A COMPARISON OF THE CORROSION PERFORMANCE OF UNCOATED, GALVANIZED, AND EPOXY COATED REINFORCING STEEL IN CONCRETE BRIDGE DECKS

MICHIGAN
DEPARTMENT OF TRANSPORTATION

MATERIALS and TECHNOLOGY
DIVISION

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M•DOT

A COMPARISON OF THE CORROSION PERFORMANCE OF UNCOATED, GALVANIZED, AND EPOXY COATED REINFORCING STEEL IN CONCRETE BRIDGE DECKS

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by the Michigan Department of Transportation
in Cooperation With the
Federal Highway Administration

Research and Technology Section
Materials and Technology Division
Research Projects 68 F-103 and 73 F-131
Research Report No. R-1321

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ACTION PLAN

1. Materials and Technology Division

   A. Distribute copies of the report with a cover letter to the Maintenance Division, the Districts, and the FHWA. The cover letter should indicate the major findings of this work (i.e. a copy of the Executive Summary along with the following text would be suitable). While galvanized reinforcement appeared to have better corrosion performance than uncoated reinforcement in cored specimens from the experimental decks, no major differences were seen in actual deck performance (i.e. the percentage of observed spalls and delaminations). Future use of galvanized reinforcement would not appear to be justified based on its greater expense (over epoxy coating) and its lack of superior performance at the deck level (over uncoated reinforcement). While there has been a considerable amount of recent controversy regarding the quality of epoxy coatings used on steel reinforcement, major problems were not detected on the three bridge decks built in 1978 that were part of the original project or the nine newer structures that were examined as part of a project extension. At the present time, epoxy coating appears to represent the most cost effective means of protecting steel reinforcement in concrete from levels of corrosion that may damage the concrete.

2. Engineering Operations Committee

   A. No action necessary upon approval of this report.

EXECUTIVE SUMMARY/ABSTRACT

As northern states initiated bare pavement policies in the late 1950s and early 1960s, the greater deicing salt exposure became an increasing maintenance problem for bridge decks. Chloride intrusion into the concrete resulted in corrosion of the reinforcement that, in turn, eventually resulted in pot holes on the bridge decks, which required repairs much sooner than would previously have been necessary.

The increased use of deicing salt, the cause of the problem, could not be simply eliminated. The bare pavements created improved safety and had economic benefits that must be retained. With this in mind, solutions were sought that could improve the corrosion performance of the reinforcement.

Research in the 1960s suggested that galvanizing might be the answer and additional research in the early 1970s suggested that epoxy coating might be an even better solution. Michigan initiated two research projects to investigate the field performance of these proposed alternatives.

Michigan research project 68 F-103 compared the performance of uncoated and galvanized reinforcement in adjacent spans of five different bridge decks built in 1972. Thirty six simulated bridge deck slabs (3' x 4' x 7-1/2") were also used to evaluate the effects of increased clear cover and concrete mix design on both salt penetration and the performance of uncoated and galvanized reinforcement.

Michigan research project 73 F-131 compared the performance of uncoated, galvanized, and epoxy coated reinforcement in the adjacent spans of three separate bridge decks built in 1976 and 38 simulated bridge deck slabs (3' x 4' x 7-1/2"). The slabs also compared the effects of using galvanizing in the top mat only or both mats, as well as differing degrees of surface preparation of the reinforcement prior to epoxy coating for three different epoxy coatings.

The performance of the actual bridge decks is detailed in this report. The performance of the simulated bridge deck slabs has been reported in Michigan Department of Transportation (MDOT) Research Report R-1320.

While the galvanized reinforcement in research project 68 F-103 demonstrated better corrosion performance compared to uncoated reinforcement at the reinforcement level under similar conditions (i.e. depth of clear cover, salt concentration, and presence/absence of cracking), no major differences were found in the performance of the decks as measured by the percent of deck area having either spalls or delaminations.

For research project 73 F-131, reinforcement corrosion performance at the reinforcement level and under similar conditions (i.e. depth of clear cover, salt concentration, and presence of cracking) is best for the epoxy coated and worst for the uncoated, with the galvanized being intermediate. These 15-year-old (i.e. age in 1991 when last surveys were performed) bridge decks have not, however, been exposed long enough for spalling or delaminations to occur. Consequently, there is still some question as to how significant differences in actual deck performance might eventually be.

Cores taken from younger bridge decks with epoxy-coated reinforcement suggest that there are no major problems with these newer epoxy coatings, but the coatings appear to show better corrosion performance at the reinforcement level for those decks that used epoxy-coated reinforcement in both top and bottom mats. Prior to 1980 epoxy coated reinforcement, when used, was required in only the top mat. These decks are also too young, however, to determine if these differences will result in significant differences in actual deck performance (i.e. spalls and delaminations).

Half-cell data from both projects suggest that such information is very limited in predicting location and extent of corrosion in bridge decks when only one set of readings is used, but can be more useful if multiple readings over time are available.

INTRODUCTION AND BACKGROUND

When a concrete bridge deck was constructed prior to the late 1950s, it was expected to last a minimum of 30 to 50 years before even minor maintenance was needed. Expectations changed dramatically during the 1960s as concrete bridge decks began to deteriorate at an ever more alarming rate. Major maintenance was needed on some bridge decks in as little as four years.

Many theories for the accelerated deterioration were investigated. The list includes such things as delayed concrete delivery during placement, adverse weather conditions, and structural vibrations during the finishing and curing periods. Early cracking may be caused by restraint to volume change due to curing shrinkage, drying, and temperature changes, or to stringer flexure. In addition, precise control of the depth of concrete cover over the reinforcement is difficult. A plane-of-weakness roughly parallel to the surface was believed to form in the deck at the level of the top reinforcement as a result of entrapment of rising bleed water from the mix. Transverse vertical cracks often formed directly over the transverse reinforcement shortly after deck construction allowing early infiltration of water and deicing salts. Bar expansion due to corrosion and freeze/thaw action in these cracks then contributed to the failure along the plane-of-weakness parallel to the surface and just above the top layer of reinforcement.

It gradually became apparent, however, that the major culprit was corrosion of the reinforcement steel, which in turn appeared to be accelerating because of the increased use of chloride deicing salts with the advent of the winter bare pavements policies introduced in many states during the late 1950s and early 1960s. While salt was apparently the major contributor to deck deterioration, the salt could not simply be eliminated to alleviate the problem. Deicing salt contributed to significant economic and safety benefits that could not be discarded. The solution would have to incorporate measures that could reduce the corrosion damage to the reinforcement by either reducing the amount of salt penetrating to the reinforcement or using reinforcement materials that would not be as susceptible to corrosion.

Concrete is normally a relatively safe environment for reinforcing steel. The steel forms a "passive" oxide layer in the highly alkaline concrete environment that provides a barrier to further corrosion. The addition of chloride ions begins to change this situation as the chlorides reach a certain concentration level and combine with the reinforcement, water, and oxygen. The volume of oxide produced during such corrosion is several times larger than the metal that forms it. The expansion in turn produces pressures in the concrete that exceed the tensile strength of the concrete. The expansive pressure of the oxide can reach 1200 psi or more, which surpasses the tensile strength at which concrete cracks (approximately 600 psi). Once the concrete is cracked, corrosion can accelerate even further as more of the ingredients necessary for corrosion penetrate the deck. As horizontal cracks from adjacent bars grow together, delaminations are created that eventually turn into the potholes that necessitate deck repair.

During the 1960s several different sources were indicating that galvanized bridge deck reinforcement might be a considerable improvement over uncoated reinforcement. The American Hot Dip Galvanizers Association was circulating information regarding a Bermuda structure that had both uncoated and galvanized reinforcement. The International Lead Zinc Research Organization sponsored research at the University of California at Berkeley that showed galvanized reinforcement to last twice as long (i.e. time to "deck" cracking) as uncoated reinforcement under identical conditions.

The favorable information regarding galvanized reinforcement prompted Michigan to initiate Research Project 68 F-103, which has evaluated the comparative performance of galvanized and uncoated reinforcement. Uncoated and galvanized reinforcement were placed in adjacent spans of five separate bridge decks. Thirty six simulated bridge deck slabs (3' x 4' x 7-1/2") were also built to evaluate the effects of increased clear cover depth and mix design (i.e. cement content and water/cement ratio). The performance of the simulated bridge deck slabs has been separately reported in MDOT Research Report R-1320.

During the early 1970s, the National Bureau of Standards under contract with the Federal Highway Administration (FHWA) examined 40 non-metallic coatings for their potential use with bridge deck reinforcing steel. Four coatings were identified as suitable candidates. These coatings, being electrically non-conducting as well as a barrier, provided a greater promise of protection than galvanizing. While zinc, like steel, corrodes and produces oxides that are larger than the parent metal and might eventually result in corrosion expansion problems, the epoxy coatings might eliminate corrosion completely.

The favorable potential of the epoxy coatings prompted Michigan to initiate Research Project 73 F-131, which has evaluated the comparative performance of uncoated, galvanized, and epoxy-coated (the three coatings suitable for commercial coating) reinforcement placed in the adjacent spans of three different bridge decks. Thirty eight simulated bridge deck slabs (3' x 4' x 7-1/2") were also constructed to compare the performance of these different materials, as well as differing degrees of surface preparation prior to epoxy coating. The performance of the simulated bridge deck slabs has been separately reported in MDOT Research Report R-1320.

The early findings of this (i.e. research project 68 F-103 and 73 F-131) and similar research efforts have resulted in policy changes that have probably reduced corrosion damage in newer structures (see Appendix A). However, over 3,800 structures remain on Michigan's trunklines with unprotected steel reinforcement, and the replacement or rehabilitation of these structures will be expensive. Many years will be required to eliminate the most critical, most susceptible ones from our highway system.

Economic figures supplied by the FHWA show that rehabilitation of our national bridge population cost the American public over 1.2 billion dollars during the 1990 fiscal year. Although these numbers include other repair categories, the portion that relates to rehabilitation of concrete damaged due to rebar corrosion is a significant part of this total figure. Conservative estimates show that as a country we are spending less than 50 percent of what is needed to keep our transportation system at status quo. To reduce the number of obsolete or load restricted bridges, and to improve the condition of our bridges, would require spending about five billion dollars per year. Therefore, research that can shed light on the causes of bridge deck deterioration and propose life extending solutions is both desirable and necessary if we are to satisfactorily maintain our state's and nation's highways on the limited budget currently available for this purpose.

SCOPE

Galvanized (68 F-103)

Five bridge decks were constructed in 1972 with galvanized and uncoated reinforcement in adjacent spans to allow direct comparison of the performance of these two materials in a real-world environment. For this project galvanized reinforcement was only used in the top mat for the galvanized spans. Typically these structures were constructed with uncoated reinforcement in one half of the bridge deck spans and galvanized reinforcement in the top mat of the remainder.

Epoxy Coated (73 F-131)

Three bridge decks were constructed in 1976 with uncoated, galvanized, and epoxy coated reinforcement in adjacent spans to allow direct comparison of these materials in a real-world environment. For this project galvanized reinforcement was used in both the top and bottom mats. For the epoxy test sections, coated reinforcement was used in both the top and bottom mats. Typically all three structures have four spans: one with uncoated reinforcement, one with galvanized reinforcement, and the remaining two with a different epoxy-coated reinforcement in each span.

Project Extension

Given the relatively recent controversy regarding epoxy coated reinforcement, nine newer bridge decks with epoxy coated reinforcement (built between 1977 and 1982), which were not part of the original research proposals, were also examined. Five of these structures had epoxy coated reinforcement in the top mat only, while the remaining four used epoxy coated reinforcement in both mats.

OBJECTIVES

Galvanized (68 F-103)

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

2.) To evaluate the performance of galvanized reinforcement in full-scale experimental bridge decks.

Epoxy Coated (73 F-131)

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

2.) To evaluate the performance of epoxy coated reinforcement in full-scale experimental bridge decks.

Project Extension

To evaluate the performance of newer, production run epoxy coatings in full-scale bridge decks.

PROCEDURE

Galvanized (68 F-103)

Galvanized steel reinforcement was placed in the top mat for roughly half the deck spans of five separate structures (Figures 1-5). All structures were otherwise built as per the MDOT's Standard Specifications for Construction in effect at the time of construction. The five structures selected are all located in heavily traveled urban areas where heavier salt usage was expected to allow performance differences to show up sooner than might otherwise be the case.

Initial measurements were made of the thickness of the galvanizing on the steel reinforcement and the depth of clear concrete cover over the bars in the decks.

Periodic examination of the individual decks, usually performed annually, included visual examination, half-cell measurements, and delamination testing. Cores were also taken on several occasions from each deck to determine the condition of the reinforcement.

Regular inspections were made from 1972 until 1986. Staff reductions within the department made it difficult to continue this data collection, however, an additional inspection was made in 1991.

Visual examination involved surveying for cracking, spalled areas, and bituminous patches. These areas were recorded on a deck map, which was color coded for each years' inspection.

Copper-copper sulfate reference electrodes were used to take half-cell measurements. These readings were typically taken during the summer or early fall of each year. Half-cell readings were taken at five-foot intervals starting at roughly one foot from both the joint and the curb and moving in the direction of traffic flow and perpendicular to the curb, creating a grid pattern across the deck. Since the bridges for this project were in the Detroit Metropolitan area and subject to heavy traffic, measurements were only taken in the lane closest to the curb.

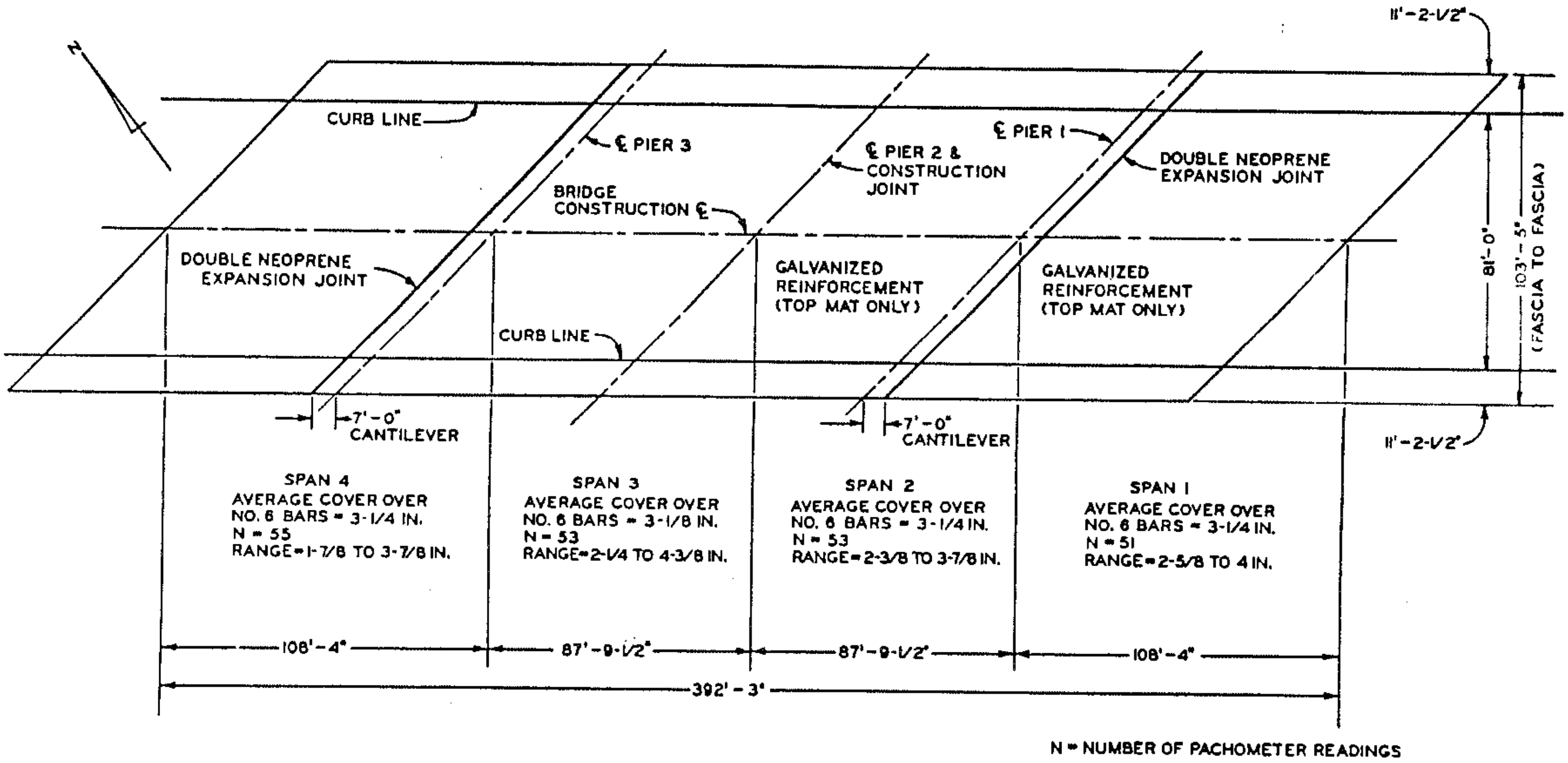


Figure 1. S16 of 82123--Grand River Avenue over I-96 (Jeffries Freeway).

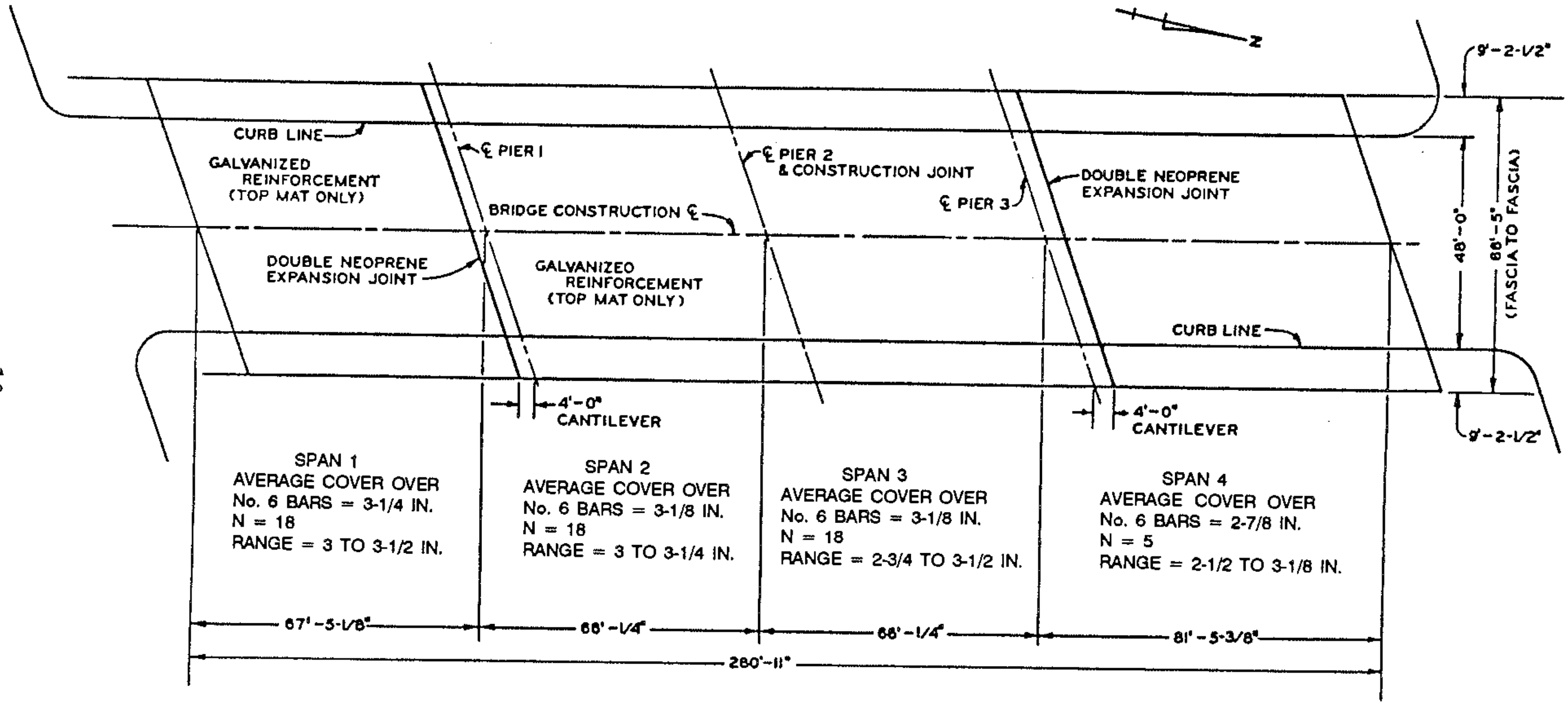


Figure 2. S12 of 82123--Hubbell Avenue over I-96 (Jeffries Freeway).

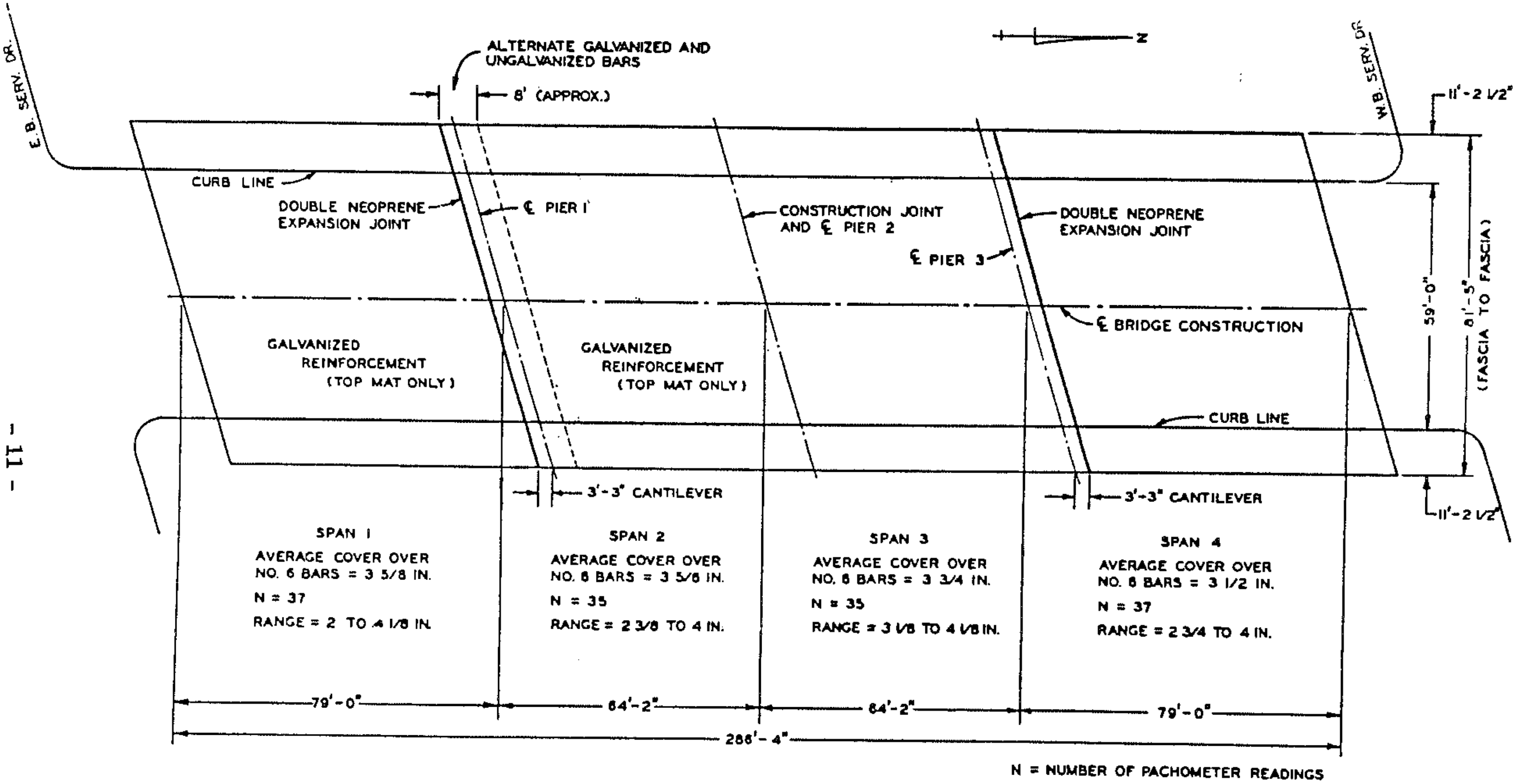


Figure 3. S14 of 82123--Schaefer Road over I-96 (Jeffries Freeway).

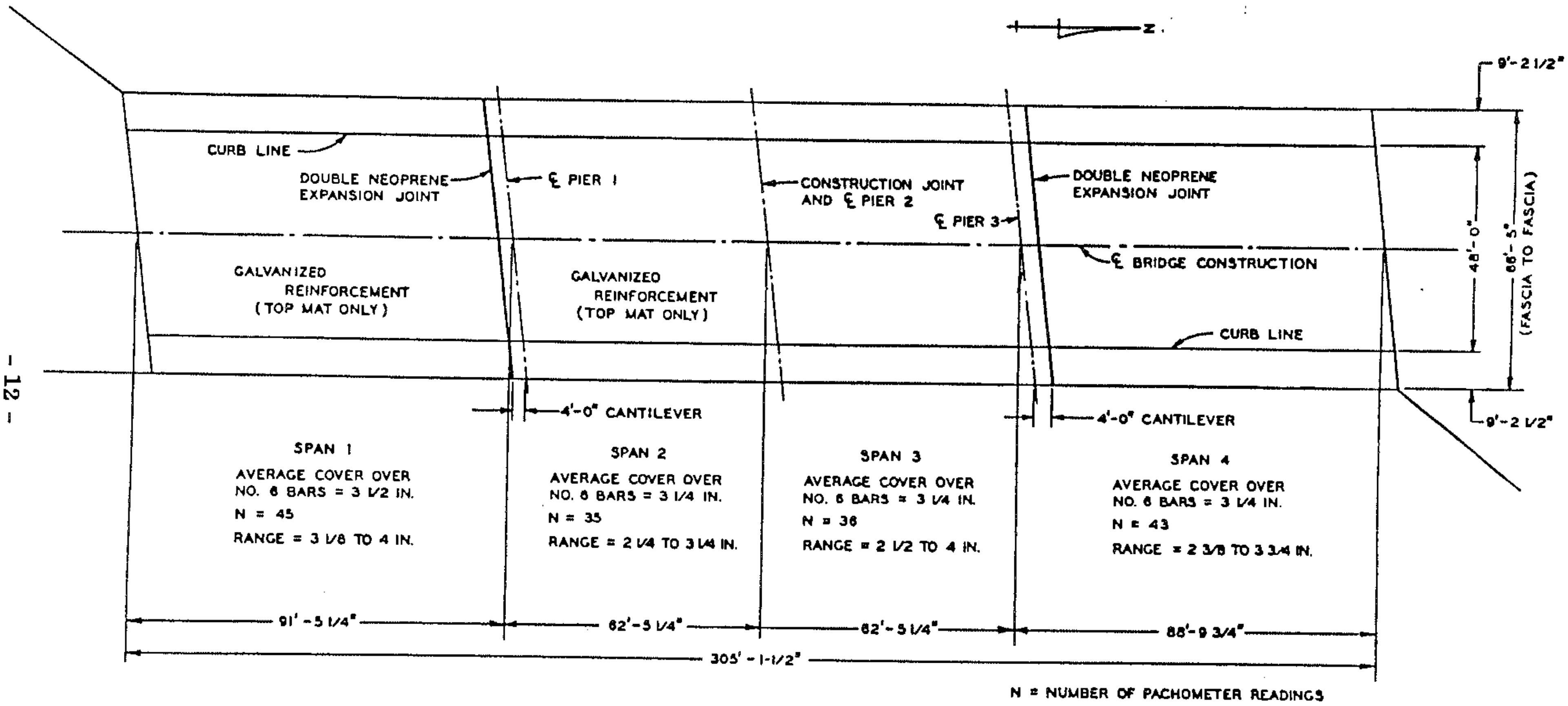


Figure 4. S17 of 82123--Meyers Avenue over I-96 (Jeffries Freeway).

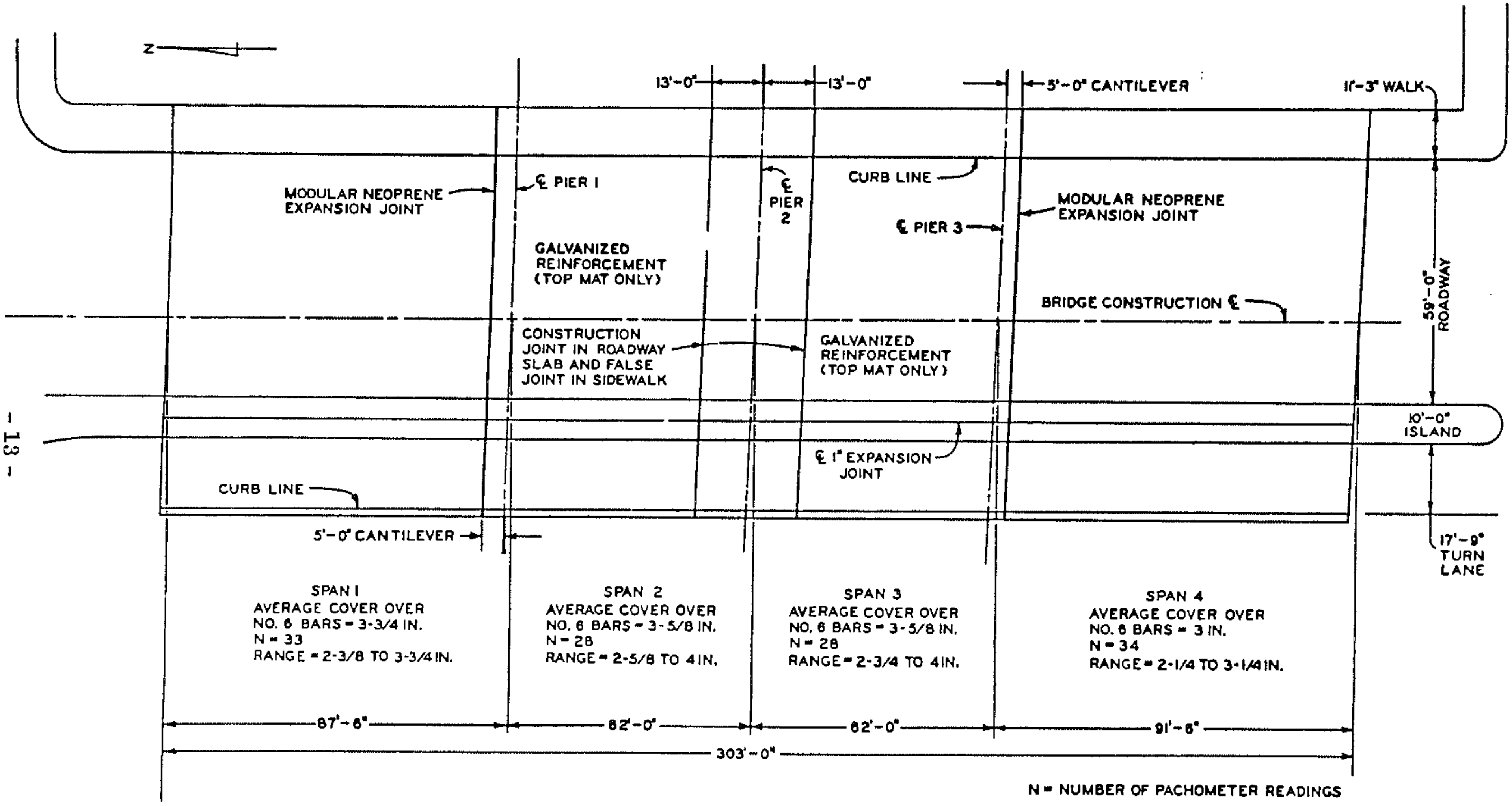
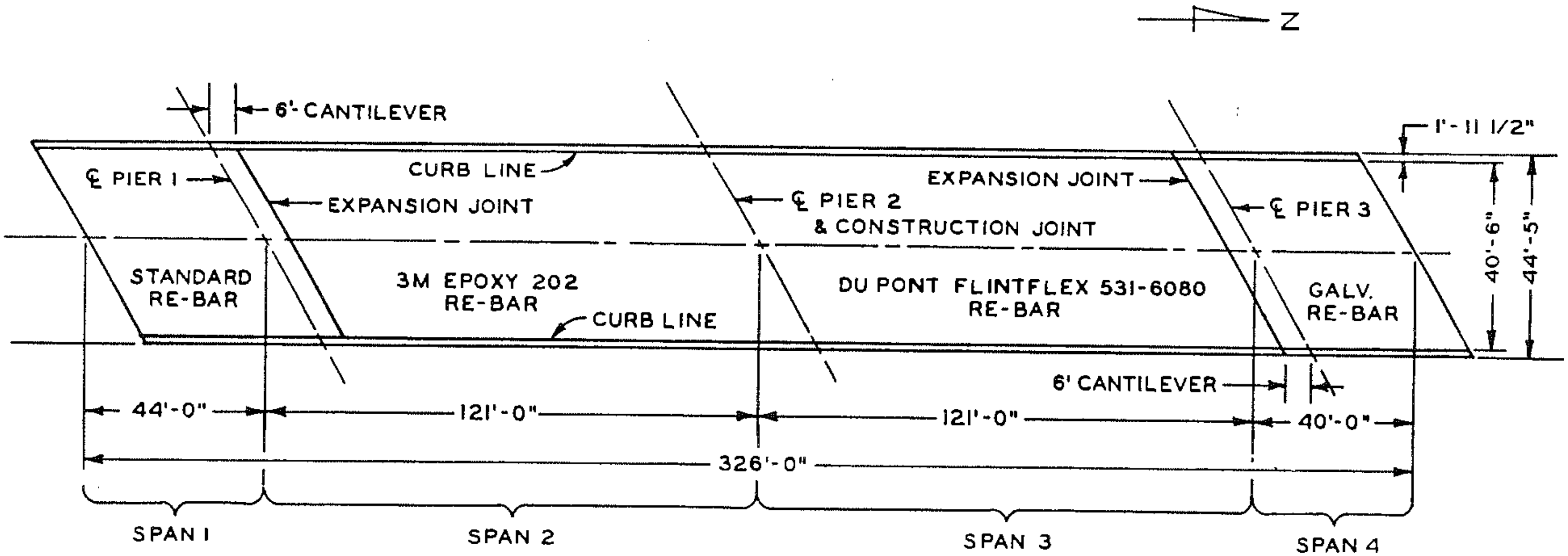


Figure 5. S18 of 82123--Wyoming Avenue over I-96 (Jeffries Freeway).



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.

AVERAGE COVER OVER
No. 6 BARS = 2-9/16 IN.
N = 198, S = 0.20 IN.
RANGE = 1-7/8 TO 3 IN.
COATING THICKNESS
MEASUREMENTS NOT TAKEN

AVERAGE COVER OVER
No. 6 BARS = 2-9/16 IN.
N = 176, S = 0.25 IN.
RANGE = 2 TO 3-1/4 IN.
AVERAGE EPOXY COATING
THICKNESS = 7.0 MILS
N = 202, S = 2.4 MILS
RANGE = 2.0 TO 14.0 MILS

AVERAGE COVER OVER
No. 6 BARS = 2-3/16 IN.
N = 64, S = 0.22 IN.
RANGE = 1-5/8 TO 2-5/8 IN.
AVERAGE ZINC COATING
THICKNESS = 5.1 MILS
N = 236, S = 1.43 MILS
RANGE = 2.0 TO 12.0 MILS

N = NUMBER OF READINGS TAKEN

S = STANDARD DEVIATION

Figure 6. S13 of 81103--Curtis Road over M-14 east of Ann Arbor.

Delamination detection was performed with the aid of a mechanical device developed by MDOT. This device uses a hammer and a frequency sensor to sound out hollow areas. Anytime this device shows an indication of a hollow area, it activates a paint spotter that marks the edges of the hollow area. As an added precaution, these areas were then checked by a technician using either a hammer or chain drag. The outline of the delaminated area was then marked with spray paint and recorded.

Six cores were removed from the Grand River structure in 1985, 40 cores were removed from the experimental structures in 1988, and 41 were removed from these structures again in 1991. Salt levels at the reinforcement level were determined for all cores and the condition of the reinforcement was examined and rated.

The 1988 cores were split into two groups. The first 20 cores were taken at random sites, one from each span of each structure. The other 20 cores were taken from areas that showed consistently high half-cell readings.

Generally, the 1991 cores were taken two per span. For all decks the cores were taken either from areas that had shown consistently high half-cell readings or over existing cracks.

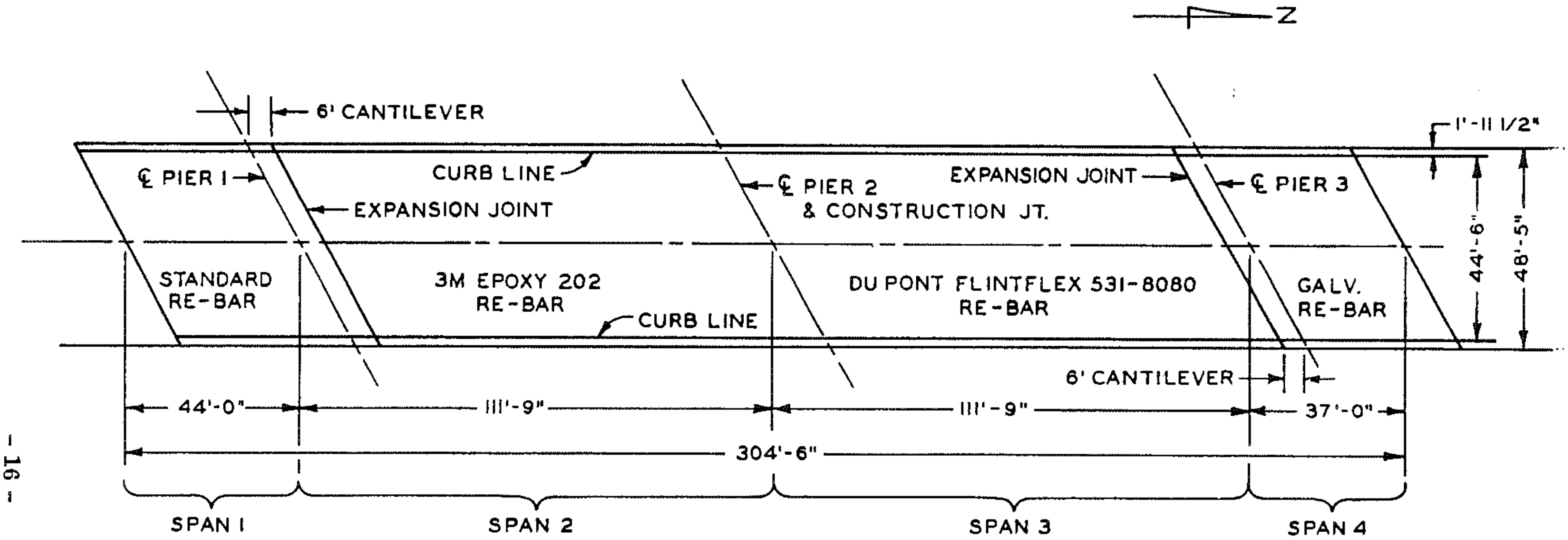
Epoxy Coated (73 F-131)

Three bridge decks were constructed with uncoated, galvanized, and epoxy coated reinforcement in adjacent spans (Figures 6-8). Galvanized reinforcement was used in both the top and bottom mats for the galvanizing test spans. For the epoxy test sections, coated reinforcement was used in both the top and bottom mats. All three structures have four spans: one used uncoated reinforcement, one used galvanized reinforcement, and the remaining two used a different epoxy-coated reinforcement in each span. All three structures were otherwise constructed according to the MDOT's Standard Specifications for Construction in effect at the time.

Periodic examination of these three structures followed essentially the same procedures used for 68 F-103 with only a few exceptions. Since epoxy coating acts as an electrical barrier, half-cell measurements could not be taken on the epoxy test spans.

Twelve cores were removed from these structures in 1988, and 19 cores were removed in 1991. Salt levels at the reinforcement level were determined for all cores and the condition of the reinforcement was examined and rated.

The 1988 cores were taken at random sites, one from each span of each structure.



AVERAGE COVER OVER
No. 6 BARS = 2-1/4 IN.
N = 81, S = 0.23 IN.
RANGE = 1-7/8 TO 3 IN.

AVERAGE COVER OVER
No. 6 BARS = 2-3/8 IN.
N = 180, S = 0.26 IN.
RANGE = 2 TO 3-1/8 IN.
AVERAGE EPOXY COATING
THICKNESS = 4.7 MILS
N = 190, S = 1.06 MILS
RANGE = 2.0 TO 7.5 MILS

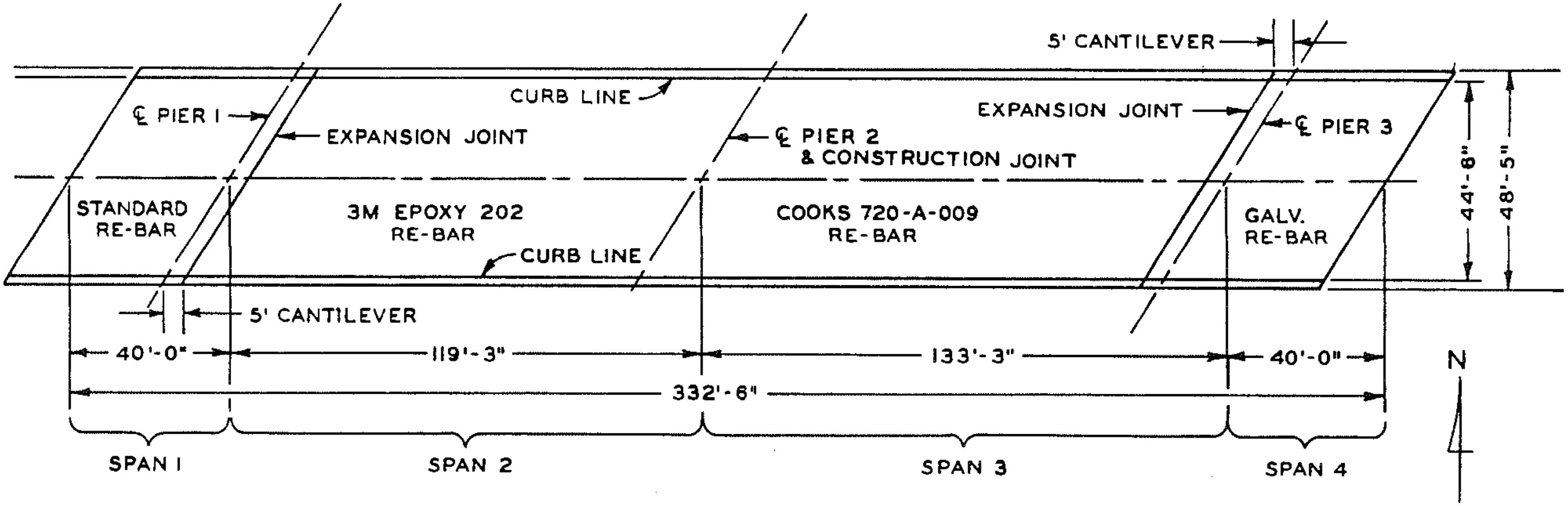
AVERAGE COVER OVER
No. 6 BARS = 2-3/8 IN.
N = 180, S = 0.24 IN.
RANGE = 1-3/4 TO 3 IN.
AVERAGE EPOXY COATING
THICKNESS = 6.7 MILS
N = 200, S = 2.9 MILS
RANGE = 1.5 TO 15.0 MILS

AVERAGE COVER OVER
No. 6 BARS = 2-7/16 IN.
N = 72, S = 0.19 IN.
RANGE = 2 TO 2-7/8 IN.
AVERAGE ZINC COATING
THICKNESS = 5.1 MILS
N = 100, S = 2.24 MILS
RANGE = 2.0 TO 12.0 MILS

N = NUMBER OF READINGS TAKEN

S = STANDARD DEVIATION

Figure 7. S02 of 82102--Napier Road over M-14 east of Ann Arbor.



AVERAGE COVER OVER
No. 6 BARS = 3-1/8 IN.
N = 80, S = 0.17 IN.
RANGE = 2-3/4 TO 3-1/2 IN.

AVERAGE COVER OVER
No. 6 BARS = 2-15/16 IN.
N = 110, S = 0.35 IN.
RANGE = 2-1/8 TO 3-3/4 IN.
AVERAGE EPOXY COATING
THICKNESS = 6.1 MILS
N = 200, S = 2.71 MILS
RANGE = 2.5 TO 14.5 MILS

AVERAGE COVER OVER
No. 6 BARS = 2-15/16 IN.
N = 120, S = 0.41 IN.
RANGE = 2 TO 3-3/4 IN.
AVERAGE EPOXY COATING
THICKNESS = 6.2 MILS
N = 193, S = 2.02 MILS
RANGE = 2.5 TO 13.0 MILS

AVERAGE COVER OVER
No. 6 BARS = 3-7/16 IN.
N = 80, S = 0.29 IN.
RANGE = 3 TO 4-1/4 IN.
AVERAGE ZINC COATING
THICKNESS = 5.6 MILS
N = 200, S = 1.43 MILS
RANGE = 2.5 TO 11.0 MILS

N = NUMBER OF READINGS TAKEN

S = STANDARD DEVIATION

Figure 8. S04 of 58151--Post Road over I-75 near Monroe.

Generally, the 1991 cores were taken two per span. For all decks the cores were taken either from areas that had shown consistently high half-cell readings or over existing cracks.

While these three structures are located over heavily traveled roadways, they carry low traffic volume rural roads. The low traffic volume allowed half cell measurements to be made on the full width of the structure. The low traffic volumes also introduce the potential for another problem--that roadway salt thrown up from below may allow salt penetration on the bottom portion of the deck to exceed that penetrating from above. If this occurred, the standard anode and cathode patterns of the bridge deck could be reversed making the bottom mat the most corrosive. With this possibility in mind, the underside of these decks was also examined visually for any evidence of cracking and spalling that might be indicative of corrosion of the bottom mats.

Project Extension

Nine additional structures, built between 1977 and 1982, were examined to help determine how our newer epoxy coatings were doing. Cores were taken on these structures to help evaluate the performance of the younger, production-run epoxy coatings used in these structures. Since Michigan's specifications changed in 1980, structures (other than experimental) built prior to this time have epoxy-coated reinforcement only in the top mat. Those structures built after 1980 have epoxy-coated reinforcement in both top and bottom mats.

RESULTS AND DISCUSSION

Some previous results have been reported (References 1, 2, 3, and 14) for both projects. These are summarized here, as necessary, to allow complete examination of the results without referring to a number of different reports.

Results have been measured in a number of ways, each of which has helped to determine the relative performance of the different test spans. Visual observations included noting and recording cracking, spalls, and obvious patches. Delamination detection helped determine additional damage before it became visually obvious. Half-cell measurements helped suggest areas where corrosion might be more active and just how extensive these areas might be. Cores allowed determination of chloride contents (i.e. total/acid soluble chlorides) at the reinforcement level as well as a first-hand look at how the different reinforcements were actually performing within the deck.

Half-cell potential values are used in the evaluation of these structures even though there are a number of limitations in their use. Half-cell potentials are, at best, only an instantaneous measure of corrosion activity. Therefore, they can, at most, give a very rough idea of the cumulative corrosion occurring since corrosion can shift with respect to both position and intensity with time. Typically, corrosion is most active at one location for one set of readings and most active at another location for the next set of readings. The relative shift of half-cell potential values and the probable underlying corrosion is illustrated in Appendix B where the half-cell potential maps and cumulative frequency distribution plots of several spans of one bridge deck are given for 13 sets of readings taken between 1972 and 1991. While it would be nice to be able to show all of the half-cell potential maps and cumulative frequency distribution plots, this is not feasible for the over 1,500 pages that this would represent for these two projects.

A computer program was written for helping to make equipotential plots and cumulative frequency distribution plots for the half-cell values (satisfies the information requirements of ASTM C 876; Half Cell Potentials of Uncoated Reinforcing Steel in Concrete). The program, as used in MS-DOS Fortran, has been listed in MDOT Research Report R-1320, Appendix A. Sample input and output cases are given in the text that follows (see Figures 15 and 16).

Half-cell potential values are compared for uncoated and galvanized reinforcement using the standard groupings of potential values listed in ASTM C 876 categorizing regions of 90 percent probability of no corrosion (>-.20 V), corrosion uncertain (<-.20 but >-.35 V), and 90 percent probability of corrosion (<-.35 V). This comparison would, in general, not be appropriate since pure zinc has a half cell potential roughly 500 mV more negative than steel for roughly equivalent circumstances. This great a difference, however, has not been seen for these two projects. Half-cell potentials for the two materials have been running fairly close in magnitude. There are several possible reasons for this, the most likely being that the galvanizing had a very slight or non-existent pure zinc layer, and the half-cell values for the galvanized reinforcement reflect the combined potentials of both iron and zinc in the alloy portions of the galvanizing.

The deck maps showing cracking, delamination, spalling, and patching history for the duration of these projects are presented in Appendix C. While these may provide more detail than the average reader would find interesting, they are a valuable reference source for those with sufficient curiosity.

Galvanized (68 F-103)

Initial Details

Coating thicknesses for the galvanized reinforcement were checked prior to construction of the experimental decks. The material specifications used on this project required galvanizing in accordance with ASTM A 123, with the exception that the weight of coating average no less than 1-1/2 oz/sq ft and with no individual measurement less than 1 oz/sq ft. Test results showed an average coating of 3 oz/sq ft, well above the 1-1/2 oz/sq ft specified minimum.

Figures 1-5 detail the configurations of the experimental bridge decks as well as the concrete cover depths over the experimental reinforcements.

Concrete mixes used on each of the decks are detailed in Table 1.

During construction of the Schaefer Road structure, an error in the plans was discovered that required the addition of reinforcing steel to the negative moment area of the deck. Since additional galvanized reinforcement was not readily available, uncoated reinforcement was substituted. Close attention was paid to this area during the condition surveys.

Individual Structure Assessment

Each structure is discussed individually since performance differences would be expected to be most readily detectible for a given structure. Differences between the environment of individual bridges will, in general, be greater than the differences between individual spans of the same structure. Spans 1 and 4 and Spans 2 and 3 on any given structure are most directly comparable, given the location of the cantilevered expansion joints and the fact that some of the concrete spalling relates to problems with these joints.

