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GALVANIZED STEEL REINFORCED CONCRETE BRIDGE DECKS

Construction Report

MICHIGAN DEPARTMENT OF STATE HIGHWAYS

GALVANIZED STEEL REINFORCED CONCRETE BRIDGE DECKS
Construction 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
Research Project 68 F-103
Research Report No. R-845
Job No. 97303

Michigan State Highway Commission
E. V. Erickson, Chairman;
Charles H. Hewitt, Claude J. Tobin, Peter B. Fletcher
Lansing, January 1973

Introduction

This report covers the construction of laboratory specimens and experimental bridge decks for the evaluation of galvanized reinforcement as a deterrent to bridge deck deterioration. The work is being done by the Research Laboratory Section of the Michigan Department of State Highways as a Highway Planning and Research study in cooperation with the Federal Highway Administration. The project carries Michigan designation 68 F-103, and is being done in accordance with the proposal dated May 1969, revised August 1969.

Severe deck deterioration, in areas where deicing salts are used, initiated numerous investigations of methods to delay such deterioration. Several investigators found that reinforcing steel in porous or cracked concrete contaminated with chlorides is susceptible to corrosion, and that advanced corrosion causes spalling of adjacent concrete. Professors B. Bresler and I. Cornet at the University of California at Berkeley[1], conducted experiments with the relative corrosion rates of galvanized and plain re-bars in small laboratory specimens. They reported considerable reductions in the rate of corrosion for galvanized bars, and bond performance equal to or better than similar black bars.

This project was proposed to extend the investigation to larger simulated deck sections, and ultimately to actual full-scale experimental decks.

Objectives

The objectives of the study were stated in the proposal as follows:

1) To determine the feasibility of using galvanized reinforcement in Michigan bridge deck construction.

2) To evaluate the effect of galvanized reinforcement on the performance of laboratory specimens and full scale experimental bridge decks.

Scope

Twenty-nine 3 ft by 4 ft by 7-1/2 in. slabs were cast in the laboratory for field exposure and periodic treatment with salt and water. Along with

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[1] Bresler, B. and Cornet, I., "Galvanized Steel Reinforcement in Concrete." International Association for Bridge and Structural Engineering. Final Report, 7th Congress, 1964, Reprint V 2, pp. 449-457.

TABLE 1

EXPERIMENTAL DETAILS OF THE LABORATORY SPECIMENS

Slab No.	Cover, in.	Bars Spliced	Concrete Design		Air Content, percent	Slump, in.	28-day Compressive Strength, psi
			Cement sacks/cu yd	Water gal/sack			
1	1-1/4	No	7-1/4	4-4/5	5.4	2-3/8	5530
2	2	No	6	5-2/5	7.6	4-1/8	3760
3	1/2	No	7-1/2	4-1/2	5.7	3-1/2	4580
4	2	No	6	5-1/4	7.4	5-1/2	3810
5	1/2	Yes	6	5-1/4	5.5	3	4810
6	1-1/4	No	6	5-1/4	6.1	2-7/8	3310
7	1-1/4	No	6	6	5.6	7-1/2	3950
8	2	Yes	6	5-1/4	7.7	3-7/8	3440
9	2	Yes	6	5-1/4	7.5	4-1/2	4400
10	1/2	No	6	5-1/4	5.9	2-1/8	4080
11	1-1/4	Yes	6	5-1/4	6.7	3-1/2	4540
12	2	No	6	6	7.0	8-3/8	3420
13	1/2	No	7-1/2	4-1/2	5.3	1-7/8	5080
14	1/2	No	6	6	7.4	7-1/8	3960
15	1-1/4	No	6	5-1/4	4.1	1-1/2	4740
16	1/2	No	6	6	5.8	7	4200
17	1/2	No	6	5-1/4	5.1	2-1/8	4380
18	2	No	6	5-1/4	5.2	2-3/8	4520
19	1-1/4	No	6	6	4.8	7-1/8	3950
20	1-1/4	Yes	6	5-1/4	4.2	1-7/8	5140
21	1/2	Yes	6	5-1/4	5.9	4-1/4	4390
22	1-1/4	No	5-3/4	5-3/5	12.4	7-1/8	2650
23	1-1/4	P+LS*	6	6	4.3	7-3/4	3990
24	1-1/4	P+LS*	6	6	3.4	3-3/4	3730
25	2	P+LS*	6	6	4.4	7-3/4	3950
26	1-1/4	G+PD**	6	6	4.2	8-1/4	4350
27	1/2	G+PD**	6	6	4.2	6-3/4	4450
28	1/2	G+PD**	6	6	4.3	7-1/4	4100
29	1-1/4	G+PD**	6	6	4.3	8	4150
Field Beam (4 ft, 7-1/2 in. by 30 ft by 7-1/2 in. on 36-in. WF 150 Beam with Shear Developers)							
Section							
1	1/2	Yes (3)	6	5+	5.8	5-1/4	2920
2	1	No	6	5+			
3	1-1/2	No	6	5+			
4	2	No	6	5+			
5	2-1/2	No	6	5+			
6	3	No	6	5+			
7	3-1/2	No	6	5+			

