1067

EPOXY RESIN COATED REINFORCING STEEL

Construction and Progress Report

MICHIGAN DEPARTMENT OF STATE HIGHWAYS AND TRANSPORTATION

TESTING AND RESEARCH DIVISION
RESEARCH LABORATORY SECTION

EPOXY RESIN COATED REINFORCING STEEL

Construction and Progress Report

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Progress Report on a Highway Planning and Research
Investigation Conducted in Cooperation with the
U. S. Department of Transportation, Federal Highway Administration

Research Laboratory Section
Testing and Research Division
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Introduction

This report covers the construction of laboratory specimens, field exposure specimens, and experimental bridge decks, for the evaluation of epoxy coated steel reinforcement as a deterrent to bridge deck deterioration. The work is being done by the Michigan Department of State Highways and Transportation Research Laboratory, as a Highway Planning and Research study in cooperation with the Federal Highway Administration. The project is being done in accordance with a Research Proposal dated October 1973, as a cooperative effort by the Concrete and Surface Treatments Group and the Structures Group of the Research Laboratory Section.

Severe deterioration of concrete bridge decks in areas where deicing chemicals are used has led to many investigations of methods to increase the useful life of the decks. Increased concrete cover over the bars, modified less-porous concrete overlays, impermeable membranes, and coated reinforcement, have been used to improve deck durability.

Several types of coatings were evaluated by the National Bureau of Standards for the Federal Highway Administration and the results showed the epoxies to have potential for coating deck reinforcement.

This project was proposed to extend the investigation to larger specimens, commercial applications, and experimental bridge decks. At the time the proposal was prepared, only two such coatings were commercially available, Scotchkote (3M) and Flintflex (DuPont). Cook's epoxy was approved while the project was in progress and was included to the extent possible.

Objectives

The objectives of the study, as stated in the proposal, were to determine the feasibility of using epoxy coated reinforcement in Michigan bridge deck construction; and to evaluate the effect of epoxy coated reinforcement on the performance of laboratory specimens and experimental decks.

Scope

The project includes 132 small laboratory specimens; including three different epoxies, with three different surface preparations for each epoxy, and some purposely damaged epoxy coatings; and galvanized bars and plain bars for comparison. Twenty more specimens had plain bars and various concrete mixes.

Thirty-nine field exposure specimens were cast with typical bridge deck reinforcement, including three different epoxy coatings and three surface preparations, as well as galvanized bars, mixed galvanized and plain bars, and plain bars for comparison. "Bend tests" were run on the epoxy coated bars.

Three experimental bridge decks were built, each having four spans; one span each with two different epoxy coatings, one span galvanized and one span plain. Both top and bottom mats were coated, in the epoxy coated and galvanized spans.

Details

Rebar samples were coated by two different shops for use in the laboratory and field exposure specimens. It was immediately apparent that wide variations were occurring in the quality of the coatings. However, the numerous variables of preparation, coating, and bar size; the lack of experience of the coating contractors in work with reinforcing steel; cost limitations on the experimental project; and a desire to determine the effects of such variations; led to the use and evaluation of bars that were not coated in strict accordance with the proposed Federal specification. Coating thicknesses were measured and recorded and bend tests were made to check the various combinations of factors that occurred. Many of the bars required patching before they would pass the continuity tests, and patching mixtures furnished for use with the coatings were quite poor. Bars for embedment in laboratory and field exposure specimens were chosen from the best coatings available within each type.

Approximately 620 bars selected for bend test evaluation showed the following variations in coating thickness: Fabricator A coated about 530 bars, of which 18 percent had coatings below the specified 5-mil minimum and 11 percent above the specified 9-mil maximum. Thicknesses for coatings on 90 bars from Fabricator B were 61 percent below 5 mils and 4 percent above 9 mils.