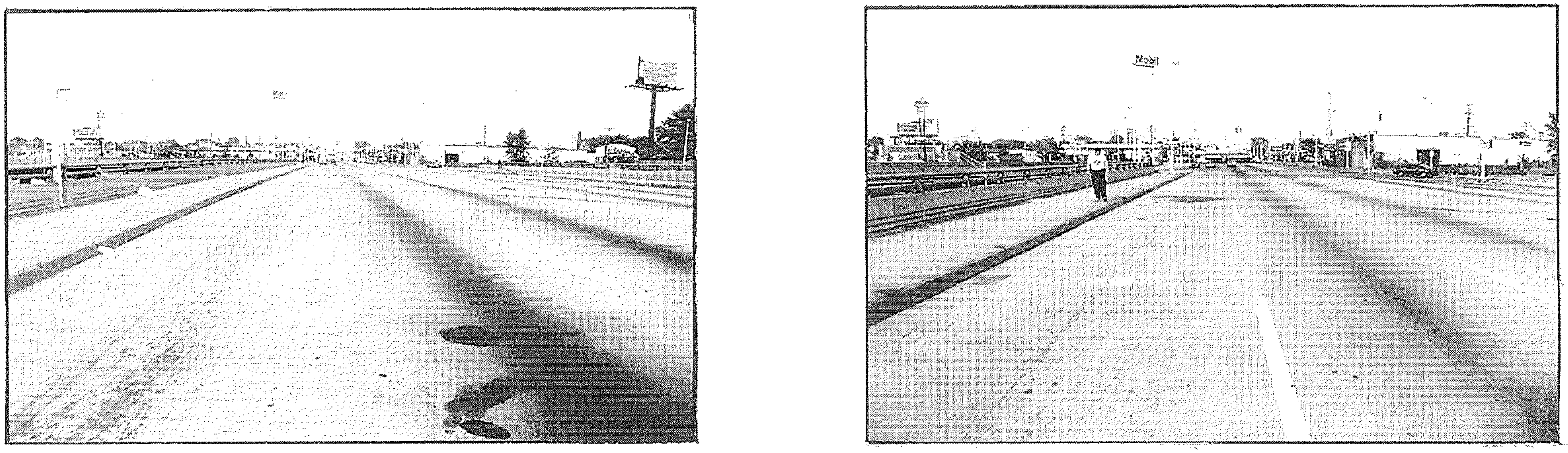
Grand River Avenue

This structure may be viewed in the pictures in Figure 9. Primary data for this structure are contained in Figure 1 and Tables 2 and 3.

The half-cell potential data suggest that both galvanized and uncoated reinforcement had higher corrosion activity the first year than occurred the next few years, and that the galvanized reinforcement may have been corroding more than the uncoated reinforcement the first year. After several years of exposure, the uncoated reinforcement has slightly more negative half-cell potentials than the galvanized reinforcement, however the differences are not very great. Corrosion activity appears to have increased gradually with time for both the galvanized and the uncoated reinforcement spans. From 1981 onward there does not appear to be any relevant portion of either the galvanized or uncoated reinforcement spans that would be regarded as being definitely free from corrosion.

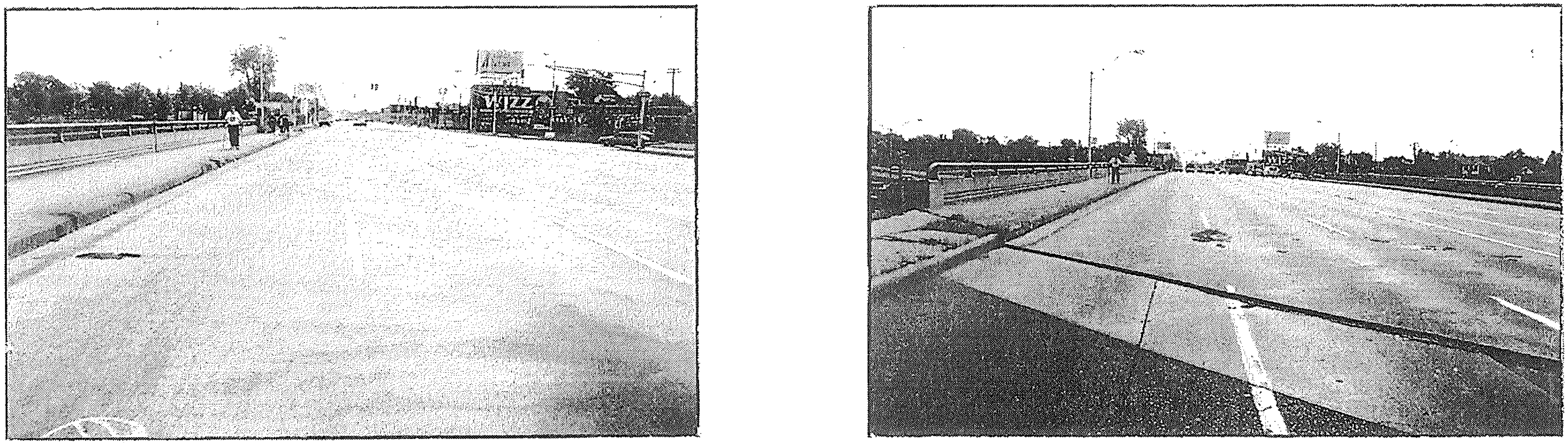
Data from the cores suggest that the galvanized reinforcement is holding up better at comparable salt concentrations when no cracking is present, but can corrode significantly when deck cracks (and salt) are present.

This structure has the highest traffic volumes of all of the structures comparing uncoated and galvanized reinforcement and has roughly the worst ratings for spalls and delaminations. The galvanized and uncoated reinforcement spans have roughly comparable ratings for spalls and delaminations, however.



A. Looking North--Spans 1 and 2 (Galvanized Reinforcement--Top Mat Only) in Foreground.

B. Looking North--Spans 3 and 4 (Uncoated Reinforcement) in Foreground.



C. Looking South--Spans 2 and 1 (Galvanized Reinforcement--Top Mat Only) in Foreground.

D. Looking South--Spans 4 and 3 (Uncoated Reinforcement) in Foreground.

Figure 9 S16 of 82123--Grand River Avenue over I-96 (Jeffries Freeway). Pictures Taken in 1991.

TABLE 1 - CONCRETE MIX DESIGN FOR EXPERIMENTAL BRIDGE DECKS

Structure	Quantity of Course Aggregate per Sack[1] of Cement (lb)	Quantity of Fine Aggregate per Sack[1] of Cement (lb)	Moisture Content of Aggregate (%) Course/ (%) Fine	Water/Cement Ratio Using Net Water	Slump (in.)	Air Entrainment (%)	Cement Content (Sacks[1]/ cu yd)
Grand River Avenue[3]	238.0	226.5	5.1/5.2	.45	4.75	6.5	6
Hubbell Avenue[4]	197.0	321.5	5.2/1.2	.42	4.50	7.0	6
Schaefer Road[3]	235.5	226.5	5.4/2.7	.44	4.00	7.4	6
Meyers Road[2]	234.0	226.5	5.1/5.2	.45	4.50	5.6	6
Wyoming Avenue[2]	195.0	321.5	5.1/1.2	.42	4.50	5.6	6
Curtis Road	199.8	177.8	5.7/4.3	NA	3.25	NA	NA
Napier Road	184.8	210.0	NA	NA	3.50	NA	NA
Post Road	192.0	197.3	NA	NA	2.75	NA	NA

[1] 94 Pound Sack

[2] 4 oz Possolith R (i.e. a water reducer) added per sack of cement.

[3] 3 oz Possolith R (i.e. a water reducer) added per sack of cement.

[4] 2 oz Possolith R (i.e. a water reducer) added per sack of cement.

TABLE 2 - SUMMARY OF HALF-CELL READINGS FOR GRAND RIVER AVENUE

Grand River Avenue Constructed in 1972 Slag Aggregate	Readings Taken (Month/ Year)	Span 1 Galvanized Reinforcement (Top Mat Only)			Span 2 Galvanized Reinforcement (Top Mat Only)			Span 3 Uncoated Reinforcement			Span 4 Uncoated Reinforcement		
		>-.20	<-.20 but >-.35	<-.35	>-.20	<-.20 but >-.35	<-.35	>-.20	<-.20 but >-.35	<-.35	>-.20	<-.20 but >-.35	<-.35
Half-cell data are expressed as the percent of the total span data that falls within the indicated range of values. These ranges, from ASTM C876, are regarded as indicating: >-.20 - 90 percent chance of no corrosion <-.20 but >-.35 - corrosion uncertain <-.35 - 90 percent chance of corrosion	09/72	0.9	38.2	60.9	0.9	11.3	87.8	0.0	49.0	51.0	0.0	100.0	0.0
	09/73	7.7	87.3	2.5	3.5	96.5	0.0	0.0	93.0	7.0	0.0	95.0	5.0
	06/74	7.5	85.8	6.7	2.6	93.0	4.4	0.0	45.6	54.4	0.0	70.0	30.0
	06/75	17.5	74.2	8.3	10.6	69.2	20.2	15.8	70.2	14.0	5.8	44.2	50.0
	09/76	0.8	70.4	28.3	0.0	94.7	5.3	0.9	86.9	12.3	8.3	73.4	18.3
	08/78	20.8	55.8	23.4	1.8	56.1	42.1	0.0	29.0	71.0	4.2	56.6	39.2
	10/79	11.7	50.8	37.5	6.2	22.4	61.4	0.9	43.8	55.3	5.8	39.2	55.0
	08/80	3.4	63.9	32.7	6.4	61.1	32.5	4.4	58.8	38.6	12.5	38.3	49.2
	09/81	0.0	17.3	72.7	0.0	41.2	58.8	0.0	0.9	99.1	1.6	58.5	39.9
	10/82	0.8	57.5	41.7	1.7	39.0	69.3	0.0	56.1	43.9	2.5	51.7	45.8
	10/84	0.0	37.5	62.5	1.8	14.0	84.2	0.0	0.0	100.0	0.0	39.2	60.8
	09/86	3.3	24.2	67.5	0.0	3.5	96.5	0.0	22.8	77.2	0.8	31.7	67.5
	07/91	0.0	47.5	52.5	0.9	43.7	55.4	1.8	39.9	58.3	0.8	41.7	57.8

TABLE 3 - DECK AND REINFORCEMENT CONDITION - GRAND RIVER AVENUE

Grand River Avenue Constructed in 1972 29,900 ADT[1]; 800 ADTT[2] Slag Aggregate	Spalls and Delaminations (Percent)	Core Information					
		Clear Cover, in.	Core Taken (Year)	Half Cell Readings (Negative Volts)	Chloride Level (Acid Soluble) at Reinforcement (lbs/cu yd)	Reinforcement Condition[3] (Ranking)	Concrete Cracking[4] (Vertical/ Horizontal
Span 1 - Galvanized Reinforcement (Top Mat Only)	<2	4.00[5]	1988		0.6		
		2.65	1988		8.0		
		3.40	1991	.52	5.2	1	No/No
		2.40	1991	.62	22.8	4	No/Yes[6]
Span 2 - Galvanized Reinforcement (Top Mat Only)	5 - 7		1985		10.4		
		3.15	1988		1.6		
		2.65	1988		6.4		
		2.65	1991	.56	7.3	1	No/No
Span 3 - Uncoated Reinforcement	>5	3.75[5]	1988		0.5		
		2.50[5]	1988		8.2		
		2.50	1991	.65	2.4	2	No/No
		2.75	1991	.53	3.8	3	No/No
Span 4 - Uncoated Reinforcement	2 -3		1985		0.7		
			1985		0.4		
			1985		0.8		
			1985		0.4		
			1985		3.9		
		3.25[5]	1988		0.3		
		3.25	1988		3.0		
		3.50	1991	.60	3.0	2	No/No
		3.00	1991	.45	8.4	2	No/No
		2.65	1991	.78	13.3	3	No/No

[1] ADT - Average Daily Traffic. Data from MDOT Planning, 1991.

[2] ADTT - Average Daily Truck Traffic. Data from MDOT Planning, 1991.

[3] Condition is ranked on a scale from 1 to 6 with 1 being the best (i.e. no visible corrosion) and 6 being the worst (i.e. major corrosion). This rating system is discussed in more detail in Figure 10.

[4] M, when used, denotes multiple cracking. P, when used, indicates cracking perpendicular (i.e. transverse) to the top mat reinforcement.

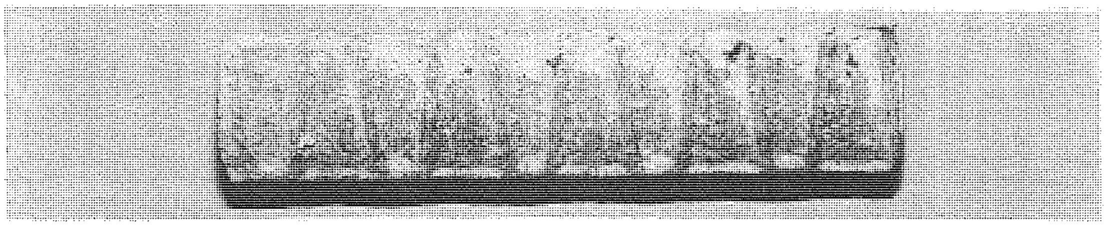
[5] Clear cover distance was not available for these cores. This is, instead, the depth at which chloride levels were tested.

[6] Galvanizing no longer visible - some deformations lost.

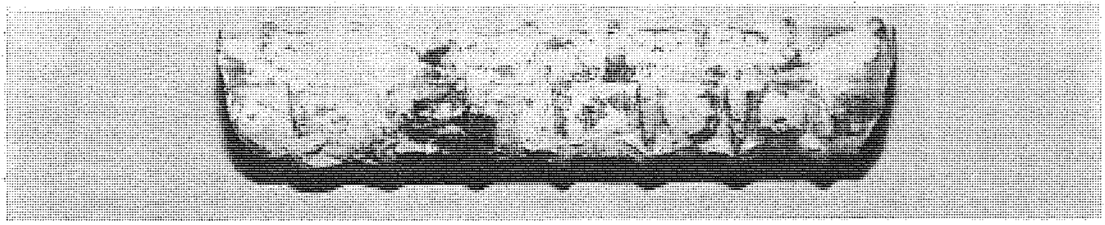
Figure 10 Rating of Reinforcement Removed from Experimental Deck Cores.

Reinforcement specimens were ranked on a scale from 1 to 6 according to how extensively they were corroded. A rating of 1 indicates no visible corrosion. A rating of 2 indicates very minor corrosion on the deformations. A rating of 3 indicates that some of the corrosion is also on the flat surfaces of the reinforcement. A rating of 4 indicates more extensive corrosion but with a significant portion of the reinforcement still left uncorroded. A rating of 5 indicates extensive corrosion of almost all of the reinforcement surface but with no major loss of cross section. A rating of 6 indicates extensive corrosion with losses of cross section.

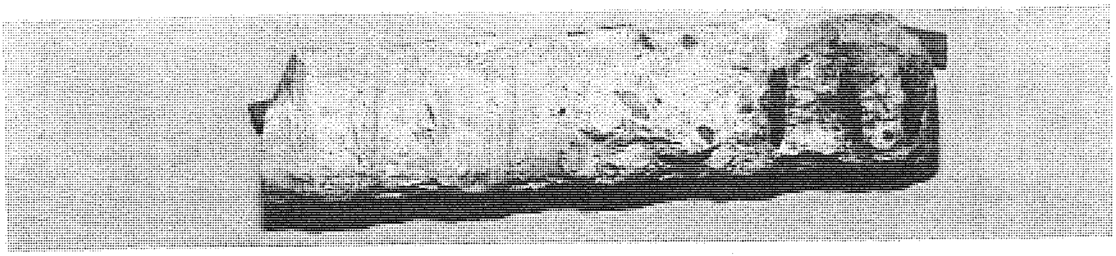
Photographic examples for all the reinforcements follow with their appropriate rating. For some materials not all ratings will be represented since not all ratings were present in the core specimens.



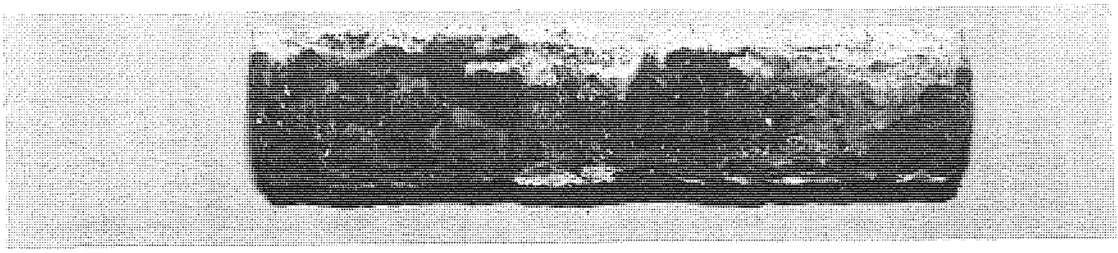
Galvanized Reinforcement--Rating 1



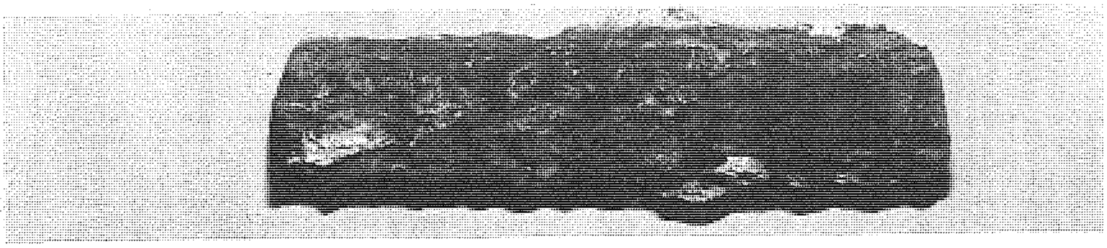
Galvanized Reinforcement--Rating 2



Galvanized Reinforcement--Rating 3

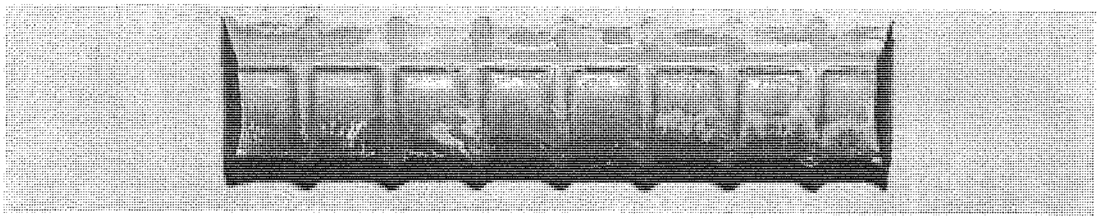


Galvanized Reinforcement--Rating 4

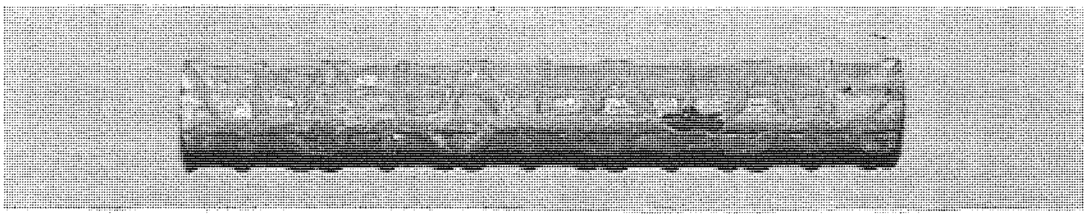


Galvanized Reinforcement--Rating 5

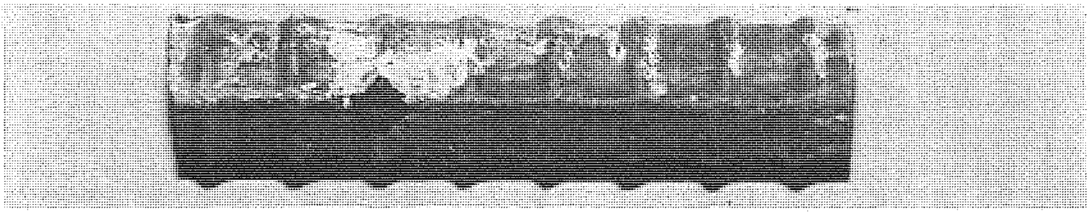
Figure 10 Continued--Galvanized Reinforcement with Ratings of 3, 4, and 5.



Epoxy Coated Reinforcement--Rating 1

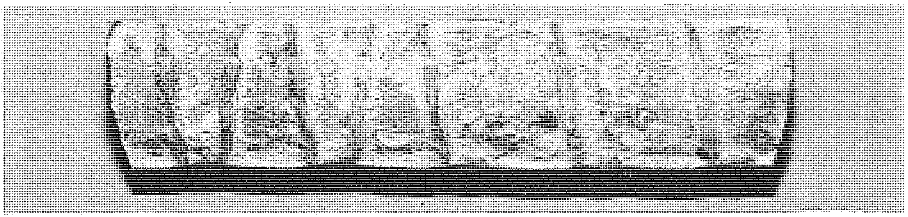


Epoxy Coated Reinforcement--Rating 2

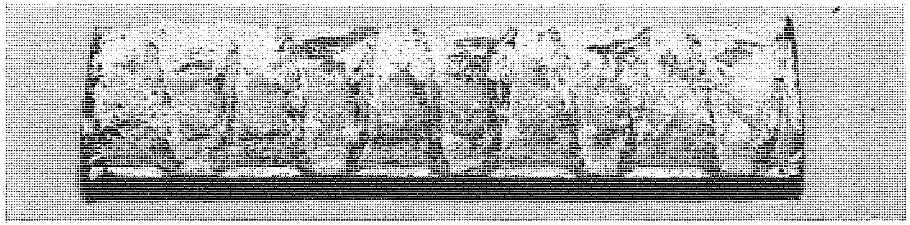


Epoxy Coated Reinforcement--Rating 3

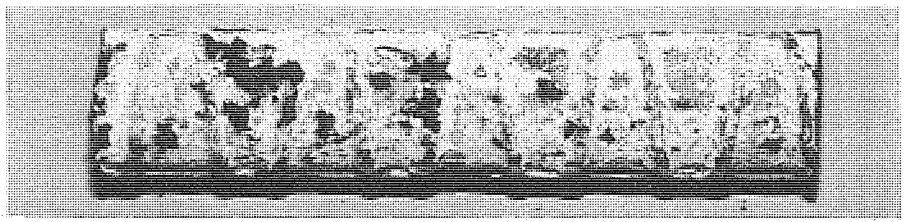
Figure 10 Continued--Epoxy Reinforcement with Ratings of 1, 2, and 3.



Uncoated Reinforcement--Rating 1

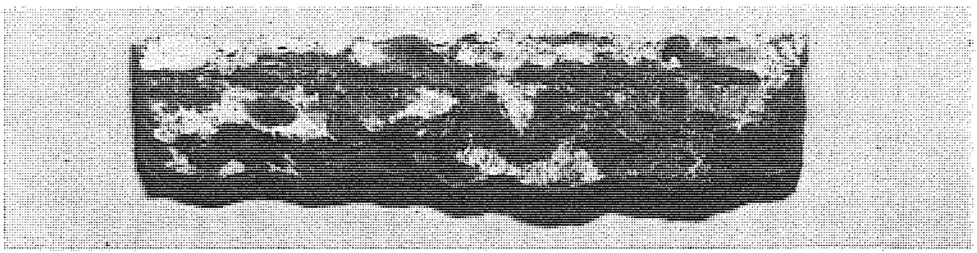


Uncoated Reforcement--Rating 2

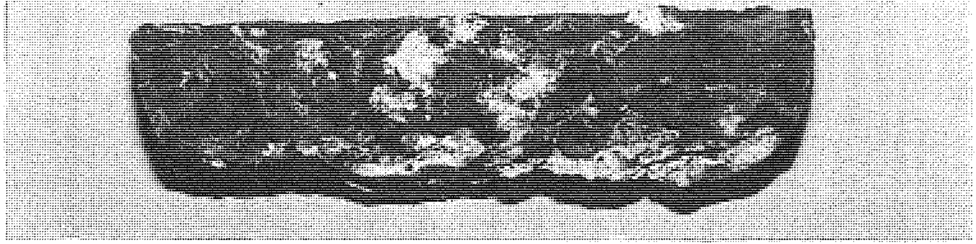


Uncoated Reinforcement--Rating 3

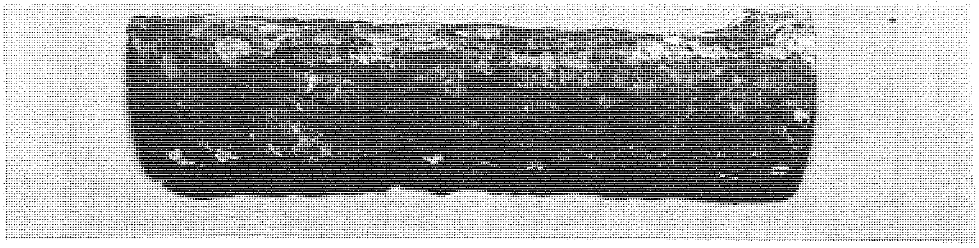
Figure 10 Continued--Uncoated Reinforcement with Ratings of 1, 2, and 3.



Uncoated Reinforcement--Rating 4



Uncoated Reinforcement--Rating 5



Uncoated Reinforcement--Rating 6

Figure 10 Continued--Uncoated Reinforcement with Ratings of 4, 5, and 6.

Hubbell Avenue

This structure may be viewed in the pictures in Figure 11. Primary data for this structure are contained in Figure 2 and Tables 4 and 5.

Half-cell potentials for this structure suggest virtually no corrosion for either the galvanized or uncoated reinforcement spans at the time of the first set of readings (January 1973) and for several years thereafter. (The cold temperatures probably present at the time of the first set of readings were most likely responsible for the lack of any relative magnitude of potential values.) Half-cell values suggest that corrosion starts and progresses gradually for all spans. The uncoated reinforcement, with the exception of several years, shows a slightly greater average decrease in half-cell potential values over time.

The core data suggest that both the galvanized and uncoated reinforcement can corrode relatively badly when cracks are present. The uncoated reinforcement, however, corrodes to a greater extent when other variables (i.e. salt concentration, depth of cover, etc) are equalized.

This structure has only a small traffic volume compared to the other structures in the study. Spalls and delaminations are essentially equal for spans 2 and 3 (galvanized and uncoated reinforcement respectively) where clear cover distances are roughly the same for both spans. Spalls and delaminations cover almost three times as much area on span 4 (uncoated reinforcement) as on span 1 (galvanized reinforcement) but the clear cover depth is greater on span 1 by roughly 3/8" on average and 1/2 to 1" on individual cores taken at crack locations.

Schaefer Road

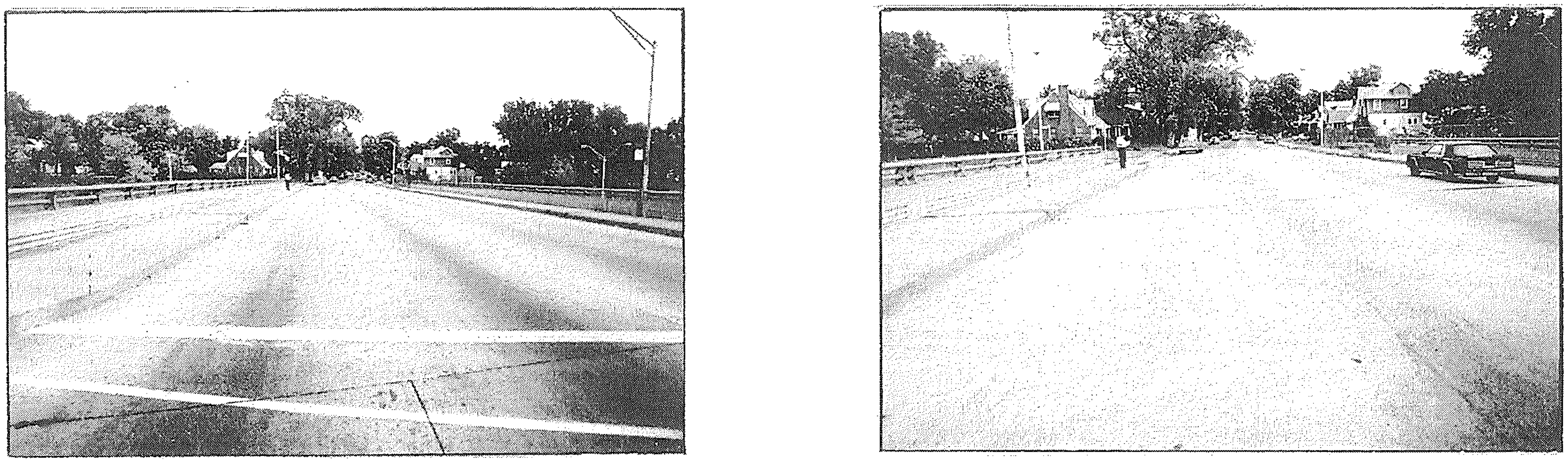
This structure may be viewed in the pictures in Figure 12. Primary data for this structure are contained in Figure 3 and Tables 6 and 7.

The half-cell potential data for this structure suggest that initial corrosion activity is relatively low and gradually builds up over time for both the galvanized and uncoated reinforcement spans. Corrosion activity for both the galvanized and uncoated reinforcement spans appear to reach a peak between 1979 and 1981, then subside and start building up again. At the final reading in 1991, corrosion activity appears to be of only moderate intensity. Half-cell potential values are, in general, slightly more negative for the uncoated reinforcement spans.

The core data indicate that the galvanized reinforcement is holding up better than the uncoated reinforcement for roughly comparable environments.

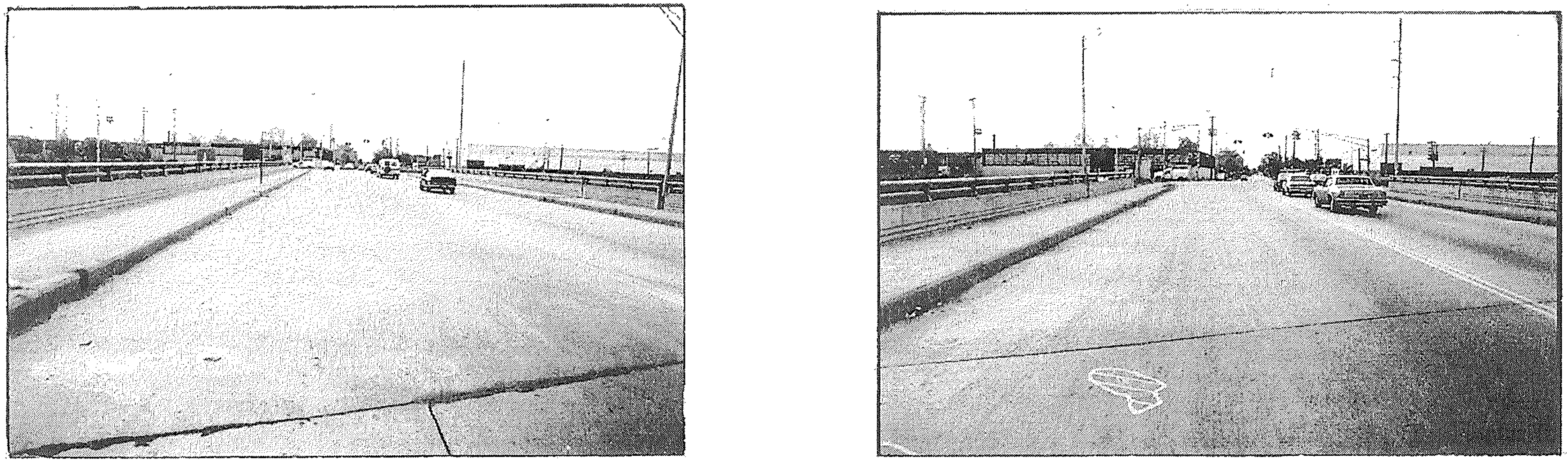
TABLE 4 - SUMMARY OF HALF-CELL READINGS FOR HUBBELL AVENUE

Hubbell Avenue Constructed in 1972 Limestone Aggregate	Readings Taken (Month/Year)	Span 1 Galvanized Reinforcement (Top Mat Only)			Span 2 Galvanized Reinforcement (Top Mat Only)			Span 3 Uncoated Reinforcement			Span 4 Uncoated Reinforcement		
		>-.20	<-.20 but >-.35	<-.35	>-.20	<-.20 but >-.35	<-.35	>-.20	<-.20 but >-.35	<-.35	>-.20	<-.20 but >-.35	<-.35
Half-cell data are expressed as the percent of the total span data that falls within the indicated range of values. These ranges, from ASTM C876, are regarded as indicating: >-.20 - 90 percent chance of no corrosion <-.20 but >-.35 - corrosion uncertain <-.35 - 90 percent chance of corrosion	01/73	100.0	0.0	0.0	100.0	0.0	0.0	100.0	0.0	0.0	100.0	0.0	0.0
	06/74	98.7	1.3	0.0	94.0	4.8	1.2	96.4	3.6	0.0	95.3	4.7	0.0
	05/75	28.5	67.7	3.8	92.6	7.4	0.0	94.0	6.0	0.0	78.1	20.9	1.0
	09/76	62.8	37.2	0.0	94.0	6.0	0.0	94.0	6.0	0.0	78.1	20.9	1.0
	09/76	62.8	37.2	0.0	94.0	6.0	0.0	96.4	3.6	0.0	70.0	28.9	1.1
	08/78	23.0	61.6	15.4	14.3	76.2	9.5	46.2	6.2	47.6	25.0	50.0	25.0
	09/79	46.2	42.2	11.6	42.6	49.1	8.3	15.5	76.1	8.4	41.5	44.7	13.8
	09/80	42.3	43.6	14.1	21.4	60.8	17.8	0.0	88.1	11.9	3.2	78.3	18.5
	09/81	55.1	44.9	0.0	19.1	70.2	10.7	33.3	29.8	36.9	32.3	39.6	28.1
	11/82	66.7	33.3	0.0	23.8	68.1	8.1	33.3	60.8	5.9	41.3	39.6	19.1
	10/84	10.2	37.2	52.6	17.8	66.0	26.2	48.8	42.9	8.3	0.0	73.1	26.9
	09/86	---	---	---	---	---	---	---	---	---	---	---	---
	07/91	35.9	61.1	2.6	28.9	54.5	16.6	22.2	63.7	14.1	37.5	39.6	22.9



A. Looking North--Spans 1 and 2 (Galvanized Reinforcement--Top Mat Only) in Foreground.

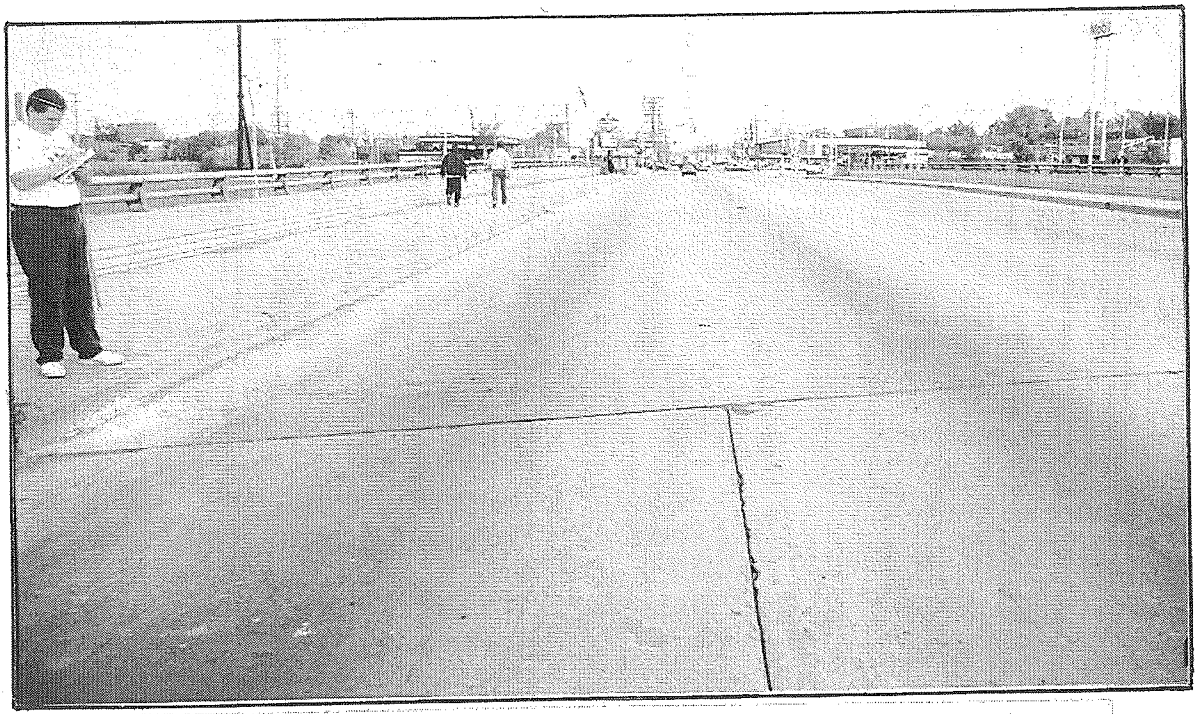
B. Looking North--Spans 3 and 4 (Uncoated Reinforcement) in Foreground.



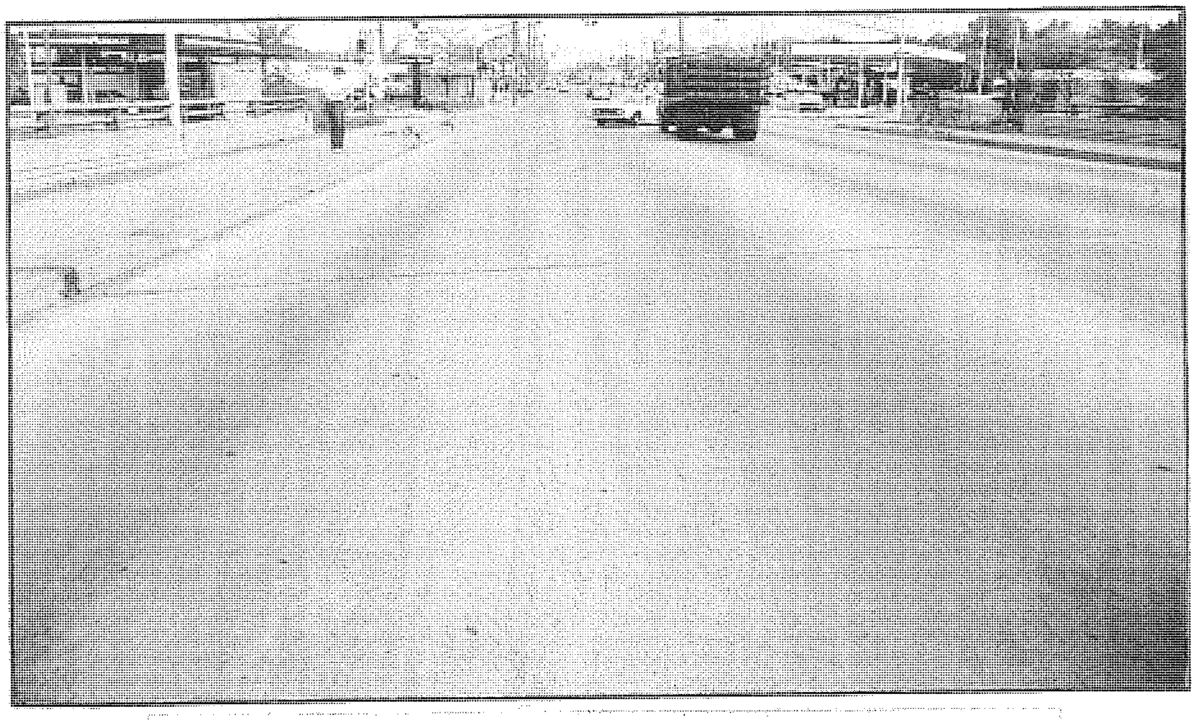
C. Looking South--Spans 2 and 1 (Galvanized Reinforcement--Top Mat Only) in Foreground.

D. Looking South--Spans 4 and 3 (Uncoated Reinforcement) in Foreground.

Figure 11 S12 of 82123--Hubbell Avenue over I-96 (Jeffries Freeway). Pictures Taken in 1991.



A. Looking North--Spans 1 and 2 (Galvanized Reinforcement--Top Mat Only) in Foreground.



B. Looking North--Part of Span 3 and Span 4 (Uncoated Reinforcement) in Foreground.

Figure 12 S14 of 82123--Schaefer Road over I-96 (Jeffries Freeway). Pictures Taken in 1991.

TABLE 5 - DECK AND REINFORCEMENT CONDITION - HUBBELL AVENUE

Hubbell Avenue Constructed in 1972 4,565 ADT[1]; ADTT[2] N/A Limestone Aggregate	Spalls and Delaminations (Percent)	Core Information					
		Clear Cover, in.	Core Taken (Year)	Half Cell Readings (Negative Volts)	Chloride Level (Acid Soluble) at Reinforcement (lbs/cu yd)	Reinforcement Condition[3] (Ranking)	Concrete Cracking[4] (Vertical/ Horizontal
Span 1 - Galvanized Reinforcement (Top Mat Only)	<2 (1991)	4.15	1988		0.7		
Span 2 - Galvanized Reinforcement (Top Mat Only)	3 - 4	3.75	1988		1.6		
		4.15	1988		0.9		
		4.25	1991	.30	13.3	5	Yes/Yes[6]
		3.80	1991	.52	14.6	1	No/No
Span 3 - Uncoated Reinforcement	3 - 4	3.90[5]	1988		1.2		
		3.75	1988		1.6		
		4.10	1991	.20	11.4	6	Yes/Yes[7]
		4.00	1991	.42	16.2	6	Yes/Yes[7] (M)
Span 4 - Uncoated Reinforcement	5 - 7	4.00[5]	1988		0.9		
		3.15	1988		2.9		
		3.60	1991	.20	8.4	4	Yes/Yes
		3.00	1991	.40	15.5	2	Yes/Yes (M)

[1] ADT - Average Daily Traffic. Data from SEMCOG, 1986.

[2] ADTT - Average Daily Truck Traffic.

[3] Condition is ranked on a scale from 1 to 6 with 1 being the best (i.e. no visible corrosion) and 6 being the worst (i.e. major corrosion). This rating system is discussed in more detail in Figure 10.

[4] M, when used, denotes multiple cracking. P, when used, indicates cracking perpendicular (i.e. transverse) to the top mat reinforcement.

[5] Clear cover distance was not available for these cores. This is, instead, the depth at which chloride levels were tested.

[6] The vertical crack extends to the top mat reinforcement.

[7] The vertical crack extends below the top mat reinforcement.

TABLE 6 - SUMMARY OF HALF-CELL READINGS FOR SCHAEFER ROAD													
Schaefer Road Constructed in 1972 Slag Aggregate	Readings Taken (Month/Year)	Span 1 Galvanized Reinforcement (Top Mat Only)			Span 2 Galvanized Reinforcement (Top Mat Only)			Span 3 Uncoated Reinforcement			Span 4 Uncoated Reinforcement		
		>-.20	<-.20 but >-.35	<-.35	>-.20	<-.20 but >-.35	<-.35	>-.20	<-.20 but >-.35	<-.35	>-.20	<-.20 but >-.35	<-.35
Half-cell data are expressed as the percent of the total span data that falls within the indicated range of values. These ranges, from ASTM C876, are regarded as indicating: >-.20 - 90 percent chance of no corrosion <-.20 but >-.35 - corrosion uncertain <-.35 - 90 percent chance of corrosion	07/72	72.2	27.8	0.0	77.8	22.2	0.0	29.8	70.2	0.0	12.2	86.7	1.1
	09/73	28.0	71.0	1.0	23.8	73.8	2.4	1.2	97.6	1.2	2.2	95.6	2.2
	06/74	14.4	84.5	1.1	10.7	81.0	8.3	1.2	91.7	7.1	11.1	85.6	3.3
	06/75	45.6	4.4	50.0	50.0	45.2	4.8	35.7	58.4	5.9	64.4	35.6	0.0
	09/76	30.5	68.5	1.0	17.8	76.3	5.9	---	---	---	43.1	55.8	1.1
	08/78	20.0	77.6	2.4	23.8	71.4	4.8	3.6	84.5	11.9	15.6	76.6	7.8
	11/79	17.8	32.3	50.0	1.2	28.6	70.2	0.0	2.4	97.6	1.1	85.6	13.3
	09/80	2.2	75.6	22.2	13.1	72.6	14.3	1.2	83.8	25.0	0.0	61.1	38.9
	10/81	8.9	84.5	6.6	14.3	77.4	8.3	0.0	3.6	96.4	2.2	82.3	14.5
	11/82	37.8	56.6	5.6	9.5	79.8	10.7	0.0	84.6	15.4	0.0	92.2	7.8
	10/84	30.0	47.8	22.2	10.7	59.5	29.8	0.0	71.4	28.6	0.0	18.9	81.1
	09/86	---	---	---	---	---	---	---	---	---	---	---	---
	07/91	9.4	69.8	20.8	1.2	45.9	42.9	11.9	48.8	39.3	0.0	37.0	63.0

TABLE 7 - DECK AND REINFORCEMENT CONDITION - SCHAEFER ROAD

Schaefer Road Constructed in 1972 16,596 ADT[1]; ADTT[2] N/A Slag Aggregate	Spalls and Delaminations (Percent)	Core Information					
		Clear Cover, in.	Core Taken (Year)	Half Cell Readings (Negative Volts)	Chloride Level (Acid Soluble) at Reinforcement (lbs/cu yd)	Reinforcement Condition[3] (Ranking)	Concrete Cracking[4] (Vertical/ Horizontal
Span 1 - Galvanized Reinforcement (Top Mat Only)	<1	4.40 1.75[5] 3.90	1988 1988 1991	.41	0.2 11.1 0.5	1	No/No
Span 2 - Galvanized Reinforcement (Top Mat Only)	<1	5.10 3.75 5.00 3.30	1988 1988 1991 1991	.36	1.0 1.3 4.0 4.7	1 1	Yes/No[6] No/No
Span 3 - Uncoated Reinforcement	2	4.25[5] 4.50 4.60	1988 1988 1991	.60	0.6 4.3 5.9	2	No/No
Span 4 - Uncoated Reinforcement	1 - 2	4.00[5] 3.75 3.13 3.50 3.50	1988 1988 1991 1991 1991	.40 .31 .64	0.2 1.4 4.8 7.9 16.2	2 4 4	No/No No/Yes[7] Yes/Yes (M)

[1] ADT - Average Daily Traffic. Data from SEMCOG, 1990.

[2] ADTT - Average Daily Truck Traffic.

[3] Condition is ranked on a scale from 1 to 6 with 1 being the best (i.e. no visible corrosion) and 6 being the worst (i.e. major corrosion). This rating system is discussed in more detail in Figure 10.

[4] M, when used, denotes multiple cracking. P, when used, indicates cracking perpendicular (i.e. transverse) to the top mat reinforcement.

[5] Clear cover distance was not available for these cores. This is, instead, the depth at which chloride levels were tested.

[6] The vertical crack extends to the top mat reinforcement.

[7] A horizontal crack is just starting at the top mat reinforcement.

This structure has a relatively high traffic volume compared to the other structures in this project. Spalls and delaminations cover slightly more area on the uncoated reinforcement spans, although the differences are not great (roughly one percent). These differences may be, at least, partly due to the slightly greater depth of clear cover, on average, over the galvanized spans.

The area of the span with galvanized reinforcement that had some uncoated reinforcement added to the top mat during construction did not show any worse performance than the remainder of the span.

Meyers Road

This structure may be viewed in the pictures in Figure 13. Primary data for this structure are contained in Figure 4 and Tables 8 and 9.

Half-cell potential data suggest corrosion activity was high for both the galvanized and uncoated reinforcement spans initially. This activity appears to have subsided for the next several years, gradually built up intensity, then subsided once more, and built up intensity again for the final set of readings. Half cell potentials are, on average, slightly more negative for the uncoated reinforcement spans.

The core data indicate that for roughly comparable conditions, the galvanized reinforcement is performing better than the uncoated reinforcement for both cracked and uncracked concrete.

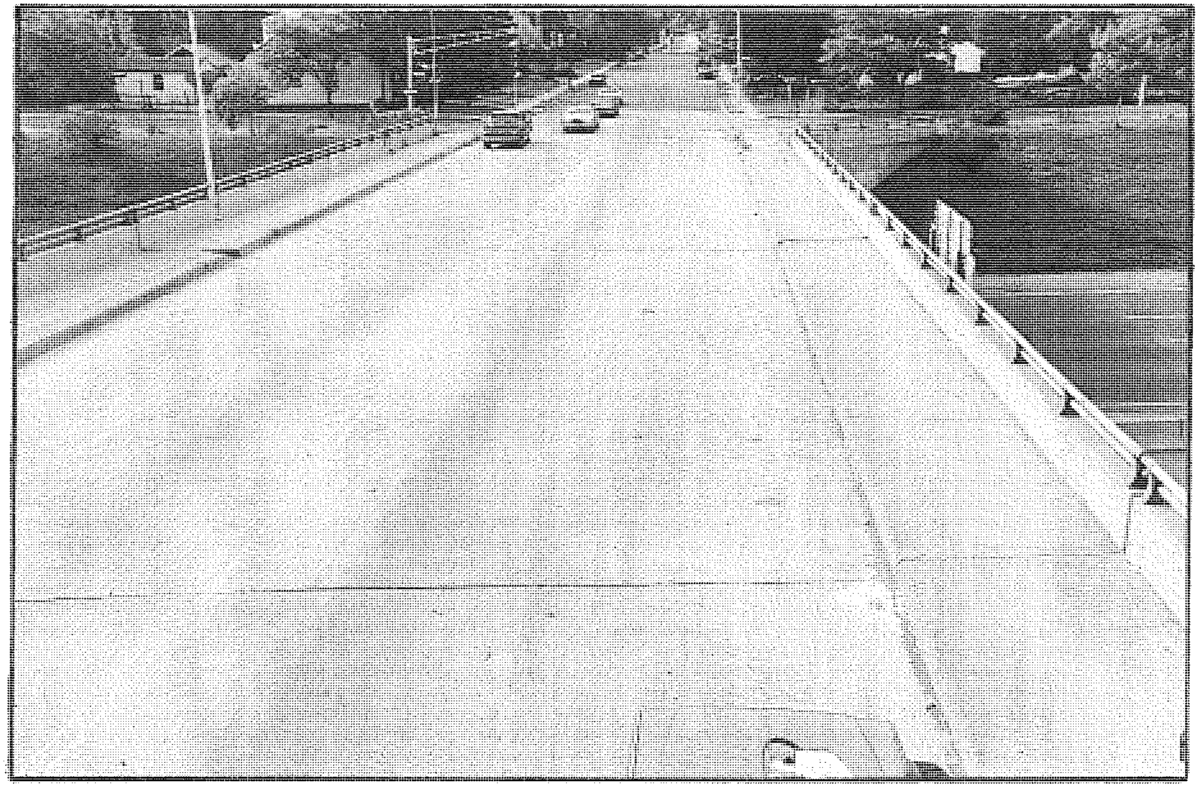
This structure has the smallest amount of traffic compared to the other structures in this project. Spalls and delaminations cover essentially equal areas for both the galvanized and the uncoated reinforcement spans.

Wyoming Avenue

This structure may be viewed in the pictures in Figure 14. Primary data for this structure are contained in Figure 5 and Tables 10 and 11.

The half cell potential data suggest that the galvanized reinforcement spans had more initial corrosion activity than the uncoated reinforcement spans. The activity subsided for a year or two for both types of reinforcement and then started increasing again. Half-cell potentials see-saw in value several times for both the galvanized and the uncoated reinforcement spans. For this structure the half-cell potentials are, in general, more negative for the galvanized spans.

The core data indicate that the galvanized reinforcement is, in general, holding up better than the uncoated reinforcement.



A. Looking South--Part of Span 4 and Span 3 (Uncoated Reinforcement) in Foreground and Spans 2 and 1 (Galvanized Reinforcement--Top Mat Only) in Background.

Figure 13 S17 of 82123--Meyers Avenue over I-96 (Jeffries Freeway). Pictures Taken in 1991.