Note: * 6 Plain bars + 2 coats linseed-mineral spirits on half of surface.
** 6 Galvanized top bars with 3 potassium dichromate treated.

these slabs a simulated composite deck section, 30-ft long, 56-in. wide and 7-1/2 in. thick, was cast on a 36-in. wide-flange beam. Concrete mixes for the laboratory specimens consisted of 6 and 7-1/2 sacks of cement per cu yd, with 4-1/2, 5-1/4 and 6 gal of water per sack of cement. Concrete cover over the bars varied from 1/2 to 2-in. in the laboratory specimens and 1/2-in. to 3-1/2 in. in the simulated deck. Typical deck reinforcement was included in the specimens and one half of the steel in the top mat was galvanized. Weekly applications of water and salt are made during winter weather (December through March).

Five experimental bridge decks were built, with galvanized steel in the top mat on approximately one half of each deck. In the deck design, the distance from the deck surface to the center of the main (transverse) bar in the top mat was 2-7/8 in. $\pm$ 1/4 in., with the longitudinal reinforcement placed on top of the transverse.

Construction Details

Phase I - Laboratory Specimens and Simulated Deck

The 29 laboratory specimens were cast during March of 1970, cured with polyethylene film for 7 days, then air dried until placement in the field during July 1970. The simulated deck section was cast at the exposure site, during August of 1970. The first salt application was made in December 1970, and further weekly applications have been made only during the winter months. A temperature recorder is kept on site to record the freeze and thaw cycles.

Details for the specimens are shown in Table 1. Specimens are numbered in the order in which they were cast, which was a randomized selection of the various mixes and amounts of cover over the bars.

Specification for the galvanizing called for 1-1/2 oz per sq ft average, with a minimum of 1 oz per sq ft. Measurements were made on the bars for Phase I specimens, before and after galvanizing, to check the actual thickness of coating applied. A total of 274 locations were checked. The average coating thickness was 2.6 oz per sq ft, with a range from 0.6 to 5.9 oz per sq ft. Only one location measured 0.6, and the 5.9 reading occurred twice in the 274 points.

Slabs No. 1 through 22 have three galvanized and three plain No. 6 rebars on 8-in. centers in the primary or "transverse" steel of the top mat. Two galvanized No. 4 bars make up the "longitudinal" portion of the top mat, and are placed below the larger bars. A typical bottom mat of six

No. 6 "transverse" and four No. 5 "longitudinal" bars, all ungalvanized, was included in each of the specimens. Slabs No. 23 through 25 had no galvanized steel, and had one-half of the surface treated with linseed oil. In slabs No. 26 through 29, all of the bars in the top mat were galvanized and three No. 6 bars in each specimen were given an additional surface treatment with potassium dichromate.

The slabs were cast in wooden forms in the laboratory, as shown in Figure 1. Holes drilled in the forms at the proper distance from the top controlled the amount of cover over the bars, and also held the bars firmly in place during subsidence and curing of the concrete. The concrete for each slab was mixed in two batches because the mixer was not large enough to mix a batch of sufficient size to fill the forms and provide the required surplus to make cylinders for strength determination. The first batch was placed in the bottom of the form, and kept below the top mat, so that all of the experimental bars would be in concrete from the same batch. The second batch filled the top portion of the slab form and the cylinder molds, with sufficient excess so that the last portions scraped from the container could be discarded.

Coarse aggregate for the mix was per Michigan Bridge Specification 6AA, which is a premium quality gravel containing some crushed material, and less than 4 percent deleterious stone. The gradation is from No. 4 through 1-in. similar to ASTM size No. 57. Fine aggregate was 2NS sand. No water reducer or retarder was used in the mix. An air-entraining additive was used.

The mix was consolidated in the forms by immersion-type vibrators, struck-off, floated, and broom finished. Polyethylene sheeting was applied as soon as the surface had taken an initial set. After seven days of polyethylene cure, the slabs were air dried in the laboratory until they were placed in the field several weeks later.

The simulated deck was cast at the field site, as a composite section on a 36-in. wide-flange beam with stud-type shear developers. Main "transverse" bars were No. 6, at 8-in. centers, supported by holes in the formwork, as in the laboratory specimens. "Longitudinal" bars for the top mat were No. 4, placed below the larger bars. There were four rows of longitudinal bars in the top mat, two of which were galvanized and two plain. Forms were supported from the ground, so that the final surface elevation would contain no dead-load sag. Concrete cover over the bars ranged from 1/2 in. to 3-1/2 in. The concrete was ready-mix, quite wet, placed on a hot day with no curing provided. This was done to provide a more porous concrete that might deteriorate at a faster rate.