Obvious differences in cure, as well as thickness, make it very difficult to draw conclusions. While the many variables involved in the research project made it more of a problem for fabricators to control the coating process, the results obtained here do not seem to be much different from the wide variety of results that have been produced by the many fabricators involved in production runs for Michigan bridge decks that have been completed subsequent to this experimental project.

Unfortunately, the lack of well controlled specimens will cloud all information to be obtained from the experiment. However, the experimental results are presented in order to show the large variability in coatings that exists, and to determine whether significant improvements in performance can be obtained in spite of that variability.

Phase I - Laboratory Experiments

A. Corrosion - One hundred-fifty-two small laboratory specimens were cast during the winter of 1975. Each specimen is 4 by 4 by 14 in., with an 18-in. No. 6 rebar embedded 12 in. on the longitudinal centerline of the block. Variables included are given in Table 1. Specimens were cast, covered with polyethylene and left in the forms for one day, then cured in the moist room for seven days and air dried 21 days. Treatment consists of partial immersion by standing on end in saturated sodium chloride solution, approximately 6 in. deep. Specimens are removed weekly for measurement of electrical potential, and visual inspection. After two years of such treatment no serious deterioration of the specimens has occurred.

Corrosion cell readings have been highly erratic, but generally have not consistently moved above the 0.35-v level. Just within the last few months have the readings for a few of the samples begun to trend upward into the "corrosive" range.

B. Bending - Coating flexibility was evaluated by bending the bars through 120° over a wooden mandrel with a 3-in. radius. Five specimens of each type were bent soon after the coated bars were returned to the Laboratory, five specimens were bent after three months outdoor exposure, and five more specimens were bent after one year of storage in the Laboratory. Results are given in Table 2.

Due to the wide variations in coatings as noted above, the bend tests were not as obviously definitive as would be desirable, but they did serve a useful purpose.

Although the data are scattered, and relatively few points are available for analysis, two factors seem to be quite evident: 1) there is considerable variation in the curing of the coatings on various bars, even within a given type of coating and bar size; and 2) commercial blast treatment is not adequate preparation for application of epoxy coatings on rebars. Most of the data points are in the "greater than 10 cracks" column. Actually in many cases the coating debonded completely and came off the bar.

TABLE 1
VARIABLES INCLUDED IN SMALL LABORATORY SPECIMENS
(Tabulated values show number of samples included)

	6 sacks/cu yd mix																
	Scotch Kote 202 (by Plant A)	Scotch Kote 202 (by Plant B)	Flintflex 531-6080 (by Plant A)	Flintflex 531-6080 (by Plant B)	Cooks 720-A-009 (by Plant A)	Cooks 720-A-009 (by Plant B)	Sheared Ends	Uncoated Tie Wires	Damaged Coating	Holidays	Standard Bridge Mix	Latex Mortar (8 sacks/cu yd)	Latex Concrete (7 sacks/cu yd)	Standard Bridge Deck Mix, Gr. 45D (7 sacks/cu yd)	Low Slump 'Iowa Mix' (8-3/4 sacks/cu yd)	'Reg-Set' and 'Embeco' Patching Concretes (8 sacks/cu yd)
White Blast Cleaned	4	4	4	4	4	4										
Near-White Blast Cleaned	4	4	4	4	4											
Commercial Blast Cleaned	4	4	4	4												
Scotch Kote 202 (by Plant A) (white metal blast cleaned)							4	4	16	4						
Flintflex 531-6080 (by Plant A) (white metal blast cleaned)							4	4	16	4						
Uncoated											8	4	4	4	4	4
Galvanized											8					

TABLE 2
INITIAL BEND TESTS *
(FABRICATOR A)

