by the time it was put into service. The projections also successfully approximated the observed damage for the Group 2 bridges.

The models indicate that for sound concrete in Groups 3 and 4, which represent the majority of structures containing epoxy-coated bars in Florida, initial damage is not expected for several decades and that this damage to the concrete would be limited to those areas with significant coating damage. Where the coated bars have lower damage, significantly longer periods are expected before the concrete exhibits any distress.

100-YEAR DESIGN LIFE

Figure 3 shows the predicted damage that is forecast for Group 1, 2 and 3 bridges, modified from the papers. The y-axis has been converted to describe the percentage of pier damage. After 30 years, the five bridges in Group 1 exhibit approximately 6 percent damage and the four bridges in Group 2 exhibit approximately 1 percent damage. Bridges in Group 3 demonstrate less than 1 percent damage, even after 100 years. Such limited damage is readily repairable and should not limit the use of epoxy-coated bars in these structures.

Thus, the data of Sagüés et al. demonstrates that appropriately constructed concrete piers, built using epoxy-coat bars in Florida marine environments, can provide 100-year design life with minimal maintenance.

Table 1: Diffusion coefficients and surface chloride assumed by the model.

Group	Diffusion coeficient (m^2/s)	Surface Chloride (kg/m^3)	Chloride Threshold (kg/m^3)
1	2×10^{-11}	12	1.55
2	1.3×10^{-12}	12	1.55
3	3×10^{-13}	12	1.55
4	3×10^{-13}	6	1.55

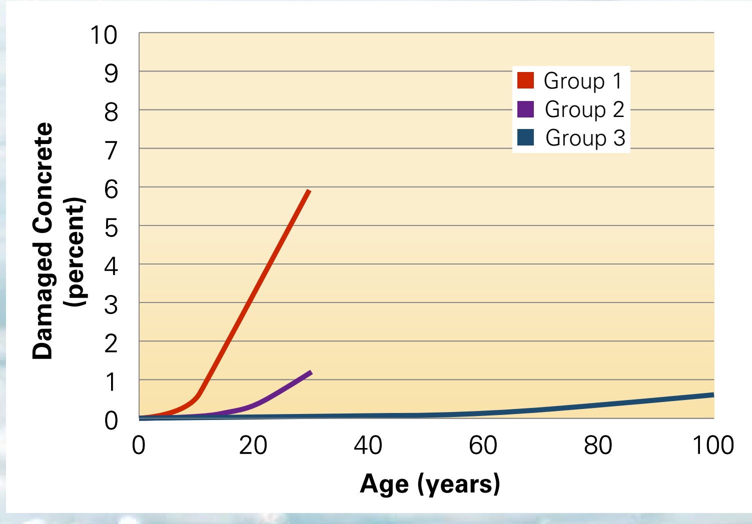

Figure 3: Percent of spalls for Groups 1, 2 and 3. (After Sagüés et al.)

EFFECTS OF CRACKS

A second paper was presented by Lau et al. This paper discusses the effect of concrete cracking on the design lives of the concrete piers. The paper concludes that: *...relatively isolated cracking should only create typical concrete corrosion damage with limited maintenance requirements. However, adverse crack orientation with respect to the rebar and chloride transport enhanced by wider cracks resulted in significantly increased damage projections.*

Based upon the work of Lau et al. it is prudent that cracks in the concrete piers be repaired as part of standard maintenance operations.

COMPARISON WITH THE PERFORMANCE OF BLACK REINFORCING BARS

The papers presented by Sagüés et al. and Lau et al., do not compare the expected performance of these structures that contained epoxy-coated bars with those containing uncoated reinforcing bars. However, general assumptions are that repairs are required to uncoated bar structures within 5 – 10 years of reaching threshold levels. Repairs are commonly made when damage levels reach around 10 percent.

Using these assumptions, extensive repairs for the uncoated bar structures would already have been required for all structures in Groups 1 and 2.

Additional research is recommended to address this specific issue; however, for companion bridges in Melbourne, Florida **(Figure 4)** containing epoxy-coated or uncoated bars, corrosion damage has been observed in the structure containing uncoated bars, while no distress was observed in the structure containing epoxy-coated bars.

Figure 4: Companion bridges containing either black (left) or epoxy-coated bars (right) in Melbourne Florida.

CONCLUSIONS

The following conclusions have been reached based upon the recent papers:

- After approximately 30 years of service, only 3 percent of all bridges containing epoxy-coated bars in Florida exhibit distress.
- Severe early age corrosion was limited to five bridges in the Florida Keys.
- The maximum damage was limited to 14 sq ft per pier.
- This damage is growing linearly with time, explainable by areas with high and moderate bar coating damage.
- Early age corrosion resulted from a combination of:
  - Highly aggressive service environment
  - Low concrete cover
  - Highly permeable concrete
- No correlation was found between corrosion damage and coating adhesion.
- Marine structures using uncoated bars would be expected to exhibit significantly less corrosion-resistance than those using epoxy-coated bars.
- Less than 1 percent damage to the piers is predicted over the 100-year design life for Group 3 and 4 structures that used low-permeability concrete with epoxy-coated bars.
- 100-year design life for structures using epoxy-coated bars is predicted with minimal maintenance.
- Large cracks in reinforced marine concrete should be minimized and repaired.

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