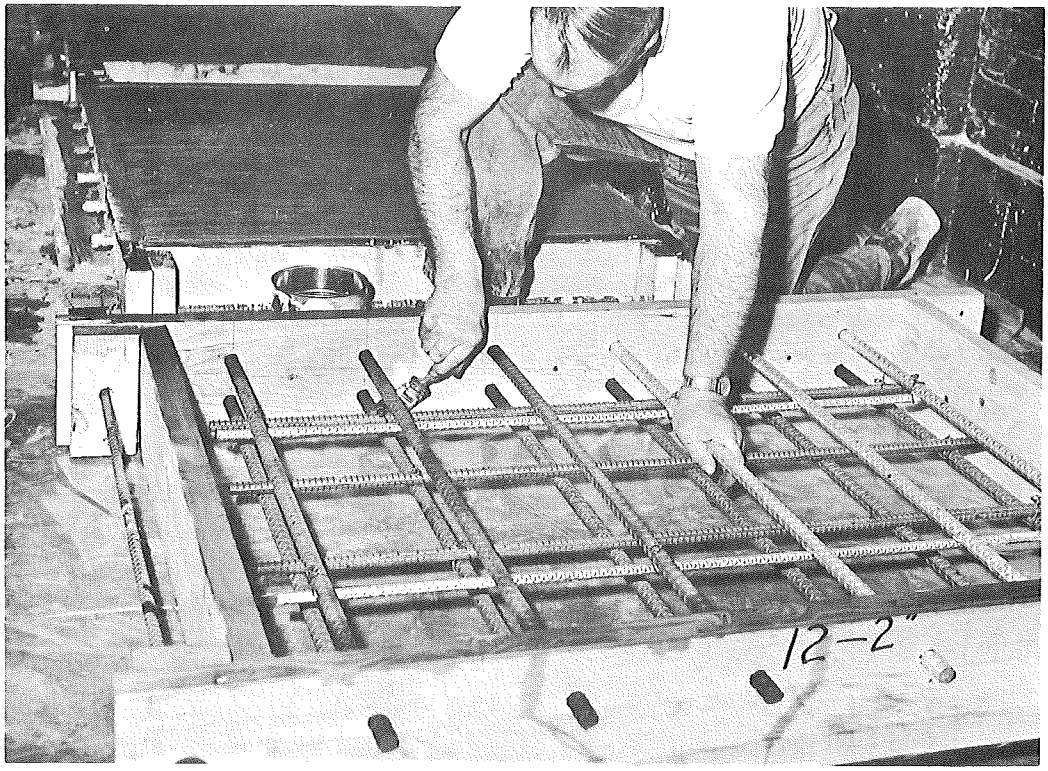

Figure 1. Slab form in preparation for casting. Note three galvanized No. 6 bars in top mat at right, and two galvanized No. 4 bars as "temperature" or "longitudinal" steel. Bottom mat of No. 5 and No. 6 bars, all ungalvanized.

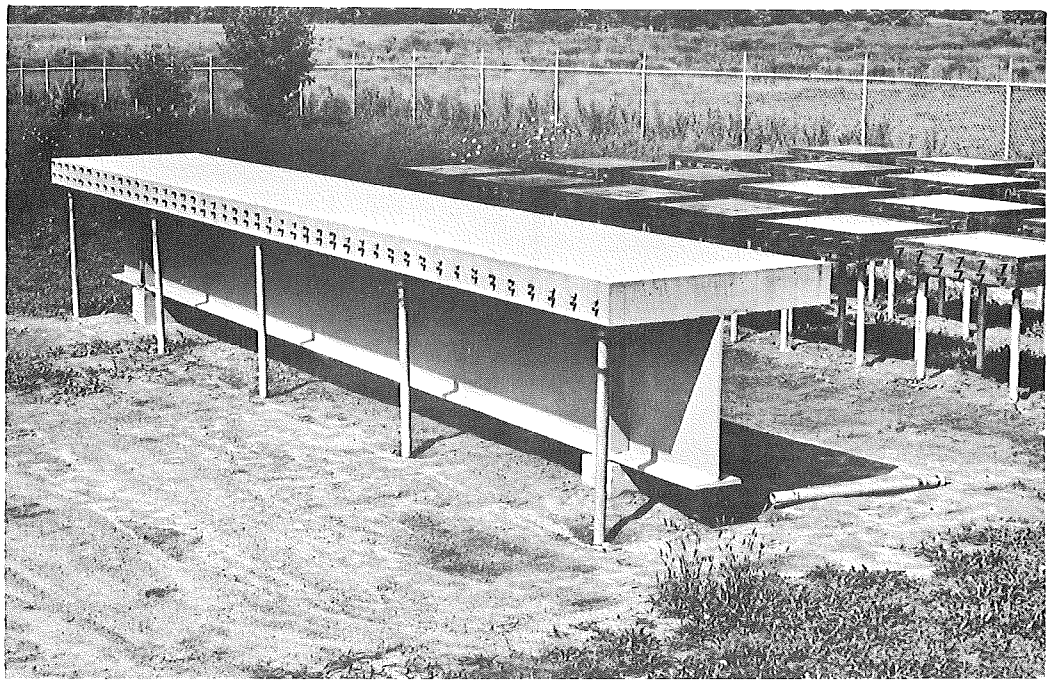

Figure 2. Field installation of laboratory specimens and simulated deck section. Water retaining dikes were added to the larger section at a later date.