	Surface Preparation	No. of Cracks	Coating Thickness: Thin < 5 mils, No. 4 Bar	Thin < 5 mils, No. 5 Bar	Thin < 5 mils, No. 6 Bar	Within Spec. 5 - 9 mils, No. 4 Bar	Within Spec. 5 - 9 mils, No. 5 Bar	Within Spec. 5 - 9 mils, No. 6 Bar	Thick > 9 mils, No. 4 Bar	Thick > 9 mils, No. 5 Bar	Thick > 9 mils, No. 6 Bar
3M	White Metal Blast	0 - 1	1			2	5	2	2		3
		2 - 10									
		> 10									
	Near-White Metal Blast	0 - 1			1	2	4	4	2		
		2 - 10				1	1				
		> 10									
	Commercial Blast	0 - 1	1			2			2		
		2 - 10									
		10			2		5	3			
DuPont	White Metal Blast	0 - 1				2		4	3	5	1
		2 - 10									
		> 10									
	Near-White Metal Blast	0 - 1			1	5	4	4		1	
		2 - 10									
		> 10									
	Commercial Blast	0 - 1	1			3	2		1		
		2 - 10									
		> 10		1			2	4			1
Cook's	White Metal Blast	0 - 1		1		3	1	3	2	1	
		2 - 10					2	1			1
		> 10									
	Near-White Metal Blast	0 - 1		3		2	2	3	1		1
		2 - 10						1			
		> 10	1			1					
	Commercial Blast	0 - 1				1			2		
		2 - 10								2	
		> 10				1	1	4	1	2	1

TABLE 2 (Cont.)
INITIAL BEND TESTS
(FABRICATOR B)

	Surface Preparation	No. of Cracks	Coating Thickness: Thin < 5 mils, No. 4 Bar	Thin < 5 mils, No. 5 Bar	Thin < 5 mils, No. 6 Bar	Within Spec. 5 - 9 mils, No. 4 Bar	Within Spec. 5 - 9 mils, No. 5 Bar	Within Spec. 5 - 9 mils, No. 6 Bar	Thick > 9 mils, No. 4 Bar	Thick > 9 mils, No. 5 Bar	Thick > 9 mils, No. 6 Bar
3M	White Metal Blast	0 - 1	1			2		2			
		2 - 10		1			1	2			
		> 10		1		1	1	1			
	Near-White Metal Blast	0 - 1		1							
		2 - 10									
		> 10	1	3	1	3		4			
	Commercial Blast	0 - 1									
		2 - 10									
		> 10	2			1	4	3	1	1	2
DuPont	White Metal Blast	0 - 1	5	5	4			1			
		2 - 10									
		> 10									
	Near-White Metal Blast	0 - 1									
		2 - 10			2						
		> 10	5	5	3						
	Commercial Blast	0 - 1									
		2 - 10									
		> 10	5	5	4			1			
Cook's	White Metal Blast	0 - 1									
		2 - 10									
		> 10			1			4			
	Near-White Metal Blast	0 - 1									
		2 - 10									
		> 10									
	Commercial Blast	0 - 1									
		2 - 10									
		> 10									

* Tabulated values indicate number of specimens in each category.

TABLE 2 (Cont.)
BEND TESTS AFTER 90 DAYS OUTDOORS EXPOSURE
(FABRICATOR A)

	Surface Preparation	No. of Cracks	Coating Thickness: Thin < 5 mils, No. 4 Bar	Thin < 5 mils, No. 5 Bar	Thin < 5 mils, No. 6 Bar	Within Spec. 5 - 9 mils, No. 4 Bar	Within Spec. 5 - 9 mils, No. 5 Bar	Within Spec. 5 - 9 mils, No. 6 Bar	Thick > 9 mils, No. 4 Bar	Thick > 9 mils, No. 5 Bar	Thick > 9 mils, No. 6 Bar
3M	White Metal Blast	0 - 1				5	2	2			2
		2 - 10					2			1	1
		> 10									
	Near-White Metal Blast	0 - 1		1		1		3			
		2 - 10				1	1			1	
		> 10			1	1	1	1	2	1	
	Commercial Blast	0 - 1				3					
		2 - 10							2		
		> 10					3	3		1	2
DuPont	White Metal Blast	0 - 1				5		3		2	
		2 - 10					2			1	
		> 10						1			1
	Near-White Metal Blast	0 - 1	2			3	5	2			
		2 - 10			1			2			
		> 10									
	Commercial Blast	0 - 1				3					
		2 - 10		1		1	1				
		> 10		1	2	1	2	3			
Cook's	White Metal Blast	0 - 1				2	2		2		
		2 - 10									
		> 10				1	3	5			
	Near-White Metal Blast	0 - 1		2		3		4			
		2 - 10		1			1		1		
		> 10					1	1			
	Commercial Blast	0 - 1	1			1	3	3			
		2 - 10				2	2	2			
		> 10							1		