TABLE 8 - SUMMARY OF HALF-CELL READINGS FOR MEYERS ROAD

Meyers Road Constructed in 1972 Slag Aggregate	Readings Taken (Month/Year)	Span 1 Galvanized Reinforcement (Top Mat Only)			Span 2 Galvanized Reinforcement (Top Mat Only)			Span 3 Uncoated Reinforcement			Span 4 Uncoated Reinforcement		
		>-.20	<-.20 but >-.35	<-.35	>-.20	<-.20 but >-.35	<-.35	>-.20	<-.20 but >-.35	<-.35	>-.20	<-.20 but >-.35	<-.35
Half-cell data are expressed as the percent of the total span data that falls within the indicated range of values. These ranges, from ASTM C876, are regarded as indicating: >-.20 - 90 percent chance of no corrosion <-.20 but >-.35 - corrosion uncertain <-.35 - 90 percent chance of corrosion	09/72	0.0	6.8	93.2	0.0	0.0	100.0	0.0	26.2	73.8	12.5	68.9	28.6
	09/73	10.3	86.9	2.8	8.4	91.6	0.0	0.0	86.9	13.1	0.0	92.0	8.0
	06/74	20.9	75.3	3.8	19.0	79.8	1.2	0.0	73.8	26.2	0.0	56.9	43.1
	06/75	91.5	7.6	0.9	41.6	53.8	4.6	38.1	61.9	0.0	26.4	72.6	1.0
	09/76	17.9	77.3	4.8	39.3	50.2	10.5	0.0	92.9	7.1	2.0	44.1	53.9
	08/78	43.6	17.2	39.2	0.0	44.1	55.9	0.0	7.2	92.8	5.9	46.1	48.0
	10/79	8.4	49.0	42.6	45.2	29.8	25.0	4.8	36.9	58.3	34.3	43.2	22.5
	09/80	0.0	19.5	80.5	0.0	39.3	60.7	1.2	26.2	72.6	0.0	6.4	93.6
	09/81	0.0	62.8	41.3	0.0	3.5	96.5	0.0	29.6	70.3	1.0	31.4	67.6
	11/82	0.0	62.8	37.2	0.0	83.9	16.1	0.0	68.4	31.6	0.0	40.2	59.8
	10/84	12.9	75.4	11.7	7.2	45.2	47.6	0.0	32.2	67.8	16.6	64.1	19.3
	09/86	30.6	46.8	22.6	3.6	73.8	22.6	40.5	35.7	23.8	41.2	35.3	23.5
	07/91	0.0	58.5	41.5	0.0	41.7	58.3	0.0	50.0	50.0	0.0	39.5	60.5

TABLE 9 - DECK AND REINFORCEMENT CONDITION - MEYERS ROAD

Meyers Road Constructed in 1972 3,479 ADT[1]; ADTT[2] N/A Slag Aggregate	Spalls and Delaminations (Percent)	Core Information					
		Clear Cover, in.	Core Taken (Year)	Half Cell Readings (Negative Volts)	Chloride Level (Acid Soluble) at Reinforcement (lbs/cu yd)	Reinforcement Condition[3] (Ranking)	Concrete Cracking[4] (Vertical/ Horizontal
Span 1 - Galvanized Reinforcement (Top Mat Only)	<2	3.25	1988		1.3		
		2.50	1988		5.4		
		3.75[5]	1988		0.3		
		3.50	1991	.44	10.4	5	Yes/?
		3.25	1991	.55	13.8	4	Yes/Yes[6] (M)
Span 2 - Galvanized Reinforcement (Top Mat Only)	2 -3	4.00[5]	1988		0.3		
		2.45	1991	.50	10.1	1	No/No
Span 3 - Uncoated Reinforcement	<2	3.25	1988		3.5		
		2.75[5]	1988		5.4		
			1991	.50	5.7	2	No/No
			1991	.50	6.6	2	No/No
Span 4 - Uncoated Reinforcement	<3	3.75[5]	1988		0.3		
		2.50[5]	1988		14.7		
		3.25	1991	.53	12.5	6	Yes/Yes (M)
		2.65	1991	.54	16.5	6	Yes/Yes

[1] ADT - Average Daily Traffic. Data from SEMCOG, 1987.

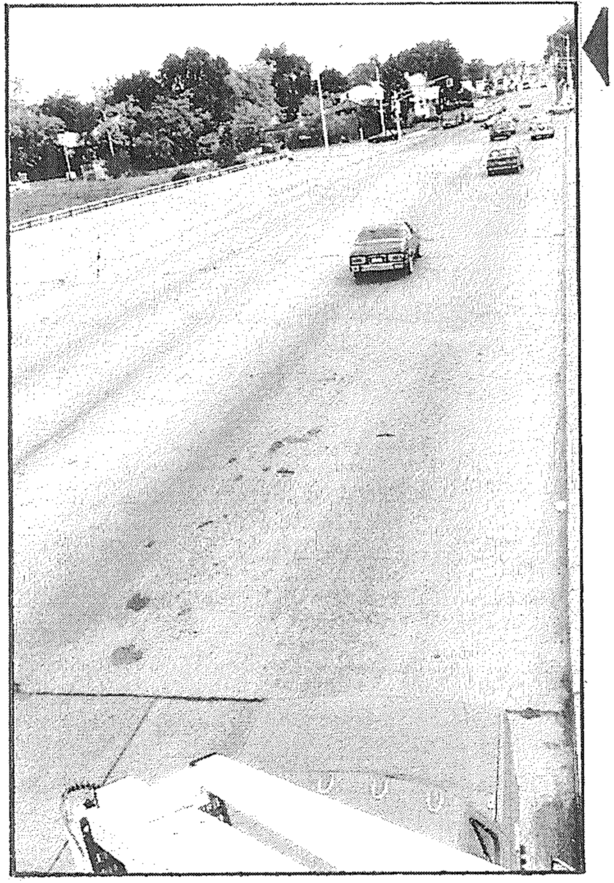
[2] ADTT - Average Daily Truck Traffic.

[3] Condition is ranked on a scale from 1 to 6 with 1 being the best (i.e. no visible corrosion) and 6 being the worst (i.e. major corrosion). This rating system is discussed in more detail in Figure 10.

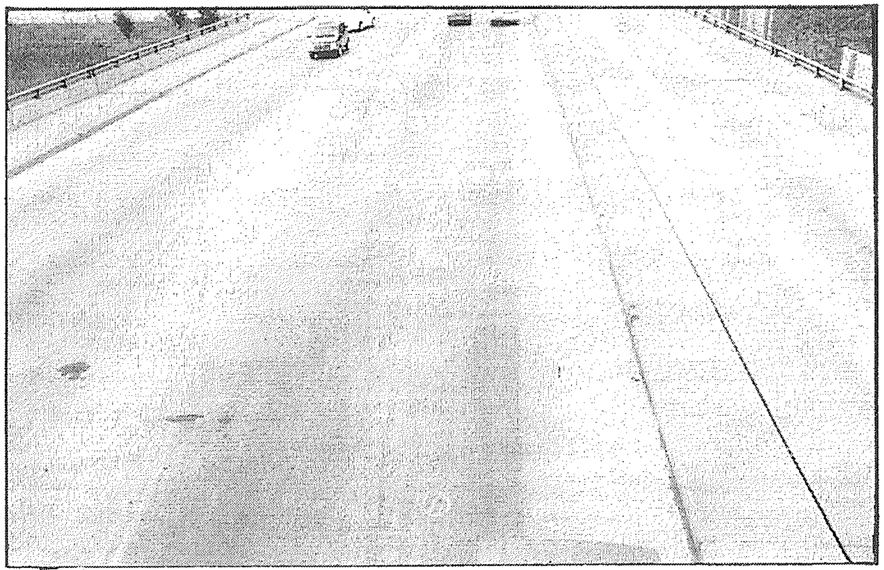
[4] M, when used, denotes multiple cracking. P, when used, indicates cracking perpendicular (i.e. transverse) to the top mat reinforcement.

[5] Clear cover distance was not available for these cores. This is, instead, the depth at which chloride levels were tested.

[6] The vertical crack extends below reinforcement.



A. Looking North--Part of Span 1 (Uncoated Reinforcement) in Foreground and Spans 2 and 3 (Galvanized Reinforcement--Top Mat Only) and Span 4 (Uncoated Reinforcement) in Background.



B. Looking South--Part of Span 4 (Unocated Reinforcement) in Foreground followed by spans 3 and 2 (Galvanized Reinforcement--Top Mat Only) and Span 1 (Uncoated Reinforcement) in the Background.

Figure 14 S18 of 82123--Wyoming Avenue over I-96 (Jeffries Freeway). Pictures Taken in 1991.

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RESEARCH PROJECT 73F-131--EPOXY RESIN COATED REINFORCED CONCRETE BRIDGE
DECKS                   STRUCTURE S13 OF 81103--CURTIS ROAD OVER I 75 EA
ST OF ANN ARBOR                                 SPAN 1--UNCOATED REINFOR
CEMENT                  SPAN 4--GALVANIZED REINFORCEMENT
1 SOUTH BOUND10/24/8410 5
.32.34.31.31.28
.19.25.24.25.22
.20.27.19.24.18
.28.30.24.23.19
.22.26.24.23.22
.24.42.29.21.22
.24.28.25.24.21
.23.35.25.22.20
.24.40.01.13.22
.29.38.09.15.19
^Z
```

Figure 15 Sample Computer Input Giving Deck Information and Half Cell Values

Figure 16 Sample Computer Output Giving Half Cell Equipotential Plots

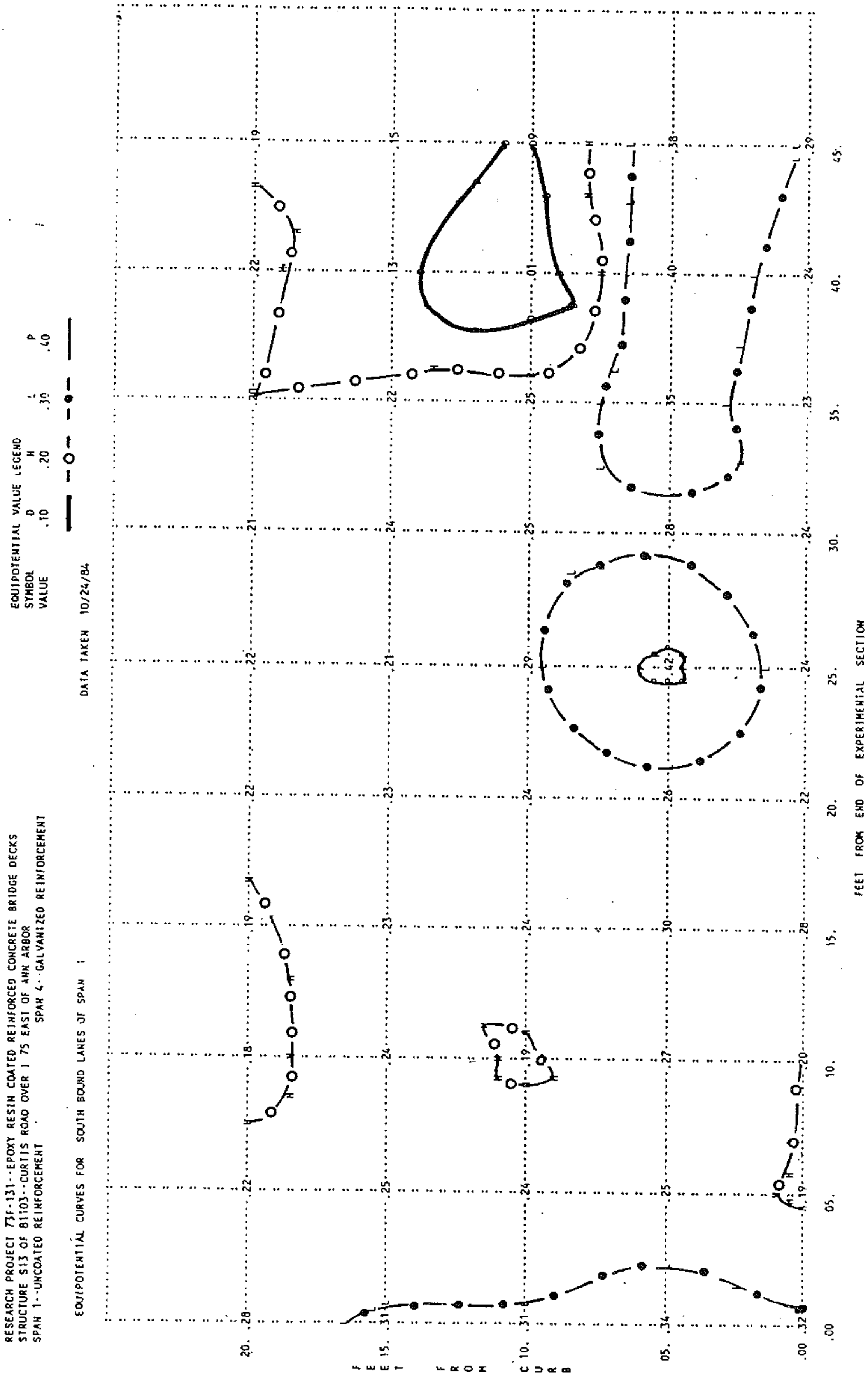

Figure 16 (Continued) Sample Computer Output Giving Half Cell Cumulative Frequency Distribution

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:TRUCTURE S13 OF 81103--CURTIS ROAD OVER I 75 EAST OF ANN ARBOR                                    STATISTICAL DATA & HALF  CELL FREQUENCY DISTRIBUTION
        STATISTICS FOR  SOUTH BOUND LANES OF SPAN 1                                         DATA TAKEN 10/24/84
             FOR   50 DATA POINTS;              MEAN =  .24          MODE= .24          STANDARD DEVIATION= .07
                                        18.0  PERCENT OF DATA POINTS ARE BELOW .20 VOLTS             6.0  PERCENT OF DATA POINTS ARE ABOVE .35 VOLTS.

        CUMULATIVE FREQUENCY DISTRIBUTION
```

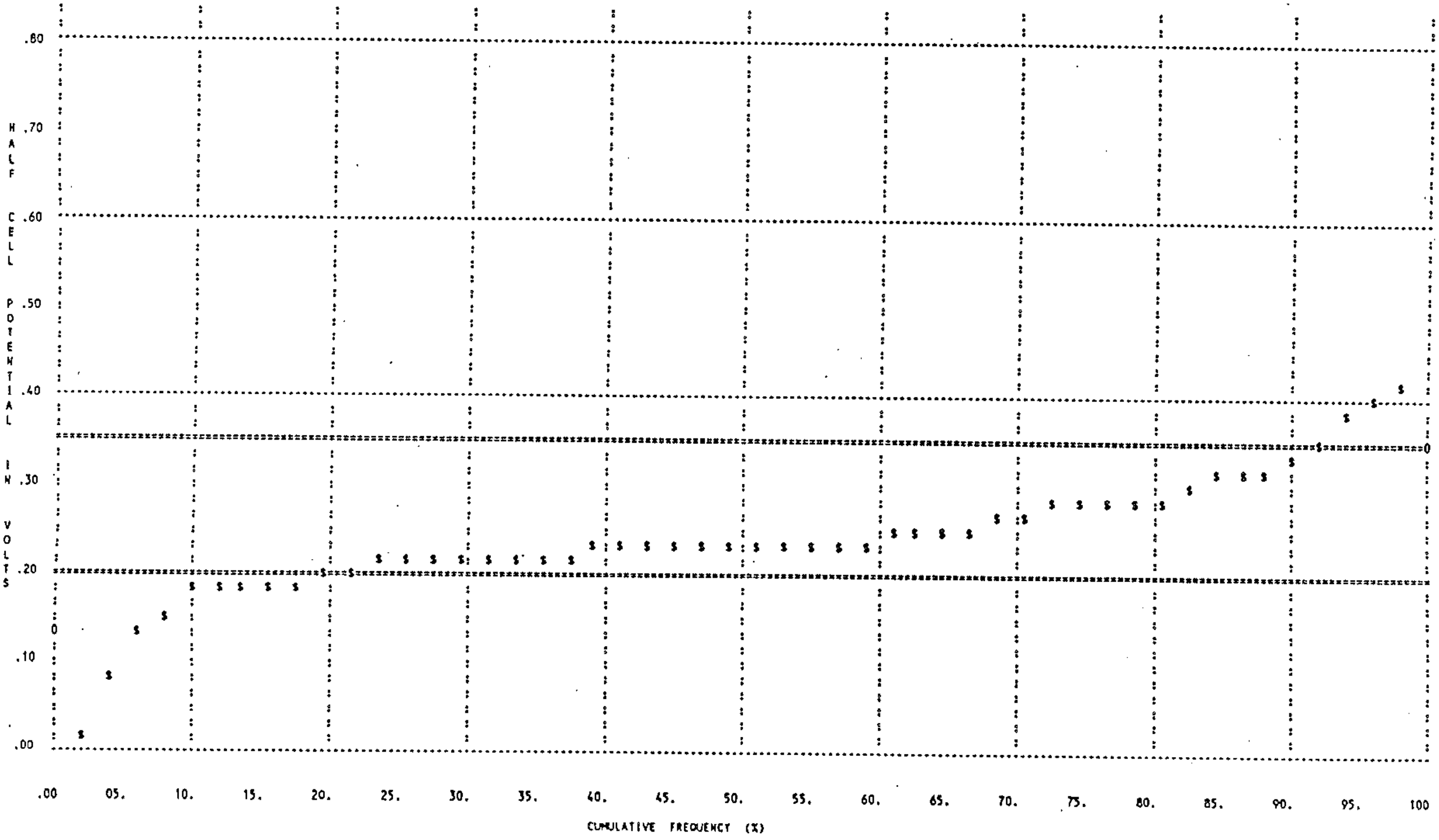

TABLE 10 - SUMMARY OF HALF-CELL READINGS FOR WYOMING AVENUE

Wyoming Avenue Constructed in 1972 Limestone Aggregate	Readings Taken (Month/Year)	Span 1 Galvanized Reinforcement (Top Mat Only)			Span 2 Galvanized Reinforcement (Top Mat Only)			Span 3 Uncoated Reinforcement			Span 4 Uncoated Reinforcement		
		>-.20	<-.20 but >-.35	<-.35	>-.20	<-.20 but >-.35	<-.35	>-.20	<-.20 but >-.35	<-.35	>-.20	<-.20 but >-.35	<-.35
Half-cell data are expressed as the percent of the total span data that falls within the indicated range of values. These ranges, from ASTM C876, are regarded as indicating: >-.20 - 90 percent chance of no corrosion <-.20 but >-.35 - corrosion uncertain <-.35 - 90 percent chance of corrosion	08/72	0.9	38.2	60.9	0.9	11.3	87.8	0.0	49.0	51.0	0.0	100.0	0.0
	09/73	7.7	87.3	2.5	3.5	96.5	0.0	0.0	93.0	7.0	0.0	95.0	5.0
	06/74	7.5	85.8	6.7	2.6	93.0	4.4	0.0	45.6	54.4	0.0	70.0	30.0
	06/75	17.5	74.2	8.3	10.6	69.2	20.2	15.8	70.2	14.0	5.8	44.2	50.0
	09/76	0.8	70.4	28.3	0.0	94.7	5.3	0.9	86.9	12.3	8.3	73.4	18.3
	08/78	20.8	55.8	23.4	1.8	56.1	42.1	0.0	29.0	71.0	4.2	56.6	39.2
	10/79	11.7	50.8	37.5	6.2	22.4	61.4	0.9	43.8	55.3	5.8	39.2	55.0
	09/80	3.4	63.9	32.7	6.4	61.1	32.5	4.4	58.8	38.6	12.5	38.3	49.2
	09/81	0.0	17.3	72.7	0.0	41.2	58.8	0.0	0.9	99.1	1.6	58.5	39.9
	10/82	0.8	57.5	41.7	1.7	39.0	69.3	0.0	56.1	43.9	2.5	51.7	45.8
	10/84	0.0	37.5	62.5	1.8	14.0	84.2	0.0	0.0	100.0	0.0	39.2	60.8
	09/86	3.3	24.2	67.5	0.0	3.5	96.5	0.0	22.8	77.2	0.8	31.7	67.5
	07/91	0.0	47.5	52.5	0.9	43.7	55.4	1.8	39.9	58.3	0.8	41.7	57.8

TABLE 11 - DECK AND REINFORCEMENT CONDITION - WYOMING AVENUE

Wyoming Avenue Constructed in 1972 20,406 ADT^1; ADTT^2 N/A Limestone Aggregate	Spalls and Delaminations (Percent)	Core Information					
		Clear Cover, in.	Core Taken (Year)	Half Cell Readings (Negative Volts)	Chloride Level (Acid Soluble) at Reinforcement (lbs/cu yd)	Reinforcement Condition^3 (Ranking)	Concrete Cracking^4 (Vertical/ Horizontal
Span 1 - Galvanized Reinforcement (Top Mat Only)	2 - 5	4.00^5	1988		1.0		
		3.50	1988		1.2		
		2.80	1991	.42	1.4	1	No/No
		3.60	1991	.30	14.4	4	Yes/Yes^6 (M)
Span 2 - Galvanized Reinforcement (Top Mat Only)	5	3.75^5	1988		0.9		
		2.65	1988		1.2		
		4.10	1991	.59	1.2	1	No/No
		4.10	1991	.46	5.3	3	Yes/No^7
Span 3 - Uncoated Reinforcement	<5	3.50^5	1988		1.4		
		3.30	1988		1.7		
		3.90	1991	.52	0.9	1	No/No
Span 4 - Uncoated Reinforcement	<5	3.25^5	1988		1.0		
		2.75	1988		1.4		
		3.00	1988		1.6		
		3.20	1991	.45	20.3	6	No/Yes
		2.50	1991	.54	20.2	4	Yes/Yes

[1] ADT - Average Daily Traffic. Data from SEMCOG, 1985.

[2] ADTT - Average Daily Truck Traffic.

[3] Condition is ranked on a scale from 1 to 6 with 1 being the best (i.e. no visible corrosion) and 6 being the worst (i.e. major corrosion). This rating system is discussed in more detail in Figure 10.

[4] M, when used, denotes multiple cracking. P, when used, indicates cracking perpendicular (i.e. transverse) to the top mat reinforcement.

[5] Clear cover distance was not available for these cores. This is, instead, the depth at which chloride levels were tested.

[6] The vertical crack extends below the top mat reinforcement.

[7] The vertical crack does not extend to the top mat reinforcement.

This structure has a relatively large amount of traffic compared to the other structures in this project. Spalls and delaminations cover slightly more surface area on the galvanized than on the uncoated reinforcement spans although the differences are not great. Clear cover depths over the galvanized reinforcement are, on average, between those over the uncoated reinforcement.

Combined Structure Assessment

Several noteworthy points are evident from the individual structure assessment.

The first point of interest is the large variation in the half-cell values from one year to another and from one span to another. This effect is further demonstrated in the half-cell potential maps and cumulative frequency plots in Appendix B. Also the half-cell potentials above core locations do not correlate well with the extent of corrosion on the reinforcement taken from the core. Both of these problems are most likely related to the fact that half cell potentials, at best, are an instantaneous measure of corrosion; one set of readings cannot tell the whole story when sites of corrosion and corrosion intensity of any given site can shift with time. Overall, the half cell potential has probably been given more credit than it deserves as a technique for locating corrosion.

Based on the extensive shifting of half-cell values, it would not seem wise to use a one time reading of these values as a criterion for either locating or determining the extent of concrete removal during repairs as some sources have recently recommended.

The second point of interest is the relative lack of difference in actual bridge deck deterioration associated with the type of reinforcement used. The galvanized reinforcement did appear to perform better, at the reinforcement level, when other variables (i.e. depth of clear cover, salt content, presence or absence of cracking, etc) were constant. The most important test criterion, overall deck performance (i.e. spalls and delaminations), did not show a significant difference.

An additional item of interest is the relative lack of corrosion for some reinforcement in cored specimens even though the chloride levels are much higher than the published corrosion threshold level of roughly 1 lb/cu yd. Several factors probably contribute to this effect. One is simply that the threshold level is just that. Corrosion may occur at this concentration level, but is not guaranteed to do so everywhere this level exists. Another factor is that the other ingredients necessary for corrosion (i.e. moisture and air) may not be readily available. The relative lack of corrosion that occurs for the specimens in uncracked concrete with relatively high salt concentrations (i.e. up to 5-7 lb/cu yd) suggests as much. In almost all cases where the concrete is cracked relatively high corrosion rates go along with high salt concentrations.

Another item of interest is the significantly lower salt concentrations for the cores that were taken at "random" locations. These cores were, in general, taken at locations well removed from deck cracking, whereas the other cores were specifically taken at cracks or areas of high half-cell potentials, which were, typically, adjacent to existing cracks. There is at least some suggestion in these data that the concrete on these structures would keep the salt/moisture concentrations to a suitable level for a much longer time if cracking did not exist to help the salt/moisture penetrate to the reinforcement level. This idea is further reinforced by the fact that the delaminations on all of these structures were located adjacent to pre-existing cracks.

Extrapolation of these data, given the lack of delaminations away from preexisting cracks, suggests that concrete bridge deck life might be greatly extended by either the elimination of deck cracking or periodic remedial repair of the deck cracks. Whether or not this life extension would be profitable would depend on the amount of cracking present and the expense necessary to either eliminate or repair the cracking.

Also of significance is the relatively good performance of the uncoated reinforcement spans of these structures after roughly 20 years. This demonstrates that with appropriate depth of clear cover (roughly 3" for these decks) and reduced water/cement ratio (roughly .44 for these decks), even uncoated reinforcement can perform satisfactorily in Michigan's deicing salt environments for a substantial length of time. Based on the results of MDOT Research Report R-1320, one would expect roughly a four-fold increase in deck life for these particular decks over the decks of the late 1950s and early 1960s that were only lasting five to six years. Doubling the depth of clear cover roughly doubles the time that it takes chlorides to reach the reinforcement. Reducing the water/cement ratio from roughly .45-.50 to .44 also increases the time that chlorides take to reach a certain level. Combining these two factors, one would expect these experimental decks to hold up satisfactorily for the length of time that they have.

One last item requiring additional mention is the apparent equal performance, at the deck level (i.e. spalls and delaminations), of the uncoated and galvanized reinforcement. While galvanizing sacrificially protects the metal that it coats, it does this by corroding itself. Further, the corrosion products of galvanizing, typically, occupy more volume than the zinc that is replaced. Some of these corrosion products can be soluble when the concrete pH is still high (i.e. greater than roughly 12.5) and may be able to migrate through the concrete pore structure. Others can form an insoluble layer that is also an electrical barrier that can make further corrosion at a particular site less likely. Once the zinc in a given area is lost, the iron underneath can start to corrode, however. While a number of things can happen when zinc corrodes, in the final analysis it would appear that sufficient oxide is being formed to result in the same delaminations that occur with uncoated reinforcement and on roughly the same time schedule.

While this analysis appears valid for the structures involved in this project, some additional factors may come into play on other structures. For these structures, the water/cement ratio (i.e. roughly .44) is probably indicative of a relatively impermeable concrete that might not allow the corrosion products to migrate through the concrete. More permeable concretes, which unfortunately would probably not be compatible with the freeze/thaw requirements of our Michigan climate, might allow migration of some corrosion products without significant build-up of internal pressures. Galvanizing might work in more porous concrete mixes in warmer climates (i.e. like the bermuda example given earlier that helped to start the experimentation with galvanized reinforcement) where salt is still a problem, but freeze/thaw durability requirements are not.

These structures also had clear cover of from roughly three to four inches. With the depth of the reinforcement and the relative lack of porosity in the concrete of these decks, chloride levels at many sites removed from cracking are just finally starting to exceed threshold levels. In these areas, galvanizing may prove to be more valuable given its ability to withstand higher chloride levels and lower pH's than uncoated reinforcement before it starts to corrode. At crack locations where the crack goes all the way to the reinforcement, the zinc coating does not have as much of an advantage since the chloride and pH levels will change much more rapidly eliminating much of the time advantage that may be present for galvanizing at locations distant from the cracks.

Epoxy Coated (73 F-131)

Initial Details

Specifications for the coating thickness of the galvanized reinforcement were the same as for Research Project 68 F-103, with the same result. Zinc coating thickness was roughly twice as thick as required. The material specification for the epoxy coating thickness required 7 mils ± 2 mils with no exclusion for individual specimen. While average thicknesses fell within this range, some individual specimens fell below this requirement (See Figures 6-8 for zinc and epoxy coating information).

Figures 6-8 also detail the configurations of these experimental bridge decks, as well as the concrete cover depths over the experimental reinforcements.

Concrete mixes used on each of these decks are also detailed, to the extent possible, in Table 1.

Structure Assessment

Each structure is discussed individually, since performance differences would be expected to be most readily detectible for a given structure. Differences between the environment of individual bridges will, in general, be greater than the differences between individual spans of the same structure. For these structures size differences between the spans, as well as the presence of cantilevered expansion joints on some spans, complicate comparisons between spans, however.

Half-cell readings could not be taken for any of the spans with epoxy coated reinforcement due to the electrical barrier created by the epoxy coating.

Curtis Road

Primary data for this structure are contained in Figure 6 and Tables 12 and 13.

TABLE 12 SUMMARY OF HALF-CELL READINGS FOR CURTIS ROAD

Curtis Road Constructed in 1976 Limestone Aggregate	Readings Taken (Month/Year)	Span 1 Uncoated Reinforcement			Span 4 Galvanized Reinforcement		
		>-.20	<-.20 but >-.35	<-.35	>-.20	<-.20 but >-.35	<-.35
Half-cell data are expressed as the percent of the total span data that falls within the indicated range of values. These ranges, from ASTM C876, are regarded as indicating: >-.20 - 90 percent chance of no corrosion <-.20 but >-.35 - corrosion uncertain <-.35 - 90 percent chance of corrosion	09/78	58.7	41.3	0.0	11.1	78.9	10.0
	10/79	41.8	58.2	0.0	92.6	7.4	0.0
	09/80	68.2	30.8	1.0	27.8	38.9	33.3
	10/81	15.2	76.5	8.3	—	—	—
	10/82	48.0	49.5	2.5	5.0	24.8	70.2
	10/84	19.0	75.5	5.5	5.0	12.0	83.0
	09/86	3.3	86.5	10.2	1.1	5.2	93.7
	08/91	4.6	53.6	41.8	5.0	1.0	94.0

Half-cell values suggest that the galvanized span, compared to the uncoated reinforcement span, may have had higher corrosion activity the first year, followed by less corrosion activity the second year, and then higher corrosion activity for subsequent years. Relatively pure zinc in the outermost layers of the galvanizing, however, could also produce the observed differences in half-cell values.

Reinforcement condition at crack locations with relatively high salt content was worst for the uncoated reinforcement and best for the epoxy coated reinforcement with the galvanized reinforcement being intermediate (see Table 13).

TABLE 13 - DECK AND REINFORCEMENT CONDITION - CURTIS ROAD

Curtis Road Constructed in 1976 ADT[1] N/A; ADTT[2] N/A	Spalls and Delaminations (Percent)	Core Information					
		Clear Cover, in.	Core Taken (Year)	Half Cell Readings (Negative Volts)	Chloride Level (Acid Soluble) at Reinforcement (lbs/cu yd)	Reinforcement Condition[3] (Ranking)	Concrete Cracking[4] (Vertical/ Horizontal
Span 1 - Uncoated Reinforcement	<1	2.90 2.30	1988 1991	.42	3.8 12.7	6	Yes/Yes (M)
Span 2 - Epoxy Coated Reinforcement 3M 202	<1	2.80[5] 3.25 2.50	1988 1991 1991		1.0 6.0 7.7	1 1	Yes/No[6] Yes/No[6]
Span 3 - Epoxy Uncoated Reinforcement DuPont Flintflex 531-6080	0	3.10 3.00	1988 1991		6.9 10.8	3	Yes/No
Span 4 - Galvanized Reinforcement (Both Top and Bottom Mats)	0	2.50 1.75 2.50	1988 1991 1991	.62 .30	6.6 8.0 11.3	3 5	Yes/No Yes/No[7]

[1] ADT - Average Daily Traffic.

[2] ADTT - Average Daily Truck Traffic.

[3] Condition is ranked on a scale from 1 to 6 with 1 being the best (i.e. no visible corrosion) and 6 being the worst (i.e. major corrosion). This rating system is discussed in more detail in Figure 10.

[4] M, when used, denotes multiple cracking. P, when used, indicates cracking perpendicular (i.e. transverse) to the top mat reinforcement.

[5] Clear cover distance was not available for these cores. This is, instead, the depth at which chloride levels were tested.

[6] The vertical crack does not extend to the top mat reinforcement.

[7] The vertical crack extends below the top mat reinforcement.

Spalls and delaminations were negligible for this structure.

Napier Road

Primary data for this structure are contained in Figure 7 and Tables 14 and 15.

Half-cell values suggest that the uncoated reinforcement span, compared to the galvanized span, may have had higher corrosion activity the first several years but less corrosion activity for the remaining six years for which measurements were made.

Reinforcement condition at crack locations with intermediate salt content was worst for the uncoated reinforcement and best for the epoxy coated reinforcement, with the galvanized reinforcement being intermediate. The salt content around the epoxy coated reinforcement was much lower, however, than around the other reinforcements.

Spalls and delaminations were negligible for this structure.

TABLE 14 SUMMARY OF HALF-CELL READINGS FOR NAPIER ROAD

Napier Road Constructed in 1976 Limestone Aggregate	Readings Taken (Month/Year)	Span 1 Uncoated Reinforcement			Span 4 Galvanized Reinforcement		
		>-.20	<-.20 but >-.35	<-.35	>-.20	<-.20 but >-.35	<-.35
Half-cell data are expressed as the percent of the total span data that falls within the indicated range of values. These ranges, from ASTM C876, are regarded as indicating: >-.20 - 90 percent chance of no corrosion <-.20 but >-.35 - corrosion uncertain <-.35 - 90 percent chance of corrosion	09/78	46.0	54.0	0.0	59.1	40.9	0.0
	10/79	23.0	51.0	26.0	64.4	35.6	0.0
	09/80	98.9	1.1	0.0	31.1	66.7	2.2
	10/81	84.0	16.0	0.0	8.4	88.2	3.4
	10/82	87.0	12.0	1.0	5.6	47.1	47.3
	10/84	77.0	19.0	4.0	6.7	66.7	26.6
	09/86	57.0	41.0	2.0	0.0	60.0	40.0
	07/91	15.4	78.3	6.3	1.1	17.8	81.1

Post Road

Primary data for this structure are contained in Figure 8 and Tables 16 and 17.

TABLE 15 - DECK AND REINFORCEMENT CONDITION - NAPIER ROAD

Napier Road Constructed in 1976 ADT[1] N/A; ADTT[2] N/A	Spalls and Delaminations (Percent)	Core Information					
		Clear Cover, in.	Core Taken (Year)	Half Cell Readings (Negative Volts)	Chloride Level (Acid Soluble) at Reinforcement (lbs/cu yd)	Reinforcement Condition[3] (Ranking)	Concrete Cracking[4] (Vertical/ Horizontal
Span 1 - Uncoated Reinforcement	0	3.70	1988		0.6		
		2.15	1991	.28	3.9	4	Yes/No[6]
		2.75	1991	.49	5.4	4	Yes/No
Span 2 - Epoxy Coated Reinforcement 3M 202	0	3.80[5]	1988		0.3	1	Yes/No[6]
		2.40	1991		0.2		
Span 3 - Epoxy Uncoated Reinforcement DuPont Flintflex 531-6080	0 (1991)	2.80	1988		0.3		
Span 4 - Galvanized Reinforcement (Both Top and Bottom Mats)	0	N/A	1988		0.6		
		2.50	1991	.44	4.2	2	No/No

[1] ADT - Average Daily Traffic.

[2] ADTT - Average Daily Truck Traffic.

[3] Condition is ranked on a scale from 1 to 6 with 1 being the best (i.e. no visible corrosion) and 6 being the worst (i.e. major corrosion). This rating system is discussed in more detail in Figure 10.

[4] M, when used, denotes multiple cracking. P, when used, indicates cracking perpendicular (i.e. transverse) to the top mat reinforcement.

[5] Clear cover distance was not available for these cores. This is, instead, the depth at which chloride levels were tested.

[6] The vertical crack does not extend to the top mat reinforcement.

TABLE 16 SUMMARY OF HALF-CELL READINGS FOR POST ROAD

Post Road Constructed in 1976 Limestone Aggregate	Readings Taken (Month/Year)	Span 1 Uncoated Reinforcement			Span 4 Galvanized Reinforcement		
		>-.20	<-.20 but >-.35	<-.35	>-.20	<-.20 but >-.35	<-.35
Half-cell data are expressed as the percent of the total span data that falls within the indicated range of values. These ranges, from ASTM C876, are regarded as indicating: >-.20 - no corrosion <-.20 but >-.35 - corrosion uncertain <-.35 - 90 percent chance of corrosion	09/78	64.8	33.0	2.2	8.9	68.9	22.2
	10/79	51.1	42.4	6.5	55.6	40.0	4.4
	10/80	12.2	75.5	12.3	28.9	53.8	17.3
	10/81	62.2	35.6	2.2	43.3	51.2	5.5
	10/82	85.6	14.4	0.0	47.8	46.7	5.5
	10/84	73.3	24.5	2.2	27.8	63.3	8.9
	09/86	57.8	41.1	1.1	2.2	45.5	52.3
	08/91	60.1	39.9	0.0	10.0	65.0	25.0

Half-cell values suggest that the uncoated reinforcement span, compared to the galvanized span, may have had less corrosion activity for all of the years that measurements were taken except for the second year when corrosion activity may have been roughly the same.

Reinforcement condition at crack locations that had relatively low salt content was best for the uncoated, galvanized reinforcement, and the 3M epoxy coated reinforcement (i.e. these cracks did not extend to the reinforcement) and worst for the Cook's epoxy coated reinforcement. The uncoated reinforcement had a much greater depth of cover and lower salt content of its surrounding concrete than the other test materials, which would help to explain its superior performance for this structure. The Cook's epoxy also performed worse than the other epoxy coatings in our simulated bridge deck slabs (MDOT Research Report R-1320).

Spalls and delaminations were negligible for this structure.

Combined Structure Assessment

The relative performance of the reinforcement alternatives used in these decks suggests that the epoxy coating, with possibly the exception of the Cook's epoxy, is superior to both the galvanized and uncoated reinforcement at locations were cracks have accelerated the increase of the chloride content of surrounding concrete. While the core data suggest that the longer term performance of the spans with epoxy-coated reinforcement will, in general, be superior, this is not fully guaranteed.

TABLE 17 - DECK AND REINFORCEMENT CONDITION - POST ROAD

Post Road Constructed in 1976 ADT[1] N/A; ADTT[2] N/A	Spalls and Delaminations (Percent)	Core Information					
		Clear Cover, in.	Core Taken (Year)	Half Cell Readings (Negative Volts)	Chloride Level (Acid Soluble) at Reinforcement (lbs/cu yd)	Reinforcement Condition[3] (Ranking)	Concrete Cracking[4] (Vertical/ Horizontal
Span 1 - Uncoated Reinforcement	0	3.25	1988		0.5		
		5.00	1991	.30	1.2	1	No/No
		4.00	1991	.30	2.3	1	Yes/No[6]
Span 2 - Epoxy Coated Reinforcement 3M 202	0	2.50[5]	1988		1.3		
		3.60	1991		3.0	1	No/No
		2.65	1991		4.2	1	Yes/No[6]
Span 3 - Epoxy Uncoated Reinforcement Cooks 270-A-009	0	2.75	1988		0.5		
		2.20	1991		7.3	3	Yes/Yes[7]
Span 4 - Galvanized Reinforcement (Both Top and Bottom Mats)	0	2.25	1988		1.0		
		2.25	1991		7.2	1	Yes/No[6]
		3.00	1991	.42	2.5	1	No/No

[1] ADT - Average Daily Traffic.

[2] ADTT - Average Daily Truck Traffic.

[3] Condition is ranked on a scale from 1 to 6 with 1 being the best (i.e. no visible corrosion) and 6 being the worst (i.e. major corrosion). This rating system is discussed in more detail in Figure 10.

[4] M, when used, denotes multiple cracking. P, when used, indicates cracking perpendicular (i.e. transverse) to the top mat reinforcement.

[5] Clear cover distance was not available for these cores. This is, instead, the depth at which chloride levels were tested.

[6] The vertical crack does not extend to the top mat reinforcement.

[7] The vertical crack extends below the top mat reinforcement.

General observation of the epoxy coated reinforcement removed in the experimental cores revealed that the epoxy does not adhere well to the reinforcement. While the concrete was still moist, exposed sections of the epoxy coatings could be removed quit easily from the bars (i.e. a fingernail was usually sufficient). If this type of performance is prevalent in the epoxy coated reinforcement in these decks, holidays in the coatings once found by deicing salts might allow corrosion to progress along the reinforcement under the coating more easily than can occur for uncoated reinforcement.

When even the uncoated reinforcement spans are not showing any significant deterioration at the deck level, it is difficult to make guesses about how well the various alternatives will perform. For the structures used in the F-103 project, (i.e. uncoated vs. epoxy coated reinforcement) superior performance at the reinforcement level did not equate with superior performance at the deck level; spalls and delaminations are essentially equal for these experimental spans and the same or worse is possible for this project.

Further examination of these decks would be necessary over the next five or so years to determine what will finally happen. While these decks might not be directly indicative of our newer decks, which now use "new and improved" epoxy coatings, continued observation would be of interest in terms of having a handle on how our other decks using these older coatings may end up performing. Since these are some of our oldest decks with epoxy coated reinforcement, they might function as a barometer to help predict what will happen on our other decks using older epoxy coatings.

While there was some concern initially that there might be a reversal of the usual anode/cathode macrocell pattern for the decks in this project, this does not appear to be the case. A reversal might have occurred if less salt reached the top of the deck than was thrown up and absorbed on the bottom of the deck. These bridge decks are, typically, on low traveled roads over a heavily traveled roadway, making anode/cathode reversal a valid concern when the cover over the top mat (from above) is almost twice the cover of the bottom mat (from below). The underside of all inspected decks, however, showed no evidence of unusual cracking or spalling that could be attributed to corrosion of the bottom mat of reinforcing steel.

Project Extension

For the nine additional structures, built between 1977 and 1982, there is insufficient data to justify discussing the structures individually. They are instead discussed in two groups--those with epoxy-coated reinforcement in the top mat only and those with epoxy-coated reinforcement in both top and bottom mats.

Data for the five "new" bridges with epoxy coated reinforcement in the top mat only are given in Table 18. The core data for these structures indicate that there has been some rusting of the reinforcement of these decks. The extent of rusting appears to be related, in general, to the level of chloride in the concrete and whether or not a crack is present. Two decks with chloride levels below 1.4 and 2.6 lbs/cu yd, respectively, and no cracks at the core sites had no core specimens with reinforcement corrosion.

Data for the four "newer" bridges with epoxy-coated reinforcement in both the top and bottom mats are given in Table 19. The core data for these structures indicate that there has been very little rusting, even though chloride levels are, in some cases, as high or higher than those for the structures with epoxy-coated reinforcement in the top mat only and cracks extend to the reinforcement level.

The epoxy-coated reinforcement from the decks with coated reinforcement in both the top and bottom mats appears to be performing better than the epoxy coated reinforcement with coated reinforcement in only the top mat. There are several possible factors at work.

The reinforcement in the decks with coated reinforcement in only the top mat may be experiencing greater corrosion because of the larger available surface of the uncoated reinforcement in the bottom mat, which may function as a relatively large cathode to accelerate corrosion in the top mat anodes. This is the most likely, but not necessarily the only, factor at work.

The decks with coated reinforcement in both top and bottom mats are, on the average, about five years younger and simply may not have had the time necessary to corrode as much. Alternately, there may be differences in the quality of the epoxy coatings or epoxy-to-reinforcement bond in the different decks.

ECONOMICS

A comparison of the material costs for each of the three types of reinforcement reveals that uncoated reinforcement costs approximately $0.58 per pound, galvanized reinforcement $1.20 - $1.80 per pound, and epoxy coated reinforcement $0.65 - $0.70 per pound. Thus, reinforcement costs for an average 10,000 sq ft bridge deck, containing 72,000 lbs of reinforcement, would be $41,760 for uncoated reinforcement, $90,000 - $129,600 for galvanized reinforcement, and $46,800 - $50,400 for epoxy coated reinforcement.

TABLE 18 - DECK AND REINFORCEMENT CONDITION - NEW BRIDGES WITH EPOXY-COATED REINFORCEMENT (TOP MAT ONLY)

Structure	Spalls and Delaminations (Percent)	Core Information				
		Clear Cover, in.	Core Taken (Year)	Chloride Level (Acid Soluble) at Reinforcement (lbs/cu yd)	Reinforcement Condition[3] (Ranking)	Concrete Cracking[4] (Vertical/ Horizontal)
US-31 Over Muskegon River ADT[1] and ADTT[2] N/A Natural Aggregate Constructed in 1977 Brown Epoxy-Coated Reinforcement						
Span 1 -	0	3.00[5]	1992	0.8		No/No
		3.00[5]	1992	3.0	2	Yes/No
		3.00[5]	1992	7.0	3	Yes/No
Span 2 -	0	3.00[5]	1992	6.2	3	No/No
Span 3 -	0	3.00[5]	1992	4.6	2	Yes/No
		3.00[5]	1992	1.3		No/No
M-99 Over Grand River ADT[1] and ADTT[2] N/A Natural Aggregate Construction in 1978 Green Epoxy-Coated Reinforcement						
Span 1 -	0	3.00[5]	1992	1.5	3	No/No
		3.00[5]	1992	1.1	1	No/No
		3.00[5]	1992	2.2	1	No/No
Span 2 -	0	3.00[5]	1992	1.3	1	No/No
		3.00[5]	1992	1.1	1	No/No
Span 3 -	0	3.00[5]	1992	1.0	1	No/No
		3.00[5]	1992	1.4	1	No/No

TABLE 18 (CON'T) - DECK AND REINFORCEMENT CONDITION - NEW BRIDGES WITH EPOXY-COATED REINFORCEMENT (TOP MAT ONLY)

Structure	Spalls and Delaminations (Percent)	Core Information				
		Clear Cover, in.	Core Taken (Year)	Chloride Level (Acid Soluble) at Reinforcement (lbs/cu yd)	Reinforcement Condition^3 (Ranking)	Concrete Cracking^4 (Vertical/ Horizontal)
I-475 Under Leith Street ADT^1 and ADTT^2 N/A Natural Aggregate Constructed in 1977 Green Epoxy-Coated Reinforcement						
Span 1 -	0	3.00^5 3.00^5	1992 1992	6.1 0.9	3 1	Yes/No No/No
Span 2 -	0	3.00^5 3.00^5	1992 1992	3.8 1.2	3 1	Yes/No No/No
Span 3 -	0	3.00^5 3.00^5	1992 1992	4.6 0.9	1 1	Yes/No No/No
M-37 Over Calvin College Service Road ADT^1 and ADTT^2 N/A Natural Aggregate Construction in 1978 Brown Epoxy-Coated Reinforcement						
Span 1 -	0	3.00^5 3.00^5 3.00^5 3.00^5 3.00^5 3.00^5	1992 1992 1992 1992 1992 1992	1.4 0.9 0.9 0.9 1.0 1.1	1 1 1 1 1 1	No/No No/No No/No No/No No/No No/No

TABLE 18 (CON'T) - DECK AND REINFORCEMENT CONDITION - NEW BRIDGES WITH EPOXY-COATED REINFORCEMENT (TOP MAT ONLY)

Structure	Spalls and Delaminations (Percent)	Core Information				
		Clear Cover, in.	Core Taken (Year)	Chloride Level (Acid Soluble) at Reinforcement (lbs/cu yd)	Reinforcement Condition[3] (Ranking)	Concrete Cracking[4] (Vertical/ Horizontal)
I-475 Under Saginaw Street ADT[1] and ADTT[2] N/A Natural Aggregate Constructed in 1977 Green Epoxy-Coated Reinforcement						
Span 1 -	0	3.00[5] 3.00[5]	1992 1992	2.6 0.9	1 1	No/No No/No
Span 2 -	0	3.00[5] 3.00[5]	1992 1992	1.1 0.9	1 1	No/No No/No
Span 3 -	0	3.00[5] 3.00[5]	1992 1992	1.2 0.9	1 1	No/No No/No
Span 4 -	0	3.00[5] 3.00[5]	1992 1992	1.3 0.9	1 1	No/No No/No

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[1] ADT - Average Daily Traffic.

[2] ADTT - Average Daily Truck Traffic.

[3] Condition is ranked on a scale from 1 to 6 with 1 being the best (i.e. no visible corrosion) and 6 being the worst (i.e. major corrosion). This rating system is discussed in more detail in Figure 10.

[4] M, when used, denotes multiple cracking. P, when used, indicates cracking perpendicular (i.e. transverse) to the top mat reinforcement.

[5] Clear cover distance was not available for these cores. This is, instead, the depth at which chloride levels were tested.

TABLE 19 - DECK AND REINFORCEMENT CONDITION
NEW BRIDGES WITH EPOXY-COATED REINFORCEMENT (BOTH TOP AND BOTTOM MATS)

Structure	Spalls and Delaminations (Percent)	Core Information				
		Clear Cover, in.	Core Taken (Year)	Chloride Level (Acid Soluble) at Reinforcement (lbs/cu yd)	Reinforcement Condition[3] (Ranking)	Concrete Cracking[4] (Vertical/ Horizontal
M-29 Over Belle River ADT[1] 9,300; ADTT[2] 130 Natural Aggregate Constructed in 1982 Green Epoxy-Coated Reinforcement						
Span 1 -	0	3.80 3.80	1992 1992	6.6 5.9	1 1	Yes/No[6] Yes/No
Span 3 -	0	3.30	1992	2.4	1	Yes/No[6]
M-19 Over I-69 ADT[1] 7,000; ADTT[2] 260 Natural Aggregate Construction in 1982 Brown Epoxy-Coated Reinforcement						
Span 1 -	0	3.70	1992	4.1	1	Yes/No[6]
Span 2 -	0	3.60	1992	3.4	1	Yes/No[6]
I-94 (Eastbound) Exit Ramp Over Pelham Road ADT[1] and ADTT[2] N/A Natural Aggregate Constructed in 1982 Brown Epoxy-Coated Reinforcement						
Span 1 -	0	3.00[5] 3.25[5]	1992 1992	3.0 2.2	1 2	Yes/No[7] Yes (P)/No[7]

The initial cost difference between uncoated and epoxy coated reinforcement is $0.07 - $0.12 per pound, or $5,040 - $8,640 for a 10,000 sq ft bridge deck. If the life of the structure can be extended by only a few years, the life-cycle cost of using epoxy coated reinforcement will actually be less than that of using uncoated reinforcement.

Among the options evaluated in these projects, the economics favor the use of epoxy coating. For the small cost differential between uncoated reinforcement and epoxy-coated reinforcement, the epoxy coating will probably more than pay back its initial investment. The same cannot, however be said for galvanizing. Based on the very similar performance of galvanized and uncoated reinforcement in overall deck performance to date, the use of galvanized reinforcement would probably not be economically justified when there is any significant cost differential between galvanized and uncoated reinforcement.

CONCLUSIONS

The objectives of the 68 F-103 and 73 F-131 research projects were to compare the long-term performance of galvanized and epoxy coated reinforcing steel with uncoated reinforcement, as well as the effect increased concrete cover and concrete mix design might have on the life of reinforced concrete bridge decks. Only the long-term performance on the reinforcement alternative is discussed in this report. Information regarding the effects of concrete cover and concrete mix design are discussed in MDOT Research Report R-1320.

Half-cell data from both projects suggest that such information is very limited in predicting location and extent of corrosion in bridge decks when only one set of readings is used, but may be more useful if multiple readings over time are available.

Galvanized (68 F-103)

Galvanizing offers superior corrosion protection of the reinforcement compared to uncoated reinforcement at similar levels of chloride penetration and circumstances (i.e. presence or absence of cracking). While galvanizing will apparently help the reinforcement in the top mat retain full cross-section for a longer period of time, this performance advantage is of questionable value when deck performance is not improved.