Water-retaining dikes separated the surface into individual areas, each with the same amount of concrete cover. Each area contained three galvanized No. 6 bars, and three plain, except for the area with 1/2-in. cover which had an additional set of three plain bars, with splices.

Figure 2 shows the field installation prior to addition of water retaining dikes on the simulated deck. The 3 by 4-ft specimens are supported on pipes driven into the ground, with threaded supports at each corner for leveling. Salt applications are made each week. Specimens are washed clean and inspected carefully in the spring of the year.

Slight rust staining was evident on some specimens with 1/2-in. cover, after the first winter of treatment. Varying amounts of surface scaling are present, generally light, but with very severe scaling and deterioration of the top surface of specimens 27 through 29. No obvious explanation for this deterioration has been discovered at this time. However, the surfaces have scaled away to such an extent that the long term evaluation of those three specimens may not be practical.

Some further rust staining is evident after the second year of treatment but no hollow areas or spalls have developed to date.

Phase II - Experimental Decks

Table 2 shows the five structures selected for use of galvanized re-bar in the top mat only, over approximately one-half of the deck.

TABLE 2
EXPERIMENTAL DECKS

Approximate Cost of Structure	Structure No.	Location
$ 612,000	S 12 of 82123	Hubbell over I 96, Detroit
$ 566,000	S 14 of 82123	Schaefer over I 96, Detroit
$1,125,000	S 16 of 82123	Grand River over I 96, Detroit
$ 482,000	S 17 of 82123	Meyers over I 96, Detroit
$ 709,000	S 18 of 82123	Wyoming over I 96, Detroit

These structures were scheduled for letting in April of 1970, but were delayed due to reductions in allocations of Federal highway funds. One contract was let late in 1970, and the other four in 1971, so the decks were not built until 1972. All five have now been completed and four opened to traffic.

Bar reinforcement for the five decks included 205,967 lb of galvanized steel at $0.30/lb, and 769,754 lb of ungalvanized steel at $0.19 to $0.22/lb.

Specifications for the coating required galvanizing in accordance with ASTM A 123, with the exception that the weight of coating average no less than 1-1/2 oz per sq ft with no individual specimen less than 1 oz per sq ft. Test results from re-bars checked, showed coating thicknesses ranging from 2.8 to 4.4 and averaging above 3 oz per sq ft. The bars were obtained and placed by the contractor without major problems, although workmen were troubled by sharp protrusions of zinc from some portions of the bars.

All five structures have steel stringers, but there is considerable variation in the size of the bridges, as indicated by the cost, and shown in the Figures.

Figure 3 shows concrete placement with the typical bucket on the galvanized portion of the Grand River Ave bridge. The Shugart finisher is shown in the transverse position, as used on this structure only. Decks were placed by bucket and finished longitudinally with the Shugart machine on the Hubbell, Schaefer, and Meyers St structures. A Gomaco finisher and concrete pump were used to place the Wyoming St deck, as shown in Figure 4.

Figures 5 through 9 show the location of the galvanized steel on the various structures. Depth of steel measurements were made with a pachometer on the finished decks, and the amount of cover over the bars is shown in the sketches. Areas shown as galvanized have all galvanized steel in the top mat, with one minor exception on the Schaefer St deck, where some ungalvanized bars were added to the mat in a negative moment area. This area is noted on the sketch, and will be examined closely to determine whether the alternating steel type on the top mat will cause any problems.

Yearly inspections will be made on the experimental decks to establish the relative performance of the galvanized and ungalvanized portions. A delamination detector is under construction as a part of this project, and will be used to locate fracture plane separation before the top portion of the deck has spalled away. Since the experimental decks were constructed with a considerable amount of concrete cover over the bars, it may be many years before deck deterioration reaches measurable proportions.

The decks are also being checked by a corrosion detector in an attempt to establish "time to an active potential," which may give some earlier indication of the initiation of bar corrosion.

Figure 3. Deck placement on the galvanized portion of the Grand River Avenue structure. Shugart finisher shown in transverse position.

Figure 4. Concrete pump and Gomaco finisher used only on Wyoming St deck. Galvanized re-bars are evident in the background.

Evaluation of the laboratory specimens and decks will continue until sufficient data have been collected to warrant conclusions. Further reports will be issued when such conclusions are made.