TABLE 2 (Cont.)
BEND TESTS AFTER 1 YEAR STORAGE IN LABORATORY
(FABRICATOR A)

	Surface Preparation	No. of Cracks	Coating Thickness: Thin < 5 mils, No. 4 Bar	Thin < 5 mils, No. 5 Bar	Thin < 5 mils, No. 6 Bar	Within Spec. 5 - 9 mils, No. 4 Bar	Within Spec. 5 - 9 mils, No. 5 Bar	Within Spec. 5 - 9 mils, No. 6 Bar	Thick > 9 mils, No. 4 Bar	Thick > 9 mils, No. 5 Bar	Thick > 9 mils, No. 6 Bar
3M	White Metal Blast	0 - 1	1			2		2			
		2 - 10		1			1	2			
		> 10		2		1		1			
	Near White Metal Blast	0 - 1		1							
		2 - 10									
		> 10	3		3	1	4	2			
	Commercial Blast	0 - 1									
		2 - 10									
		> 10	3	5	1	2		4			
DuPont	White Metal Blast	0 - 1	5	5	4			1			
		2 - 10									
		> 10									
	Near-White Metal Blast	0 - 1			1						
		2 - 10			1			1			
		> 10				5	5	2			
	Commercial Blast	0 - 1									
		2 - 10									
		> 10	5	5	4			1			
Cook's	White Metal Blast	0 - 1	1	2		3	1	3	1		
		2 - 10					2	1			1
		> 10									
	Near-White Metal Blast	0 - 1	2	3	2	1	2	2			
		2 - 10						1			
		> 10	1			1					
	Commercial Blast	0 - 1	3								
		2 - 10		2	1						
		> 10	2	1			2	3			1

Computer analysis of variance applied to the data confirmed the above, and added the following conclusions: 3) size of the bar is a highly significant variable, probably reflecting variations in the heating cycle applied during the coating process sequence involved in this particular project; 4) the types of coating are not significantly different in performance when applied by the same fabricator; 5) there was a significant difference in the performance of the same coatings when applied by two different fabricators; 6) when source was held constant, there was only slight difference in white metal and near-white metal blast treatment; and, 7) there was an effect due to aging of the coating, but at a lower level of significance. It is obvious, however, that general degradation to extreme brittleness has not occurred.

Phase II - Laboratory Controlled Exposure

Thirty-eight specimens were cast for exposure in the field. Specimen size was approximately 3 ft by 4 ft by 8 in., and typical bridge deck reinforcement was cast into each one, (six No. 6 rebars in the main "transverse" portion of both the top and bottom mats, with No. 4 and No. 5 "longitudinal" steel top and bottom, respectively). All specimens were cast with 6-sack ready-mix, using 1-1/4-in. concrete cover over the top bars. Triplicate specimens were cast with the three epoxy coatings, and three blast treatments as separate entries. In addition, galvanized bars were added in six specimens, three with all bars coated and three with galvanized bars in the top mat only. Three specimens were cast with white metal blast, 3M coating, and uncoated bar chairs, and two specimens were prepared with all bars uncoated.

The field exposure specimens were erected on site in the fall of 1974. Water retaining dikes were built on the specimens, and weekly treatment with salt and water has been completed through three winters. All specimens are still in very good condition.

