Field Evaluation of Concrete Bridge Decks Reinforced with Epoxy-Coated Steel in Indiana

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A field evaluation of a representative sample of six bridges in terms of traffic and environmental and salt exposure conditions was conducted to assess the in-service condition of concrete bridge decks reinforced with epoxy-coated steel in Indiana. The field condition assessment included (*a*) identification of any delaminated and spalled areas; (*b*) detailed mapping of the observed cracking; (*c*) identification of the concrete cover and the underlying reinforcement; (*d*) core sampling with and without reinforcement to determine the compressive strength and unit weight, and (*e*) concrete powder sampling to determine chloride concentration at various depths. No signs of steel corrosion were found in the bar samples extracted from cores in the six bridges evaluated. The chloride concentration levels at the level of the reinforcement for all but two of the bridges were well above the commonly accepted threshold value at the level of the reinforcement. Evaluation of the field data revealed that, to date, the combination of adequate concrete cover and epoxy coating has provided a good corrosion protection system in Indiana. The sample included the first bridge in Indiana on which epoxy-coated reinforcement was used (1976).

This paper presents the field phase findings from a research study sponsored by the Indiana Department of Transportation (INDOT) and FHWA. The field phase of this research study was aimed at the condition assessment of a representative sample of concrete bridge decks and slabs reinforced with epoxy-coated steel in Indiana.

A total of six bridges throughout Indiana were selected for the evaluation. The bridges selected represent a cross section of environmental conditions, traffic, and intensity of salt application. The sample included the first bridge deck in Indiana reinforced with epoxy-coated steel. This bridge was built in 1976. The field study addresses the performance of decks supported on a more flexible system (steel girder) as well as more rigid support conditions (precast, prestressed girders) and concrete slabs. None of the bridge decks included in the sample had been overlayed. The site selection was fully coordinated with personnel from INDOT. Evaluation of concrete core samples for compressive strength and concrete powder samples for chloride content was conducted by the Materials and Testing Division of INDOT.

BRIEF DESCRIPTION

The location of the bridges selected is shown in Figure 1. The first bridge selected for evaluation was built in 1985. The bridge is located in downtown Indianapolis over the White River. The structure is a six-span continuous composite steel box-girder bridge with a maximum span length of 62.8 m (206 ft). This bridge represents the case of a deck on a flexible superstructure in the central part of the state subjected to heavy urban traffic and severe deicing and salt exposure. The second bridge is located in downtown South Bend. The structure was built in 1983 and has a maximum span length of 27.4 m (90 ft). The structure is a four-span continuous composite bridge deck supported on precast, prestressed AASHTO girders (Type IV). It represents a case of concrete bridge deck built on a more rigid support system. This structure is subjected to significant urban traffic and severe salt application. The third structure is located a few miles south of the city of South Bend. It was built in 1980 and consists of a three-span continuous welded girder bridge with composite deck subjected to heavy truck traffic and heavy salt exposure condition. The maximum span length is 18.9 m (62 ft). The fourth structure is a three-span skewed continuous reinforced concrete slab bridge built in 1985. The maximum span length is 14 m (46 ft). The structure is subjected to moderate traffic and moderate deicing salt application. The fifth structure is a three-span continuous bridge deck supported on continuous steel girders located in the city of Gary in the northern part of the state. This bridge was built in 1980 with a maximum span length of 19.7 m (64 ft 6 in.). The concrete deck was built using stay-in-place metal forms. The bridge is subjected to heavy industrial traffic with heavy deicing salt application. The sixth bridge deck selected is continuous for live load and supported on prestressed concrete I-beams (Type III). The bridge was built in 1976, has three spans with a maximum span length of 22.5 m (73 ft 9 in.), and is subjected to light to moderate truck traffic and moderate salt exposure. A summary of the bridge information and traffic data is presented in Tables 1 and 2, respectively.

FIELD EVALUATION PROCEDURES

The field evaluation included the following procedures:

1. Identification of any delaminated and spalled areas by close visual inspection and the use of the chain drag procedure;
2. Detailed mapping of the observed cracking on the top of the deck, as well as delaminated and spalled areas on the selected lane;
3. Evaluation of the concrete cover using an *R*-meter (focused electromagnetic field) to ascertain concrete cover and to locate the underlying reinforcement;
4. Core samples taken with or without reinforcement for evaluation of concrete compressive strength, concrete cover, unit weight, and visual inspection of the conditions of the epoxy coating; and
5. Concrete power sampled at selected points and at various depths for laboratory determination of chloride content.