The opinions, findings, and conclusions expressed in this publication are those of the author and not necessarily those of the Federal Highway Administration.

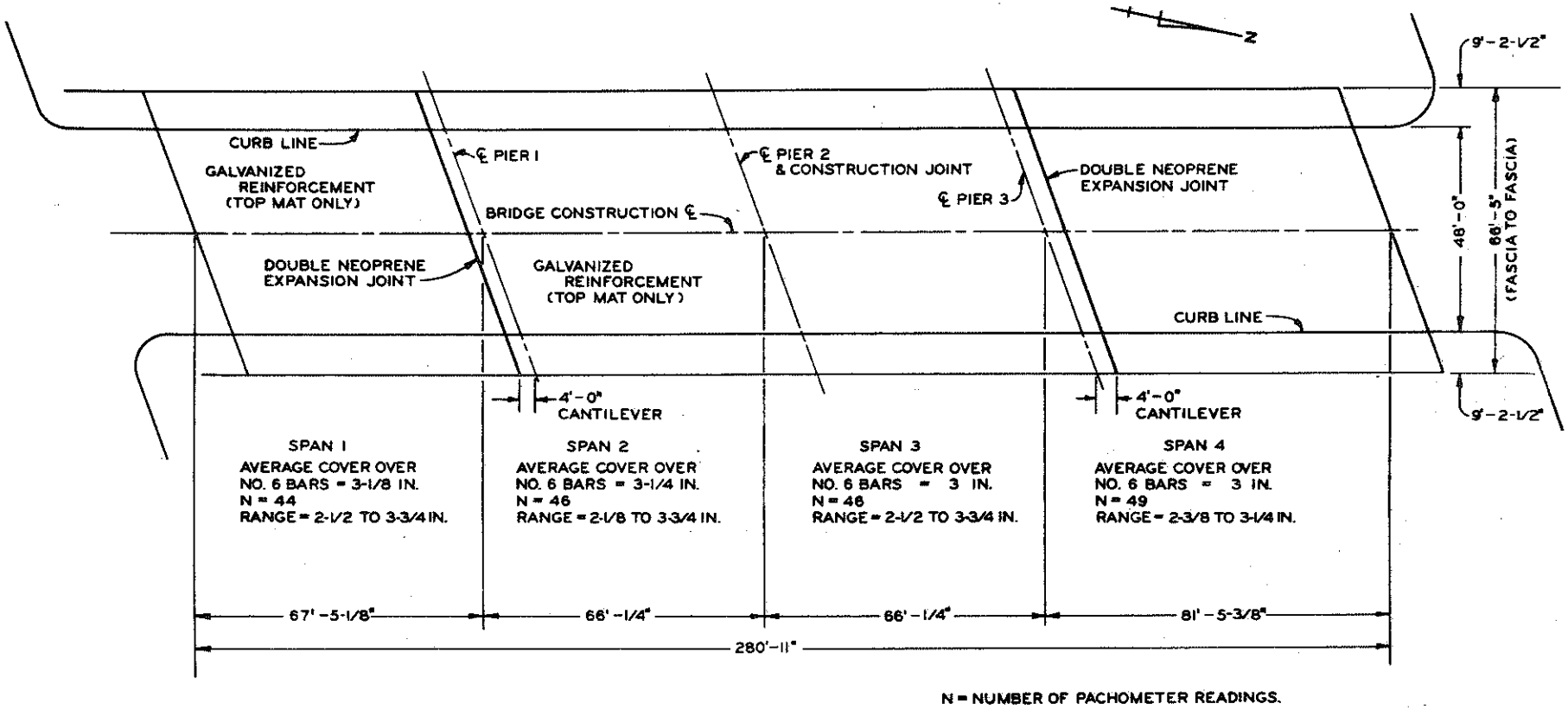

Figure 5. S12 of 82123 Hubbell Ave. over Jeffries Freeway (I 96).