Phase III - Experimental Decks

Three four-span structures were selected for the first experimental installation of epoxy coated reinforcement in Michigan. The deck reinforcement installations were arranged so as to have one span each of two different epoxy coated bars, one span of galvanized bars and one span of uncoated bars in each structure. Both top and bottom mats were included. Table 3 gives location and reinforcement costs for the three bridges, all of which were completed in the fall of 1976.

TABLE 3
EXPERIMENTAL DECK REINFORCEMENT COSTS
(Both top and bottom mats coated)

Structure Number	Location	Uncoated		3M (202)		DuPont (531-6080)		Cooks (720-A-009)		Galvanizing	
		$/lb	$/sq ft	$/lb	$/sq ft	$/lb	$/sq ft	$/lb	$/sq ft	$/lb	$/sq ft
S04 of 58152	Post Rd over I 75, Monroe	0.38	3.07	0.46	3.71	----	----	0.46	3.71	0.46	3.71
S13 of 81103	Curtis Rd over M 14, E of Ann Arbor	0.27	2.20	0.50	4.07	0.50	4.07	----	----	0.40	3.25
S02 of 82102	Napier Rd over M 14, E of Ann Arbor	0.27	2.15	0.50	3.99	0.50	3.99	----	----	0.40	3.19

TABLE 4
THICKNESS MEASUREMENTS (mils) OF EPOXY COATED
REINFORCING STEEL SAMPLED FROM JOB SITE

Random Readings at Stockpile									
3M Scotch Kote 213					DuPont Flintflex 531-6080				
No. of Readings	Max.	Min.	Avg.	Std. Dev.	No. of Readings	Max.	Min.	Avg.	Std. Dev.
200	14.0	1.5	5.79	2.56	200	14.0	1.0	5.74	2.77

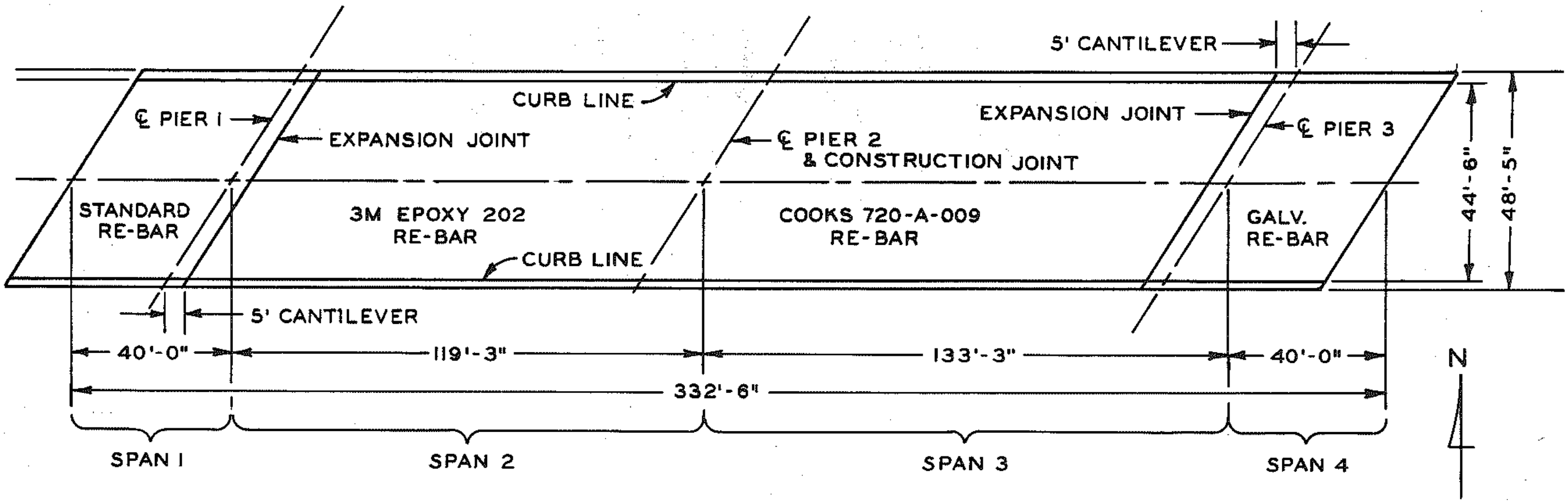
Figures 1 through 3 show sketches of the experimental decks, with the locations of the different coated rebars and data concerning depth of cover and coating thickness. Specifications required 7 ± 2 mils of epoxy coating. The measurements show the average coating to be within specifications for all spans but one (on Napier Rd), but the standard deviations indicate that many of the individual readings are outside the specified range with more on the low side of the specification.