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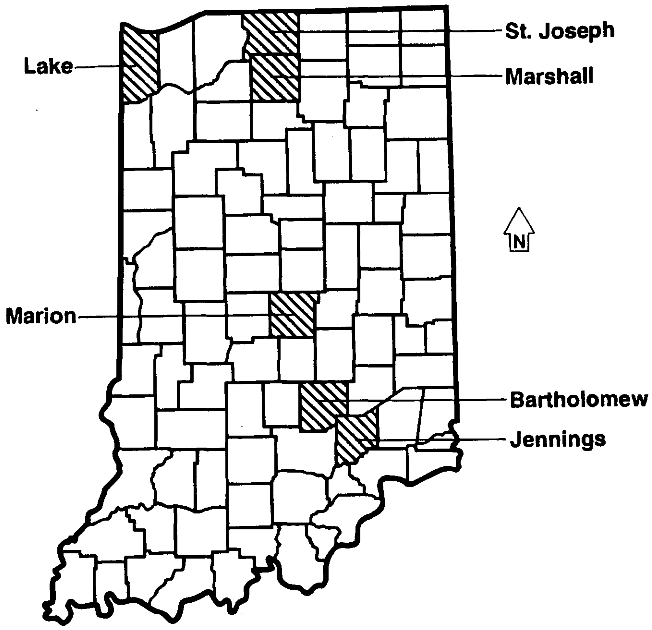


FIGURE 1 Bridge locations.

TABLE 1 Summary of Bridge Information

Bridge No.	Location	County	Bridge Type	Span Max (m)	Traffic	Deicing Salt Exposure
40-49-7032	US-40	Marion	Six-span continuous composite steel box girder bridge	62.8	Heavy urban	Severe
20-71-6538	US-2	St.Joseph	Four-span continuous composite precast pre-stressed AASHTO girder	27.4	Significant urban	Severe
31-50-2540	US-31	Marshall	Three-span continuous welded girder bridge with a composite concrete deck	18.9	Heavy truck	Heavy
7-03-6797	SR-7	Bartholomew	Three-span skewed continuous reinforced concrete slab bridge	14.0	Moderate truck	Moderate
912-45-6599	SR-912	Lake	Three-span continuous composite steel girder bridge	19.7	Heavy industrial	Heavy
7-40-6527	SR-7	Jennings	Continuous prestressed concrete I-beam (Type III)	22.5	Light to moderate truck	Moderate

Conversion Factors: 1 m = 3.281 ft.

TABLE 2 Traffic Data

Bridge	A.D.T. (V.P.D.)	A.D.T. Projected (V.P.D.)	D.H.V. (V.P.D.)	Trucks	Design Speed km/h	Access Control
40-49-7032	27,530 (1982)	44,390 (2002)	3,995 (2002)	D.H.V. 4% A.D.T. 5%	64	None
20-71-6538	11,015 (1976)	19,825 (1996)	1,190 (1996)		64	None
31-50-2540	17,080 (1978)	29,480 (1996)	-	D.H.V. 10% A.D.T. 17%	64	None
7-03-6797	5,680 (1983)	9,770 (2004)	977 (2004)	D.H.V. 7% A.D.T. 12%	113	-
912-45-6599	14,800 (1975)	25,250 (1995)	3,170 (1995)	-	97	Full
7-40-6527	2,200 (1972)	4,420 (1992)	-	D.H.V. 7% A.D.T. 17%	80	None

A.D.T. = Average Daily Traffic
D.H.V. = Design Hourly Volume
Conversion factors: 1 km/h = 0.622 mph

V.P.D. = Vehicles Per Day
- Data Not Available

During the field inspection, detailed mapping of delaminated and spalled areas as well as crack patterns were made. Crack widths were measured using a crack width comparator card. The delaminated and spalled areas were identified by close visual inspection and with the aid of chain drag procedure. Positions of reinforcement were identified by using an *R*-meter. Core samples with or without elements from the top layer of reinforcement were then taken for laboratory investigation. The chloride contents were determined through the laboratory analysis of pulverized concrete samples taken from the deck. The method used to determine chloride content approximated the automated titrator method duplicating ASTM-C114. Concrete powder samples were taken at various levels: Level A from 0 to 25.4 mm (0 to 1 in.); Level B from 25.4 to 50.8 mm (1 to 2 in.); Level C from 50.8 to 76.2 mm (2 to 3 in.); and Level D from 76.2 to 100.6 mm (3 to 4 in.). Diameters of the holes for each depth are 31.75 mm (1 1/4 in.), 25.4 mm (1 in.), 19.1 mm (3/4 in.), and 19.1 mm (3/4 in.), and 19.1 mm (3/4 in.), respectively.