Galvanizing did not appear to improve the overall performance of the experimental decks. Spalling and delaminations covered essentially identical surface areas on both uncoated reinforcement and galvanized reinforcement spans for all experimental structures.

TABLE 19 (CON'T) - DECK AND REINFORCEMENT CONDITION
NEW BRIDGES WITH EPOXY-COATED REINFORCEMENT (BOTH TOP AND BOTTOM MATS)

Structure	Spalls and Delaminations (Percent)	Core Information				
		Clear Cover, in.	Core Taken Year	Chloride Level (Acid Soluble) at Reinforcement (lbs/cu yd)	Reinforcement Condition[3] (Ranking)	Concrete Cracking[4] (Vertical/ Horizontal)
US-12 (Business Rt.) Over US-12 ADT[1] 20,490; ADTT[2] 870 Natural Aggregate Construction in 1982 3M Epoxy-Coated Reinforcement						
Span 1 -	0	3.00	1992	6.5	1	Yes/No[6]
Span 3 -	0	3.00	1992	5.1	1	Yes/No[6]

[1] ADT - Average Daily Traffic.
[2] ADTT - Average Daily Truck Traffic.
[3] Condition is ranked on a scale from 1 to 6 with 1 being the best (i.e. no visible corrosion) and 6 being the worst (i.e. major corrosion). This rating system is discussed in more detail in Figure 10.
[4] M, when used, denotes multiple cracking. P, when used, indicates cracking perpendicular (i.e. transverse) to the top mat reinforcement.
[5] Clear cover distance was not available for these cores. This is, instead, the depth at which chloride levels were tested.

Given the current cost differentials and the extent of performance advantages offered by galvanized reinforcement, galvanizing of concrete reinforcement does not appear to be cost effective.

Epoxy Coated (73 F-131)

Epoxy coating appears to offer superior corrosion protection of the reinforcement when compared to galvanized and uncoated reinforcement under similar exposure conditions.

Galvanized reinforcement did not appear to corrode as much when compared to uncoated reinforcement under similar exposure conditions.

No spalls or delaminations were present on these experimental structures, so no firm conclusions can be drawn regarding how well the different test alternatives will perform in this important performance area.

Project Extension

Differences between the corrosion performance of the epoxy coated reinforcement in these decks suggest that there is superior performance under similar conditions when both top and bottom mats are epoxy coated. Since no spalls or delaminations were present on any of these structures no firm conclusions can be drawn regarding how much coated or uncoated bottom mats may eventually influence this important performance area.

RECOMMENDATIONS

The current MDOT Guidelines and Procedures, which recommend the use of epoxy coated reinforcement in both the top and bottom mat of reinforcing steel, probably represents the most cost-effective corrosion protection of steel reinforcement currently available. For the present time the use of these guidelines, as written, should continue in combination with three-inch clear cover.

Galvanized concrete reinforcement is not recommended for use in Michigan's highway structures.

The performance of epoxy-coated reinforcement as well as possible alternative corrosion protection methods (i.e. modifications to the reinforcement--different coatings or reinforcement materials and modifications to the concrete that affect its porosity, shrinkage, or resistance to cracking) should continue to be evaluated. Continued examination of alternatives will help to ensure that the Michigan Department of Transportation implements the most cost-effective corrosion protection methods available.

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APPENDIX A

The following list details some of the changes that were made to the Michigan Department of Transportation Bridge Design Manual between 1975 and the present that relate to measures taken to help prevent early deterioration of reinforced concrete.

1.) December 1975 - Increase clear cover over the top mat of reinforcement to three inches. Introduction of the use of epoxy coated reinforcement into the top mat of all bridge decks.

2.) April 1980 - Use of epoxy coated reinforcement in the traffic facing side of the traffic barrier.

3.) October 1980 - Use of epoxy coated reinforcement in the top and bottom mats of all bridge decks.

4.) December 1980 - Use of epoxy coated reinforcement for all superstructure reinforcing steel.

5.) November 1980 - Use of latex overlays on all new bridge decks.

6.) March 1983 - Use of latex overlays on new bridge decks, but only in heavily travelled metropolitan areas.

7.) January 1984 - Epoxy coated reinforcement required in prestressed I beams.

8.) February 1984 - Only reinforcement extending into the deck will be epoxy coated for prestressed I beams.

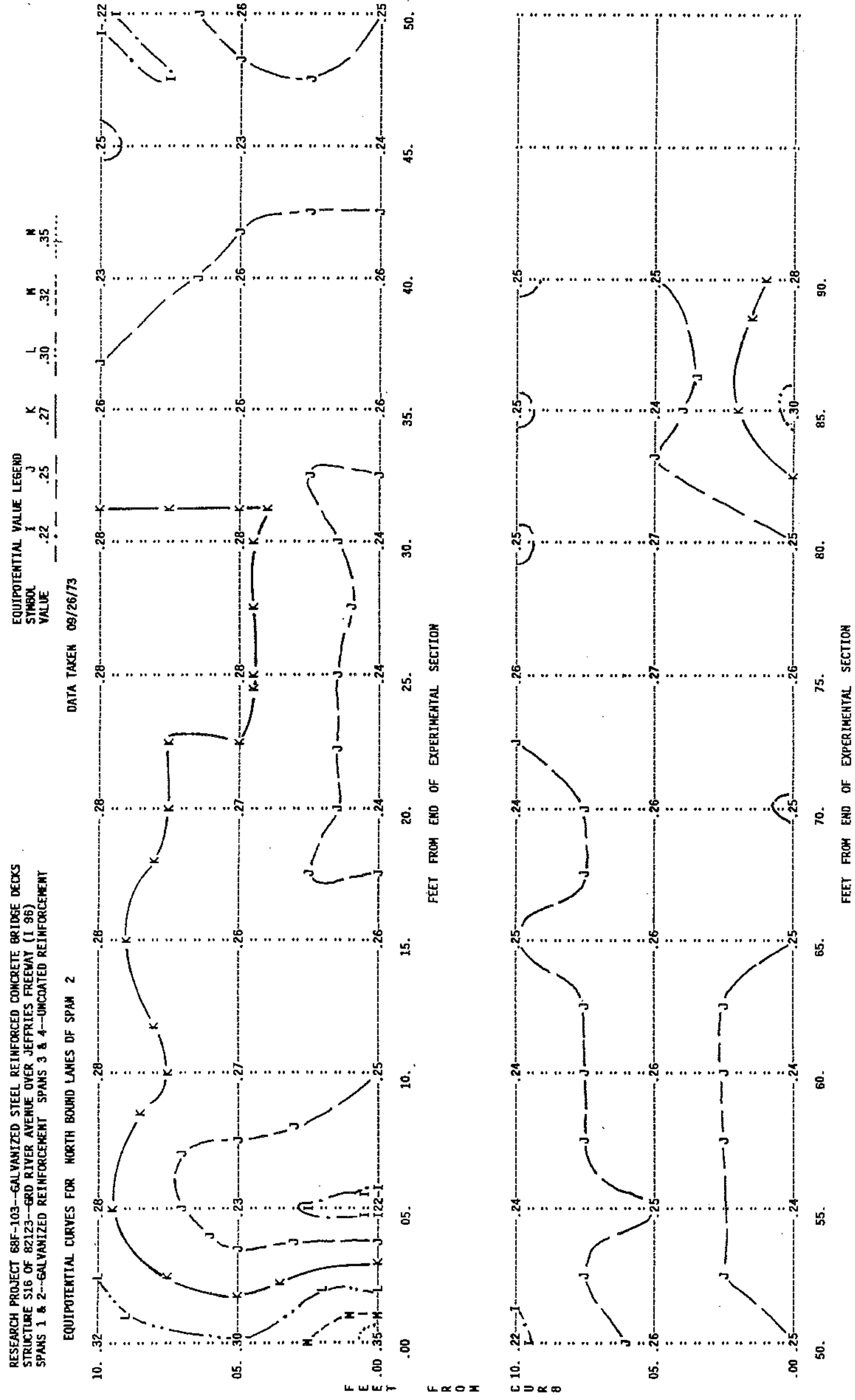
9.) June 1984 - Depressed highways will use epoxy coated reinforcement in the face mat of abutments and retaining walls and all pier steel above the footing.

APPENDIX B

Sample half cell plots and cumulative frequency distributions are given in the following pages for northbound span 2 (galvanized - top mat only) and northbound span 3 (uncoated reinforcement) of Grand River Avenue over I-96. Comparing the half cell values on a given span over time one will see shifts with respect to magnitude of half cell values and shifts of location of peak half cell values. These spans represent relatively typical cases; more extreme examples could have been used. While the combined trends of all of the readings probably conform fairly well with the cumulative corrosion in the deck, any one set of readings is much less likely to.

Appendix B (Continued)
Grand River Avenue--North Bound Span 2 (Galvanized--top mat only)
Data Taken 09/12/72

Half Cell Equipotential Plot

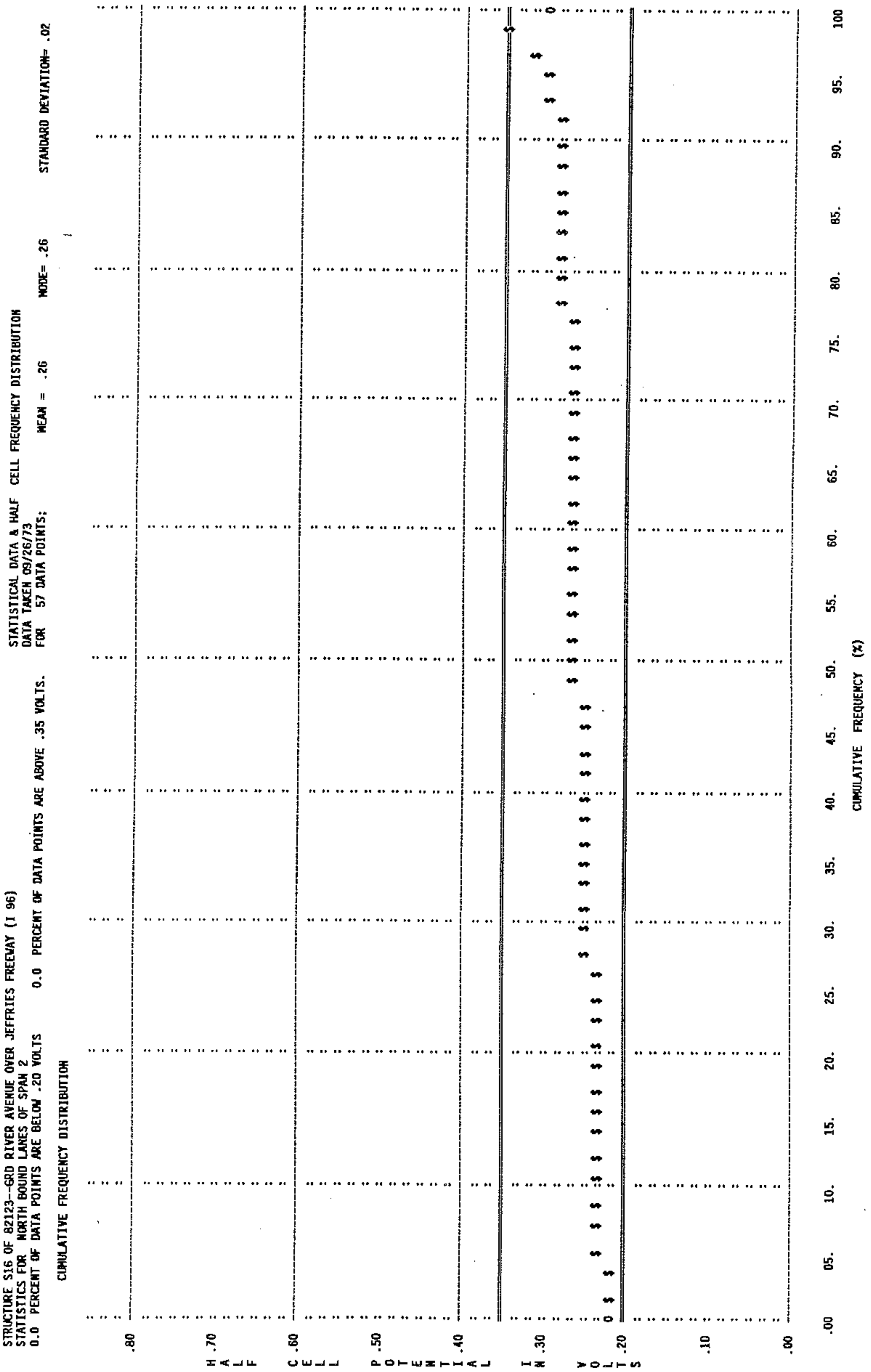


RESEARCH PROJECT 68F-103--GALVANIZED STEEL REINFORCED CONCRETE BRIDGE DECKS
STRUCTURE S16 OF 82123--GRD RIVER AVENUE OVER JEFFRIES FREEWAY (I 96)
SPANS 1 & 2--GALVANIZED REINFORCEMENT SPANS 3 & 4--UNCOATED REINFORCEMENT

EQUIPOTENTIAL CURVES FOR NORTH BOUND LANES OF SPAN 2

DATA TAKEN 09/26/73

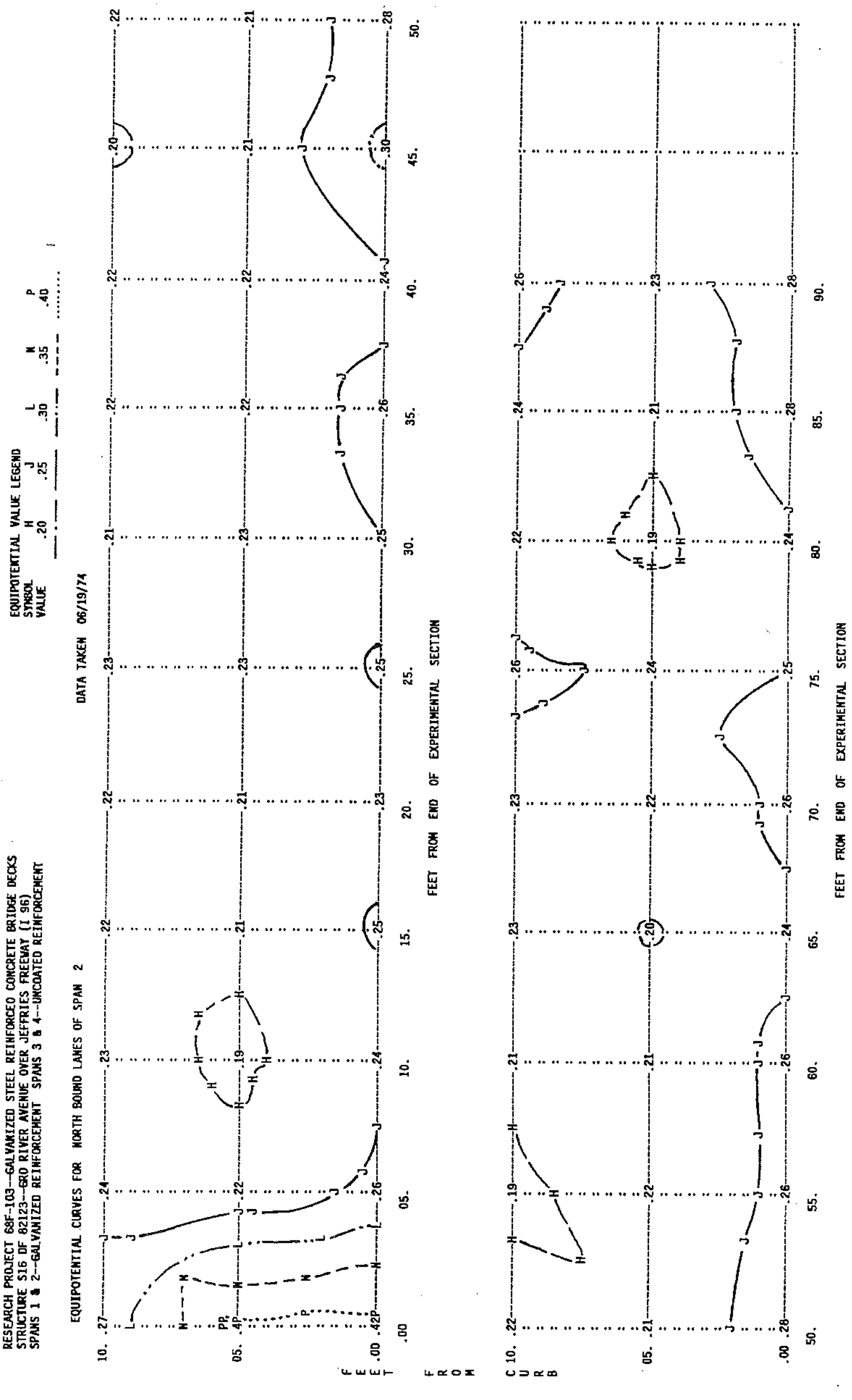
EQUIPOTENTIAL VALUE LEGEND						
SYMBOL	I	J	K	L	M	N
VALUE	.22	.25	.27	.30	.32	.35



STRUCTURE S16 OF 82123--GRD RIVER AVENUE OVER JEFFRIES FREEWAY (I 96)
STATISTICS FOR NORTH BOUND LANES OF SPAN 2
0.0 PERCENT OF DATA POINTS ARE BELOW .20 VOLTS
0.0 PERCENT OF DATA POINTS ARE ABOVE .35 VOLTS.

STATISTICAL DATA & HALF CELL FREQUENCY DISTRIBUTION
DATA TAKEN 09/26/73
FOR 57 DATA POINTS; MEAN = .26 MODE= .26 STANDARD DEVIATION= .02

CUMULATIVE FREQUENCY DISTRIBUTION


RESEARCH PROJECT 68F-103--GALVANIZED STEEL REINFORCED CONCRETE BRIDGE DECKS
STRUCTURE S16 OF 82123--GRD RIVER AVENUE OVER JEFFRIES FREEWAY (I 96)
SPANS 1 & 2--GALVANIZED REINFORCEMENT SPANS 3 & 4--UNCOATED REINFORCEMENT
EQUIPOTENTIAL CURVES FOR NORTH BOUND LANES OF SPAN 2
DATA TAKEN 06/19/74
EQUIPOTENTIAL VALUE LEGEND
SYMBOL H J L N P
VALUE .20 .25 .30 .35 .40
FEET FROM END OF EXPERIMENTAL SECTION
FEET FROM CURB
10.
05.
.00
00.
05.
10.
15.
20.
25.
30.
35.
40.
45.
50.
55.
60.
65.
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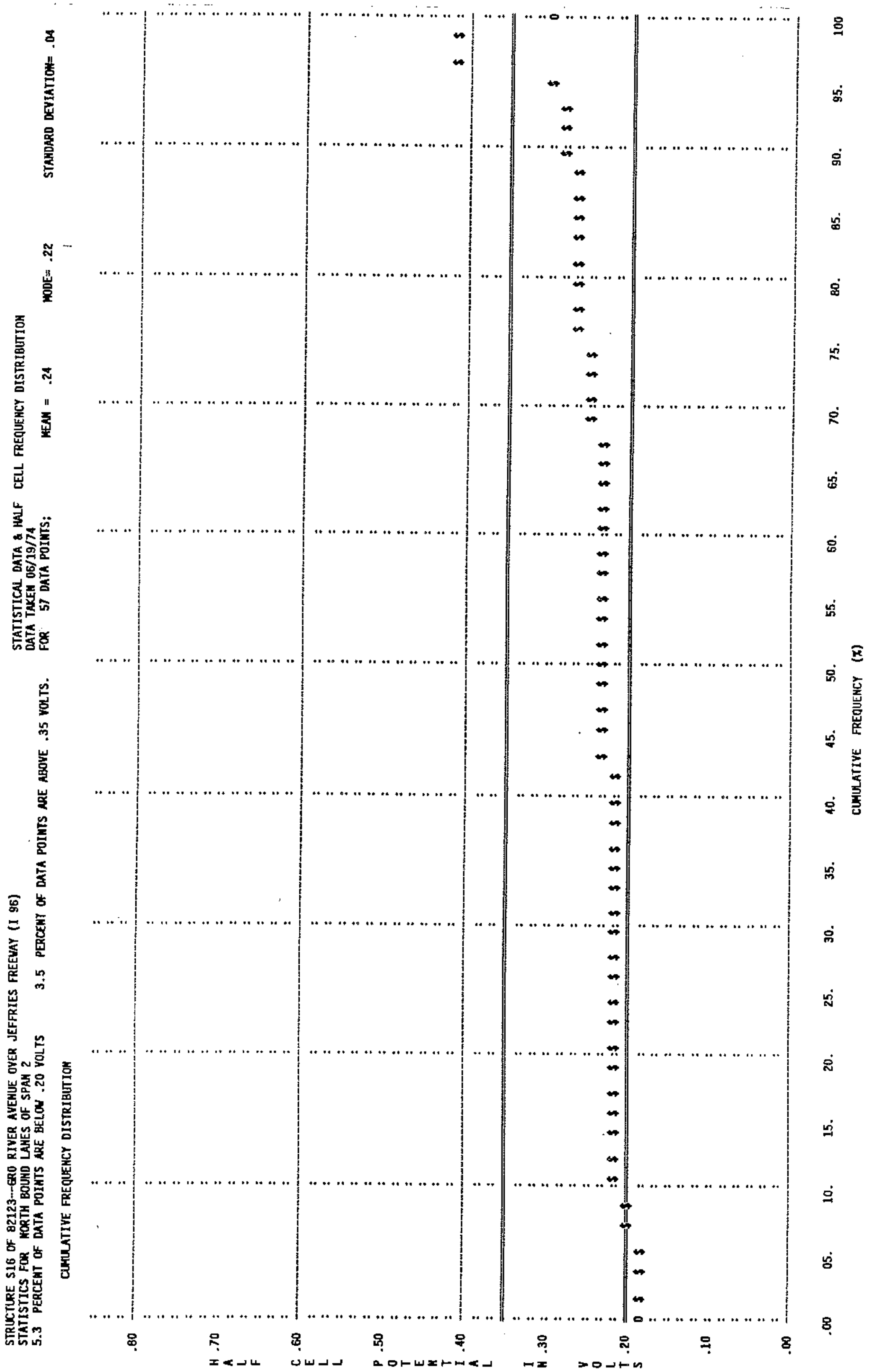
75.
80.
85.
90.



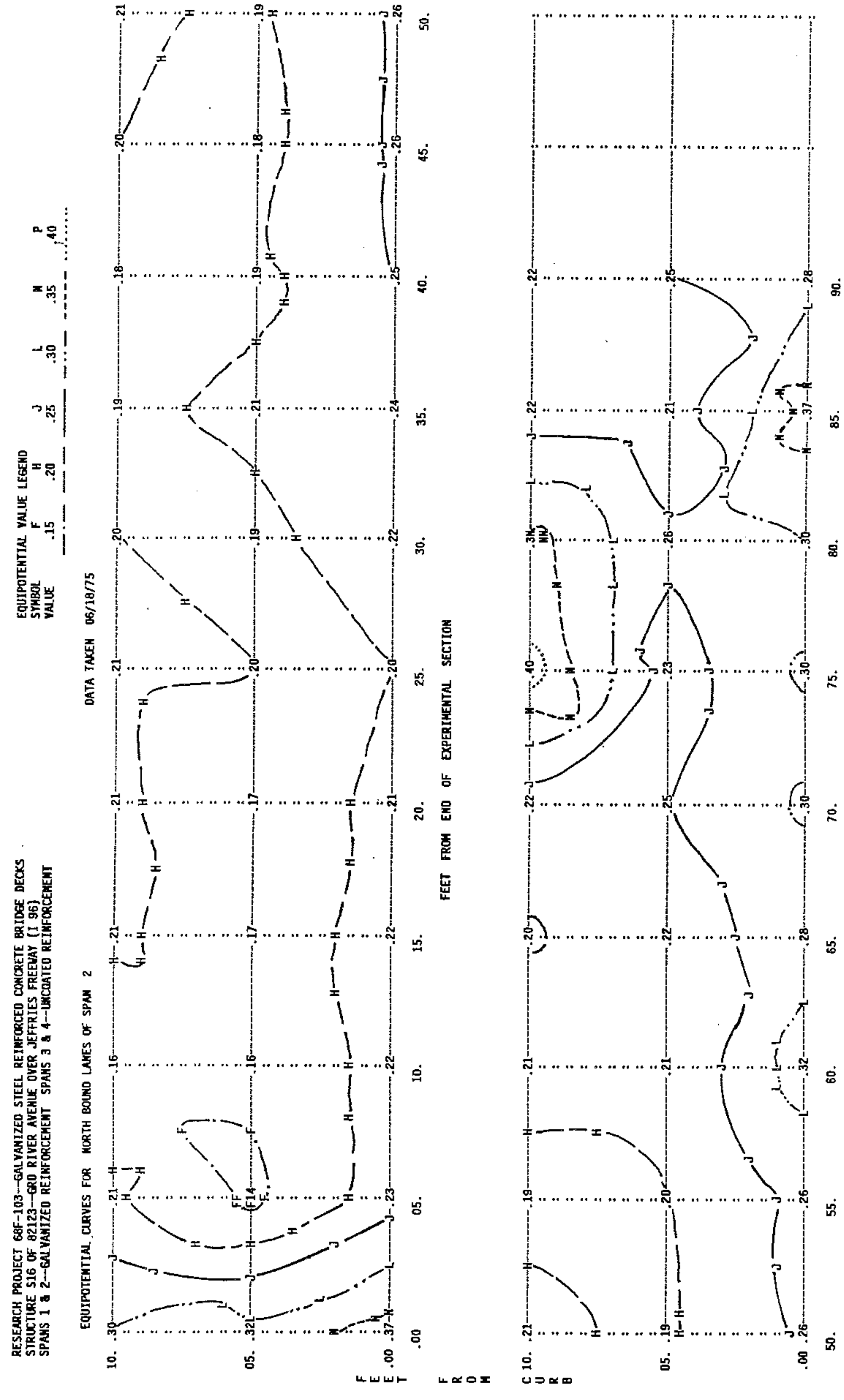
STRUCTURE S16 OF 82123--GRD RIVER AVENUE OVER JEFFRIES FREEWAY (I 96)
STATISTICS FOR NORTH BOUND LANES OF SPAN 2
5.3 PERCENT OF DATA POINTS ARE BELOW .20 VOLTS
3.5 PERCENT OF DATA POINTS ARE ABOVE .35 VOLTS.

STATISTICAL DATA & HALF CELL FREQUENCY DISTRIBUTION
DATA TAKEN 06/19/74
FOR 57 DATA POINTS;
MEAN = .24
MODE= .22
STANDARD DEVIATION= .04

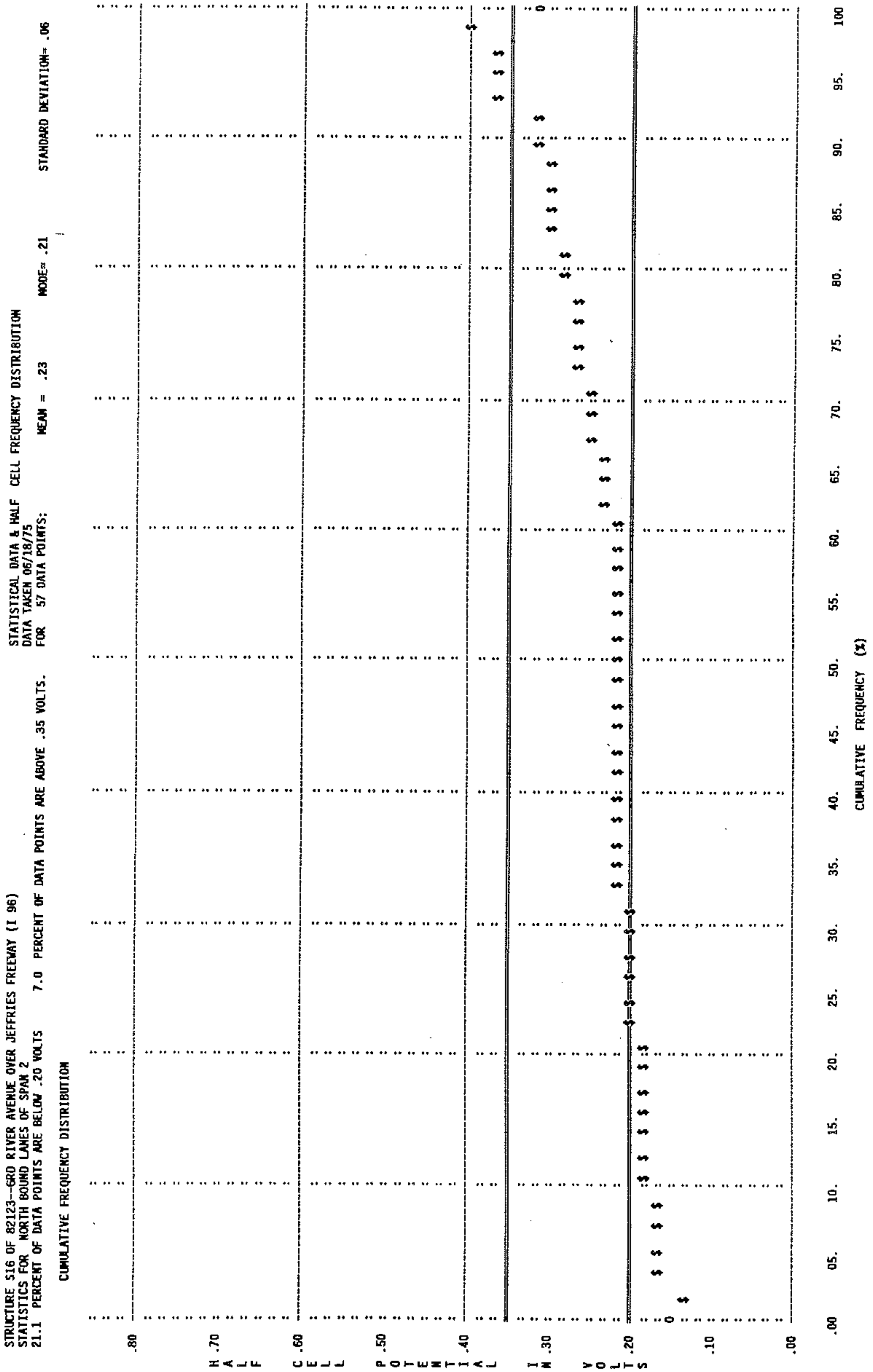
CUMULATIVE FREQUENCY DISTRIBUTION

Grand River Avenue--North Bound Span 2 (Galvanized--top mat only) Half Cell Equipotential Plot

Data Taken 06/19/74



Grand River Avenue--North Bound Span 2 (Galvanized--top mat only)
Cumulative Frequency Distribution
Data Taken D6/19/74



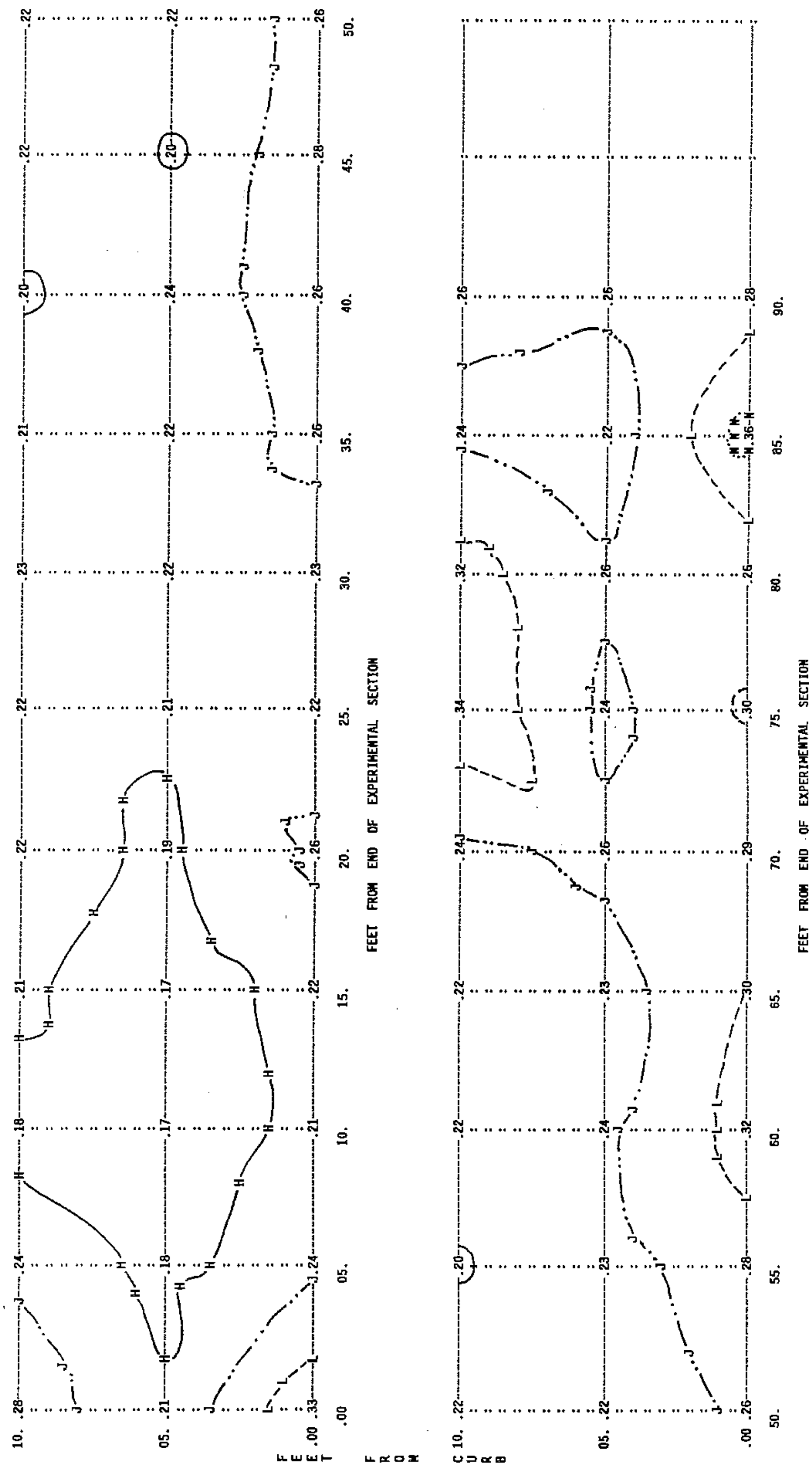
RESEARCH PROJECT 68F-103--GALVANIZED STEEL REINFORCED CONCRETE BRIDGE DECKS
STRUCTURE S16 OF 82123--GRD RIVER AVENUE OVER JEFFRIES FREEWAY (I 96)
SPANS 1 & 2--GALVANIZED REINFORCEMENT SPANS 3 & 4--UNCOATED REINFORCEMENT

EQUIPOTENTIAL CURVES FOR NORTH BOUND LANES OF SPAN 2

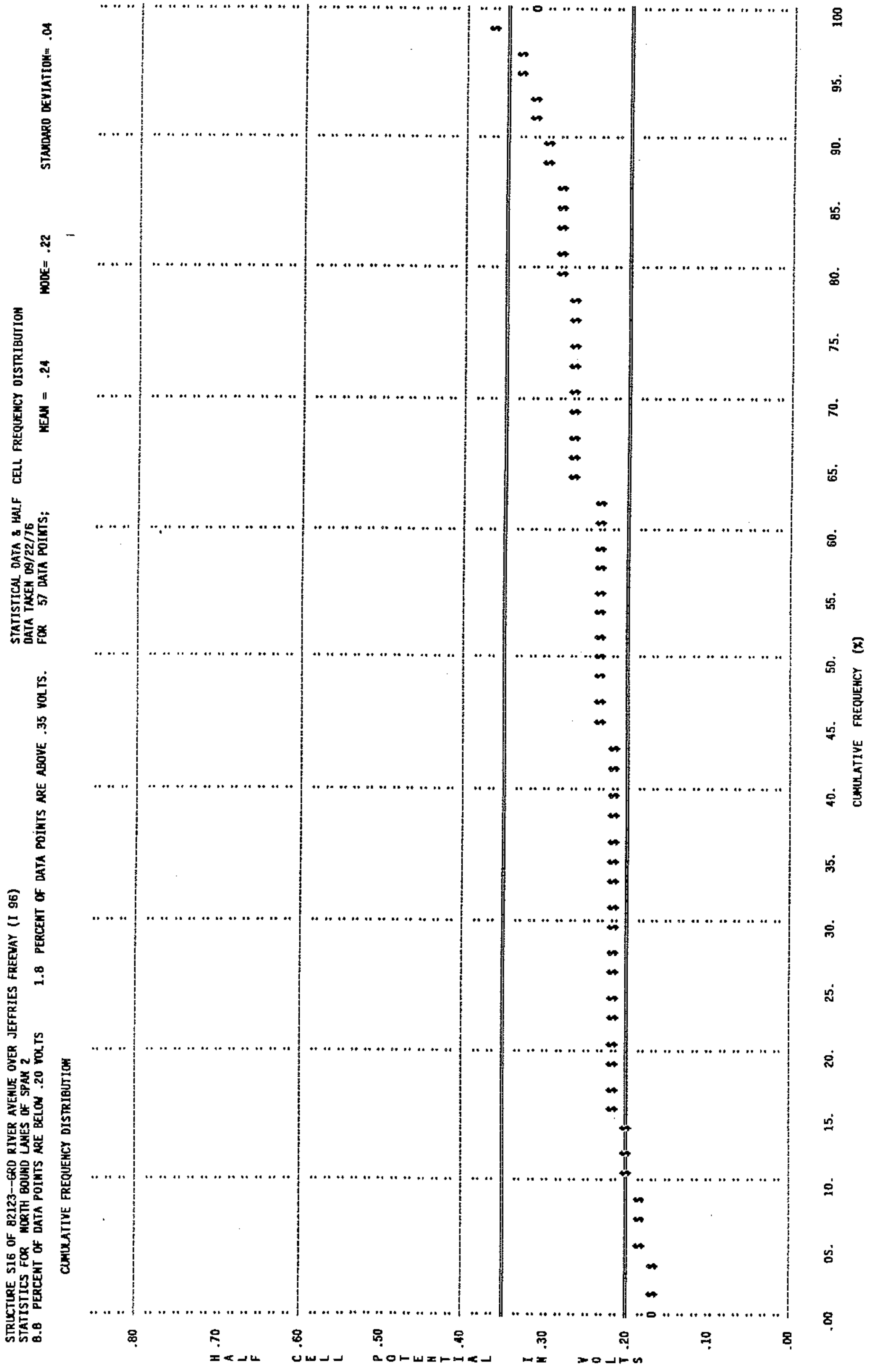
EQUIPOTENTIAL VALUE LEGEND

SYMBOL	H	J	L	M
VALUE	.20	.25	.30	.35

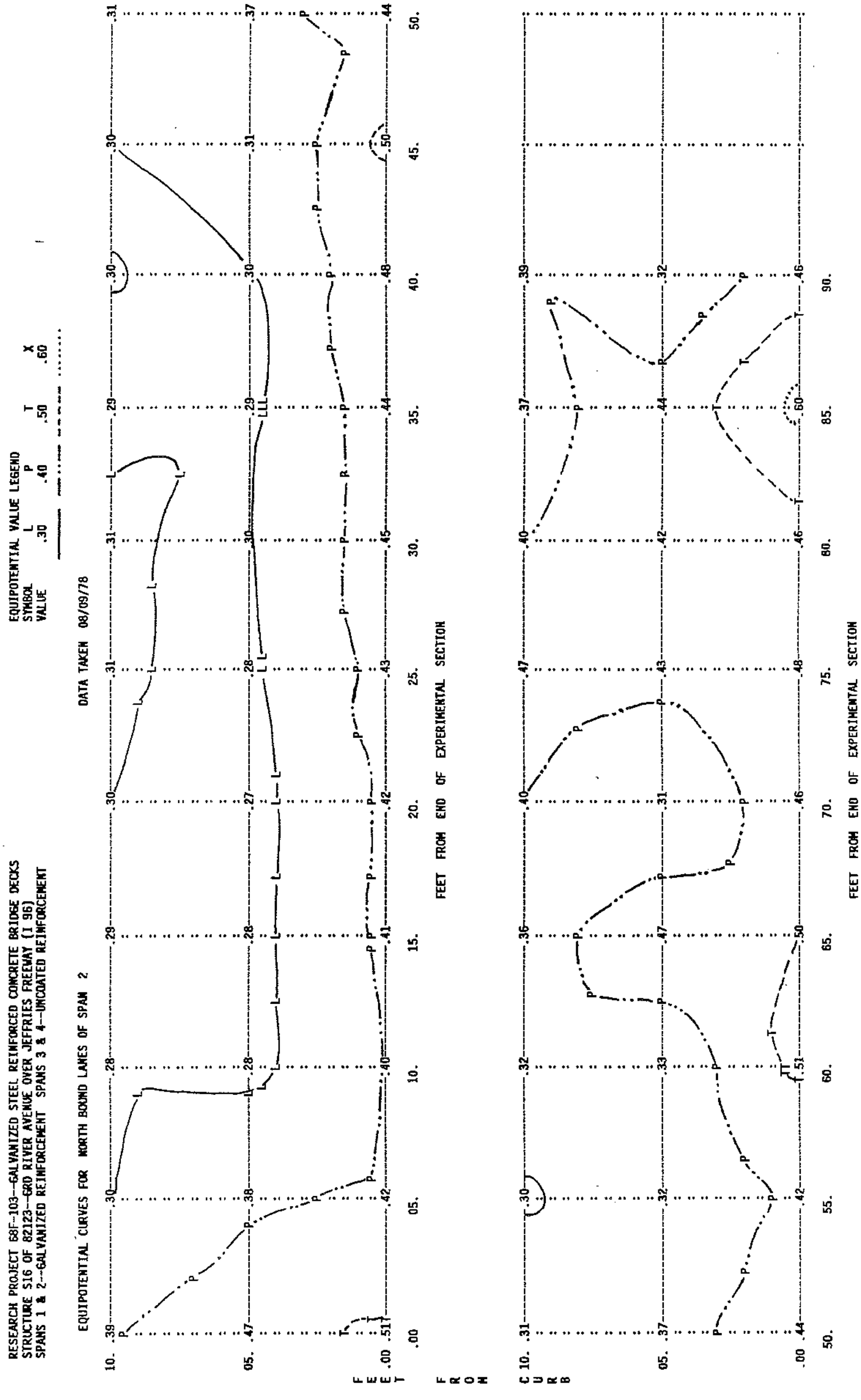
DATA TAKEN 09/22/76



Appendix B (Continued)
Grand River Avenue--North Bound Span 2 (Galvanized--top mat only)
Data Taken 06/18/75



Grand River Avenue--North Bound Span 2 (Galvanized--top mat only)
Data Taken 09/22/76



RESEARCH PROJECT 68F-103--GALVANIZED STEEL REINFORCED CONCRETE BRIDGE DECKS
STRUCTURE S16 OF 82123--GRD RIVER AVENUE OVER JEFFRIES FREEWAY (I 96)
SPANS 1 & 2--GALVANIZED REINFORCEMENT SPANS 3 & 4--UNCOATED REINFORCEMENT

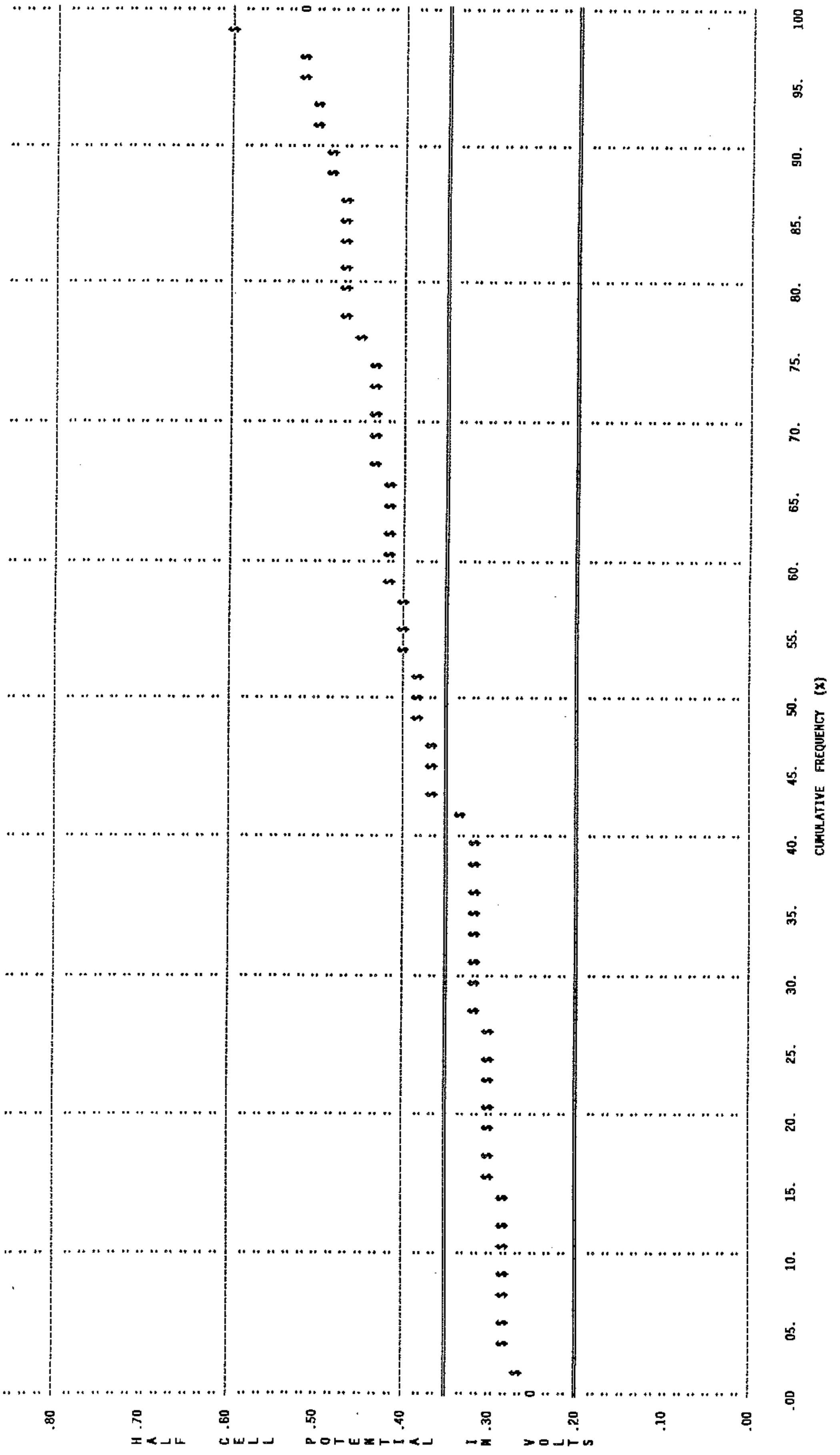
EQUIPOTENTIAL CURVES FOR NORTH BOUND LANES OF SPAN 2

DATA TAKEN 08/09/78

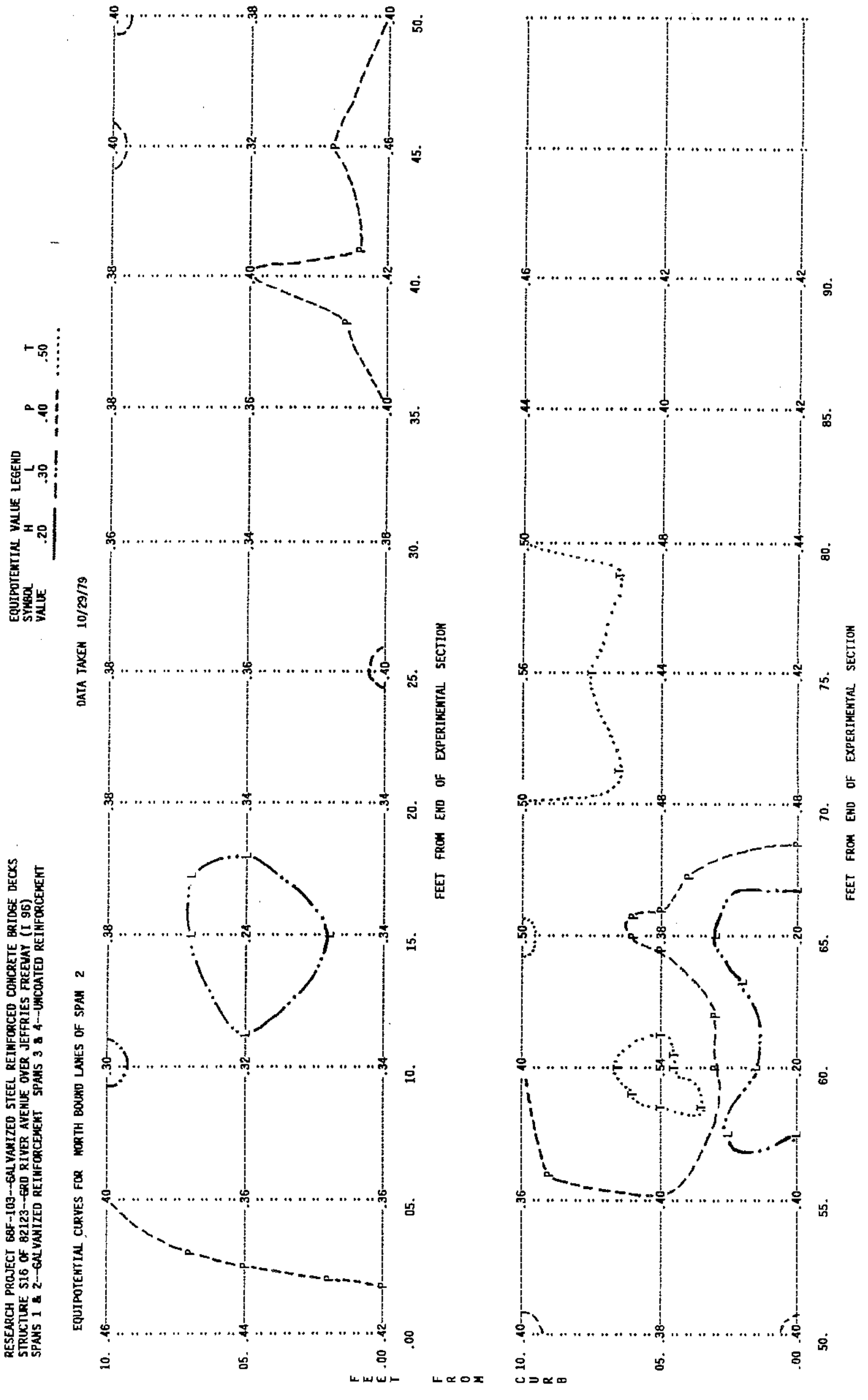
STRUCTURE S16 OF 82123--GRD RIVER AVENUE OVER JEFFRIES FREEWAY (I 96)
STATISTICS FOR NORTH BOUND LANES OF SPAN 2
D.0 PERCENT OF DATA POINTS ARE BELOW .20 VOLTS 57.9 PERCENT OF DATA POINTS ARE ABOVE .35 VOLTS.