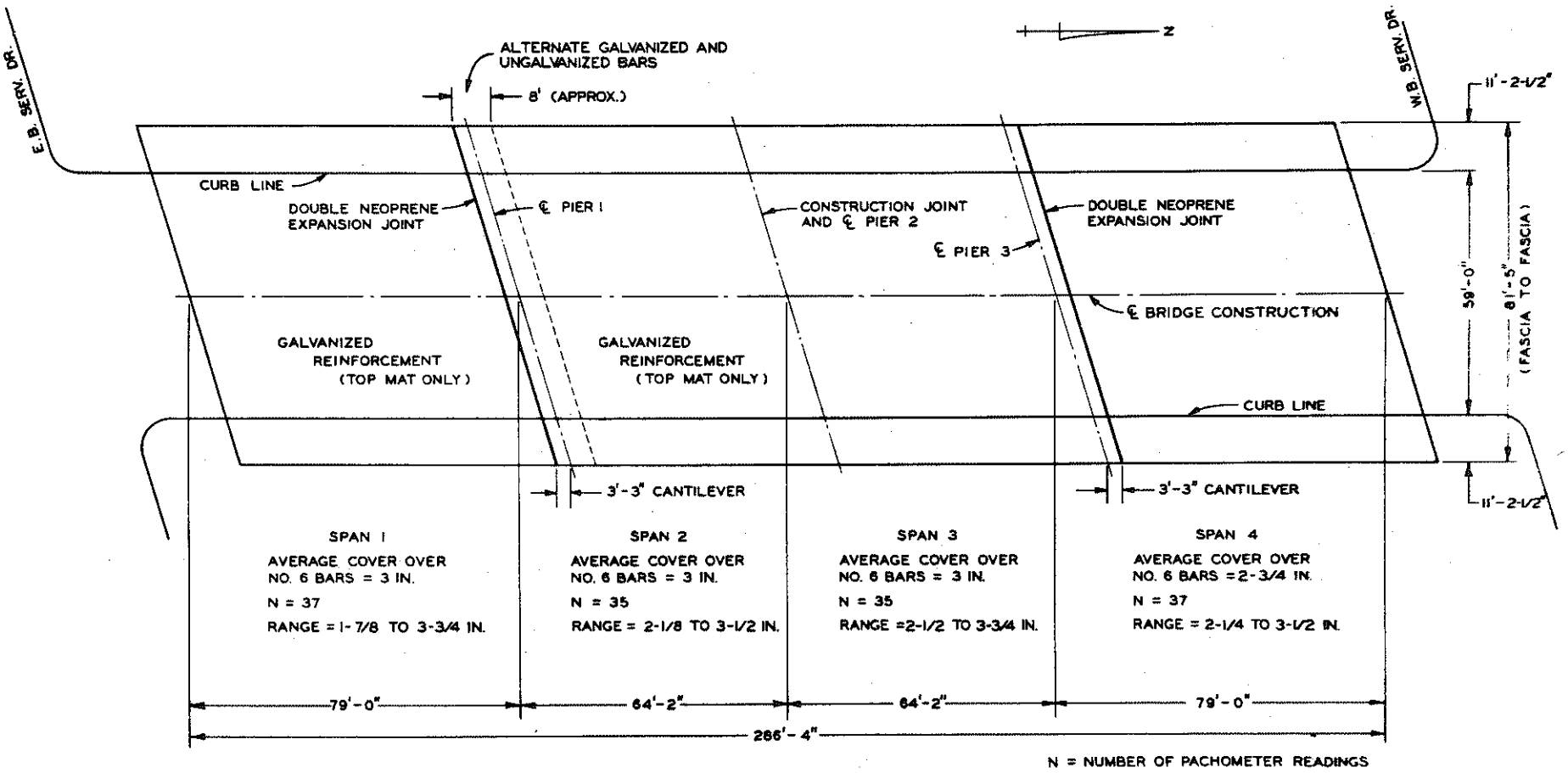

Figure 6. S14 of 82123 Schaefer Rd. over Jeffries Freeway (I 96).