RESULTS

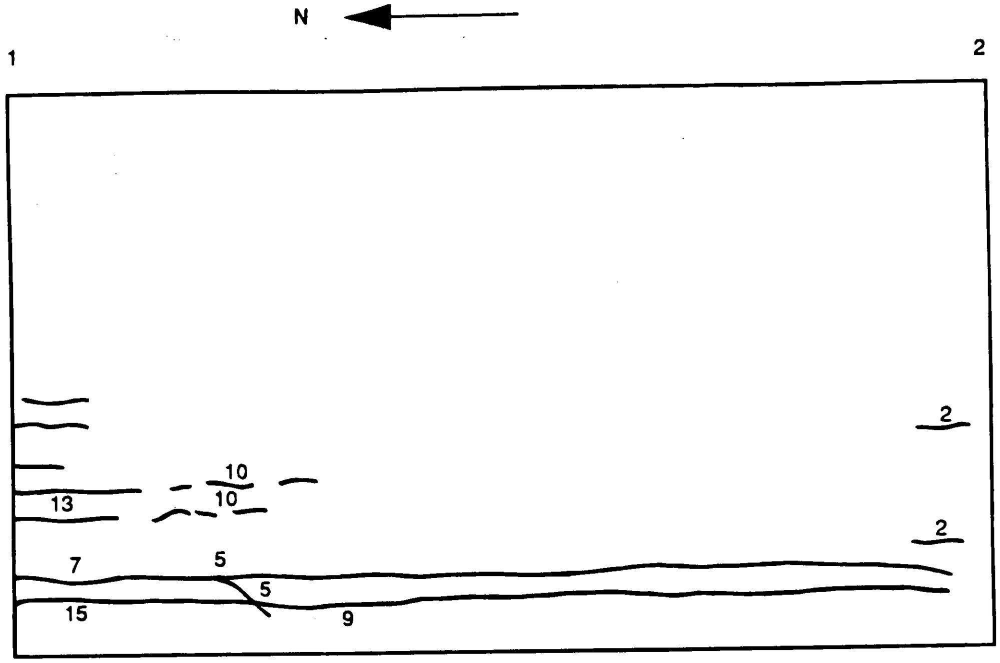
Figures 2 through 5 show the crack patterns and the core and concrete powder sample locations for one of the decks surveyed, Bridge 7-40-6527. Similar information for the other bridges evaluated can be found elsewhere (*1*). The test results of core strength, calculated cylinder strength, unit weight, concrete cover, maximum crack width, and chloride content for all the samples of each individual bridge can be found elsewhere (*1*). A summary of the average value of these results for each bridge is indicated in Table 3.

The average concrete cover ranged from 61 to 97 mm (6.1 to 3.82 in.), and the maximum crack width ranged from 0.64 mm to 1.52 mm (0.025 to 0.060 in.). Inspections of the conditions of steel extracted from cores show no indication of rusting or debonding on any of the bars. The coating was difficult to remove with a knife. From visual inspection of samples from which the coating was stripped mechanically, no sign of under-film corrosion was observed.