Continuing problems with bridge deck deterioration, coupled with FHWA sponsored work on epoxy coatings and the experience gained on this experimental project, led to a decision to require epoxy coated rebars in the top mat of all Michigan bridge decks, beginning with the March, 1976 letting.

During the fall of 1976, researchers checked coating thicknesses on bars for a large, non-experimental structure, to determine whether the coating being supplied was similar to those applied on the experimental decks covered by this research project. The bridge included two types of epoxy coatings; Scotchkote 213 (3M) and Flintflex 531-6080 (DuPont). (The 3M type 213 coating is a newer "improved" modification of the Type 202 that was used on this research project.) Table 4 gives results of the readings obtained; they are fairly typical of those obtained on the experimental decks, although coated by a different fabricator.

Yearly inspections are scheduled on the experimental decks to determine the relative performance of the epoxy coated, galvanized, and uncoated bars. A delamination detector will be used to locate any fracture planes that develop in the decks. Condition surveys will indicate any other observable deterioration of the decks. Since the experimental decks were built with a considerable amount of concrete cover over the rebars, and since corrosion protection was provided over large portions of the deck, it will be several years before significant deterioration should develop.

Evaluation of the laboratory specimens, field exposure specimens and experimental decks will continue for a number of years until sufficient data are available to warrant conclusions. Further progress reports will be issued when any such conclusions can be made.



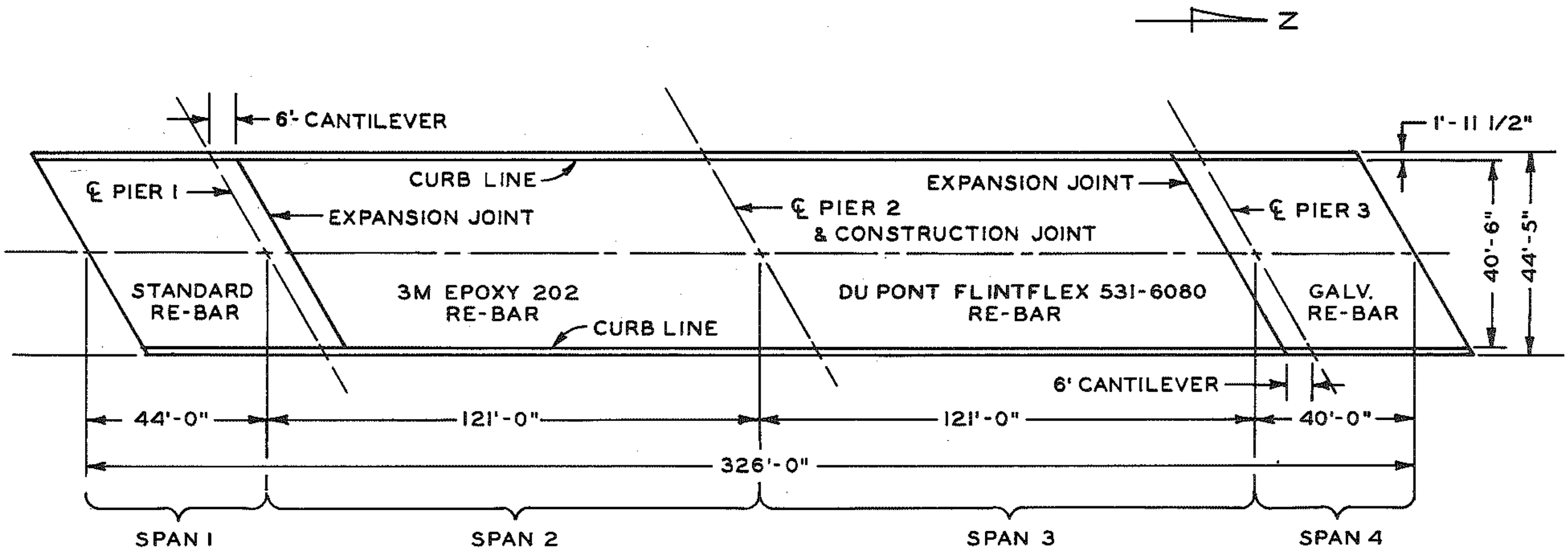
Span 1 - Average cover over No. 6 bars = 3-1/8 in., N = 80, range = 2-3/4 to 3-1/2 in., S = 0.17 in.