STATISTICAL DATA & HALF CELL FREQUENCY DISTRIBUTION
DATA TAKEN 08/09/78
FOR 57 DATA POINTS; MEAN = .38 MODE= .30 STANDARD DEVIATION= .08

CUMULATIVE FREQUENCY DISTRIBUTION



Grand River Avenue--North Bound Span 2 (Galvanized--top mat only) Half Cell Equipotential Plot
Data Taken 08/09/78



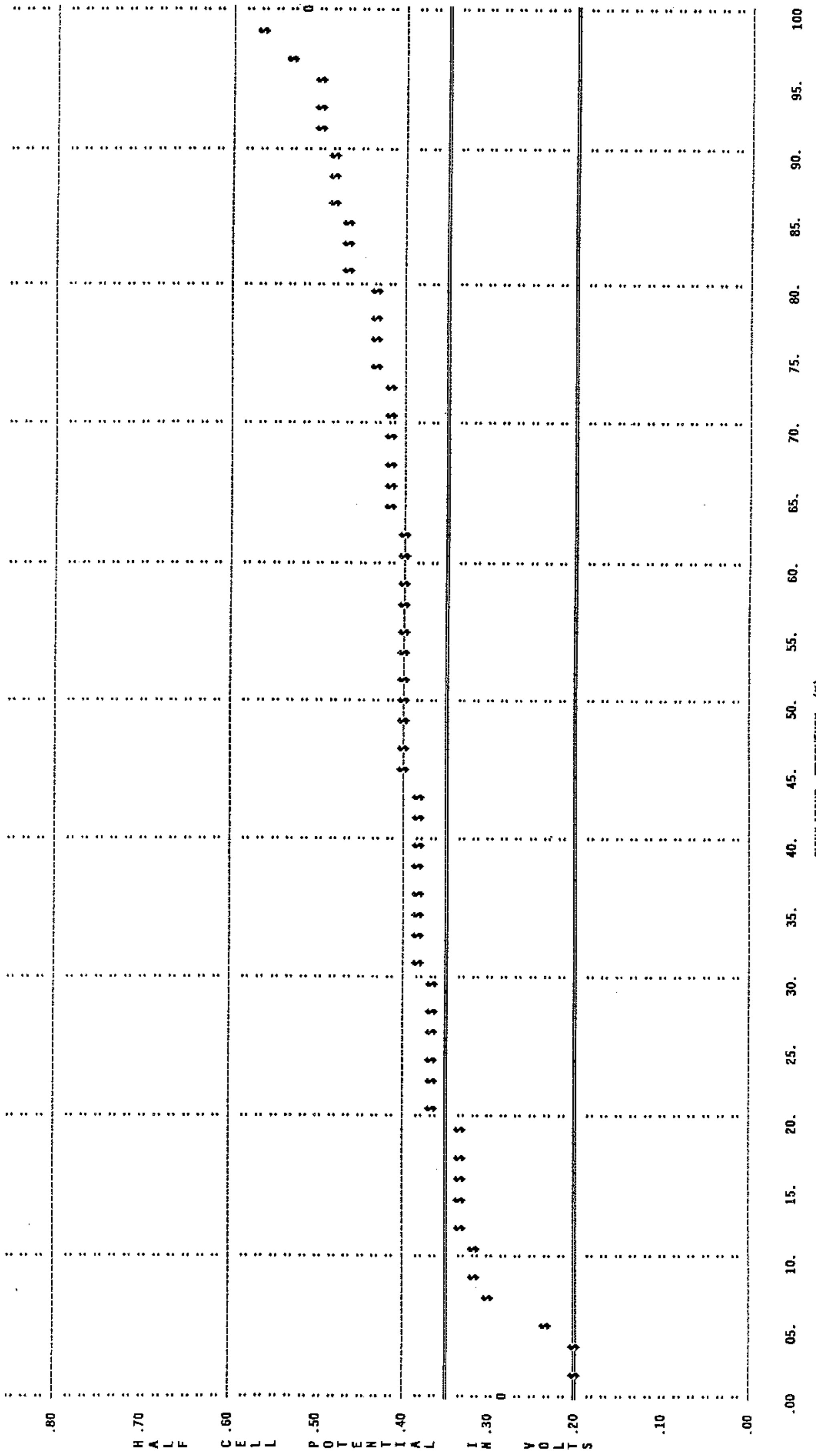
RESEARCH PROJECT 68F-103--GALVANIZED STEEL REINFORCED CONCRETE BRIDGE DECKS
STRUCTURE S16 OF 82123--GRD RIVER AVENUE OVER JEFFRIES FREEWAY (I 96)
SPANS 1 & 2--GALVANIZED REINFORCEMENT SPANS 3 & 4--UNCOATED REINFORCEMENT

EQUIPOTENTIAL CURVES FOR NORTH BOUND LANES OF SPAN 2

DATA TAKEN 10/29/79

EQUIPOTENTIAL VALUE LEGEND

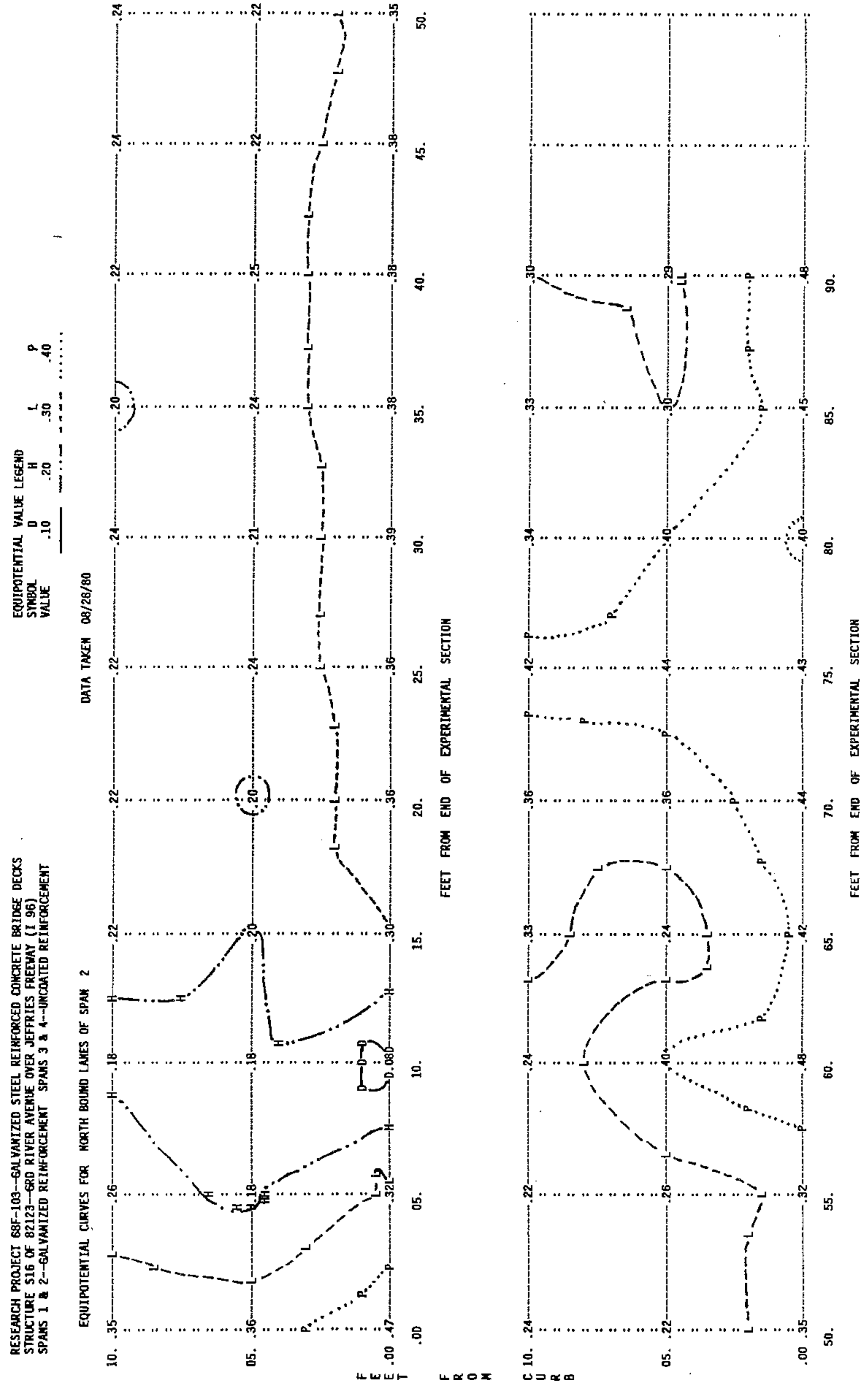
SYMBOL	H	L	P	T
VALUE	.20	.30	.40	.50



STRUCTURE S16 OF 82123--GRD RIVER AVENUE OVER JEFFRIES FREEWAY (I 96)
STATISTICS FOR NORTH BOUND LANES OF SPAN 2
0.0 PERCENT OF DATA POINTS ARE BELOW .20 VOLTS 80.7 PERCENT OF DATA POINTS ARE ABOVE .35 VOLTS.

STATISTICAL DATA & HALF CELL FREQUENCY DISTRIBUTION
DATA TAKEN 10/29/79
FOR 57 DATA POINTS; MEAN = .40 MODE= .40 STANDARD DEVIATION= .07

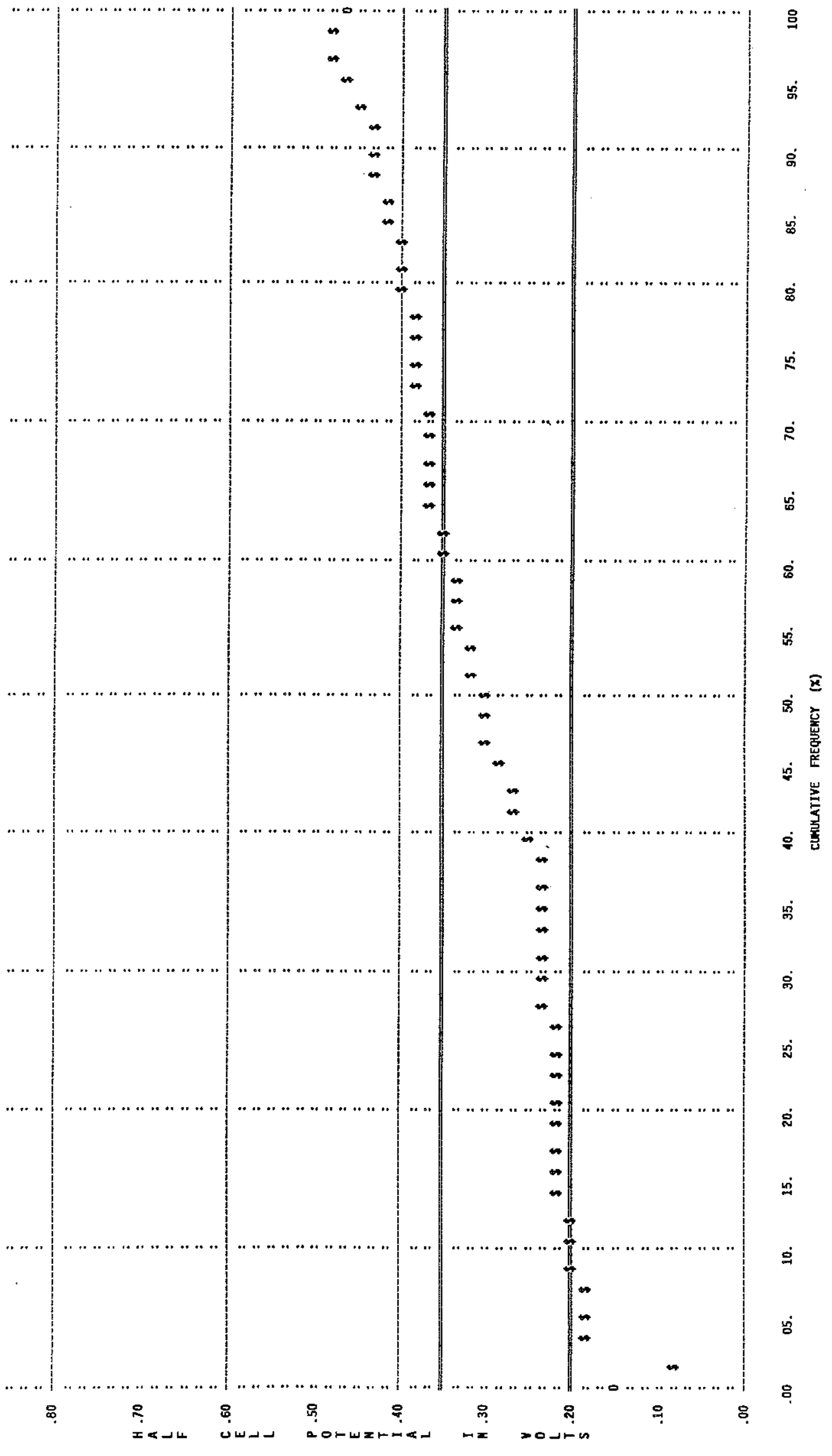
CUMULATIVE FREQUENCY DISTRIBUTION


RESEARCH PROJECT 68F-103--GALVANIZED STEEL REINFORCED CONCRETE BRIDGE DECKS
STRUCTURE S16 OF 82123--GRD RIVER AVENUE OVER JEFFRIES FREEWAY (I 96)
SPANS 1 & 2--GALVANIZED REINFORCEMENT SPANS 3 & 4--UNCOATED REINFORCEMENT
EQUIPOTENTIAL CURVES FOR NORTH BOUND LANES OF SPAN 2
DATA TAKEN 08/28/80
EQUIPOTENTIAL VALUE LEGEND
SYMBOL D H L P
VALUE .10 .20 .30 .40
FEET FROM END OF EXPERIMENTAL SECTION
FEET FROM CURB
.00 05. 10. 15. 20. 25. 30. 35. 40. 45. 50.
50. 55. 60. 65. 70. 75. 80. 85. 90.
.00 05. 10.

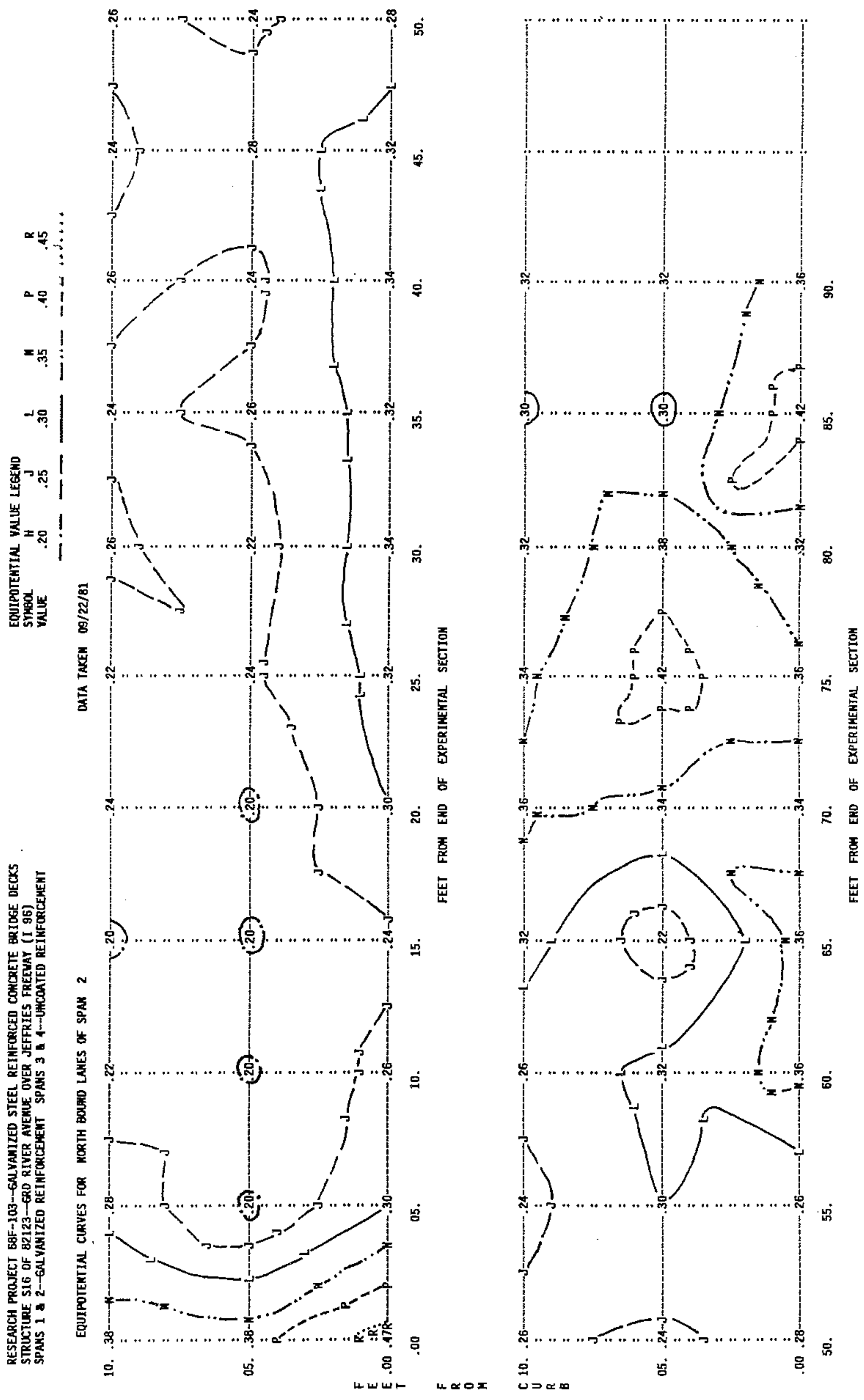
STRUCTURE S16 OF 82123--GRD RIVER AVENUE OVER JEFFRIES FREEWAY (I 96)
STATISTICS FOR NORTH BOUND LANES OF SPAN 2
7.0 PERCENT OF DATA POINTS ARE BELOW .20 VOLTS 36.8 PERCENT OF DATA POINTS ARE ABOVE .35 VOLTS.

STATISTICAL DATA & HALF CELL FREQUENCY DISTRIBUTION
DATA TAKEN 08/28/80
FOR 57 DATA POINTS; MEAN = .31 MODE= .22 STANDARD DEVIATION= .09

CUMULATIVE FREQUENCY DISTRIBUTION



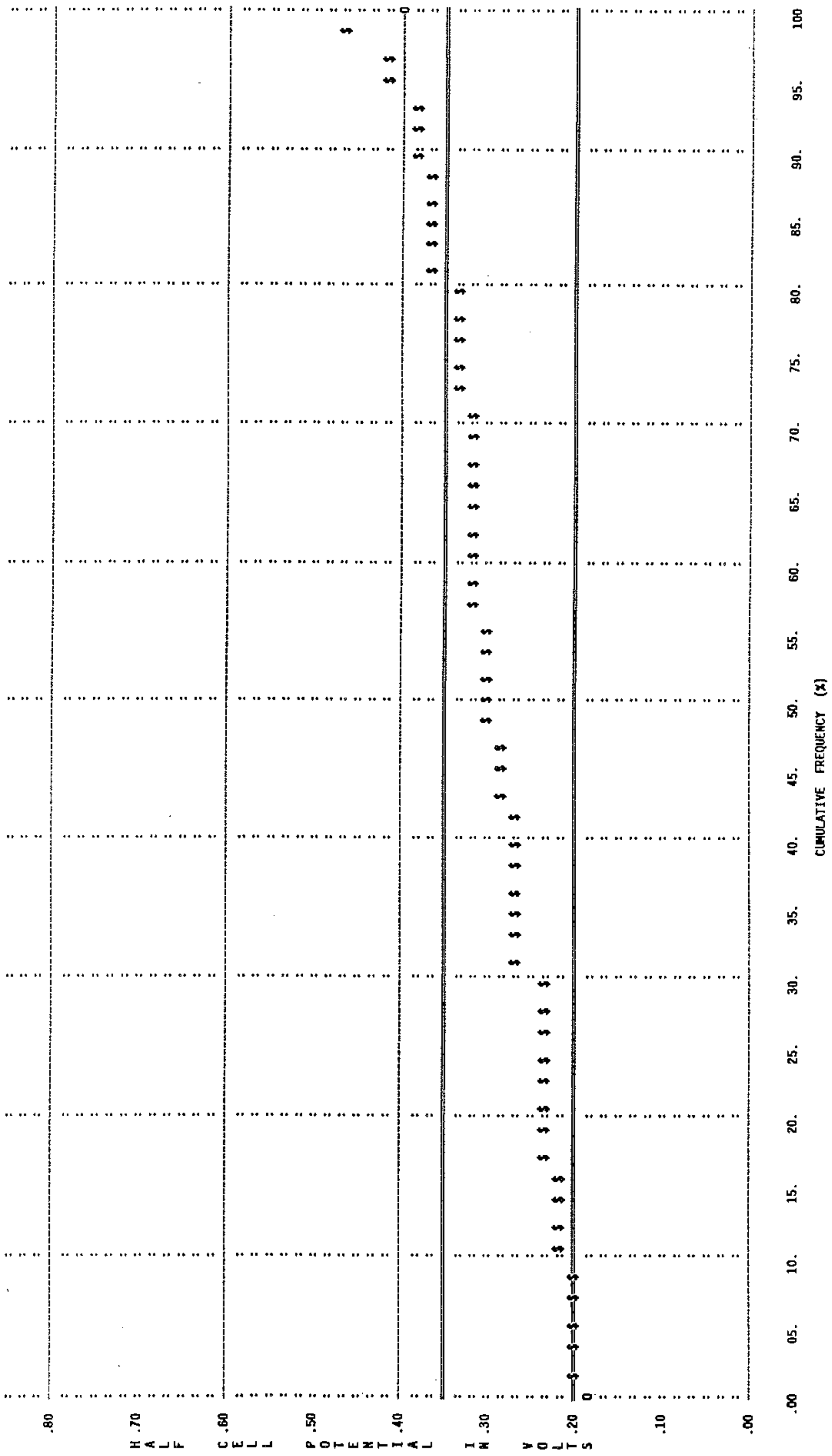
Appendix B (Continued)
Grand River Avenue--North Bound Span 2 (Galvanized--top mat only)
Data Taken 08/28/80

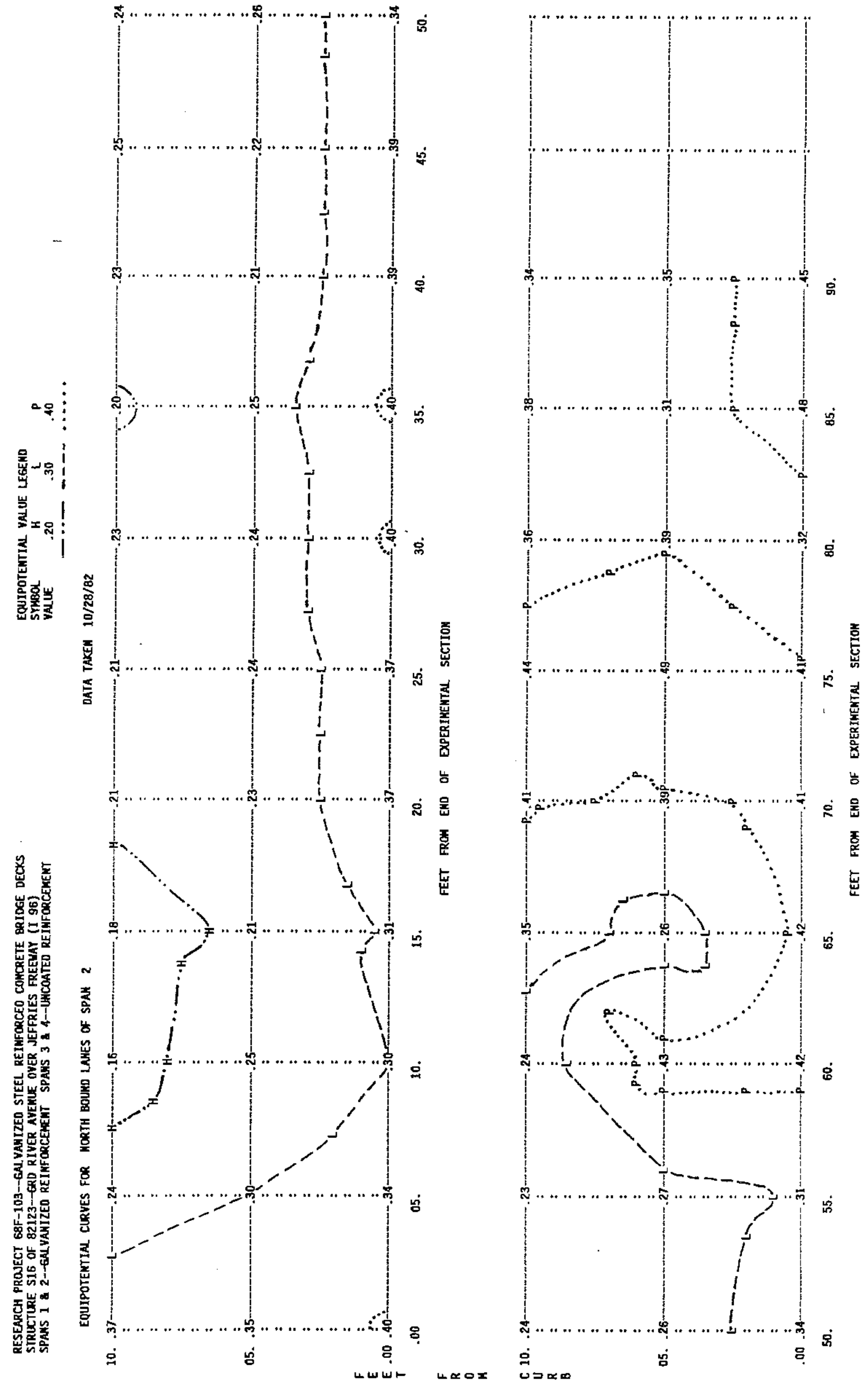


STRUCTURE S16 OF 82123--GRD RIVER AVENUE OVER JEFFRIES FREEWAY (I 96)
STATISTICS FOR NORTH BOUND LANES OF SPAN 2
0.0 PERCENT OF DATA POINTS ARE BELOW .20 VOLTS 19.3 PERCENT OF DATA POINTS ARE ABOVE .35 VOLTS.

STATISTICAL DATA & HALF CELL FREQUENCY DISTRIBUTION
DATA TAKEN 09/22/81
FOR 57 DATA POINTS; MEAN = .29 MODE= .32 STANDARD DEVIATION= .06

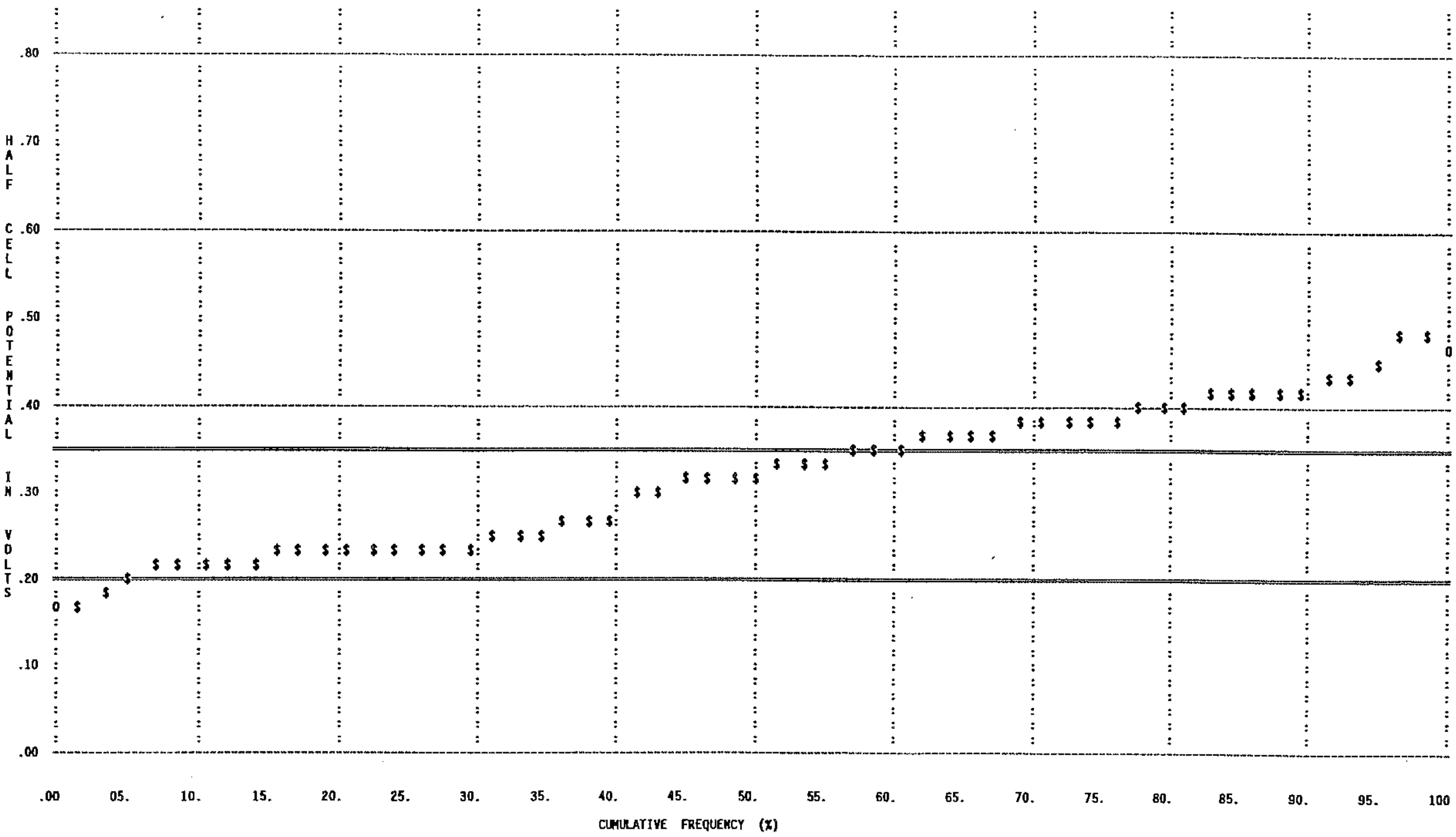
CUMULATIVE FREQUENCY DISTRIBUTION

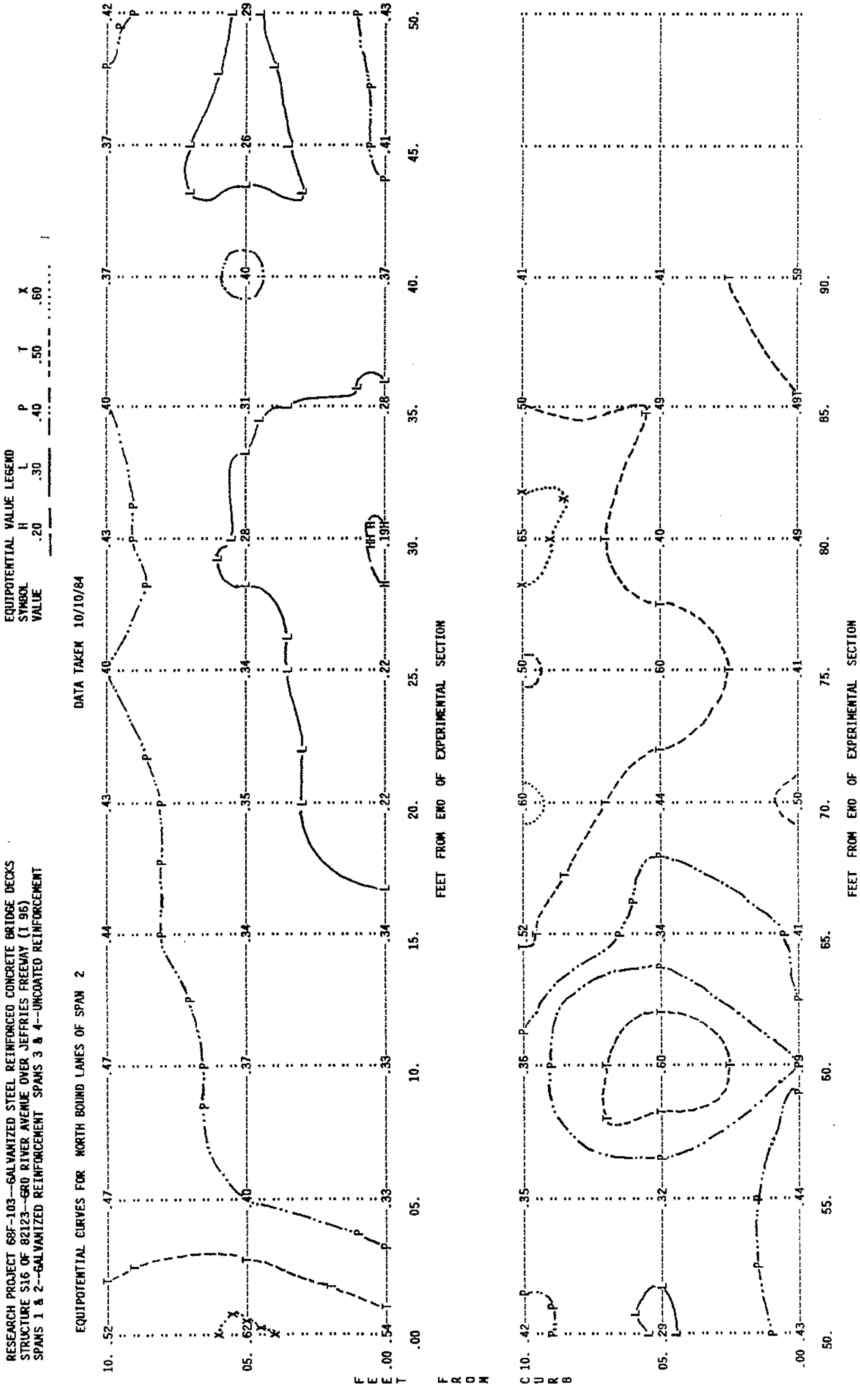



RESEARCH PROJECT 68F-103--GALVANIZED STEEL REINFORCED CONCRETE BRIDGE DECKS
STRUCTURE S16 OF 82123--GRD RIVER AVENUE OVER JEFFRIES FREEWAY (I 96)
SPANS 1 & 2--GALVANIZED REINFORCEMENT SPANS 3 & 4--UNCOATED REINFORCEMENT
EQUIPOTENTIAL CURVES FOR NORTH BOUND LANES OF SPAN 2
DATA TAKEN 10/28/82
EQUIPOTENTIAL VALUE LEGEND
SYMBOL H L P
VALUE .20 .30 .40
FEET FROM CURB
FEET FROM END OF EXPERIMENTAL SECTION
.00
05.
10.
15.
20.
25.
30.
35.
40.
45.
50.
55.
60.
65.
70.
75.
80.
85.
90.
H
L
P

```
STRUCTURE S16 OF 82123--GRD RIVER AVENUE OVER JEFFRIES FREEWAY (I 96)                                    STATISTICAL DATA & HALF  CELL FREQUENCY DISTRIBUTION
STATISTICS FOR  NORTH BOUND LANES OF SPAN 2                                                              DATA TAKEN 10/28/82
3.5  PERCENT OF DATA POINTS ARE BELOW .20 VOLTS      38.6  PERCENT OF DATA POINTS ARE ABOVE .35 VOLTS.   FOR   57 DATA POINTS;        MEAN =  .32      MODE= .24      STANDARD DEVIATION= .09
```

CUMULATIVE FREQUENCY DISTRIBUTION

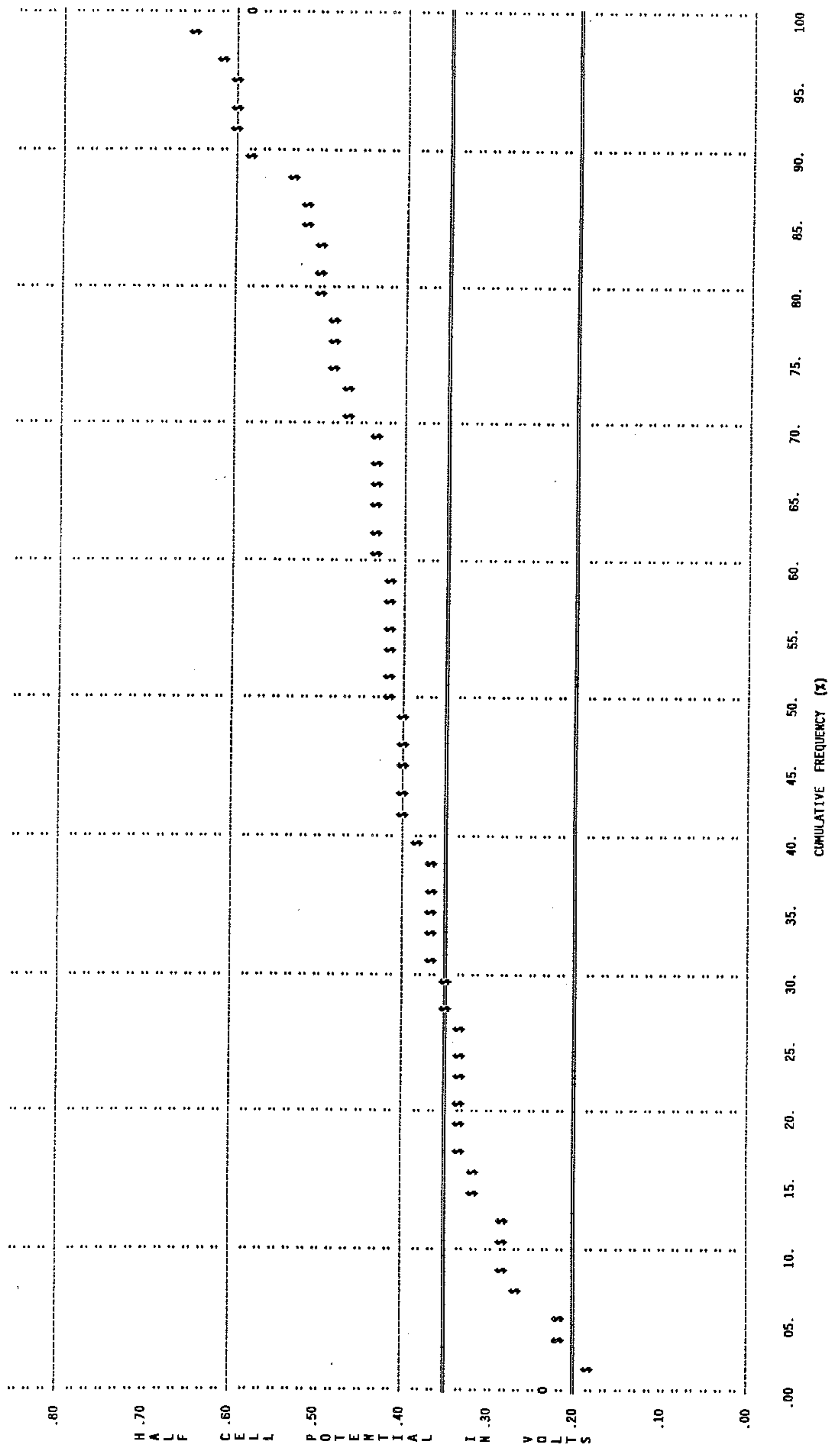


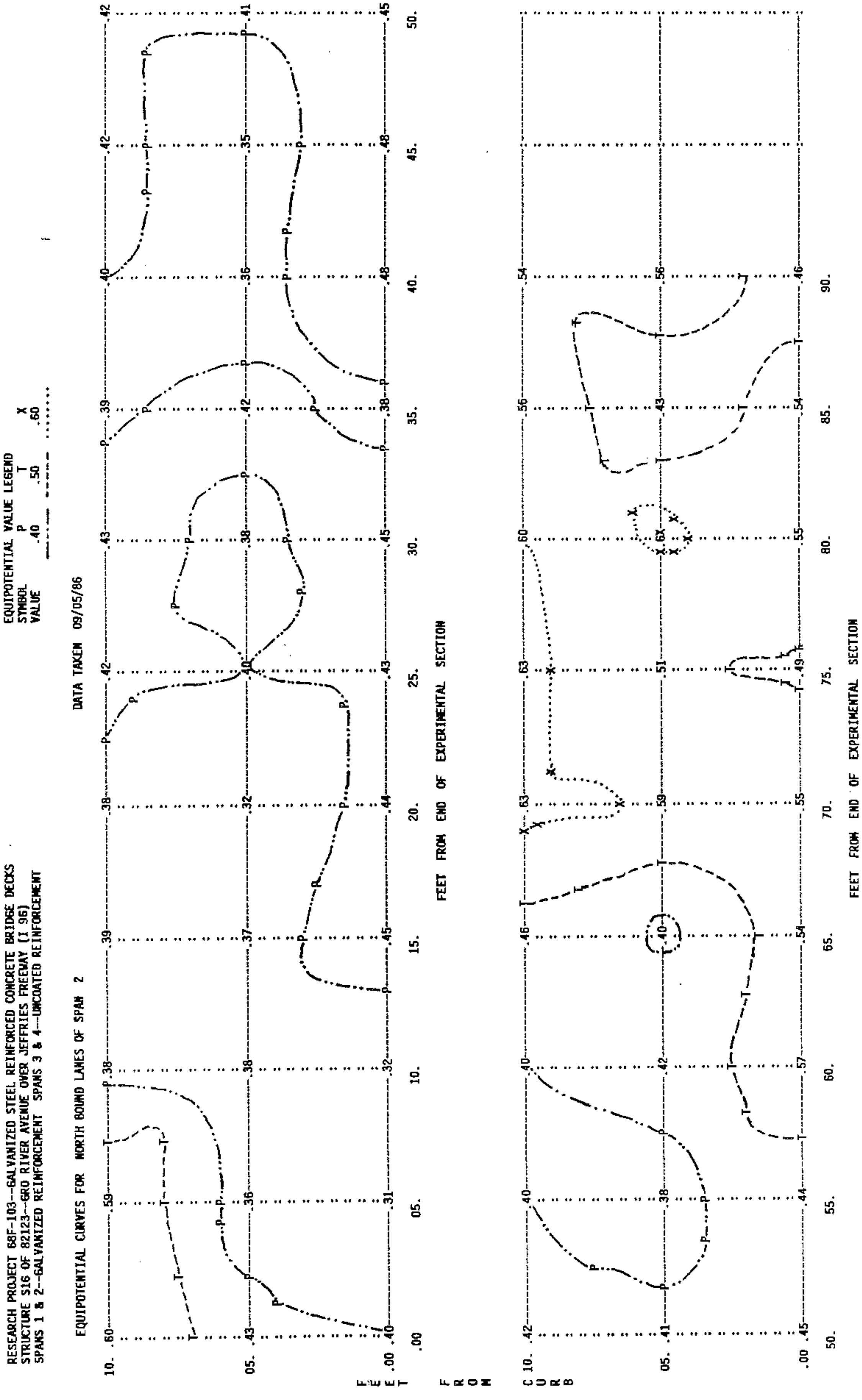

RESEARCH PROJECT 68F-103--GALVANIZED STEEL REINFORCED CONCRETE BRIDGE DECKS
STRUCTURE S16 OF 82123--GRD RIVER AVENUE OVER JEFFRIES FREEWAY (I 96)
SPANS 1 & 2--GALVANIZED REINFORCEMENT SPANS 3 & 4--UNCOATED REINFORCEMENT
EQUIPOTENTIAL CURVES FOR NORTH BOUND LANES OF SPAN 2
DATA TAKEN 10/10/84
EQUIPOTENTIAL VALUE LEGEND
SYMBOL H L P T X
VALUE .20 .30 .40 .50 .60
FEET FROM END OF EXPERIMENTAL SECTION
FEET FROM CURB
.00
05.
10.
15.
20.
25.
30.
35.
40.
45.
50.
55.
60.
65.
70.
75.
80.
85.
90.

STRUCTURE S16 OF B2123--GRD RIVER AVENUE OVER JEFFRIES FREEWAY (I 96)
STATISTICS FOR NORTH BOUND LANES OF SPAN 2
1.8 PERCENT OF DATA POINTS ARE BELOW .20 VOLTS 70.2 PERCENT OF DATA POINTS ARE ABOVE .35 VOLTS.

STATISTICAL DATA & HALF CELL FREQUENCY DISTRIBUTION
DATA TAKEN 10/10/84
FOR 57 DATA POINTS; MEAN = .41 MODE= .40 STANDARD DEVIATION= .10

CUMULATIVE FREQUENCY DISTRIBUTION




RESEARCH PROJECT 68F-103--GALVANIZED STEEL REINFORCED CONCRETE BRIDGE DECKS
STRUCTURE S16 OF 82123--GRD RIVER AVENUE OVER JEFFRIES FREEWAY (I 96)
SPANS 1 & 2--GALVANIZED REINFORCEMENT SPANS 3 & 4--UNCOATED REINFORCEMENT
EQUIPOTENTIAL CURVES FOR NORTH BOUND LANES OF SPAN 2
DATA TAKEN 09/05/86
EQUIPOTENTIAL VALUE LEGEND
SYMBOL P T X
VALUE .40 .50 .60
FEET FROM END OF EXPERIMENTAL SECTION
FEET FROM CURB
10.
05.
.00
.00
05.
10.
15.
20.
25.
30.
35.
40.
45.
50.
55.
60.
65.
70.
75.
80.
85.
90.
P
T
X

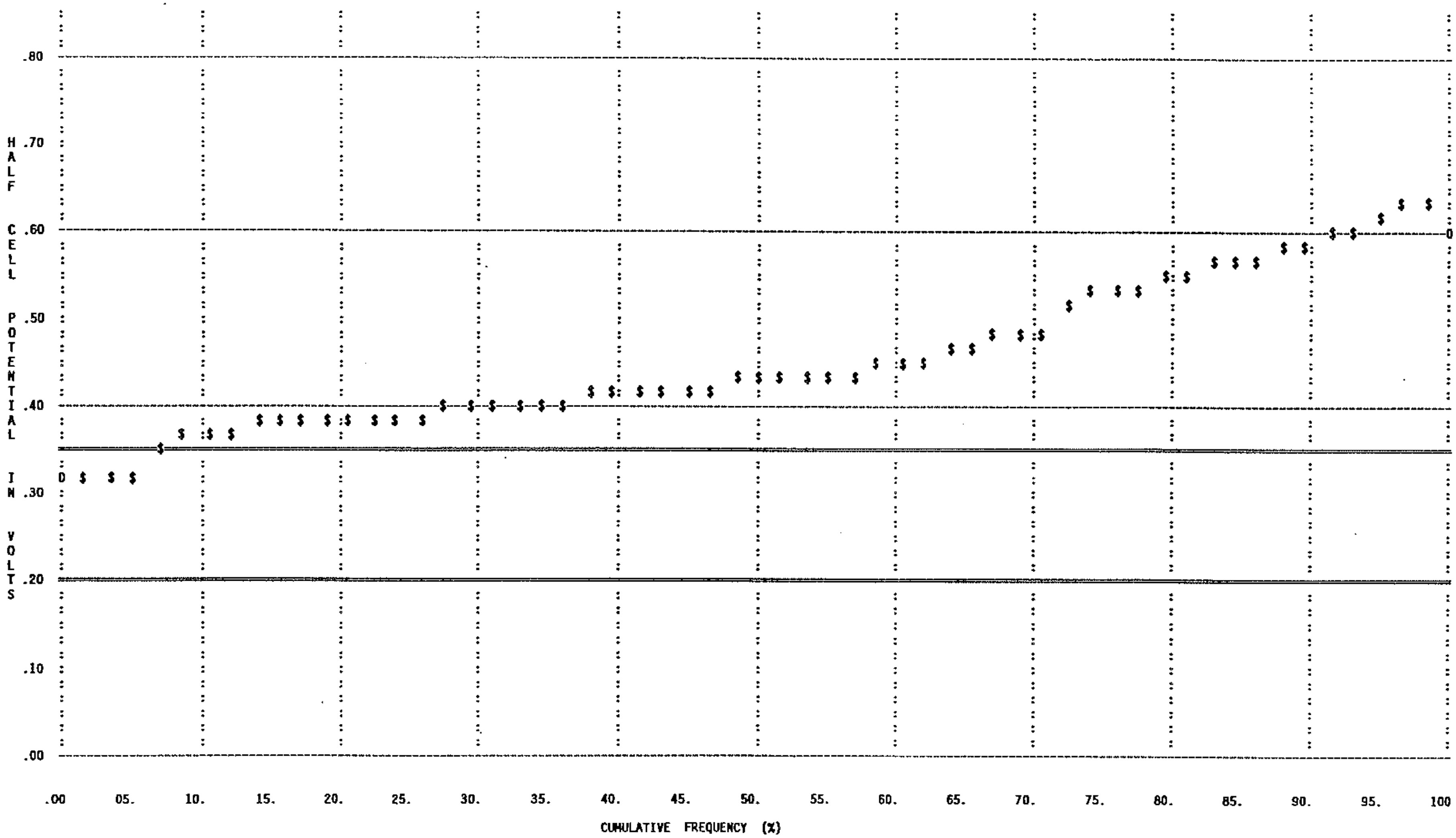
Grand River Avenue--North Bound Span 2 (Galvanized--top mat only)
Data Taken 10/10/84

Cumulative Frequency Distribution

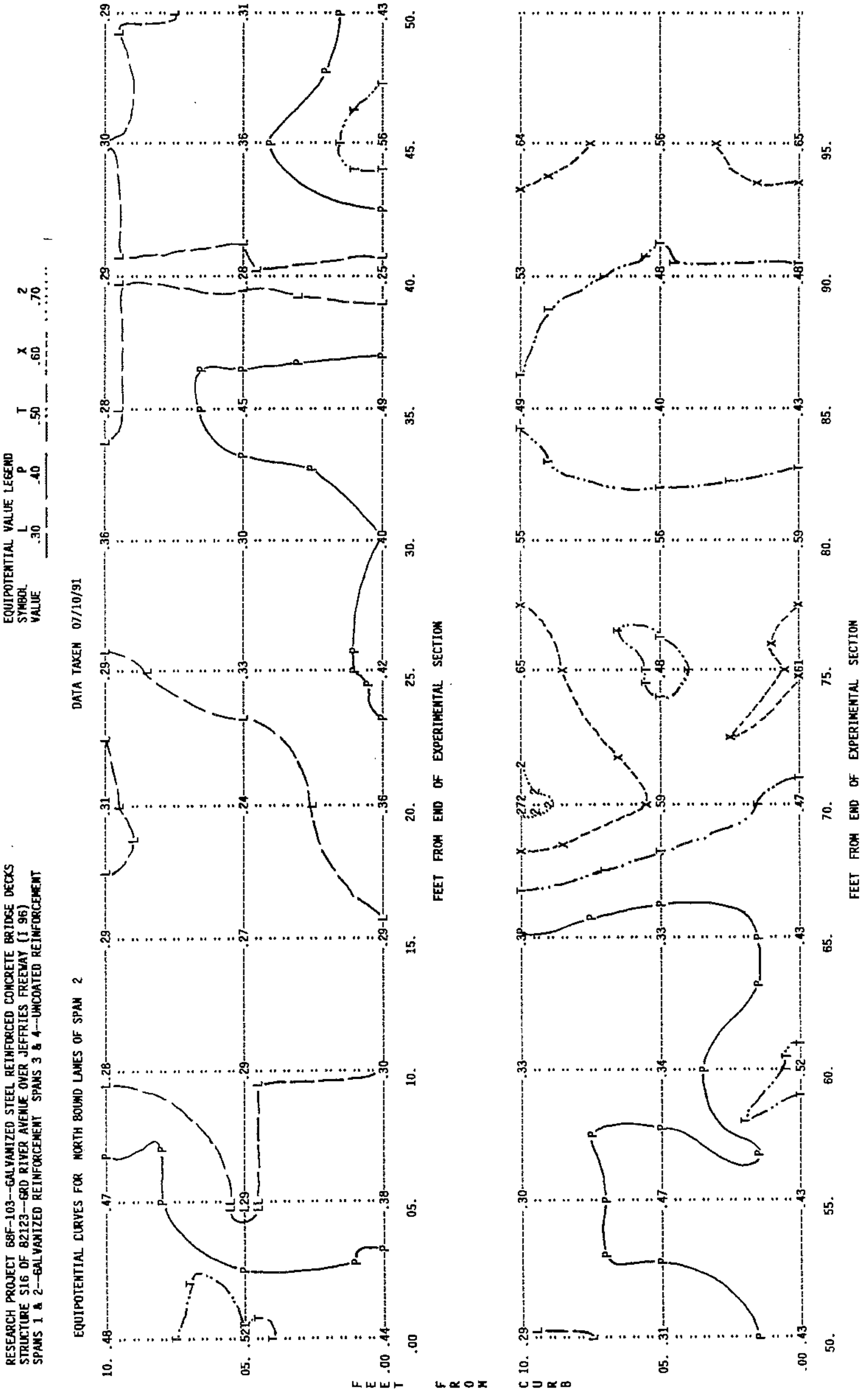
STRUCTURE S16 OF 82123--GRD RIVER AVENUE OVER JEFFRIES FREEWAY (I 96)
STATISTICS FOR NORTH BOUND LANES OF SPAN 2
0.0 PERCENT OF DATA POINTS ARE BELOW .20 VOLTS 93.0 PERCENT OF DATA POINTS ARE ABOVE .35 VOLTS.