DISCUSSION OF RESULTS

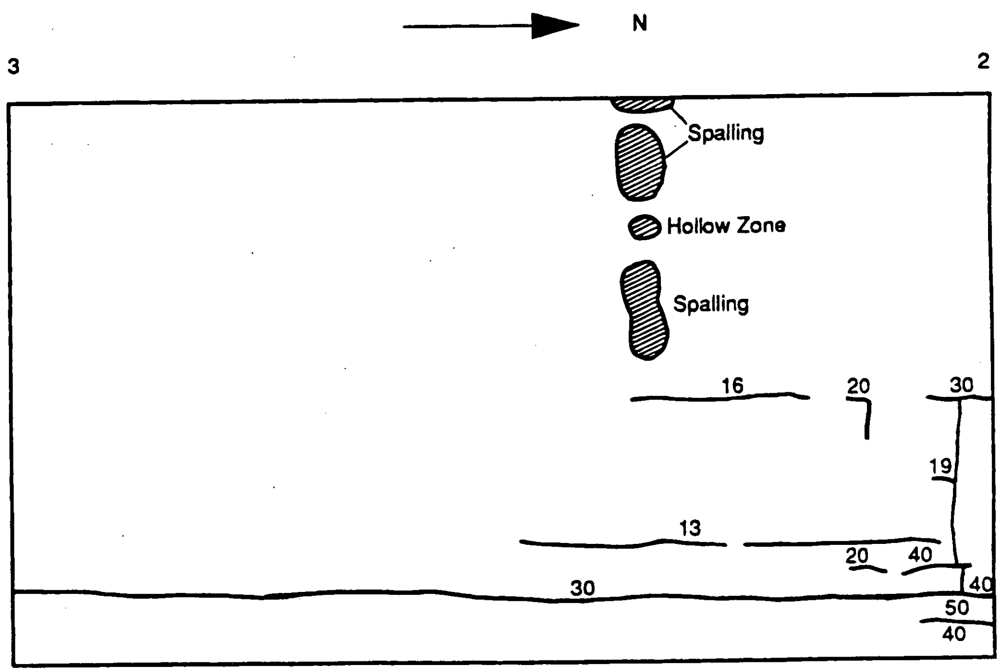
At the level of top reinforcement, except for the Marion and Bartholomew County bridges, the chloride content was found to be above the threshold value of 1.2 kg/m^3 (2.0 lb/yd^3) (*2*). This indicates that a potentially active corrosive environment was present. Inspection of the steel samples from coring showed no signs of corrosion or debonding of coating. The chloride content substantially decreased with every inch of increment in depth. This finding confirms the importance of concrete cover in reducing the risk of steel corrosion. Similar results were reported by Mckeel (*3*). From the evaluation during construction and through 13 years of service of two bridges in Virginia, it was concluded that the combination of cover and epoxy-coated reinforcement provided excellent protection against corrosion. In Mckeel's study, no signs of significant corrosion and debonding of the coating were found despite the poor initial state of the coating and its exposure to the elements from the onset of construction until placement of the deck concrete.

In addition to the concern over reduced bond to concrete of epoxy-coated steel, other significant issues concerning epoxy-



Span 1-2, East

FIGURE 2 Crack patterns, Bridge 7-40-6527, Span 1-2 east (crack widths shown × 10^{-3} in. 1 in. = 25.4 mm).



Span 2-3, West

FIGURE 3 Crack patterns, Bridge 7-49-6527, Span 2-3 west (crack widths shown × 10^{-3} in. 1 in. = 25.4 mm).