Span 2 - Average cover over No. 6 bars = 2-15/16 in., N = 110, range = 2-1/8 to 3-3/4 in., S = 0.35 in., average coating thickness = 6.1 mils, range = 2.5 to 14 mils, N = 200, S = 2.71 mils.

Span 3 - Average cover over No. 6 bars = 2-15/16 in., N = 120, range = 2 to 3-3/4 in., S = 0.41 in., average coating thickness = 6.2 mils, range = 2.5 to 13 mils, N = 193, S = 2.02 mils.

Span 4 - Average cover over No. 6 bars = 3-7/16 in., N = 80, S = 0.29 in., range = 3 to 4-1/4 in., average coating thickness = 5.6 mils, range = 2.5 to 11 mils, N = 200, S = 1.43 mils.

Figure 1. S04 of 58152, Post Rd over I 75 near Monroe.



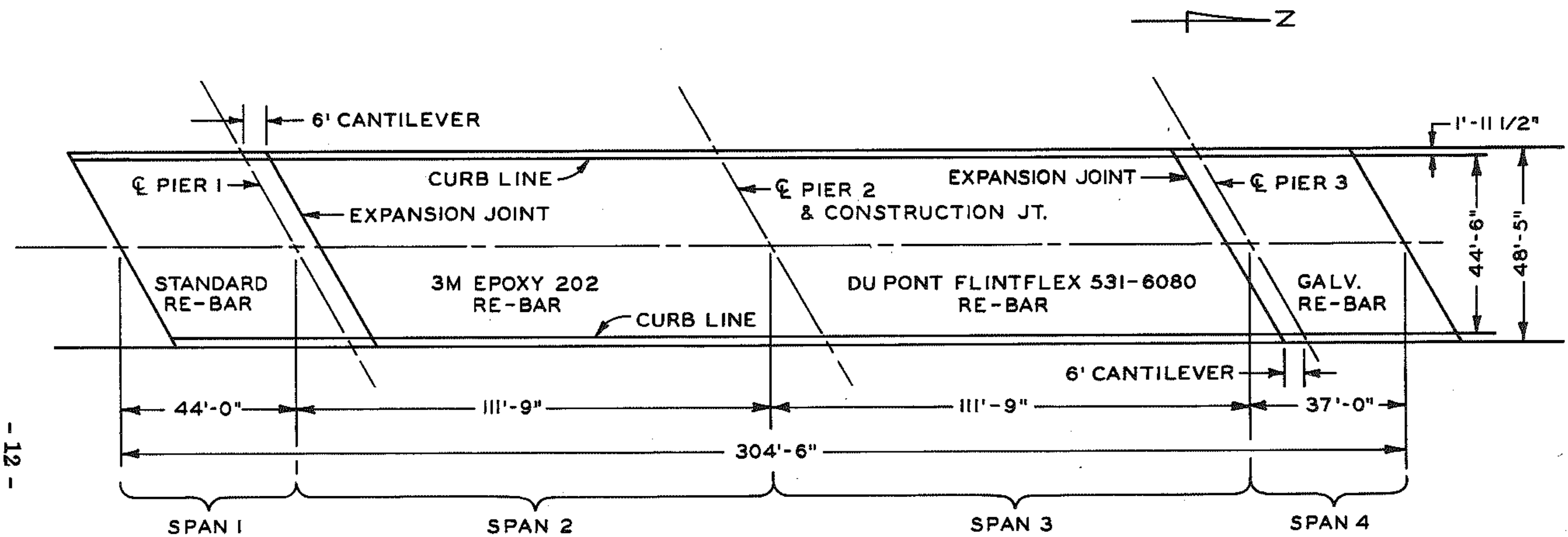
Span 1 - Average cover over No. 6 bars = 2-3/8 in., N = 81, S = 0.19 in., range = 1-7/8 to 2-7/8 in.