STATISTICAL DATA & HALF CELL FREQUENCY DISTRIBUTION
DATA TAKEN 09/05/86
FOR 57 DATA POINTS; MEAN = .45 MODE= .38 STANDARD DEVIATION= .09

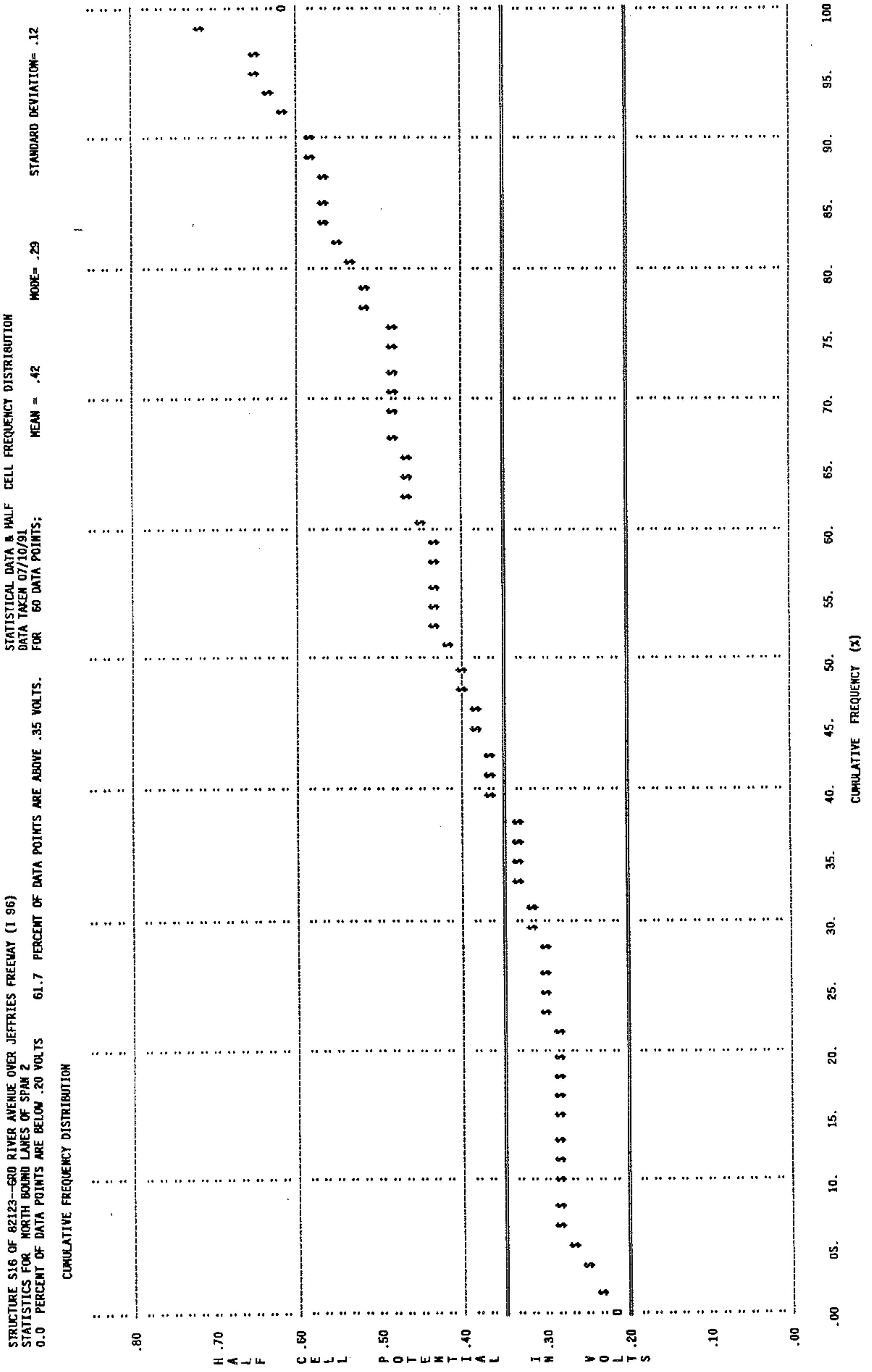
CUMULATIVE FREQUENCY DISTRIBUTION



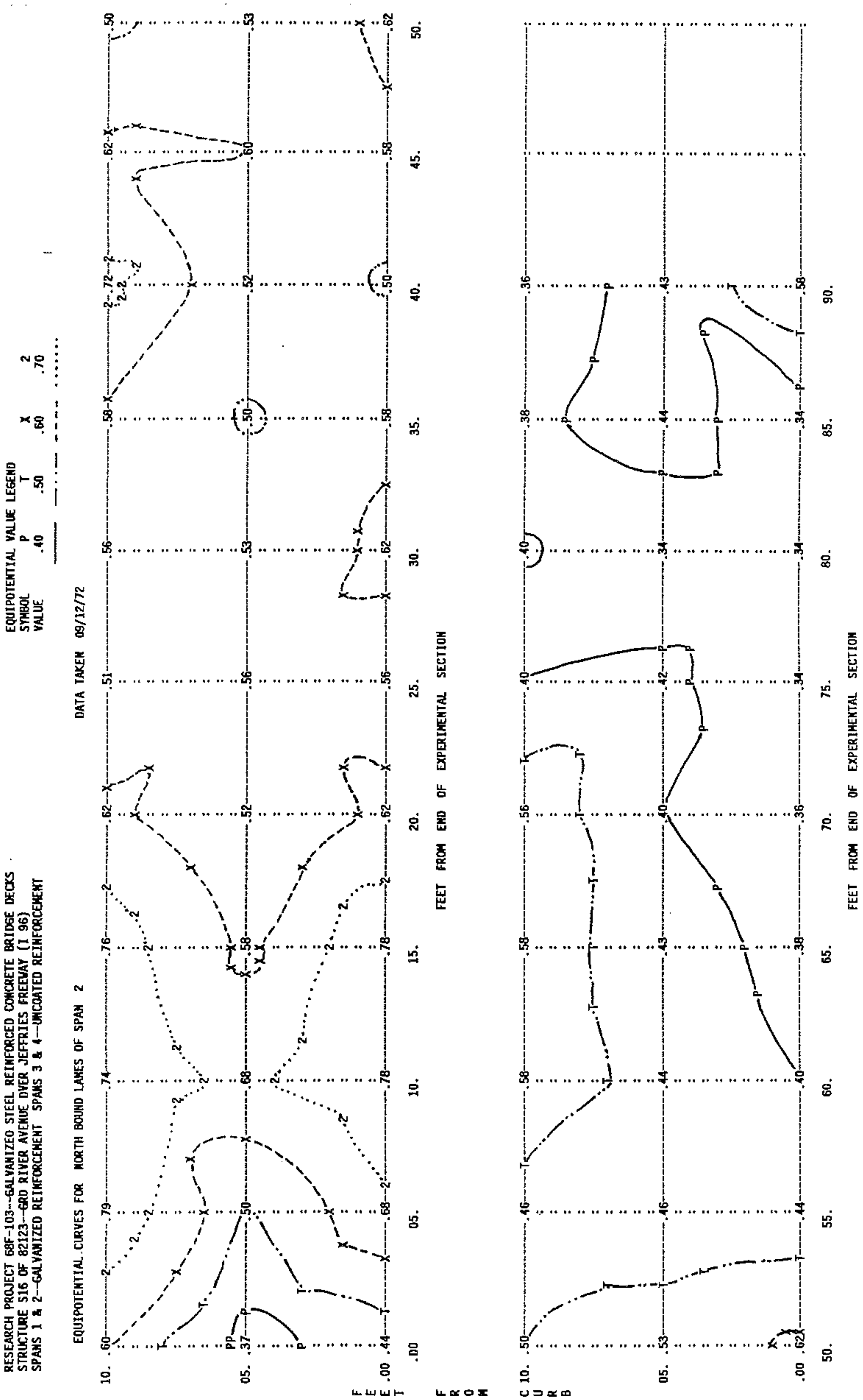
Grand River Avenue--North Bound Span 2 (Galvanized--top mat only) Half Cell Equipotential Plot
Data Taken 09/05/86



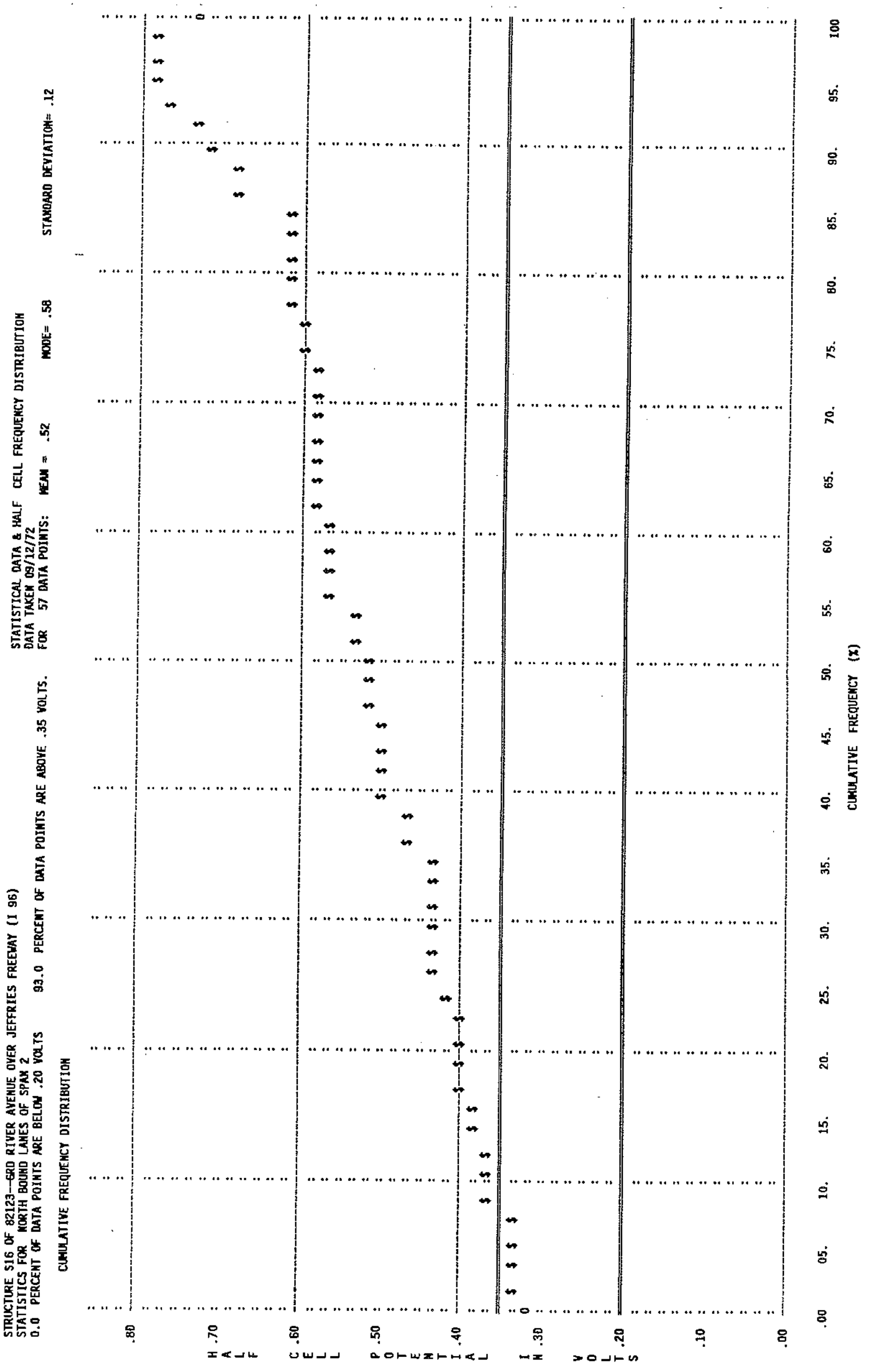
Appendix B (Continued)
Grand River Avenue--North Bound Span 2 (Galvanized--top mat only)
Data Taken 09/05/86



Grand River Avenue--North Bound Span 2 (Galvanized--top mat only)   Half Cell Equipotential Plot
Data Taken 07/10/91



Appendix B (Continued)
Grand River Avenue--North Bound Span 2 (Galvanized--top mat only)
Data Taken 07/10/91



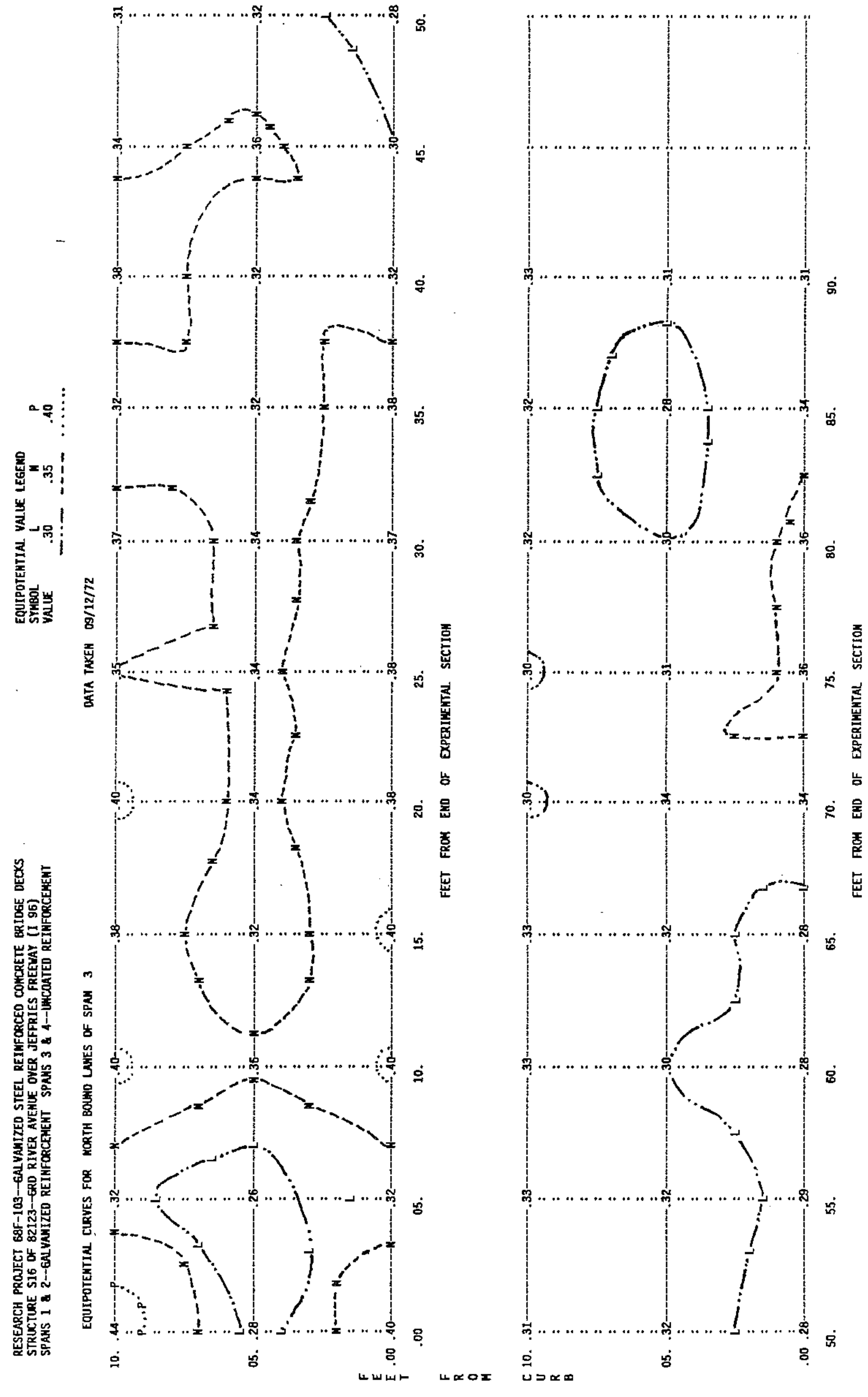
STRUCTURE S16 OF 82123--GRD RIVER AVENUE OVER JEFFRIES FREEWAY (I 96)
STATISTICS FOR NORTH BOUND LANES OF SPAN 2
0.0 PERCENT OF DATA POINTS ARE BELOW .20 VOLTS 93.0 PERCENT OF DATA POINTS ARE ABOVE .35 VOLTS.

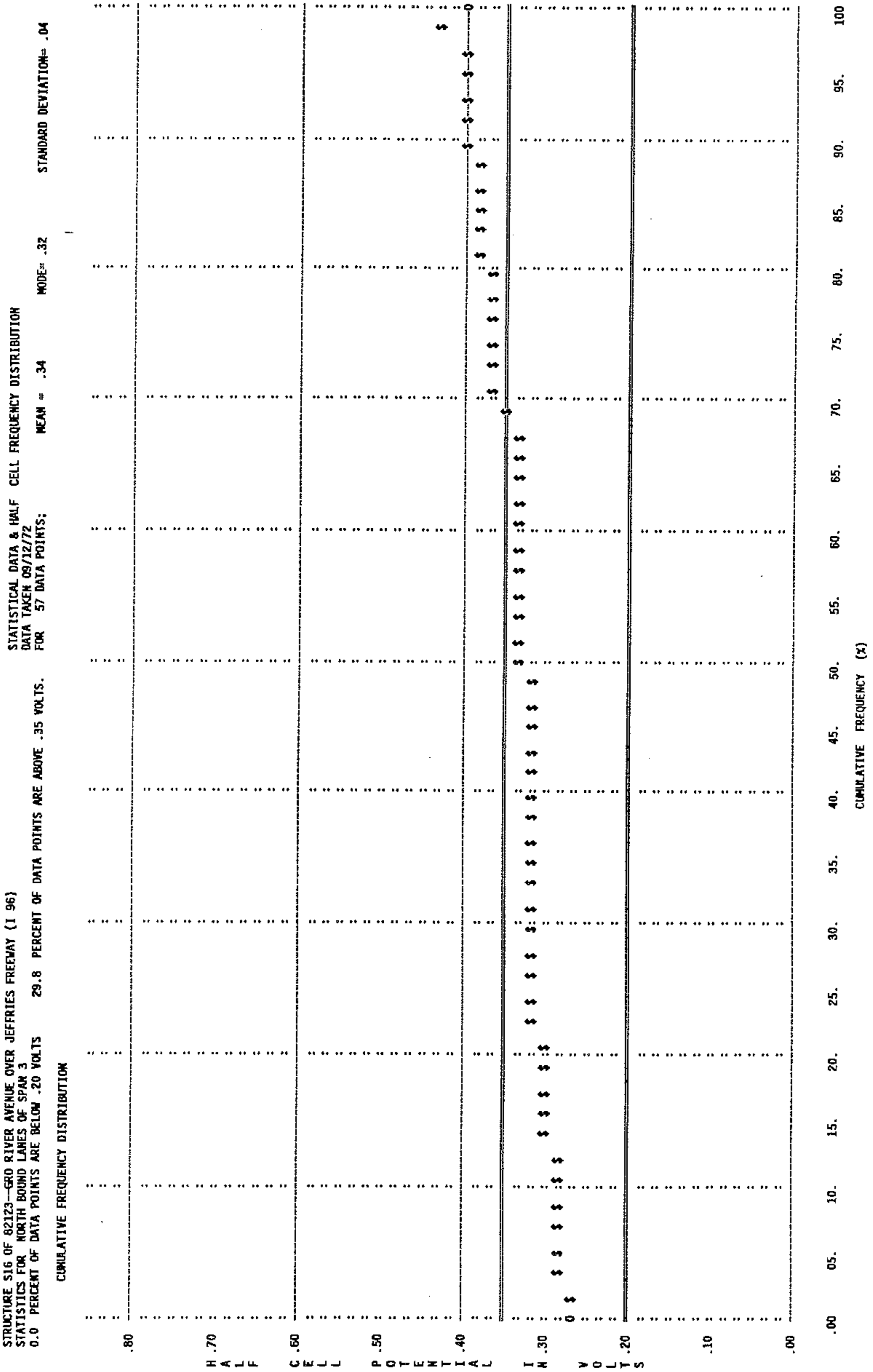
CUMULATIVE FREQUENCY DISTRIBUTION

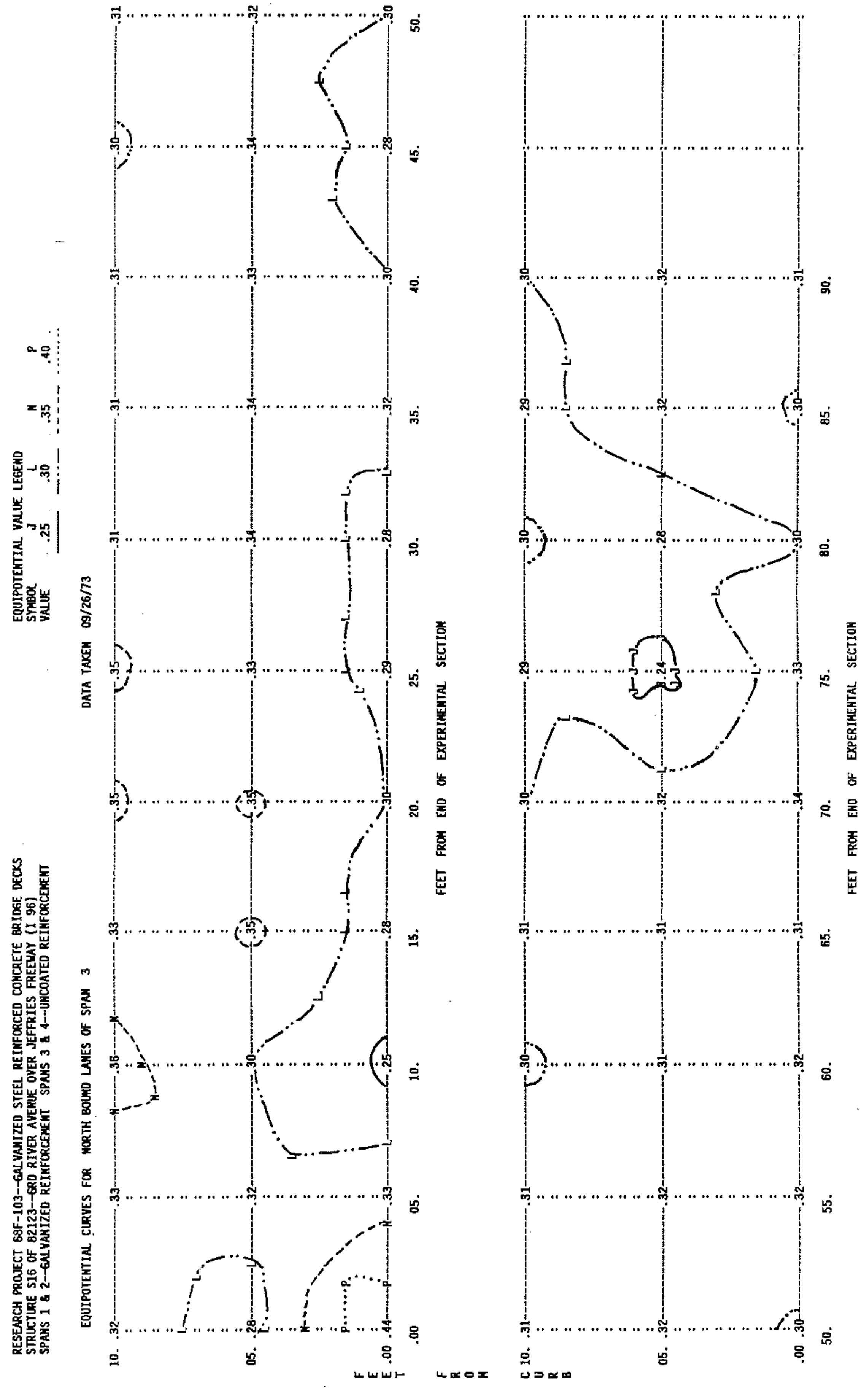
STATISTICAL DATA & HALF CELL FREQUENCY DISTRIBUTION
DATA TAKEN 09/12/72
FOR 57 DATA POINTS: MEAN = .52 MODE= .58 STANDARD DEVIATION= .12

Grand River Avenue--North Bound Span 3 (Uncoated Reinforcement)
Data Taken 09/12/72

Half Cell Equipotential Plot




STRUCTURE S16 OF 82123--GRD RIVER AVENUE OVER JEFFRIES FREEWAY (I 96)
STATISTICS FOR NORTH BOUND LANES OF SPAN 3
0.0 PERCENT OF DATA POINTS ARE BELOW .20 VOLTS
29.8 PERCENT OF DATA POINTS ARE ABOVE .35 VOLTS.
CUMULATIVE FREQUENCY DISTRIBUTION
STATISTICAL DATA & HALF CELL FREQUENCY DISTRIBUTION
DATA TAKEN 09/12/72
FOR 57 DATA POINTS;
MEAN = .34
MODE= .32
STANDARD DEVIATION= .04
HALF CELL POTENTIAL IN VOLTS
.80
.70
.60
.50
.40
.30
.20
.10
.00
00.
05.
10.
15.
20.
25.
30.
35.
40.
45.
50.
55.
60.
65.
70.
75.
80.
85.
90.
95.
100
CUMULATIVE FREQUENCY (%)


RESEARCH PROJECT 68F-103--GALVANIZED STEEL REINFORCED CONCRETE BRIDGE DECKS
STRUCTURE S16 OF 82123--GRD RIVER AVENUE OVER JEFFRIES FREEWAY (I 96)
SPANS 1 & 2--GALVANIZED REINFORCEMENT SPANS 3 & 4--UNCOATED REINFORCEMENT
EQUIPOTENTIAL CURVES FOR NORTH BOUND LANES OF SPAN 3
DATA TAKEN 09/26/73
EQUIPOTENTIAL VALUE LEGEND
SYMBOL J L N P
VALUE .25 .30 .35 .40
FEET FROM CURB
FEET FROM END OF EXPERIMENTAL SECTION
10.
05.
.00
C 10.
05.
.00
.00
05.
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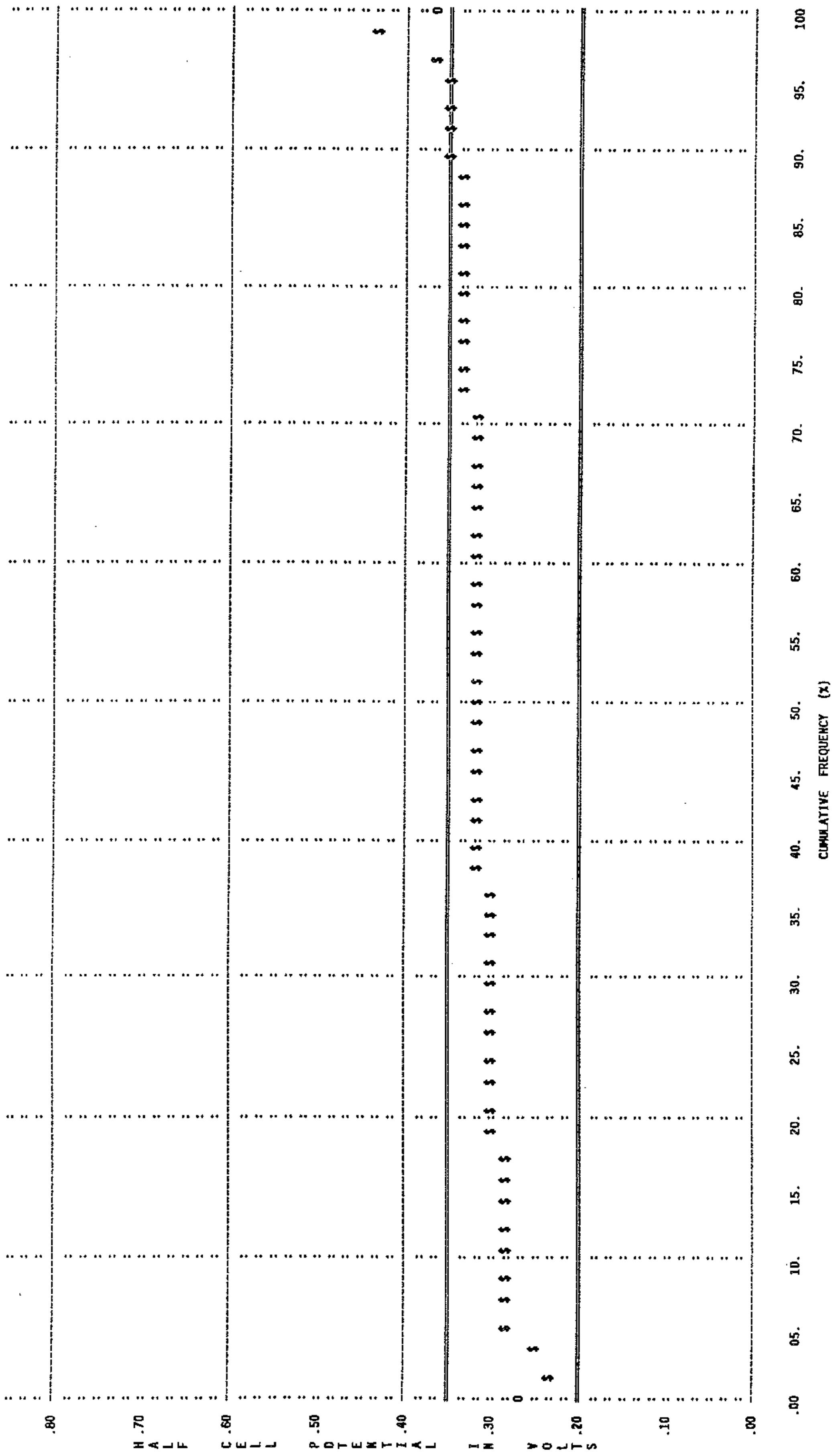
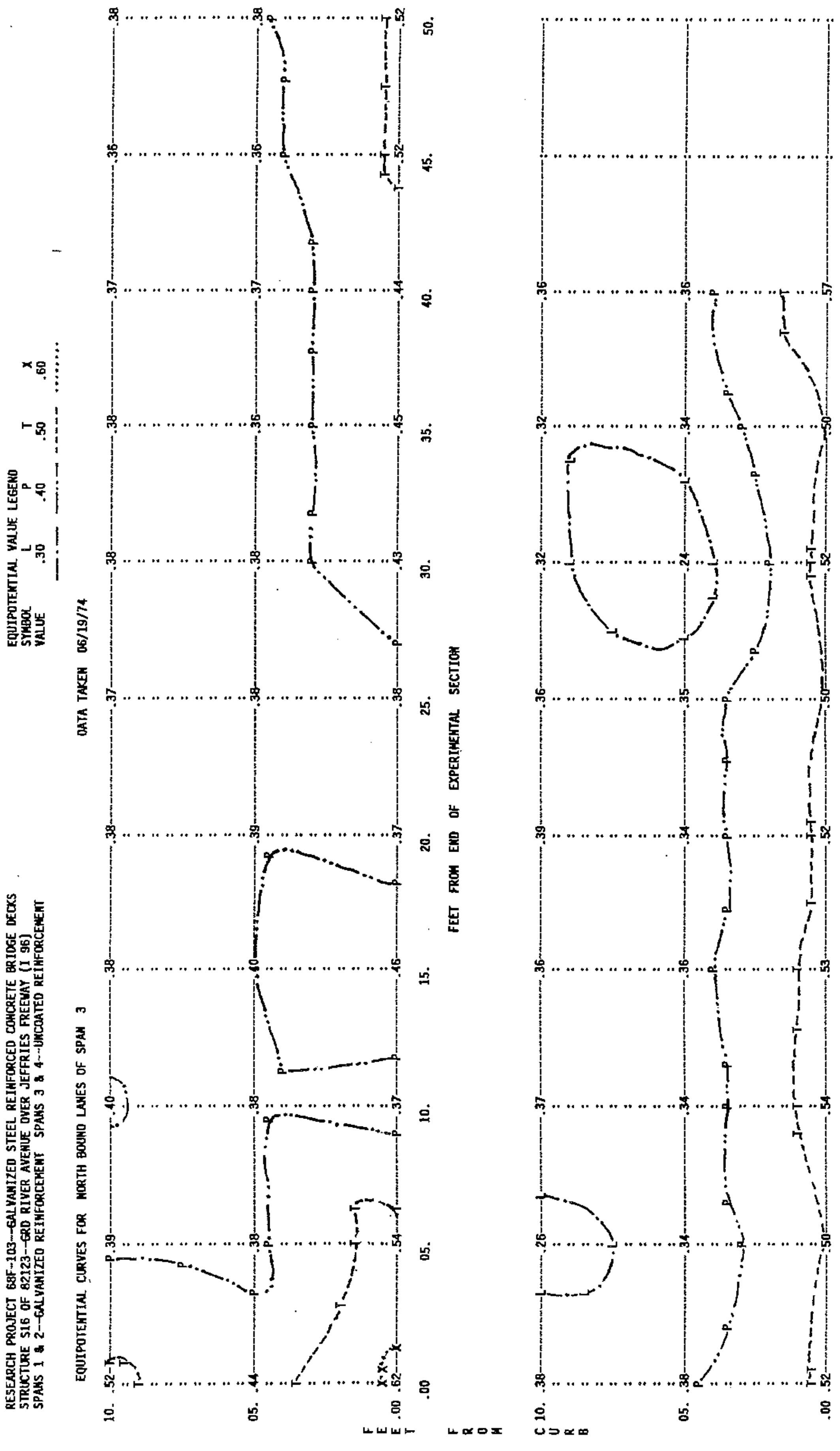
15.
20.
25.
30.
35.
40.
45.
50.
55.
60.
65.
70.
75.
80.
85.
90.
.32 .33 .36 .33 .35 .35 .31 .31 .31 .30 .31
.28 .32 .30 .35 .35 .33 .34 .34 .33 .34 .32
.44 .33 .25 .28 .30 .29 .28 .32 .30 .28 .30
.31 .31 .30 .31 .30 .29 .30 .29 .30
.32 .32 .31 .31 .32 .24 .28 .32 .32
.30 .32 .32 .31 .34 .33 .30 .30 .31
J L N P

```
STRUCTURE S16 OF 82123--GRD RIVER AVENUE OVER JEFFRIES FREEWAY (I 96)      STATISTICAL DATA & HALF  CELL FREQUENCY DISTRIBUTION
STATISTICS FOR  NORTH BOUND LANES OF SPAN 3                                DATA TAKEN 09/26/73
0.0  PERCENT OF DATA POINTS ARE BELOW .20 VOLTS     3.5  PERCENT OF DATA POINTS ARE ABOVE .35 VOLTS.    FOR   57 DATA POINTS;        MEAN =  .31        MODE= .30        STANDARD DEVIATION= .03

        CUMULATIVE FREQUENCY DISTRIBUTION
```




RESEARCH PROJECT 68F-103--GALVANIZED STEEL REINFORCED CONCRETE BRIDGE DECKS
STRUCTURE S16 OF 82123--GRD RIVER AVENUE OVER JEFFRIES FREEWAY (I 96)
SPANS 1 & 2--GALVANIZED REINFORCEMENT SPANS 3 & 4--UNCOATED REINFORCEMENT
EQUIPOTENTIAL CURVES FOR NORTH BOUND LANES OF SPAN 3
DATA TAKEN 06/19/74
EQUIPOTENTIAL VALUE LEGEND
SYMBOL L P T X
VALUE .30 .40 .50 .60
FEET FROM END OF EXPERIMENTAL SECTION
FEET FROM CURB
.00
05.
10.
05.
10.
15.
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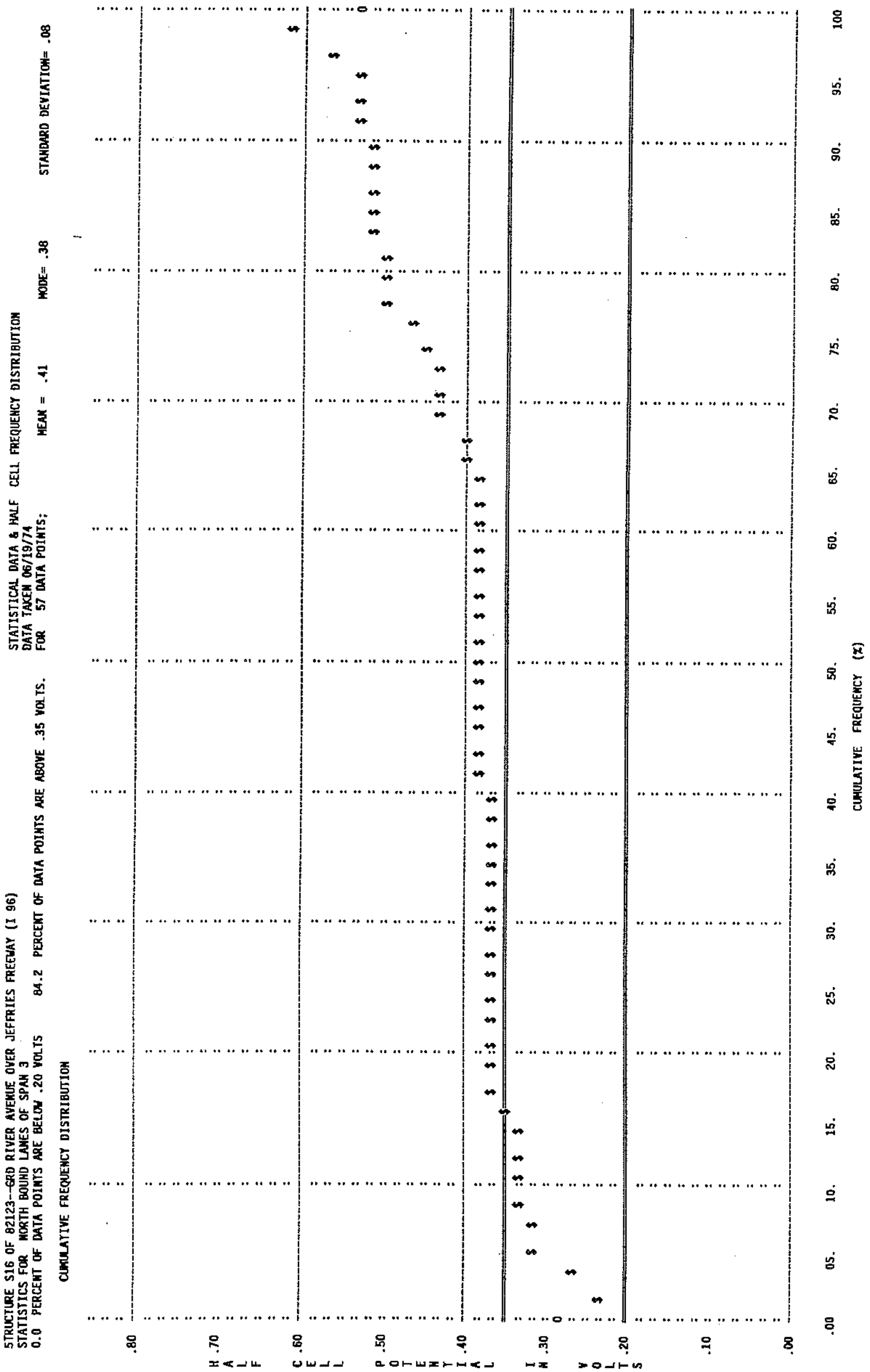
75.
80.
85.
90.



STRUCTURE S16 OF 82123--GRD RIVER AVENUE OVER JEFFRIES FREEWAY (I 96)
STATISTICS FOR NORTH BOUND LANES OF SPAN 3
0.0 PERCENT OF DATA POINTS ARE BELOW .20 VOLTS   84.2 PERCENT OF DATA POINTS ARE ABOVE .35 VOLTS.

CUMULATIVE FREQUENCY DISTRIBUTION

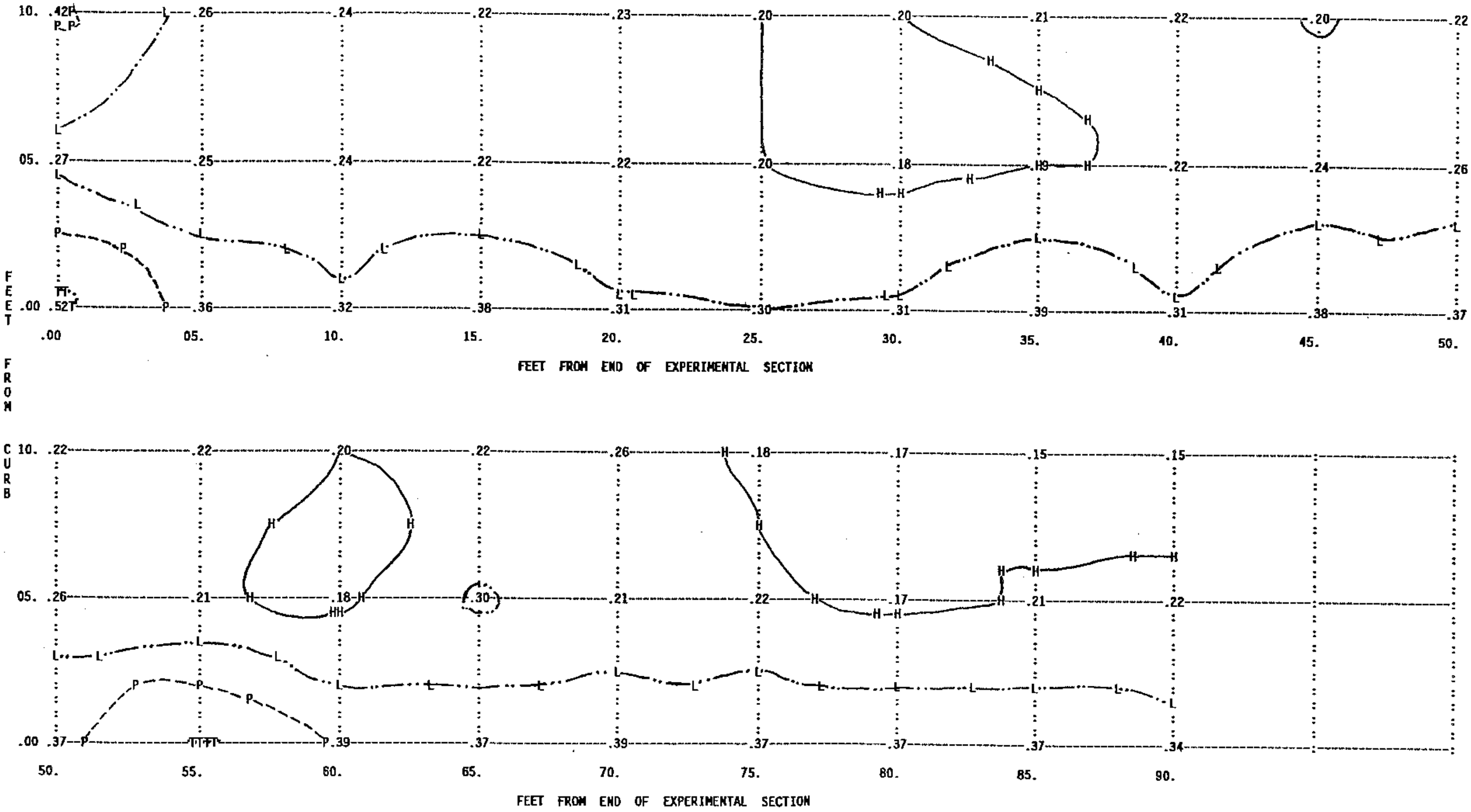
STATISTICAL DATA & HALF CELL FREQUENCY DISTRIBUTION
DATA TAKEN 06/19/74
FOR 57 DATA POINTS;   MEAN = .41   MODE= .38   STANDARD DEVIATION= .08

RESEARCH PROJECT 68F-103--GALVANIZED STEEL REINFORCED CONCRETE BRIDGE DECKS
STRUCTURE S16 OF 82123--GRD RIVER AVENUE OVER JEFFRIES FREEWAY (I 96)
SPANS 1 & 2--GALVANIZED REINFORCEMENT SPANS 3 & 4--UNCOATED REINFORCEMENT

EQUIPOTENTIAL VALUE LEGEND
SYMBOL H L P T
VALUE .20 .30 .40 .50

EQUIPOTENTIAL CURVES FOR NORTH BOUND LANES OF SPAN 3

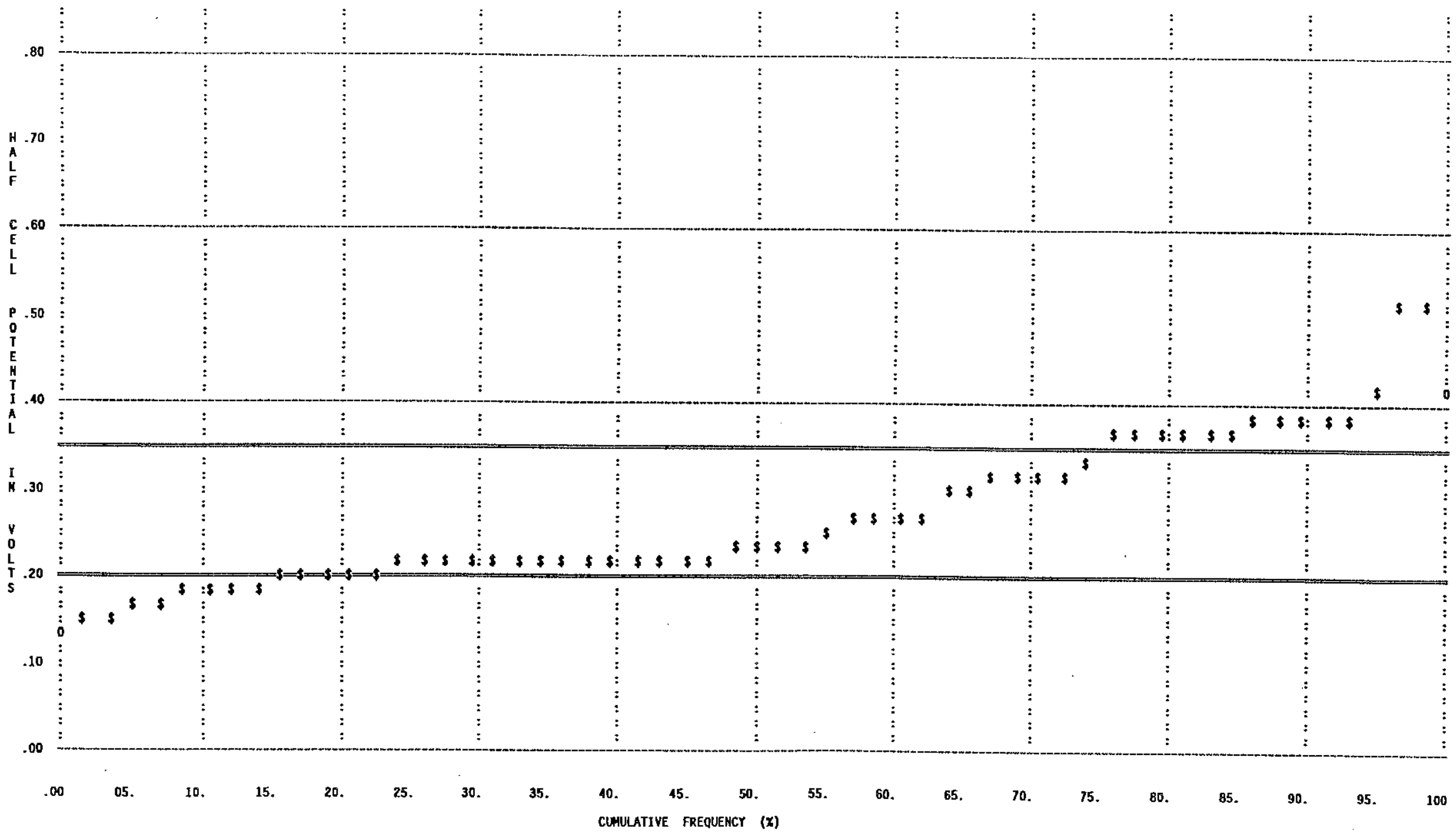
DATA TAKEN 06/18/75

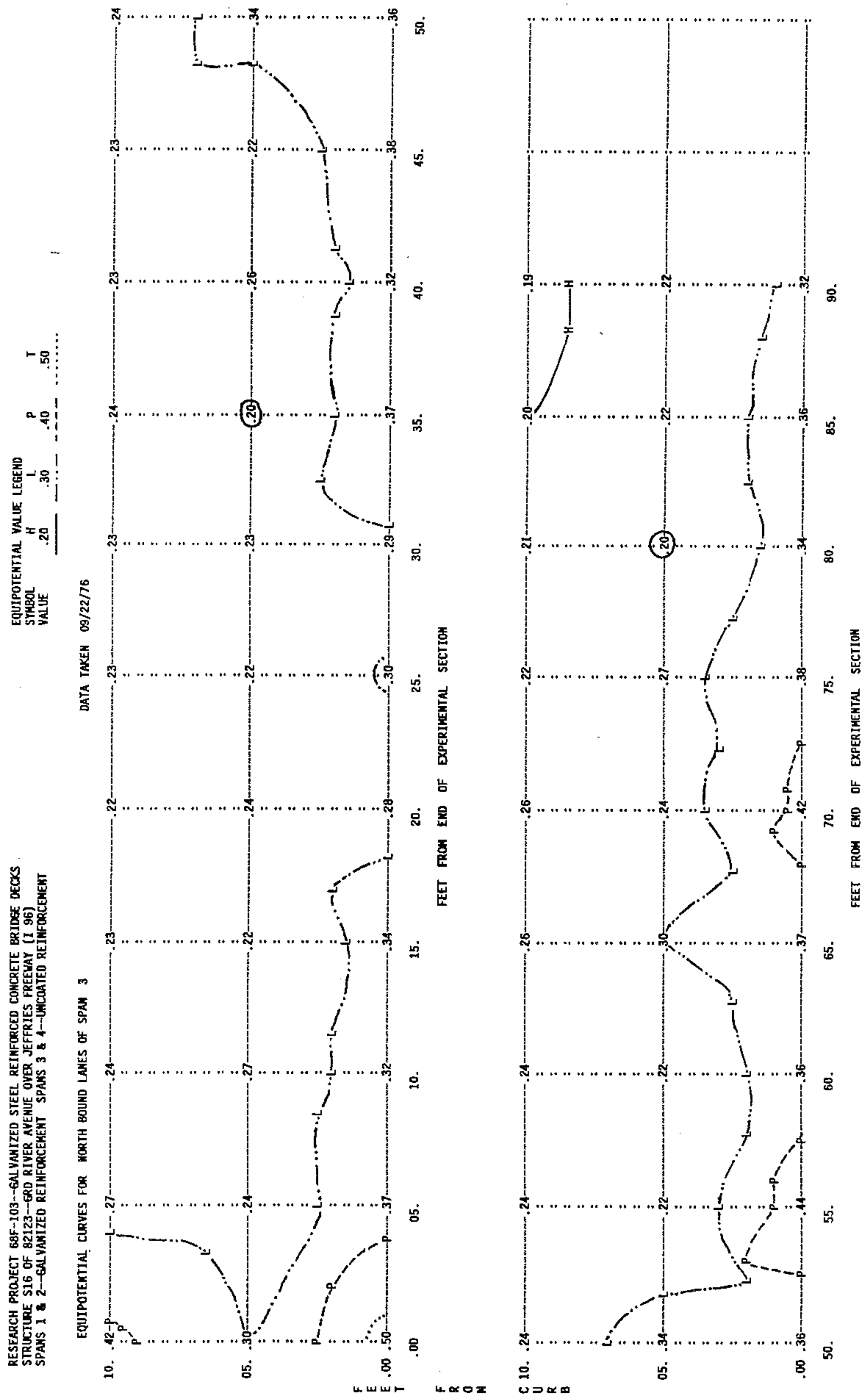


STRUCTURE S16 OF 82123--GRD RIVER AVENUE OVER JEFFRIES FREEWAY (I 96)
STATISTICS FOR NORTH BOUND LANES OF SPAN 3
14.0 PERCENT OF DATA POINTS ARE BELOW .20 VOLTS 24.6 PERCENT OF DATA POINTS ARE ABOVE .35 VOLTS.