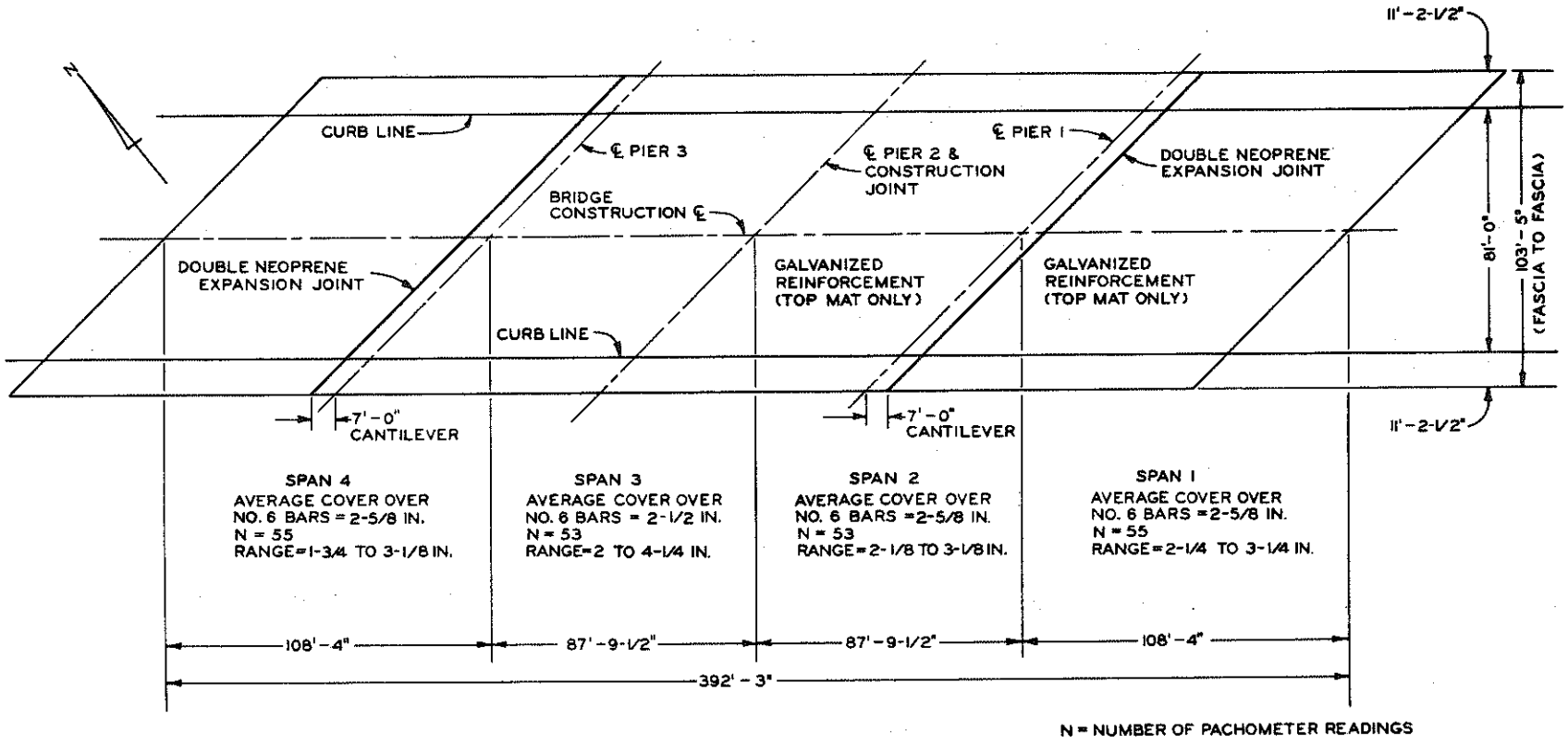

Figure 7. S16 of 82123 Grand River Ave. over Jeffries Freeway (I 96).