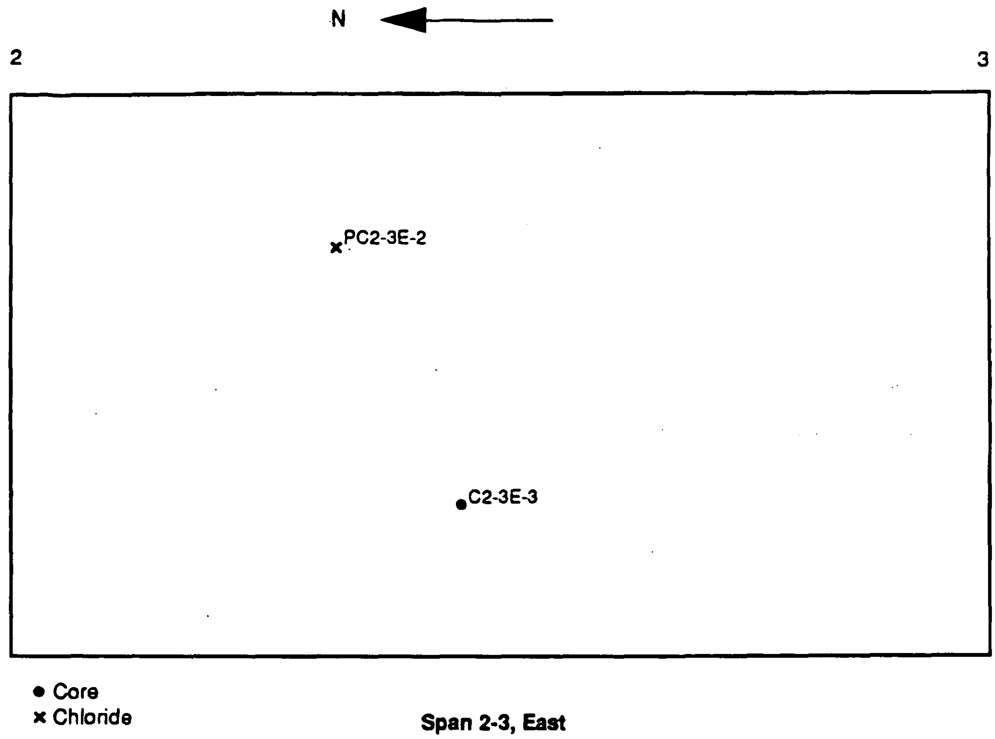


FIGURE 4 Core and chloride sampling, Bridge 7-40-6527, Span 2-3 east.

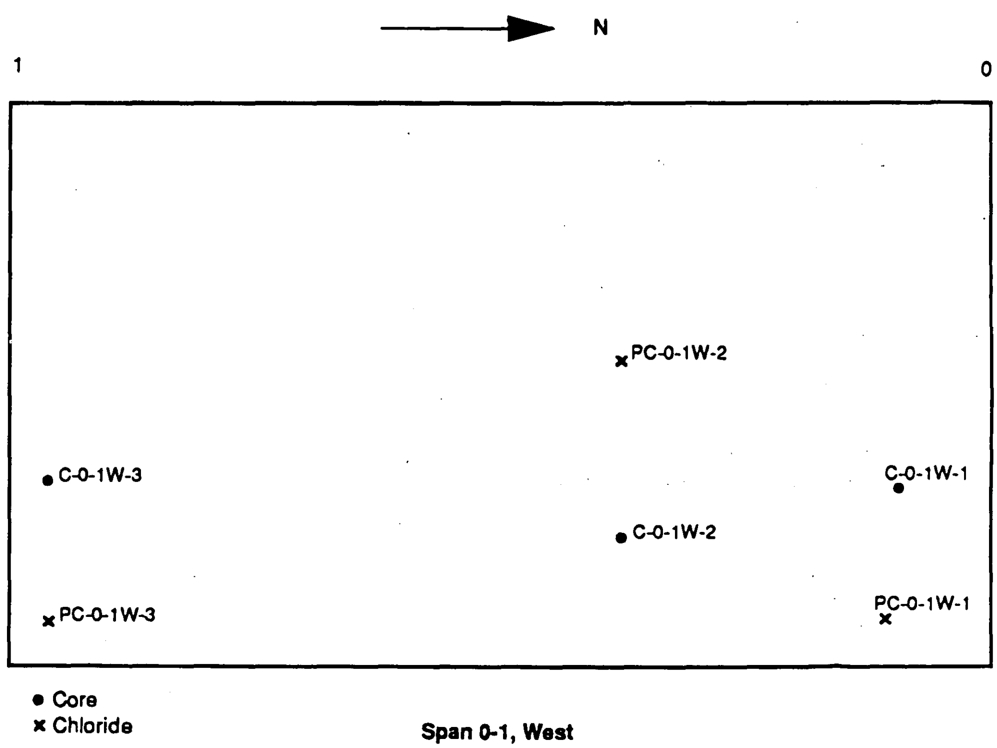


FIGURE 5 Core and chloride sampling, Bridge 7-40-6527, Span 0-1 west.