STATISTICAL DATA & HALF CELL FREQUENCY DISTRIBUTION
DATA TAKEN 06/18/75
FOR 57 DATA POINTS; MEAN = .27 MODE= .22 STANDARD DEVIATION= .09

CUMULATIVE FREQUENCY DISTRIBUTION

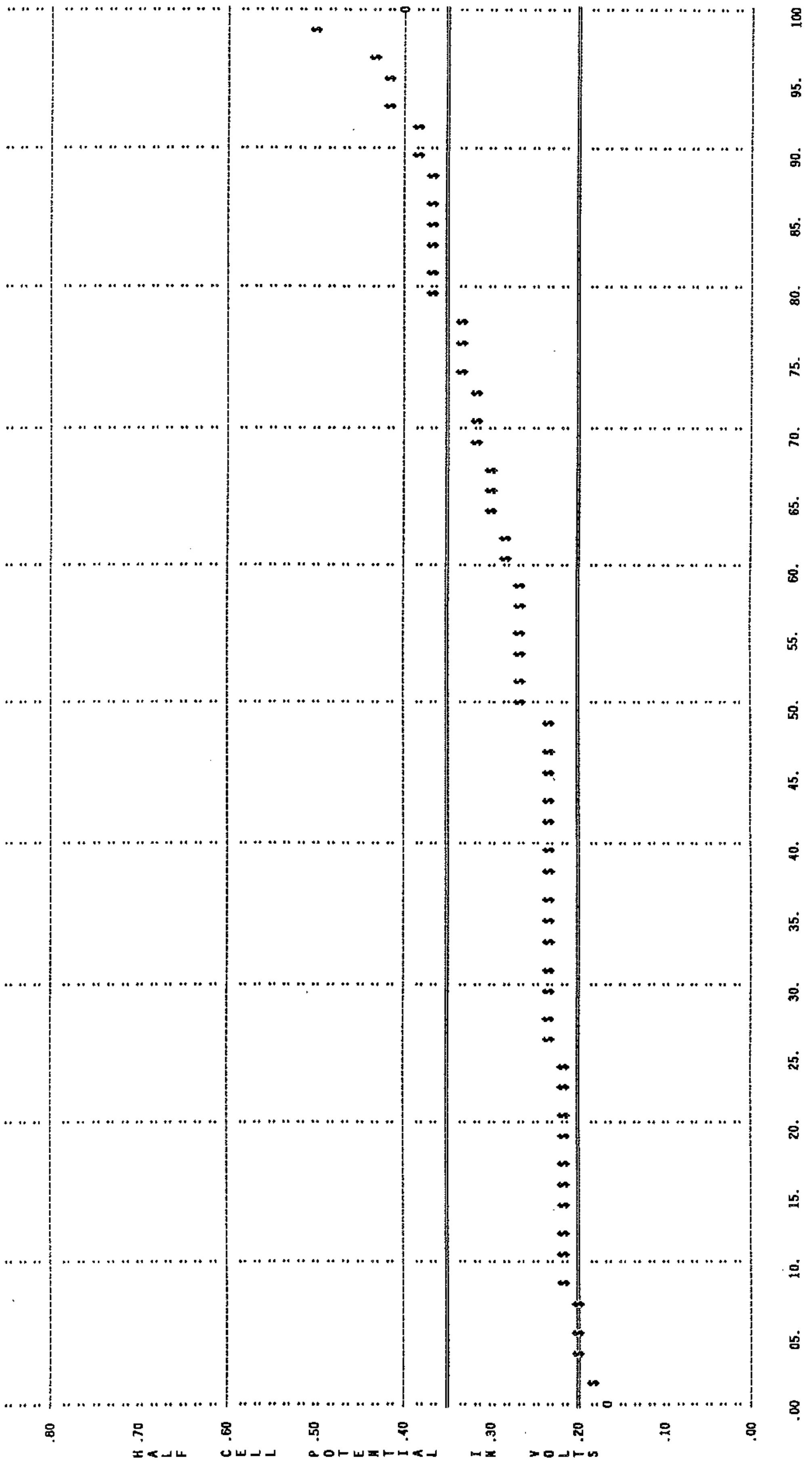


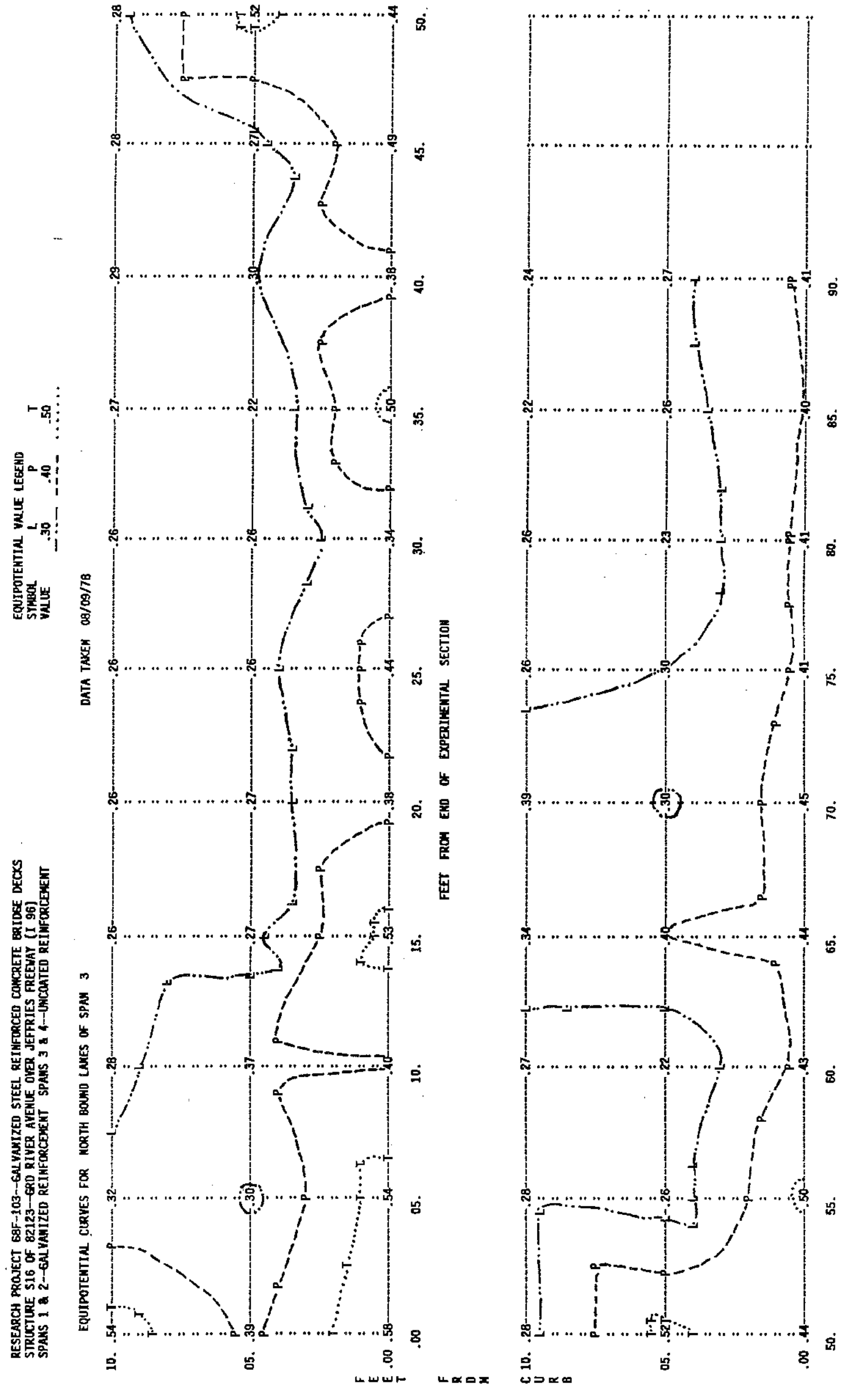

RESEARCH PROJECT 68F-103--GALVANIZED STEEL REINFORCED CONCRETE BRIDGE DECKS
STRUCTURE S16 OF 82123--GRD RIVER AVENUE OVER JEFFRIES FREEWAY (I 96)
SPANS 1 & 2--GALVANIZED REINFORCEMENT SPANS 3 & 4--UNCOATED REINFORCEMENT
EQUIPOTENTIAL CURVES FOR NORTH BOUND LANES OF SPAN 3
DATA TAKEN 09/22/76
EQUIPOTENTIAL VALUE LEGEND
SYMBOL H L P T
VALUE .20 .30 .40 .50
FEET FROM END OF EXPERIMENTAL SECTION
FEET FROM CURB
.00
05.
10.
15.
20.
25.
30.
35.
40.
45.
50.
55.
60.
65.
70.
75.
80.
85.
90.

STRUCTURE S16 OF 82123--GRD RIVER AVENUE OVER JEFFRIES FREEWAY (I 96)
STATISTICS FOR NORTH BOUND LANES OF SPAN 3
1.8 PERCENT OF DATA POINTS ARE BELOW .20 VOLTS 21.1 PERCENT OF DATA POINTS ARE ABOVE .35 VOLTS.

STATISTICAL DATA & HALF CELL FREQUENCY DISTRIBUTION
DATA TAKEN 09/22/76
FOR 57 DATA POINTS; MEAN = .28 MODE= .22 STANDARD DEVIATION= .07

CUMULATIVE FREQUENCY DISTRIBUTION

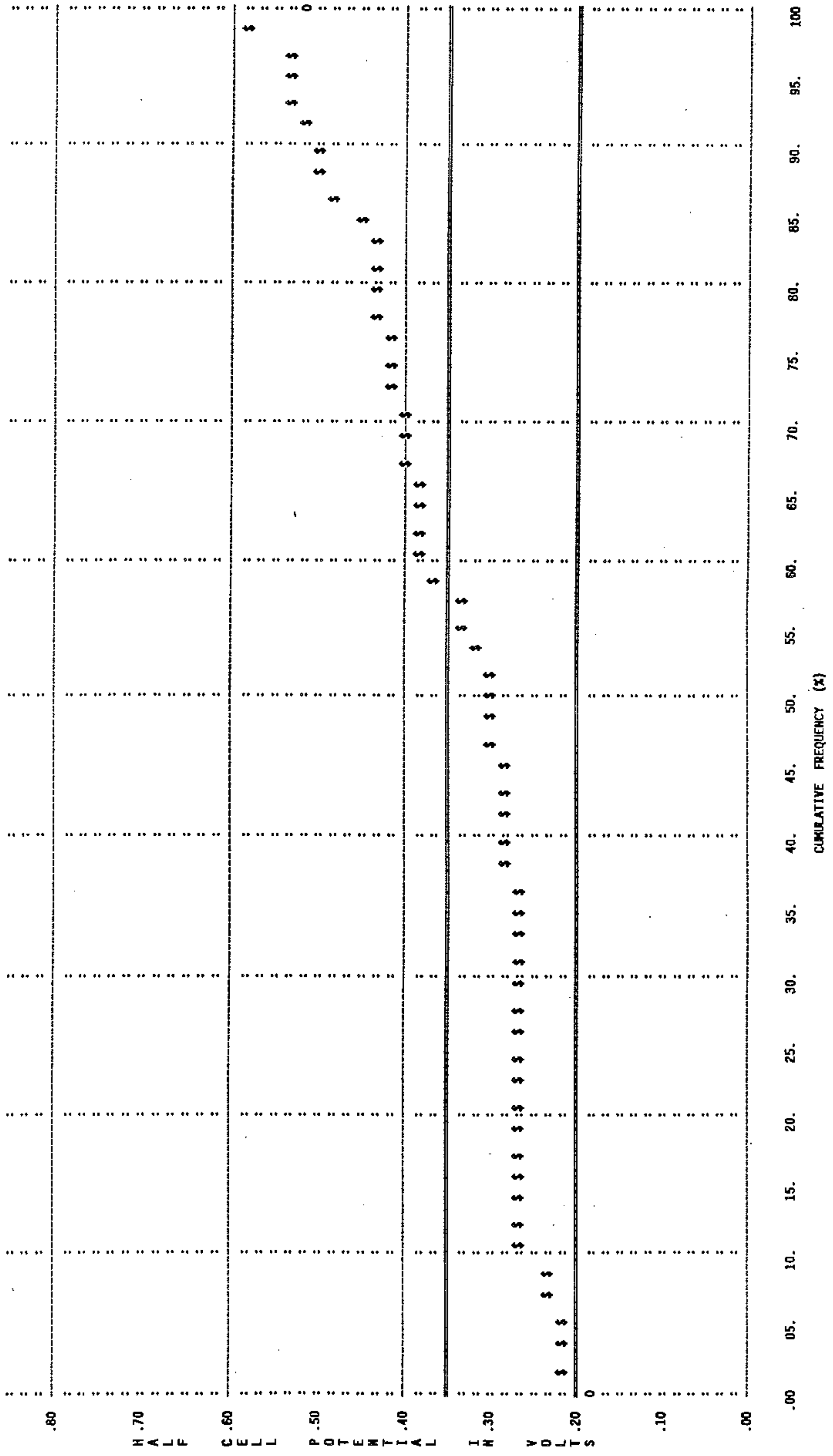


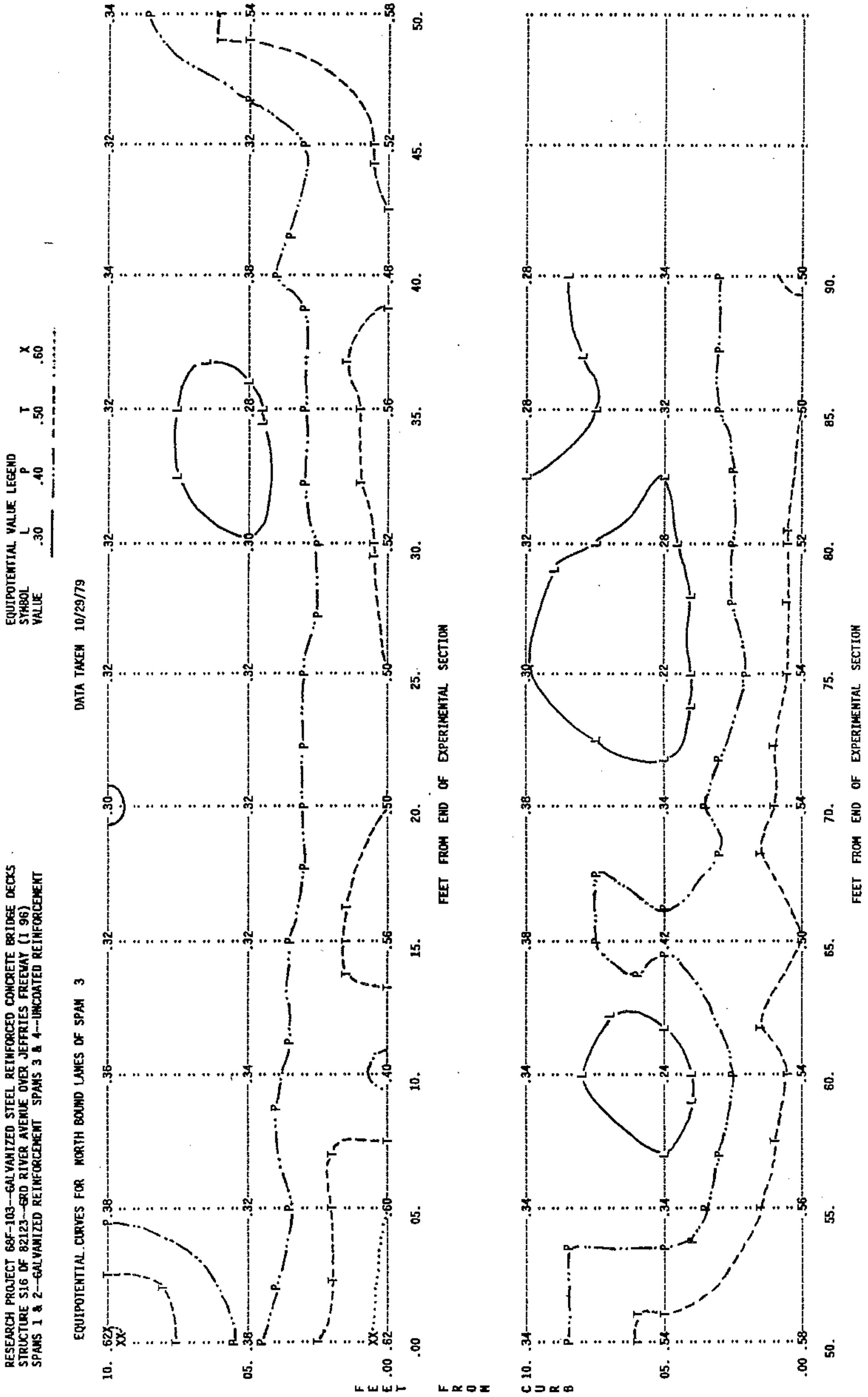

RESEARCH PROJECT 68F-103--GALVANIZED STEEL REINFORCED CONCRETE BRIDGE DECKS
STRUCTURE S16 OF 82123--GRD RIVER AVENUE OVER JEFFRIES FREEWAY (I 96)
SPANS 1 & 2--GALVANIZED REINFORCEMENT SPANS 3 & 4--UNCOATED REINFORCEMENT
EQUIPOTENTIAL CURVES FOR NORTH BOUND LANES OF SPAN 3
DATA TAKEN 08/09/78
EQUIPOTENTIAL VALUE LEGEND
SYMBOL L P T
VALUE .30 .40 .50
FEET FROM END OF EXPERIMENTAL SECTION
FEET FROM CURB
10.
05.
.00
.00
05.
10.
15.
20.
25.
30.
35.
40.
45.
50.
55.
60.
65.
70.
75.
80.
85.
90.
.54 .32 .28 .26 .26 .26 .27 .26 .29 .28 .28
.39 .30 .37 .27 .27 .26 .26 .22 .30 .27 .52
.58 .54 .40 .53 .38 .44 .34 .50 .38 .49 .44
.28 .28 .27 .34 .39 .26 .26 .22 .24
.52 .26 .22 .40 .30 .30 .23 .26 .27
.44 .50 .43 .44 .45 .41 .41 .40 .41

STRUCTURE S16 OF 82123--GRD RIVER AVENUE OVER JEFFRIES FREEWAY (I 96)
STATISTICS FOR NORTH BOUND LANES OF SPAN 3
0.0 PERCENT OF DATA POINTS ARE BELOW .20 VOLTS 42.1 PERCENT OF DATA POINTS ARE ABOVE .35 VOLTS.

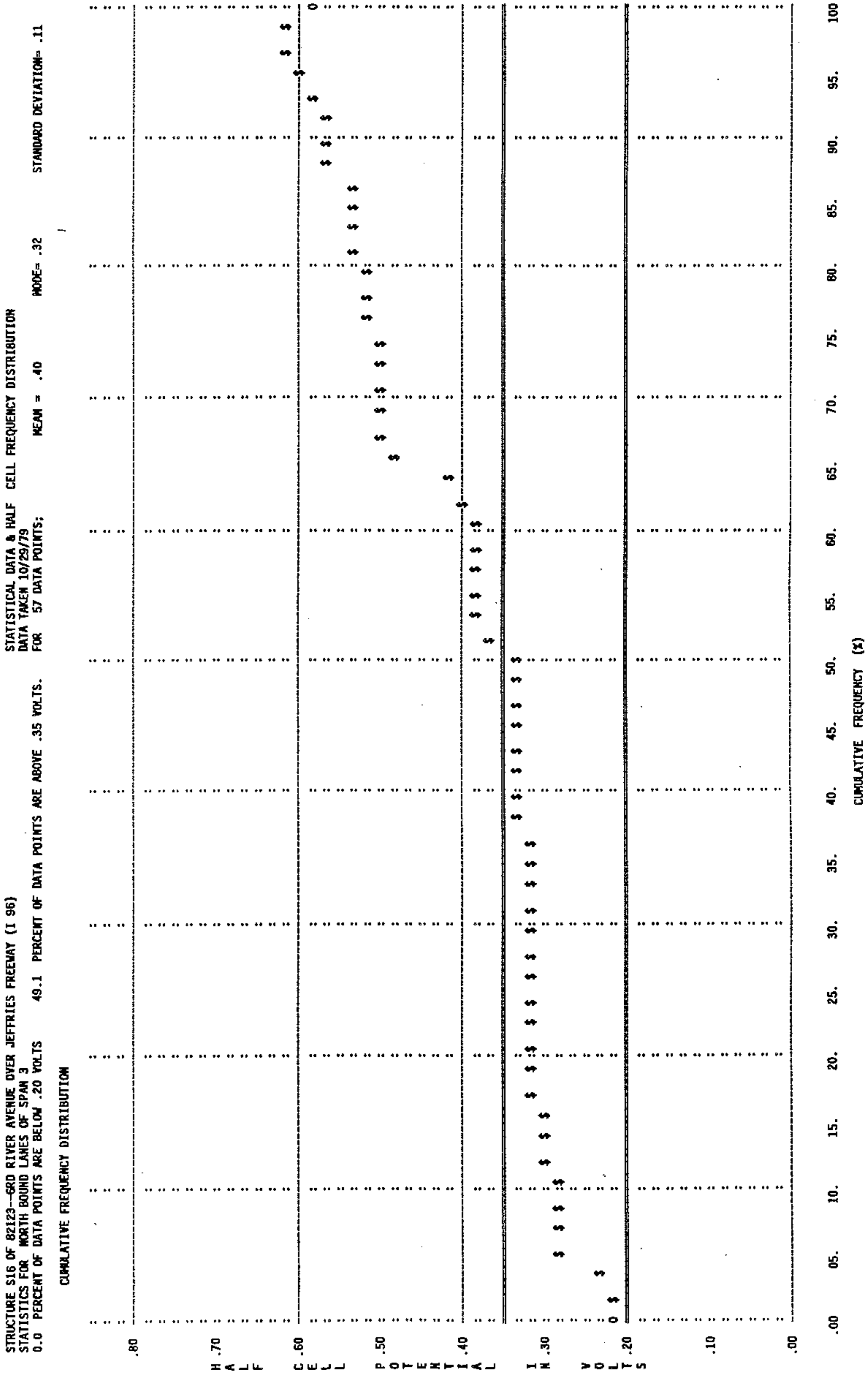
STATISTICAL DATA & HALF CELL FREQUENCY DISTRIBUTION
DATA TAKEN 08/09/78
FOR 57 DATA POINTS; MEAN = .35 MODE= .26 STANDARD DEVIATION= .10

CUMULATIVE FREQUENCY DISTRIBUTION




RESEARCH PROJECT 68F-103--GALVANIZED STEEL REINFORCED CONCRETE BRIDGE DECKS
STRUCTURE S16 OF 82123--GRD RIVER AVENUE OVER JEFFRIES FREEWAY (I 96)
SPANS 1 & 2--GALVANIZED REINFORCEMENT SPANS 3 & 4--UNCOATED REINFORCEMENT
EQUIPOTENTIAL CURVES FOR NORTH BOUND LANES OF SPAN 3
DATA TAKEN 10/29/79
EQUIPOTENTIAL VALUE LEGEND
SYMBOL L P T X
VALUE .30 .40 .50 .60
FEET FROM END OF EXPERIMENTAL SECTION
FEET FROM CURB
.00
05.
10.
15.
20.
25.
30.
35.
40.
45.
50.
55.
60.
65.
70.
75.
80.
85.
90.

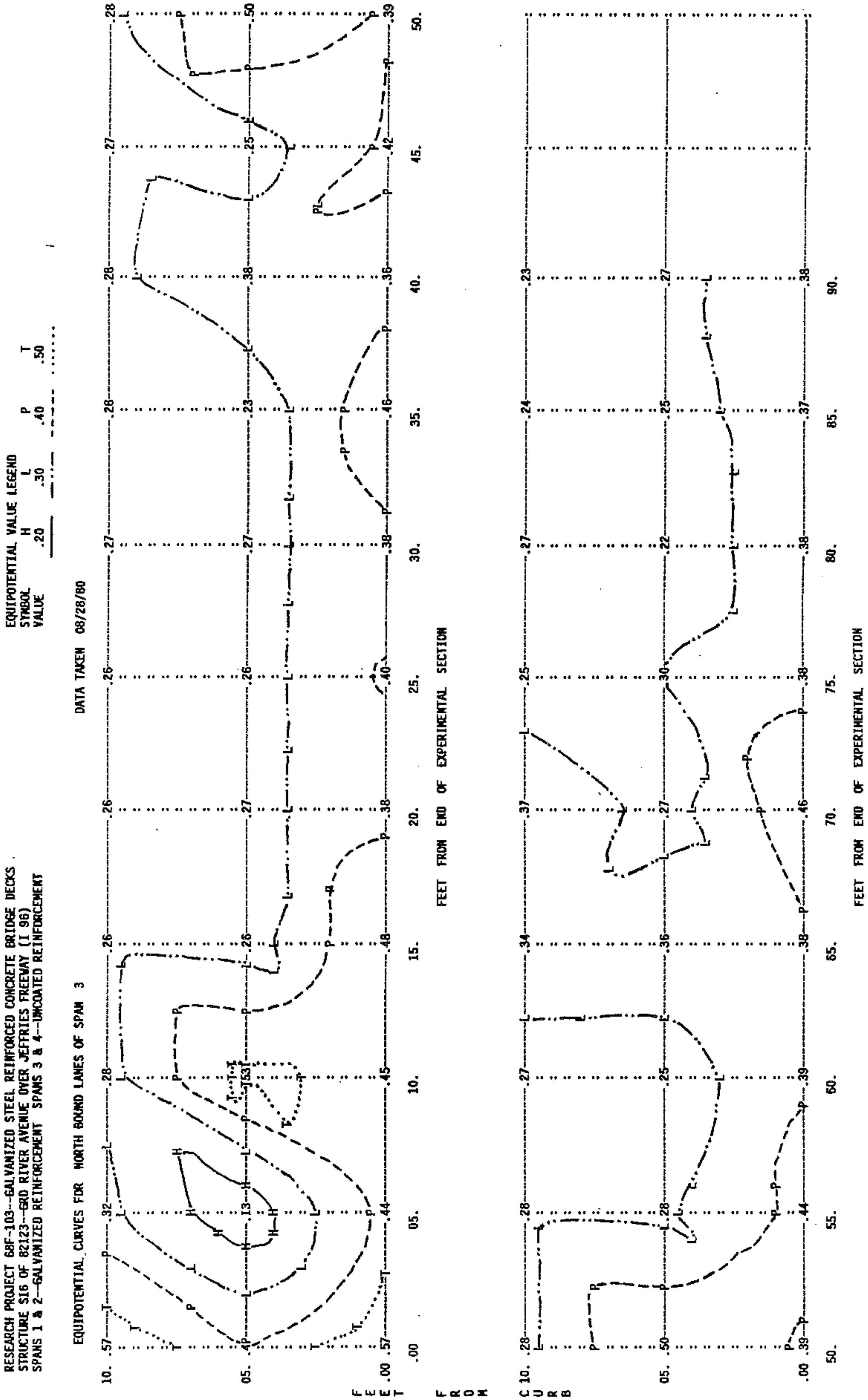
Grand River Avenue--North Bound Span 3 (Uncoated Reinforcement) Cumulative Frequency Distribution
Data Taken 10/19/79



STRUCTURE S16 OF 82123--GRD RIVER AVENUE OVER JEFFRIES FREEWAY (I 96)
STATISTICS FOR NORTH BOUND LANES OF SPAN 3
0.0 PERCENT OF DATA POINTS ARE BELOW .20 VOLTS 49.1 PERCENT OF DATA POINTS ARE ABOVE .35 VOLTS.

CUMULATIVE FREQUENCY DISTRIBUTION

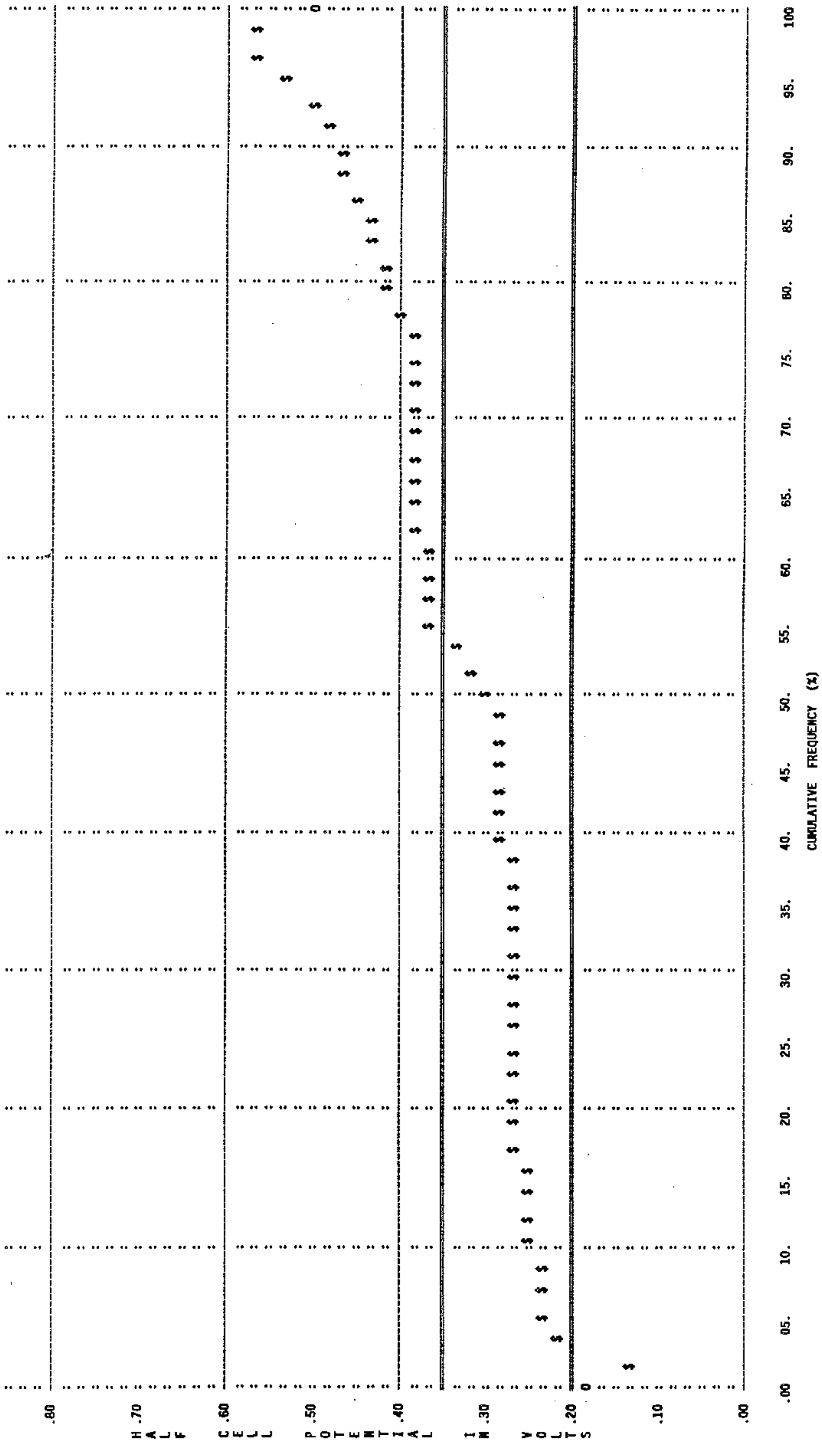
STATISTICAL DATA & HALF CELL FREQUENCY DISTRIBUTION
DATA TAKEN 10/29/79
FOR 57 DATA POINTS; MEAN = .40 MODE= .32 STANDARD DEVIATION= .11


RESEARCH PROJECT 68F-103--GALVANIZED STEEL REINFORCED CONCRETE BRIDGE DECKS
STRUCTURE S16 OF 82123--GRD RIVER AVENUE OVER JEFFRIES FREEWAY (I 96)
SPANS 1 & 2--GALVANIZED REINFORCEMENT SPANS 3 & 4--UNCOATED REINFORCEMENT
EQUIPOTENTIAL CURVES FOR NORTH BOUND LANES OF SPAN 3
DATA TAKEN 08/28/80
EQUIPOTENTIAL VALUE LEGEND
SYMBOL H L P T
VALUE .20 .30 .40 .50
FEET FROM CURB
10.
05.
.00
FEET FROM END OF EXPERIMENTAL SECTION
.00
05.
10.
15.
20.
25.
30.
35.
40.
45.
50.
55.
60.
65.
70.
75.
80.
85.
90.
.57
.32
.28
.26
.26
.26
.27
.28
.28
.27
.28
.13
.53
.26
.27
.26
.27
.23
.38
.25
.50
.57
.44
.45
.48
.38
.40
.38
.46
.36
.42
.39
.28
.27
.34
.37
.25
.27
.24
.23
.28
.25
.36
.27
.30
.22
.25
.27
.44
.39
.38
.46
.38
.38
.37
.38
H
L
P
T

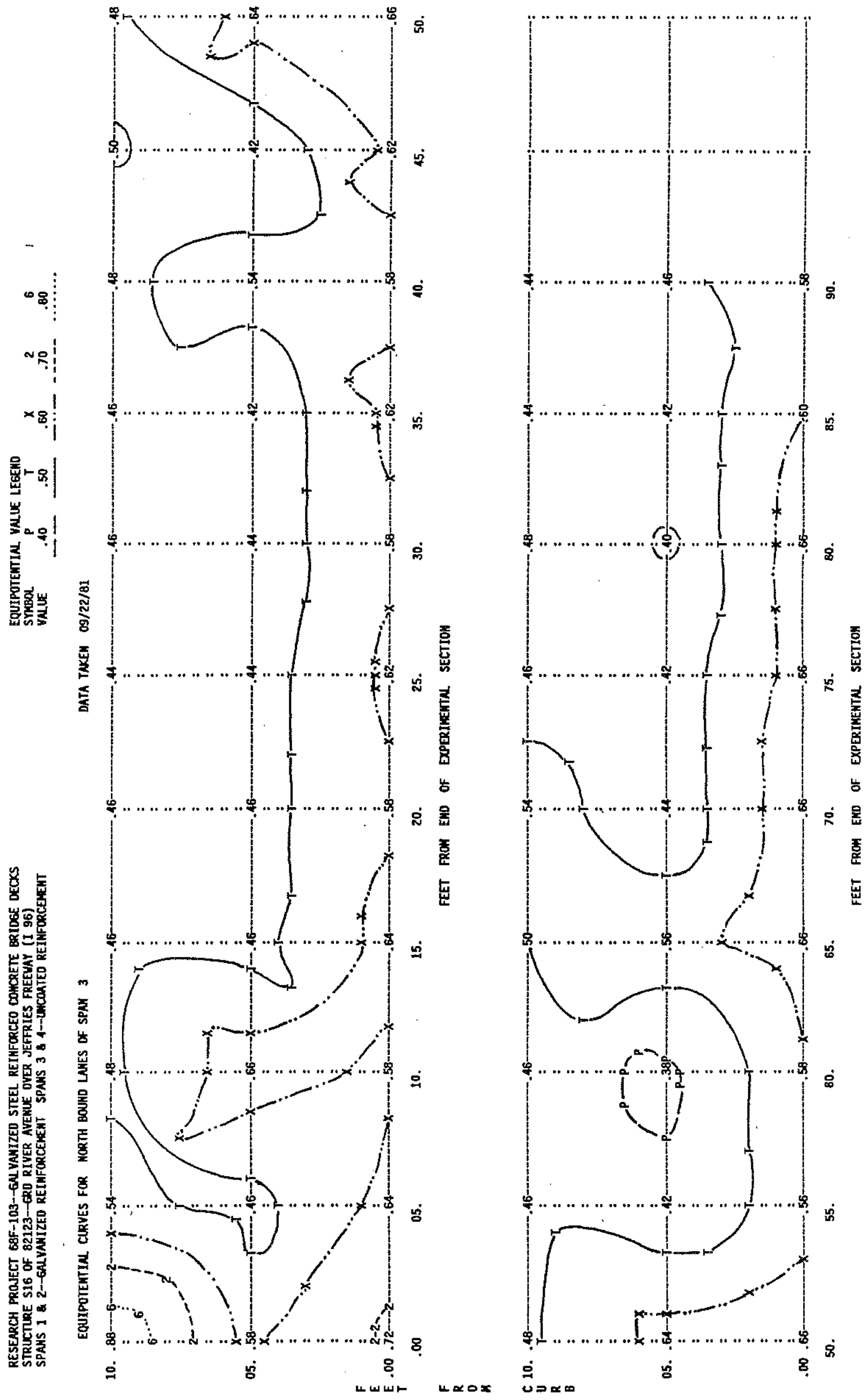
STRUCTURE S16 OF 82123--GRD RIVER AVENUE OVER JEFFRIES FREEWAY (I 96)
STATISTICS FOR NORTH BOUND LANES OF SPAN 3
1.8 PERCENT OF DATA POINTS ARE BELOW .20 VOLTS 45.6 PERCENT OF DATA POINTS ARE ABOVE .35 VOLTS.

STATISTICAL DATA & HALF CELL FREQUENCY DISTRIBUTION
DATA TAKEN 08/28/80
FOR 57 DATA POINTS; MEAN = .34 MODE= .27 STANDARD DEVIATION= .09

CUMULATIVE FREQUENCY DISTRIBUTION

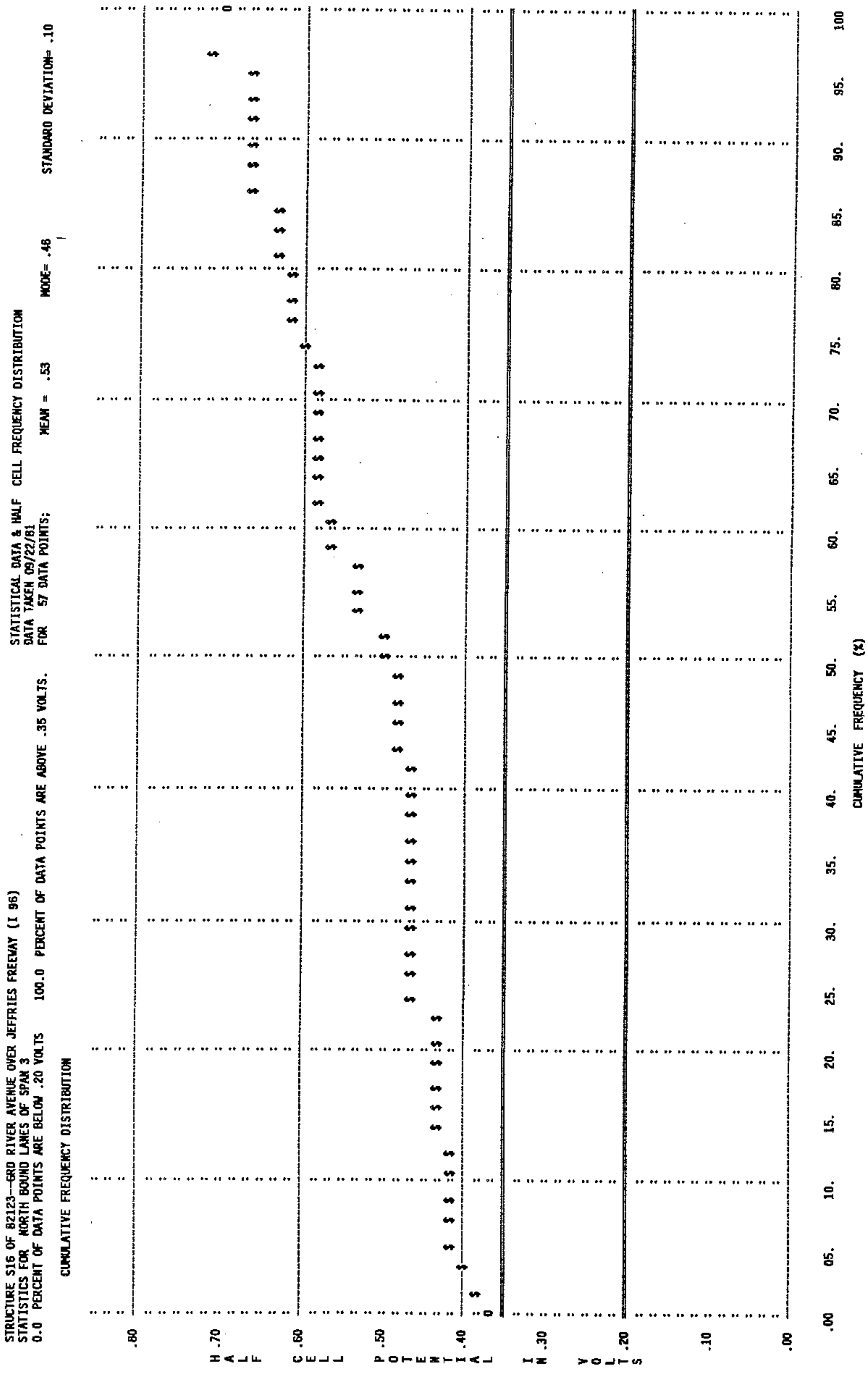


Grand River Avenue--North Bound Span 3 (Uncoated Reinforcement)
Half Cell Equipotential Plot
Data Taken 09/22/81



Grand River Avenue--North Bound Span 3 (Uncoated Reinforcement)
Data Taken 09/22/81

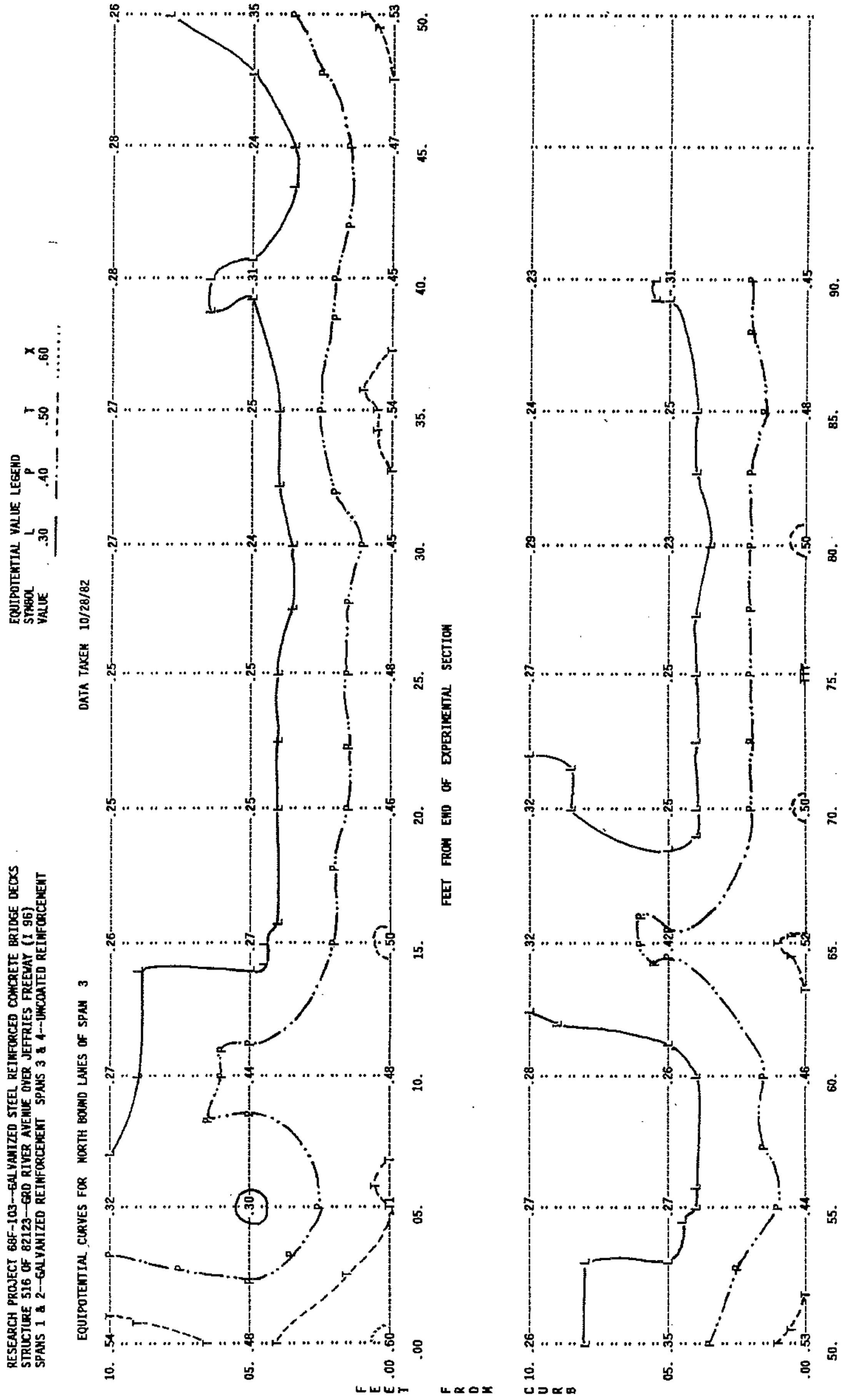
Cumulative Frequency Distribution

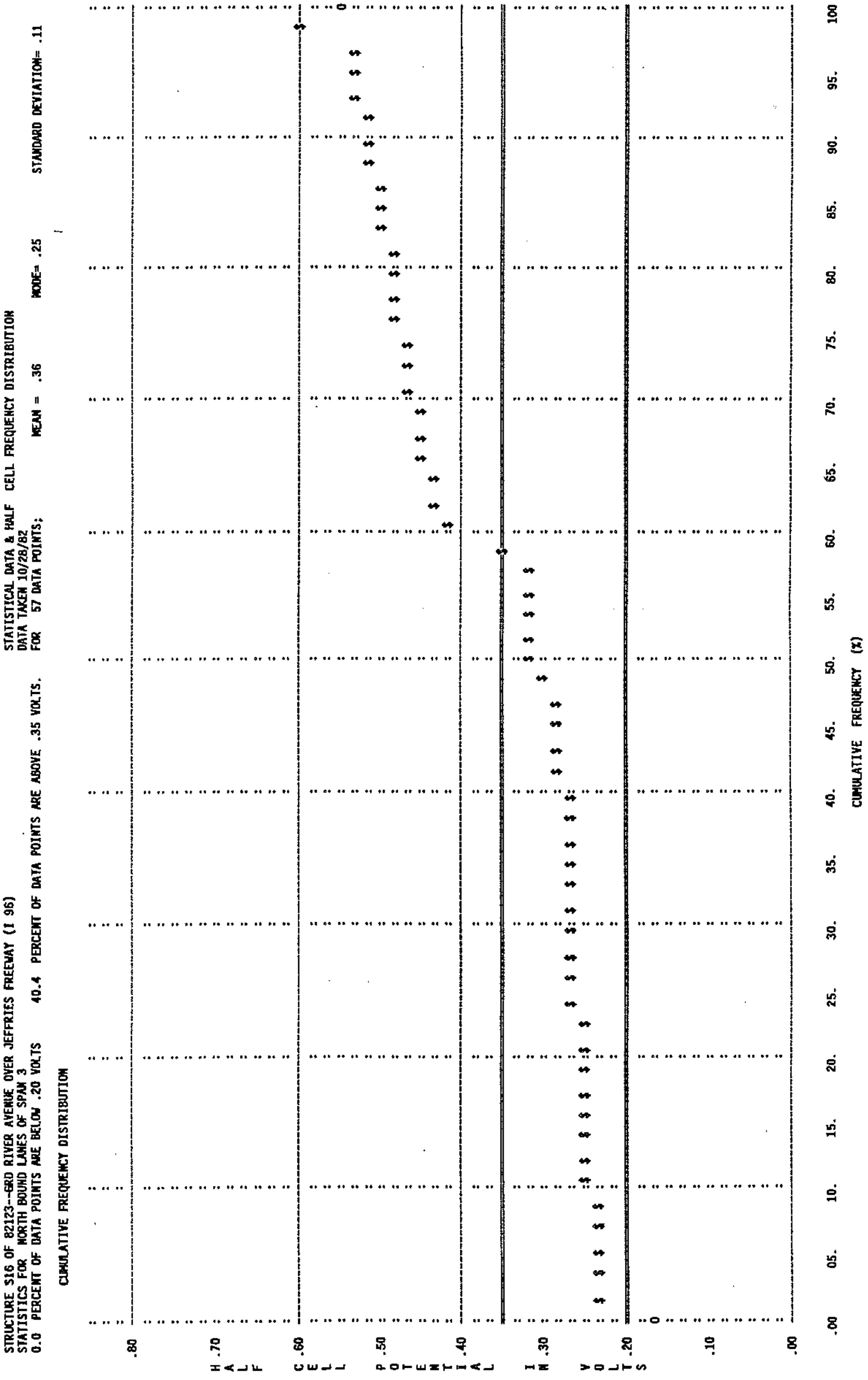


STRUCTURE S16 OF 82123—GRD RIVER AVENUE OVER JEFFRIES FREEWAY (I 96)
STATISTICS FOR NORTH BOUND LANES OF SPAN 3
0.0 PERCENT OF DATA POINTS ARE BELOW .20 VOLTS 100.0 PERCENT OF DATA POINTS ARE ABOVE .35 VOLTS.