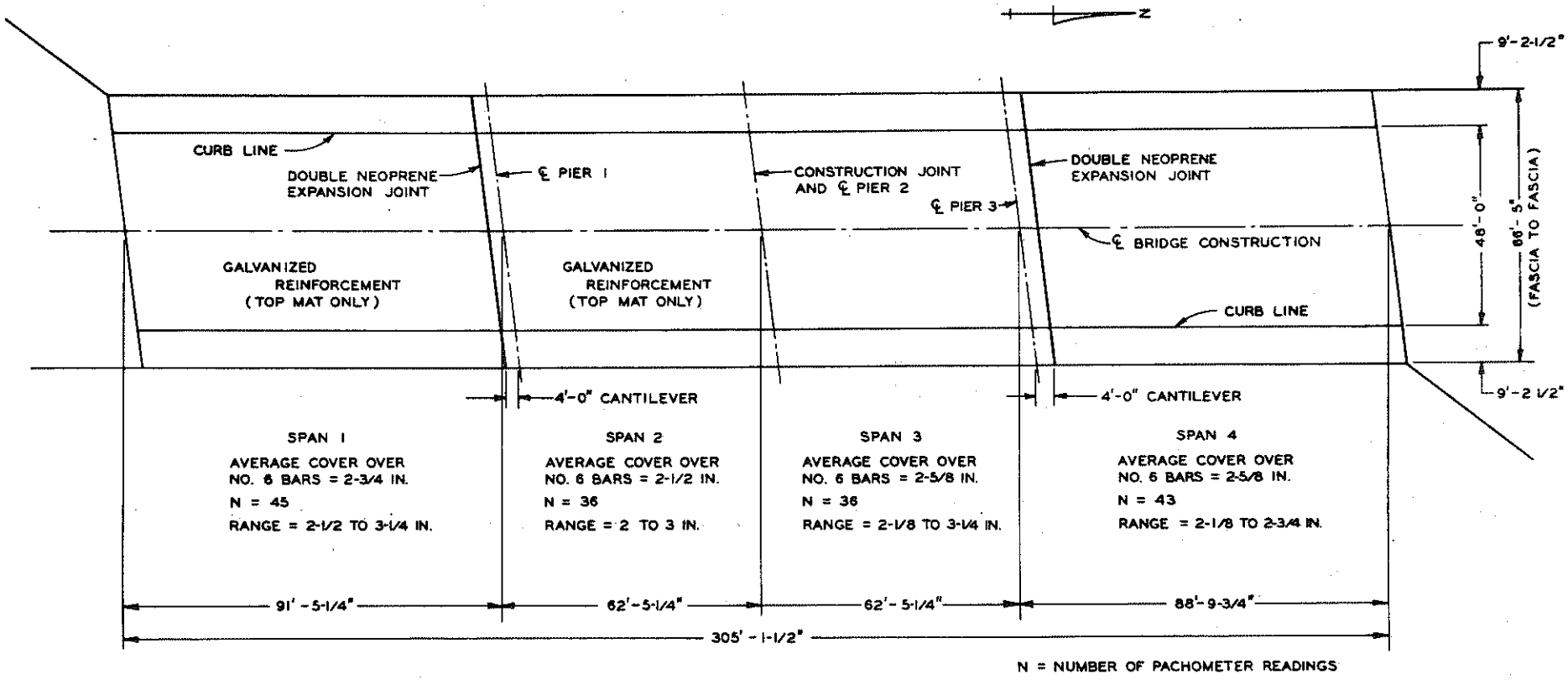

Figure 8. S17 of 82123 Meyers Ave. over Jeffries Freeway (I 96).

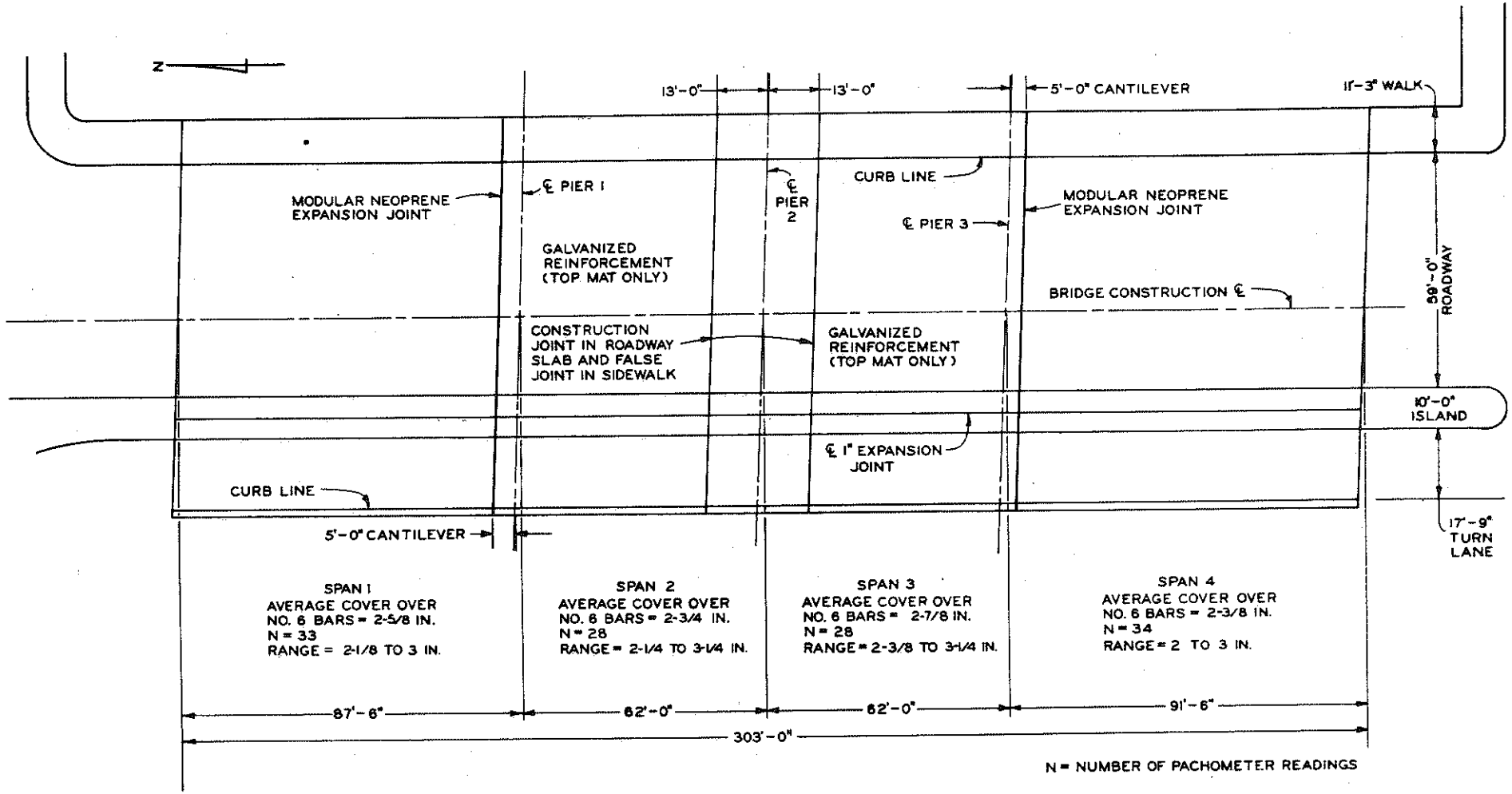

Figure 9. S18 of 82123 Wyoming Ave. over Jeffries Freeway I(96).