Span 2 - Average cover over No. 6 bars = 2-9/16 in., N = 198, range = 1-7/8 to 3 in., S = 0.20 in., coating thickness measurements not obtained.

Span 3 - Average cover over No. 6 bars = 2-9/16 in., N = 176, range = 2 to 3-1/4 in., S = 0.25 in., average coating thickness = 7.0 mils, range = 2 to 14 mils, N = 202, S = 2.40 mils.

Span 4 - Average cover over No. 6 bars = 2-3/16 in., N = 64, range = 1-5/8 to 2-5/8 in., S = 0.22 in., average coating thickness = 5.1 mils, range = 2 to 12 mils, N = 236, S = 1.43 mils.

Figure 2. S13 of 81103, Curtis Rd over M 14 (relocation) east of Ann Arbor.



Span 1 - Average cover over No. 6 bars = 2-1/4 in., N = 81, S = 0.23 in., range = 1-7/8 to 3 in.

Span 2 - Average cover over No. 6 bars = 2-3/8 in., N = 180, range = 2 to 3-1/8 in., S = 0.26 in., average coating thickness = 4.7 mils, range = 2.0 to 7.5 mils, N = 190, S = 1.06 mils.

Span 3 - Average cover over No. 6 bars = 2-3/8 in., N = 180, range = 1-3/4 to 3 in., S = 0.24 in., average coating thickness = 6.7 mils, range = 1.5 to 15 mils, N = 200, S = 2.91 mils.

Span 4 - Average cover over No. 6 bars = 2-7/16 in., N = 72, range = 2 to 2-7/8 in., S = 0.19 in., average coating thickness = 5.1 mils, range = 2 to 12 mils, N = 100, S = 2.24 mils.

Figure 3. S02 of 82102, Napier Rd over M 14 (relocation) east of Ann Arbor.

Conclusions

Patching compounds furnished for repair of coatings, were far from adequate, and bend tests indicated the following based on the rather limited quantities involved.

1) Commercial blast treatment is not adequate preparation for epoxy coatings on rebars.

2) White metal blast and near-white metal blast treatments give similar results.

3) All three types of coating performed about the same when properly applied.

4) There was only a minor effect due to 90 day outdoor exposure or one year laboratory storage.

5) There was a significant difference in the coatings applied by two different fabricators.

6) There was a significant difference in the amount of curing of the coatings involved in the experiment.

The work that has been done so far has shown that coatings applied for use in this experimental project had considerable variations in curing and thickness, but associated measurements made on non-experimental jobs indicate that the results encountered here seem to be fairly typical of production at some commercial plants.

Specimens and decks involved in the corrosion comparisons are not yet old enough to develop significant deterioration.