TABLE 3 Summary of Results

Bridge No.	Average Values of								Max
	Core Strength	Calculated Cylinder Strength	Unit Weight	Concrete Cover	Chloride Content kg/m^3 Level				Crack Width
	MPa	MPa	kg/m^3	(mm)	A	B	C	D	(mm)
40-49-7032	41.64	35.39	2341	61	3.52	1.29	0.88	0.70	0.76
20-71-6538	51.60	43.86	2423	32	8.41	4.22	2.21	2.36	0.64
31-50-2540	44.99	38.24	2387	62	10.54	7.21	1.91	0.96	0.76
7-03-6797	45.76	38.90	2483	97	4.24	1.66	0.65	0.47	0.89
912-45-6599	39.14	33.27	2328	74	7.18	2.90	1.94	1.66	1.52
7-40-6527	37.90	32.21	2384	77	8.96	5.04	2.96	1.63	1.27

Note: Level A: 0 - 2.54 cm Level B: 2.54 - 5.08 cm
Level C: 5.08 Level D: 7.62 - 10.06 cm

Conversion Factors: 1 MPa = 145 psi, 1 mm = 0.0394 in
1 kg / m^3 = 1.685 lb / cu.yd.
1 kg / m^3 = 0.0624 lb / cu.ft.

coated steel are related to its durability. In the last few years, there has been serious concern about the effectiveness and long-term durability of the epoxy-coated steel as a corrosion protection system. Smith et al. (*4*) investigated seven bridge structures in the Florida Keys. Significant corrosion of the epoxy-coated rebars was observed in four of the five major bridge substructures. It was found that corrosion occurred both in fabricated and straight epoxy-coated rebars. Furthermore, coating after fabrication did not significantly improve corrosion resistance. Disbondment occurred in "perfect" condition bars and in the bars coated after fabrication. It was concluded that epoxy-coated rebar will not provide suitable long-term protection against corrosion in the marine splash zone.

In 1990, Clear (*5*) stated that epoxy-coated rebar technology is flawed and will not ensure adequate long-term field performance in severe chloride environments, especially those involving continuous or frequent wetting of the concrete. The failure of the epoxy coating through means such as cathodic disbondment and the loss of the epoxy's insulative properties also have been reported. Clear concluded that the system "can no longer be considered a viable primary protective system for North American bridge structures in corrosive environments with expected maintenance-free lives in excess of about 15 years in northern environments or more than 5 years in hot, salty and moist southern exposures." Furthermore, he recommended against the continued usage of epoxy-coated reinforcing steel as the primary protection in adverse environments for structures for low-maintenance lives in excess of 5 years (southern) or 15 years (northern). Because of the controversy and the broad implications of the issue, the effectiveness and long-term durability issues of epoxy-coated bars have gained the attention of numerous researchers. Efforts are being made to gain a better understanding of the long-term durability and effectiveness of epoxy-coated bars (*3,6,7*).

SUMMARY

A field evaluation of a representative sample in terms of traffic and environmental and salt exposure conditions of six bridges in Indiana has been carried out. The bridges in the sample ranged in length of service from 6 to 18 years. Data gathered in this field study provided useful information with respect to the important issue of durability of structures with epoxy-coated steel. The following are important findings:

1. Chloride content is significantly decreased with increases in concrete cover.
2. Except for two of the bridges, all of the other bridge decks surveyed were under exposure to chloride contents well above the commonly accepted corrosion threshold value at the level of the reinforcing steel.
3. No sign of disbondment of the coating or corrosion was observed in the reinforcement extracted from the bridge decks surveyed.

On the basis of the findings of this study, it can be concluded that, even after 18 years, epoxy-coated steel has had a satisfactory performance to date in Indiana bridge decks surveyed. Currently, Indiana follows AASHTO Specification M284 for epoxy-coated bars. The concrete used in bridge decks is a Class C concrete with cement content of 391 kg/m^3 and a maximum water-cement ratio of 0.443. Wet curing for at least 96 hrs is required beginning immediately after initial set.

RECOMMENDATIONS

1. Adequate concrete cover should always be ensured. The chloride content is substantially reduced with a small increase in cover, hence the corrosion risk substantially decreases. In addition, extra cover also provides improvement in the anchorage of the bars. Larger diameter ratios of cover to bar are recommended in harsh environments to reduce the crack opening and should not be reduced with the expectation that the epoxy coating will be the sole corrosion protection system.
2. Good construction practices, such as adequate inspection, and good finishing and curing techniques should be emphasized because they will lead to durable concrete. The use, proper manufacturing,

and handling of epoxy-coated bars are but a few of the aspects related to durable concrete bridge decks.

3. More research is needed to clarify the long-term effectiveness and durability issues of epoxy-coated steel as a corrosion protection system for highway and bridge structures. In particular, the close inspection of bridge structures in the field should be continued to effectively assess the long-term performance of coated bars as a corrosion protection system.

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