STATISTICAL DATA & HALF CELL FREQUENCY DISTRIBUTION
DATA TAKEN 09/22/81
FOR 57 DATA POINTS; MEAN = .53 MODE= .48 STANDARD DEVIATION= .10

CUMULATIVE FREQUENCY DISTRIBUTION


RESEARCH PROJECT 68F-103--GALVANIZED STEEL REINFORCED CONCRETE BRIDGE DECKS
STRUCTURE 516 OF 82123--GRD RIVER AVENUE OVER JEFFRIES FREEWAY (I 96)
SPANS 1 & 2--GALVANIZED REINFORCEMENT SPANS 3 & 4--UNCOATED REINFORCEMENT
EQUIPOTENTIAL CURVES FOR NORTH BOUND LANES OF SPAN 3
DATA TAKEN 10/28/82
EQUIPOTENTIAL VALUE LEGEND
SYMBOL L P T X
VALUE .30 .40 .50 .60
FEET FROM END OF EXPERIMENTAL SECTION
FEET FROM CURB
.00 05. 10.
.00 05. 10. 15. 20. 25. 30. 35. 40. 45. 50.
50. 55. 60. 65. 70. 75. 80. 85. 90.
.54 .32 .27 .26 .25 .25 .27 .27 .28 .28 .26
.48 .30 .44 .27 .25 .25 .24 .25 .31 .24 .35
.60 .48 .50 .46 .48 .45 .54 .45 .47 .53
.26 .27 .28 .32 .32 .27 .29 .24 .23
.35 .27 .26 .42 .25 .25 .23 .25 .31
.53 .44 .46 .52 .50 .50 .48 .45



STRUCTURE S16 OF 82123--GRD RIVER AVENUE OVER JEFFRIES FREEWAY (I 96)
STATISTICS FOR NORTH BOUND LANES OF SPAN 3
0.0 PERCENT OF DATA POINTS ARE BELOW .20 VOLTS   40.4 PERCENT OF DATA POINTS ARE ABOVE .35 VOLTS.

STATISTICAL DATA & HALF CELL FREQUENCY DISTRIBUTION
DATA TAKEN 10/28/82
FOR 57 DATA POINTS;   MEAN = .36   MODE= .25   STANDARD DEVIATION= .11

CUMULATIVE FREQUENCY DISTRIBUTION

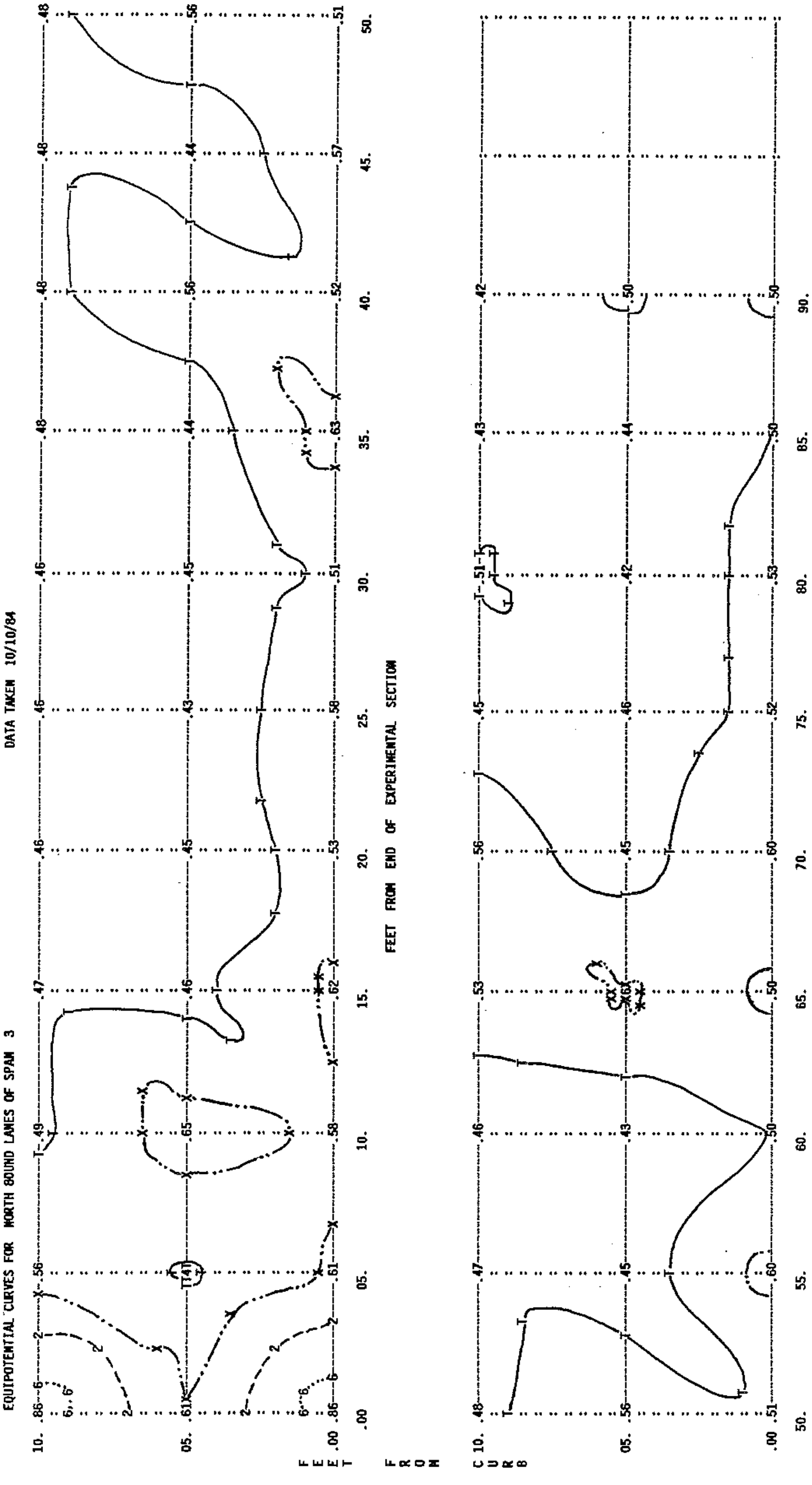
RESEARCH PROJECT 68F-103--GALVANIZED STEEL REINFORCED CONCRETE BRIDGE DECKS
STRUCTURE S16 OF 82123--GRD RIVER AVENUE OVER JEFFRIES FREEWAY (I 96)
SPANS 1 & 2--GALVANIZED REINFORCEMENT SPANS 3 & 4--UNCOATED REINFORCEMENT

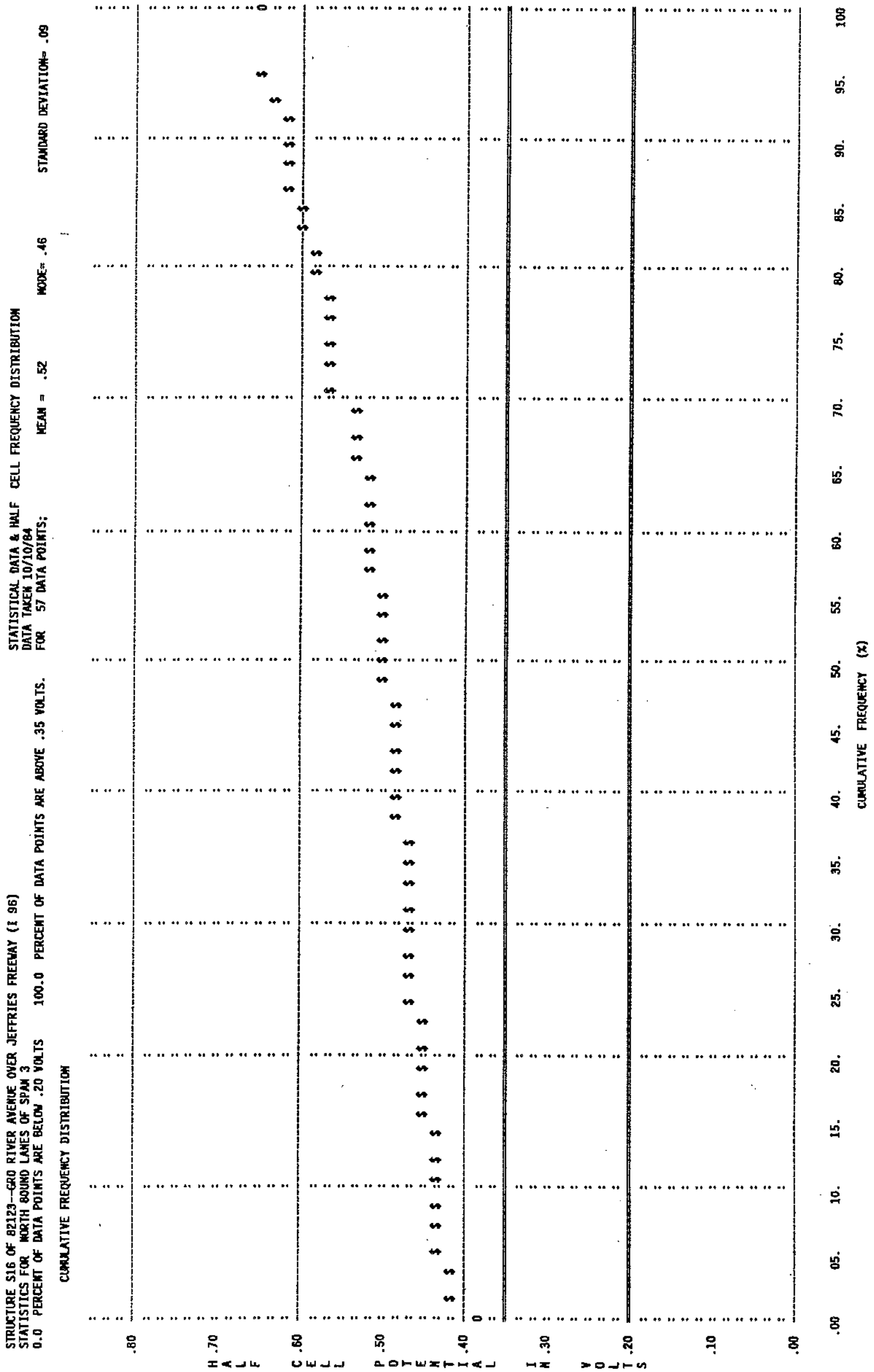
EQUIPOTENTIAL CURVES FOR NORTH BOUND LANES OF SPAN 3

DATA TAKEN 10/10/84

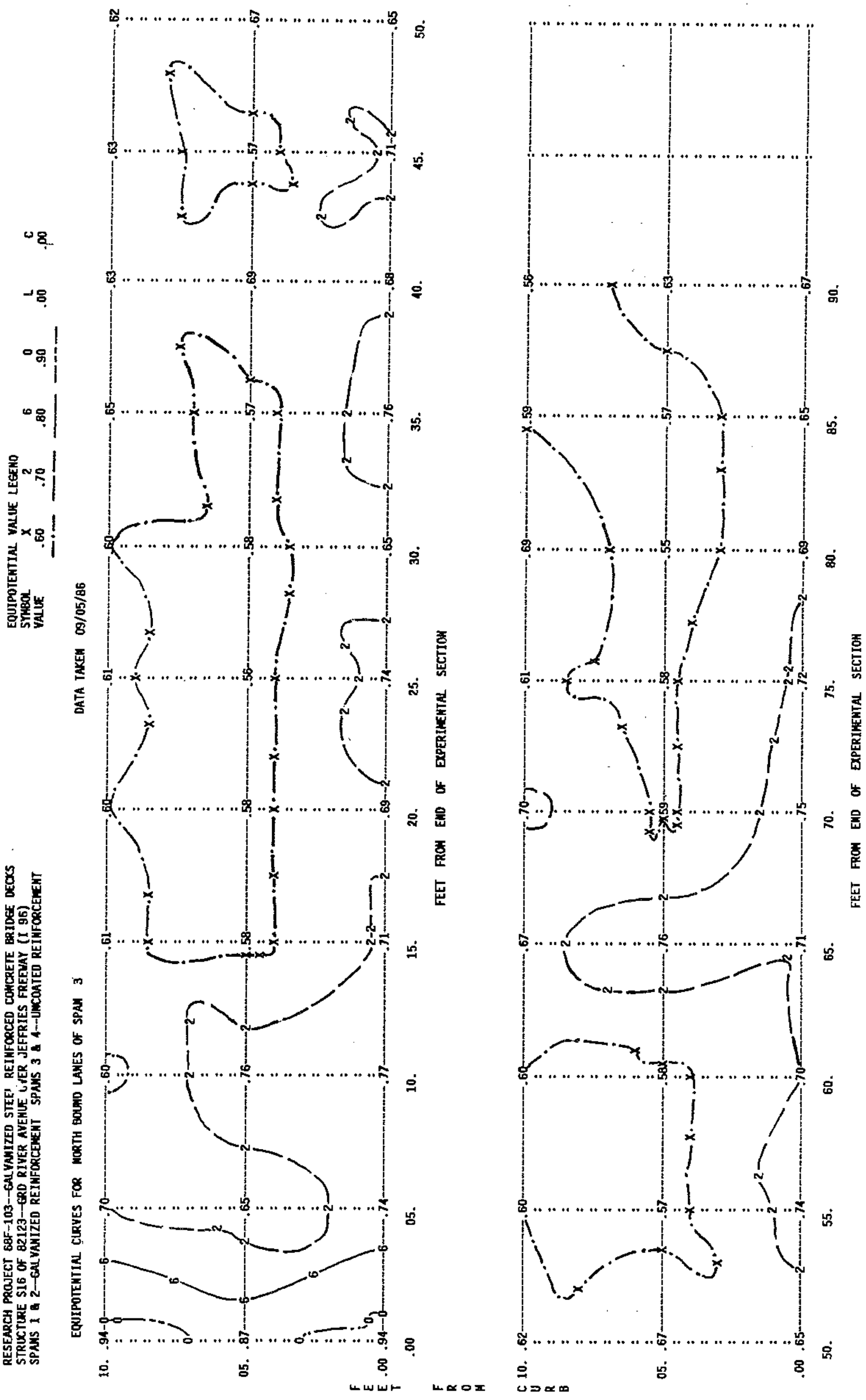
EQUIPOTENTIAL VALUE LEGEND

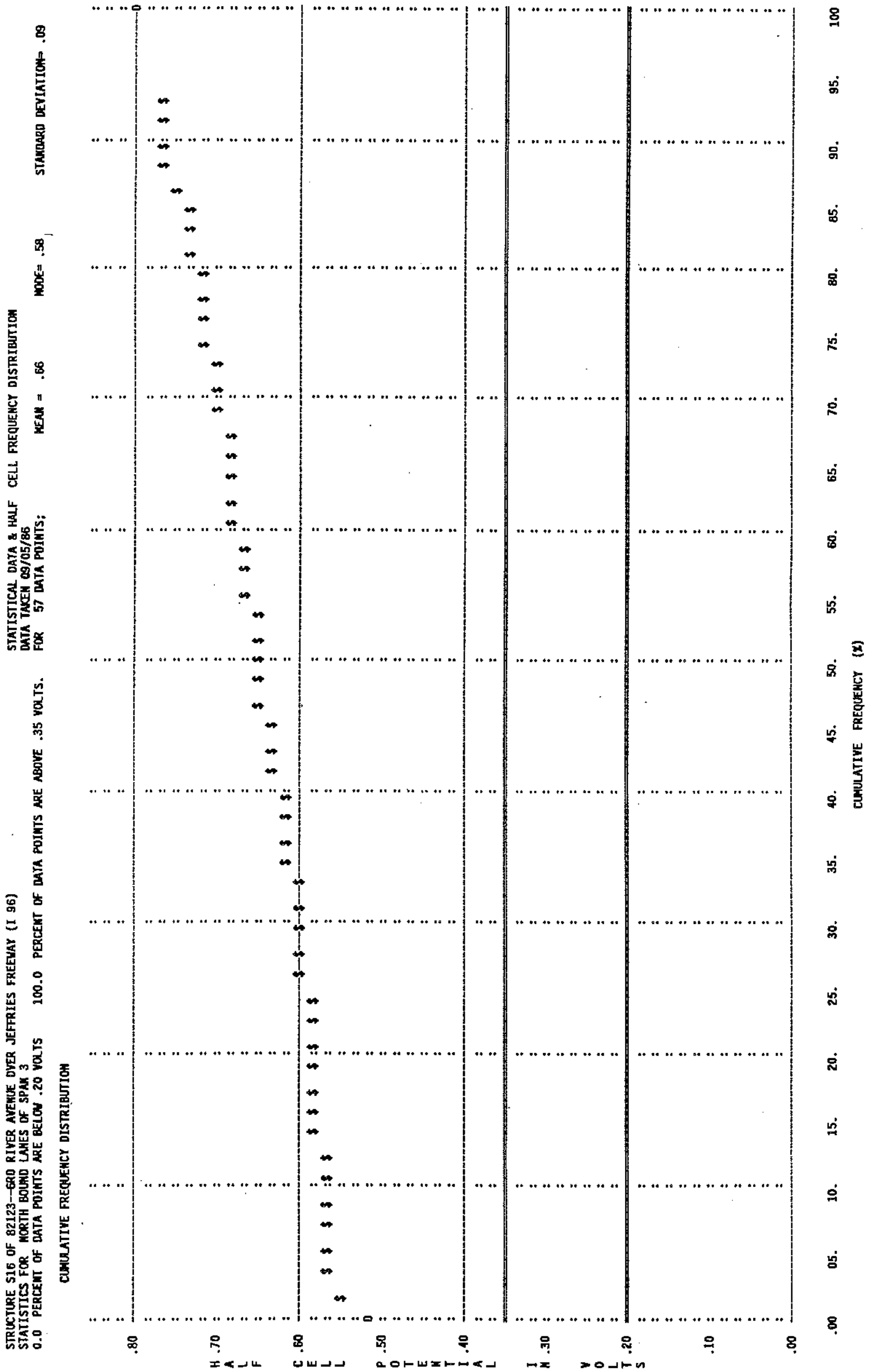
SYMBOL	T	X	2	6
VALUE	.50	.60	.70	.80




STRUCTURE S16 OF 82123--GRD RIVER AVENUE OVER JEFFRIES FREEWAY (I 96)
STATISTICS FOR NORTH BOUND LANES OF SPAN 3
0.0 PERCENT OF DATA POINTS ARE BELOW .20 VOLTS 100.0 PERCENT OF DATA POINTS ARE ABOVE .35 VOLTS.
CUMULATIVE FREQUENCY DISTRIBUTION
STATISTICAL DATA & HALF CELL FREQUENCY DISTRIBUTION
DATA TAKEN 10/10/84
FOR 57 DATA POINTS; MEAN = .52 MODE= .46 STANDARD DEVIATION= .09
HALF CELL POTENTIAL IN VOLTS
.80
.70
.60
.50
.40
.30
.20
.10
.00
CUMULATIVE FREQUENCY (%)
.00
05.
10.
15.
20.
25.
30.
35.
40.
45.
50.
55.
60.
65.
70.
75.
80.
85.
90.
95.
100

Appendix B (Continued)
Grand River Avenue--North Bound Span 3 (Uncoated Reinforcement)
Data Taken 09/05/86

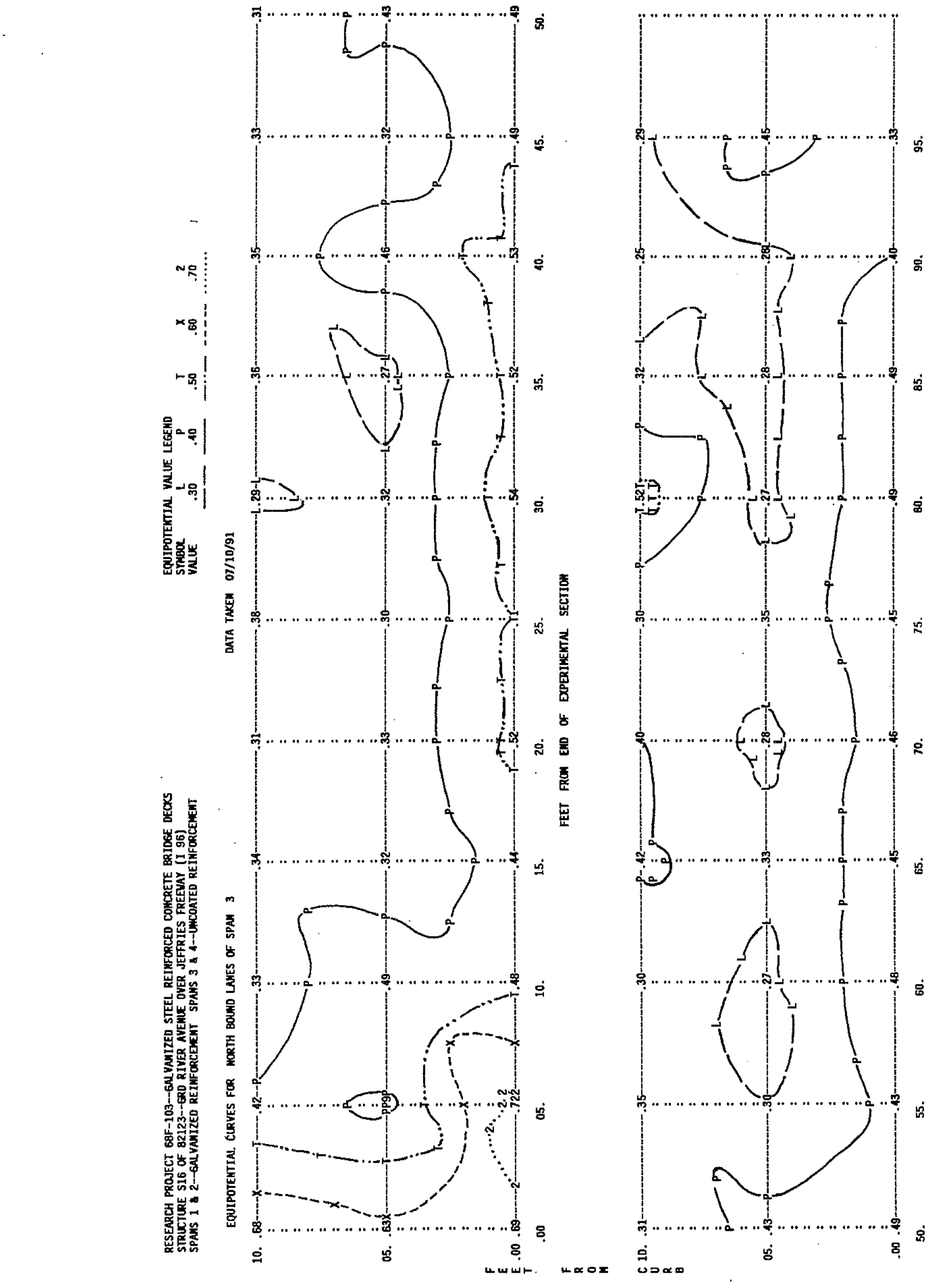


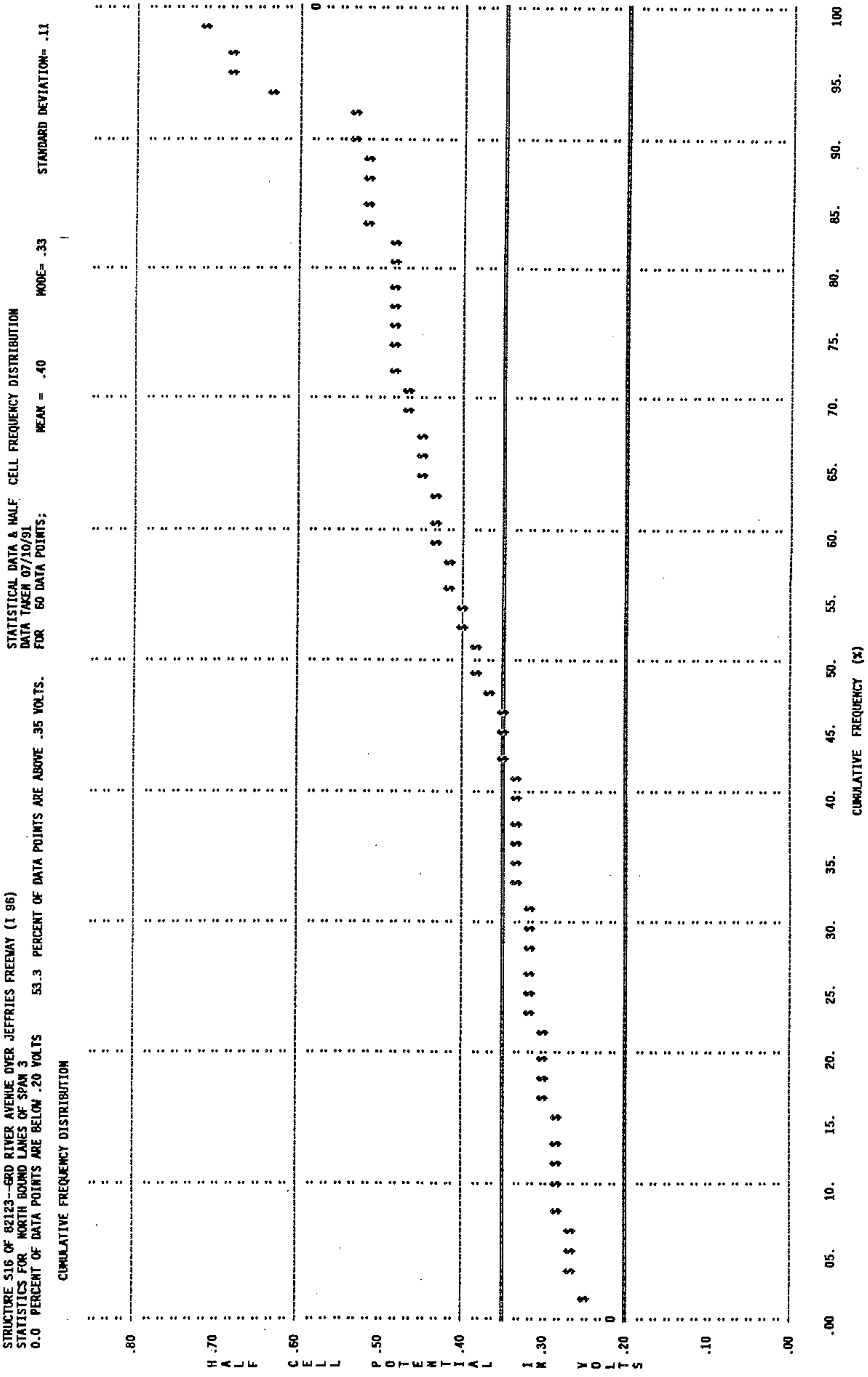


STRUCTURE S16 OF 82123--GRD RIVER AVENUE OVER JEFFRIES FREEWAY (I 96)
STATISTICS FOR NORTH BOUND LANES OF SPAN 3
0.0 PERCENT OF DATA POINTS ARE BELOW .20 VOLTS 100.0 PERCENT OF DATA POINTS ARE ABOVE .35 VOLTS.

STATISTICAL DATA & HALF CELL FREQUENCY DISTRIBUTION
DATA TAKEN 09/05/86
FOR 57 DATA POINTS; MEAN = .66 MODE= .58 STANDARD DEVIATION= .09

CUMULATIVE FREQUENCY DISTRIBUTION


RESEARCH PROJECT 68F-103--GALVANIZED STEEL REINFORCED CONCRETE BRIDGE DECKS
STRUCTURE S16 OF 82123--GRD RIVER AVENUE OVER JEFFRIES FREEWAY (I 96)
SPANS 1 & 2--GALVANIZED REINFORCEMENT SPANS 3 & 4--UNCOATED REINFORCEMENT
EQUIPOTENTIAL CURVES FOR NORTH BOUND LANES OF SPAN 3
DATA TAKEN 07/10/91
EQUIPOTENTIAL VALUE LEGEND
SYMBOL L P T X 2
VALUE .30 .40 .50 .60 .70
FEET FROM CURB
FEET FROM END OF EXPERIMENTAL SECTION
.00 05. 10. 15. 20. 25. 30. 35. 40. 45. 50.
50. 55. 60. 65. 70. 75. 80. 85. 90. 95.



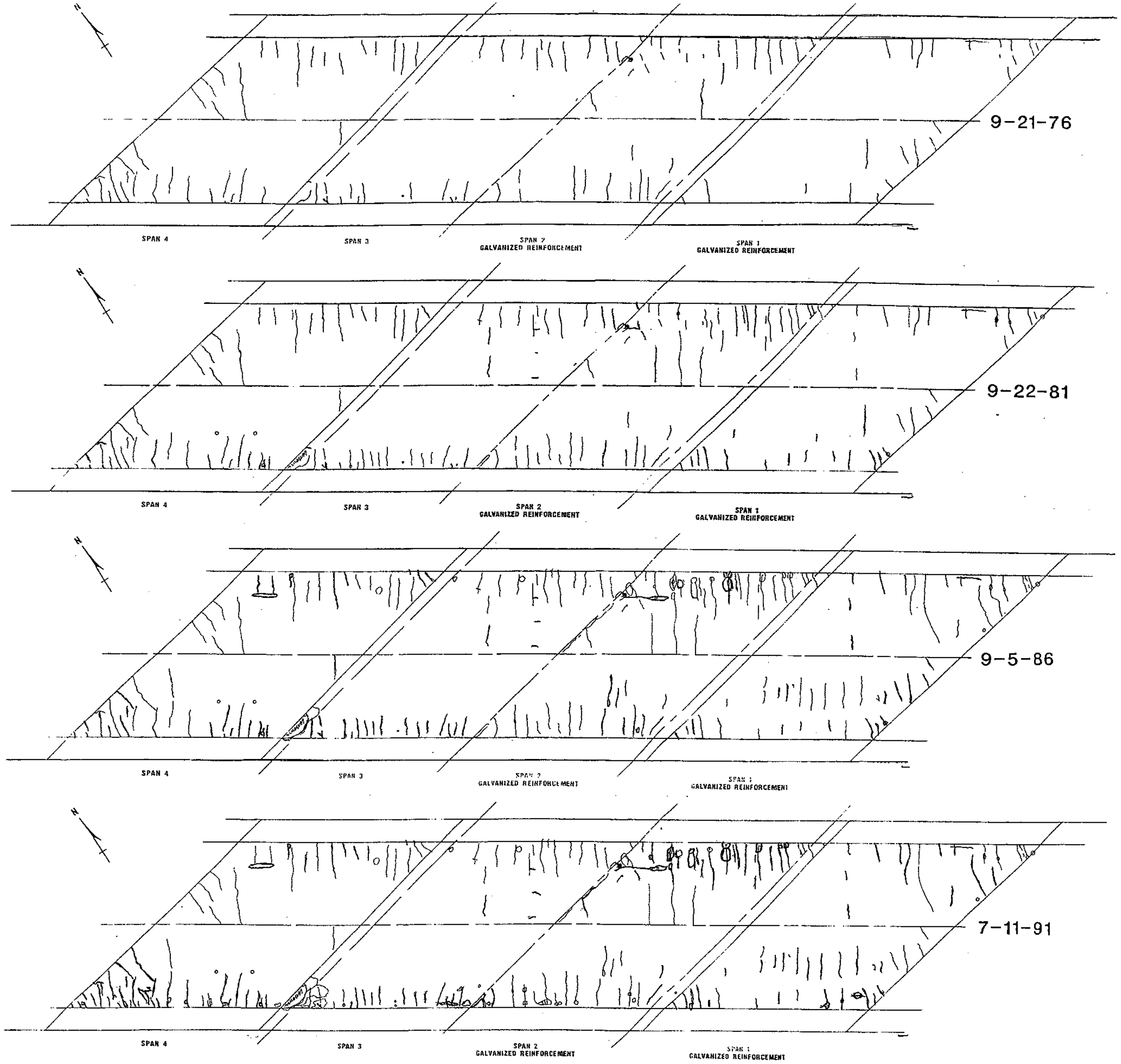
STRUCTURE S16 OF 82123--GRD RIVER AVENUE OVER JEFFRIES FREEWAY (I 96)
STATISTICS FOR NORTH BOUND LANES OF SPAN 3
0.0 PERCENT OF DATA POINTS ARE BELOW .20 VOLTS 53.3 PERCENT OF DATA POINTS ARE ABOVE .35 VOLTS.

STATISTICAL DATA & HALF CELL FREQUENCY DISTRIBUTION
DATA TAKEN 07/10/91
FOR 60 DATA POINTS; MEAN = .40 MODE= .33 STANDARD DEVIATION= .11

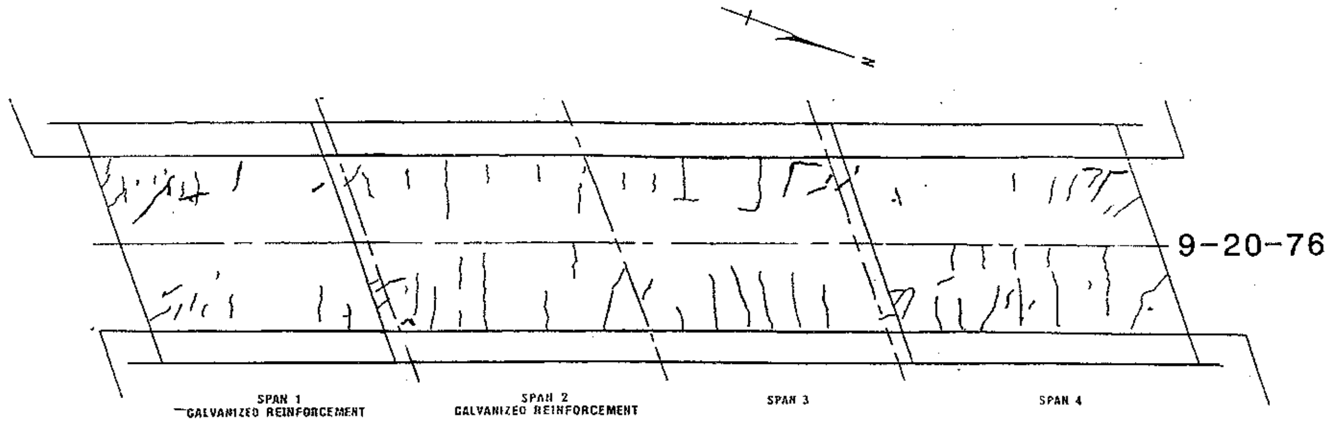
CUMULATIVE FREQUENCY DISTRIBUTION

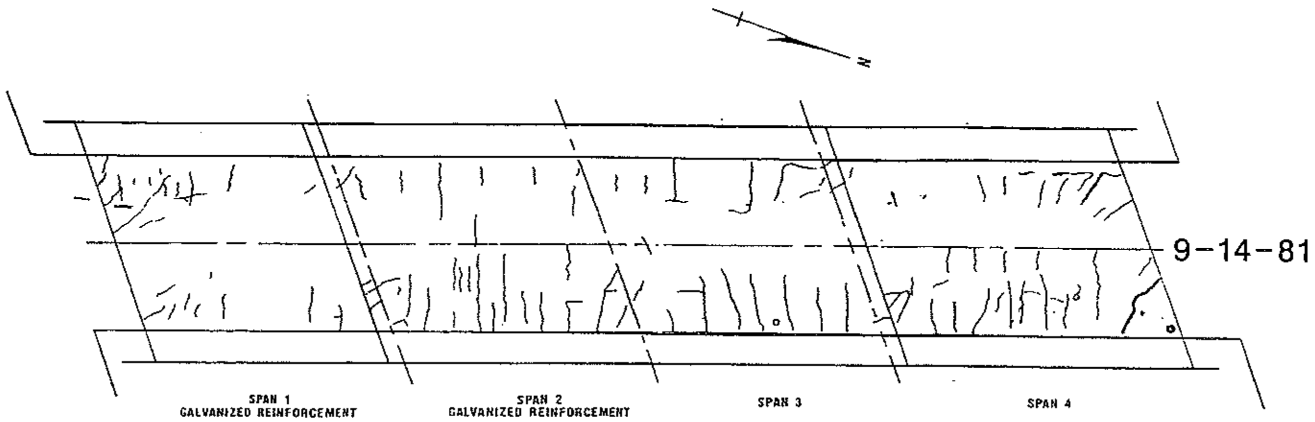
APPENDIX C

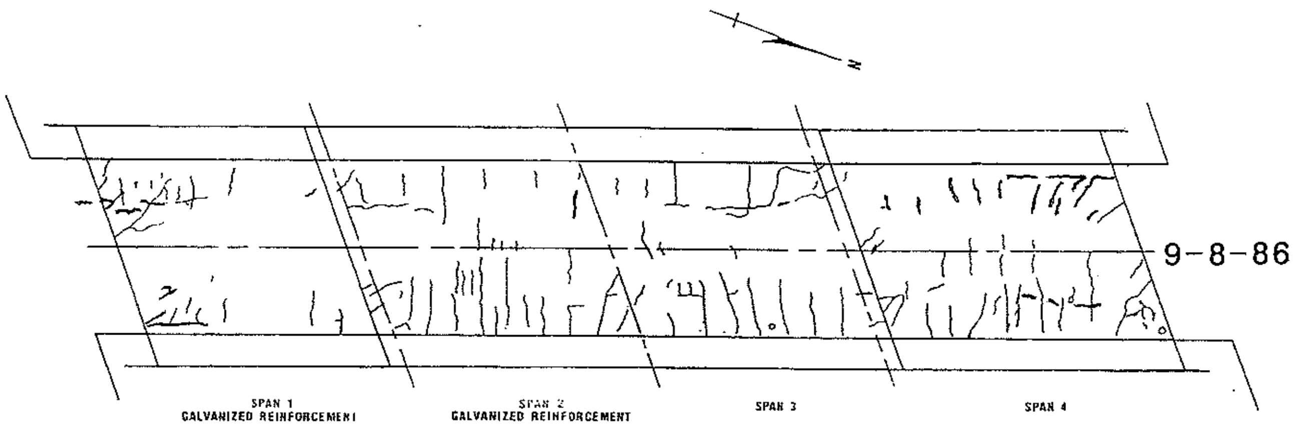
Drawings of all of the experimental bridge decks with dated indications of deck cracking, spalls, and delaminations are presented in the following pages. Lines represent cracks, open circles represent delaminations, and shaded circles represent spalls.

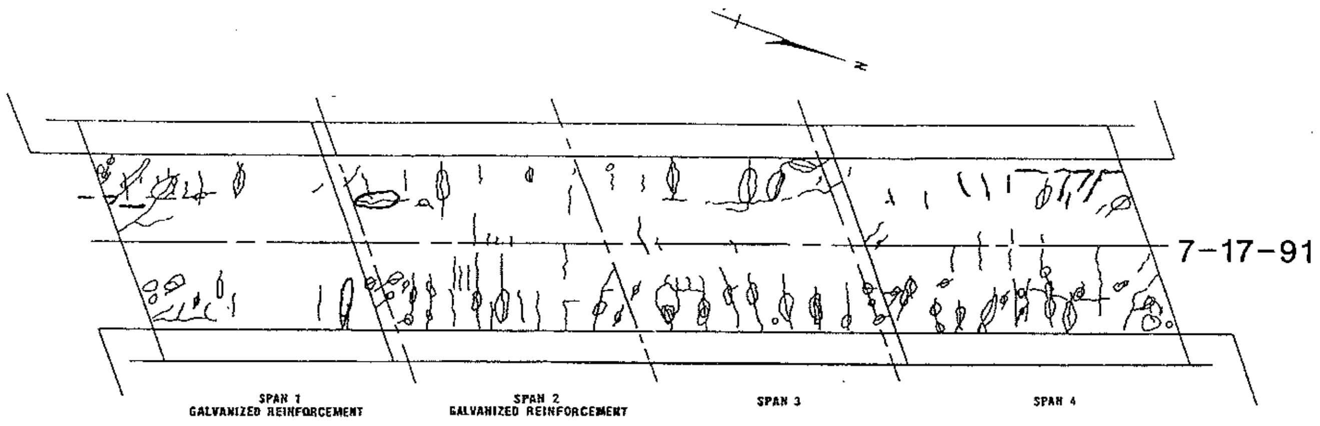


S16 of 82123
GRAND RIVER AVE. over JEFFRIES FREEWAY (I-96)

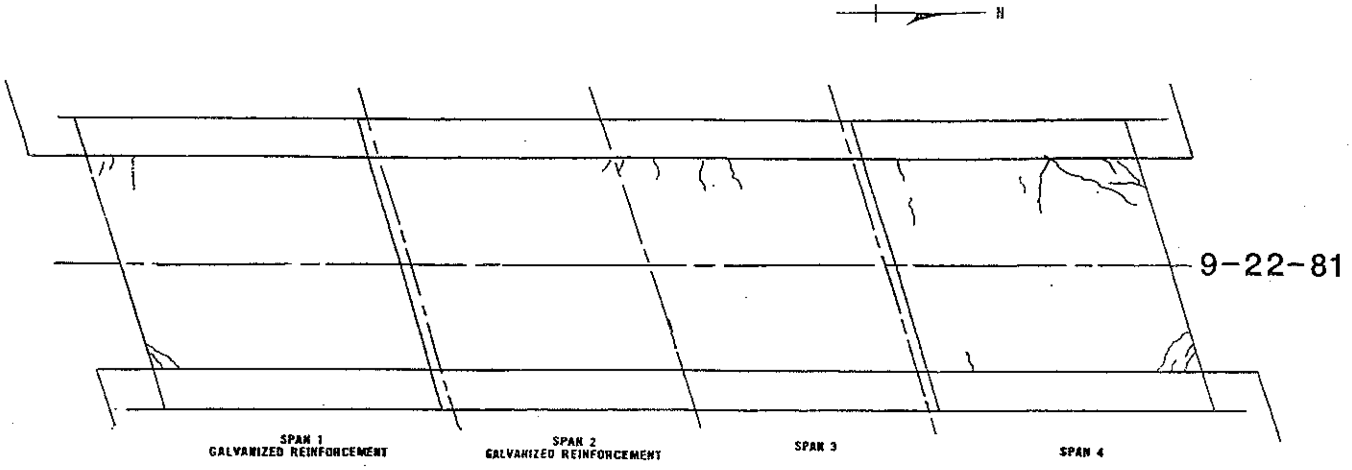


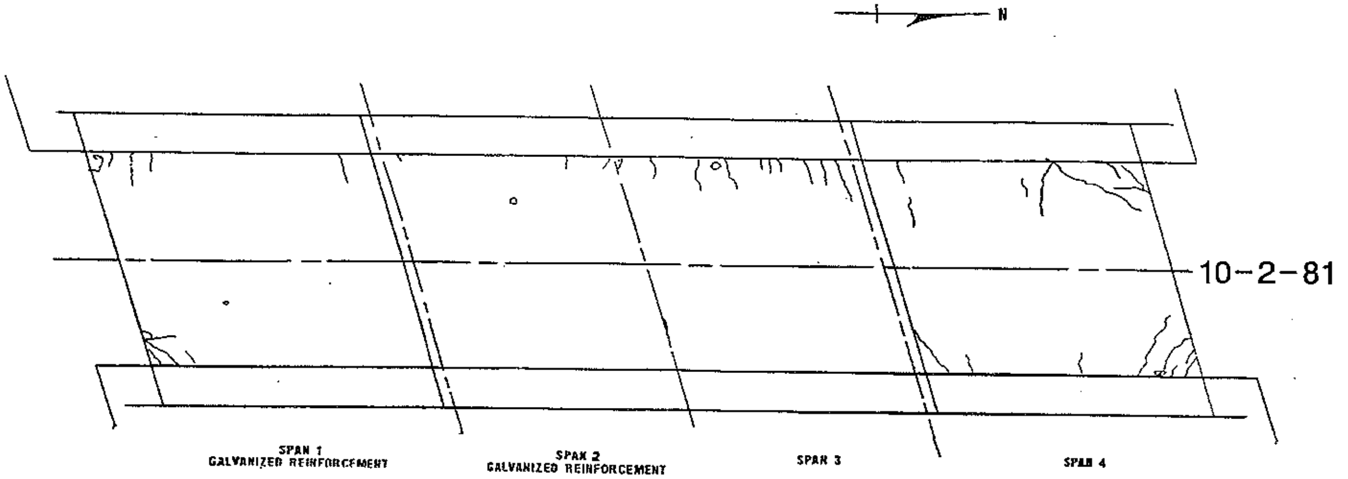


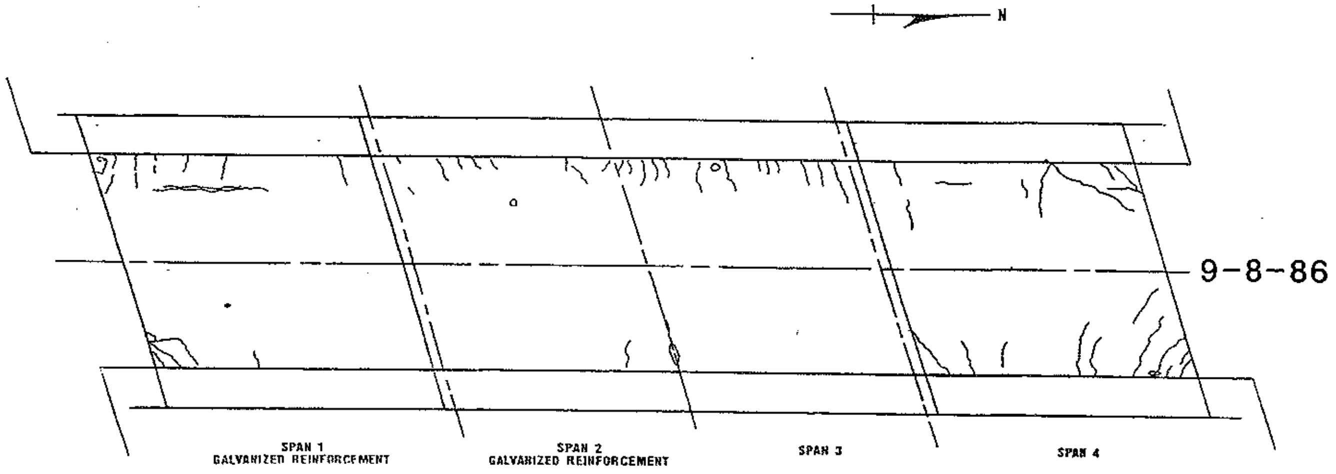


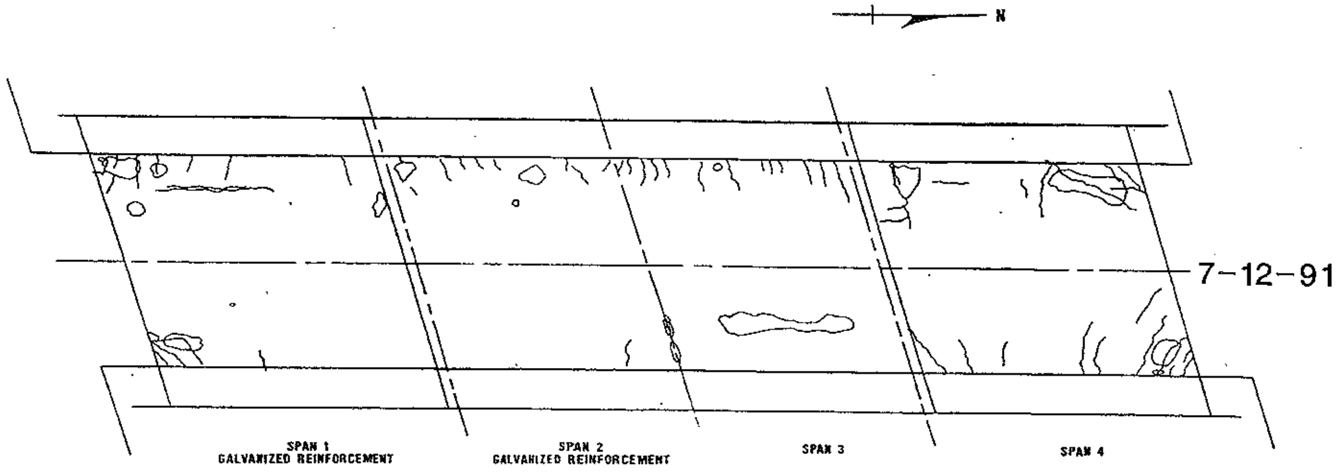


S-12 of 82123
HUBBELL AVE. over JEFFRIES FREEWAY (I-96)



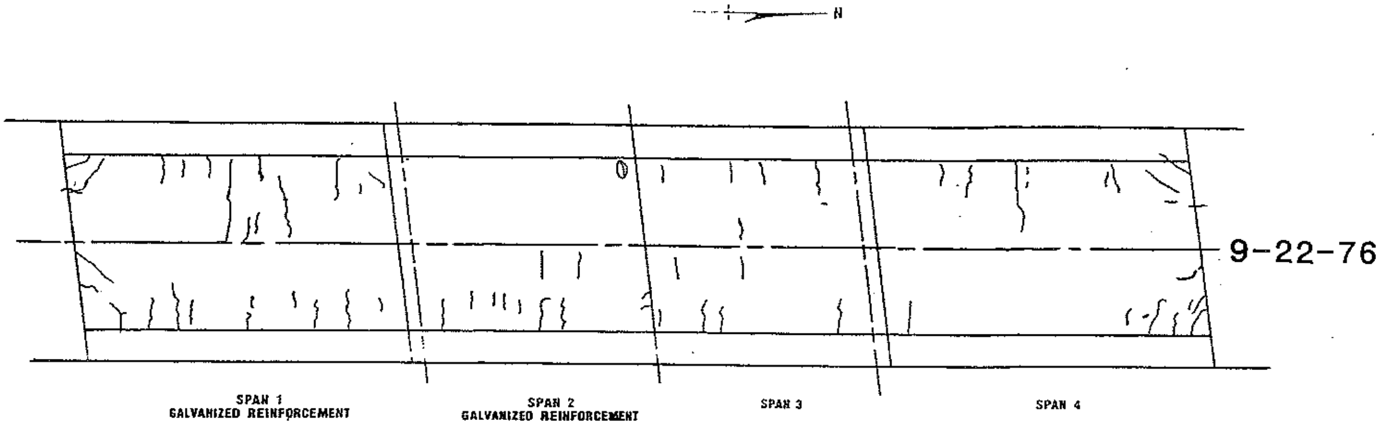


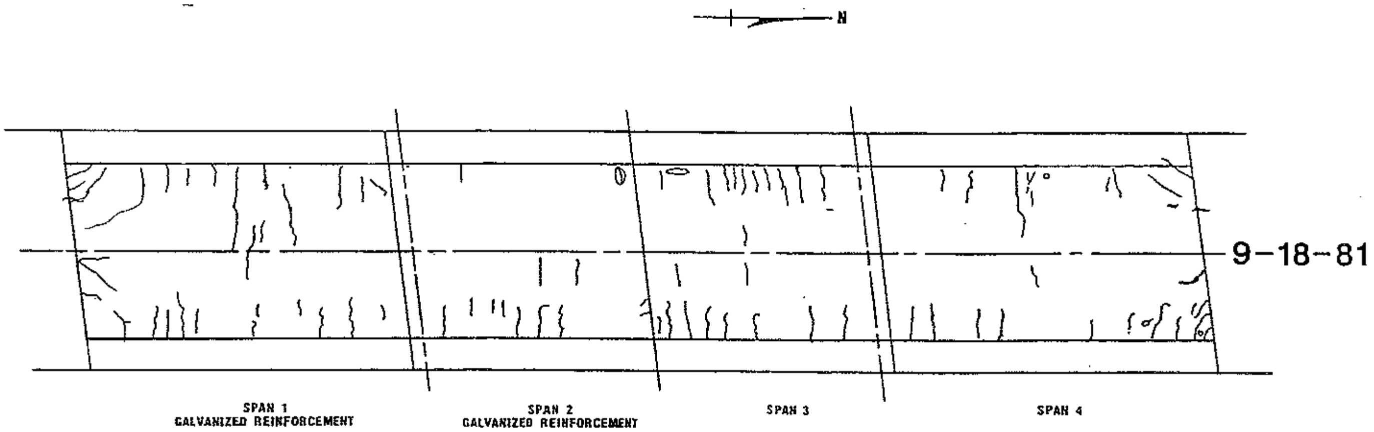


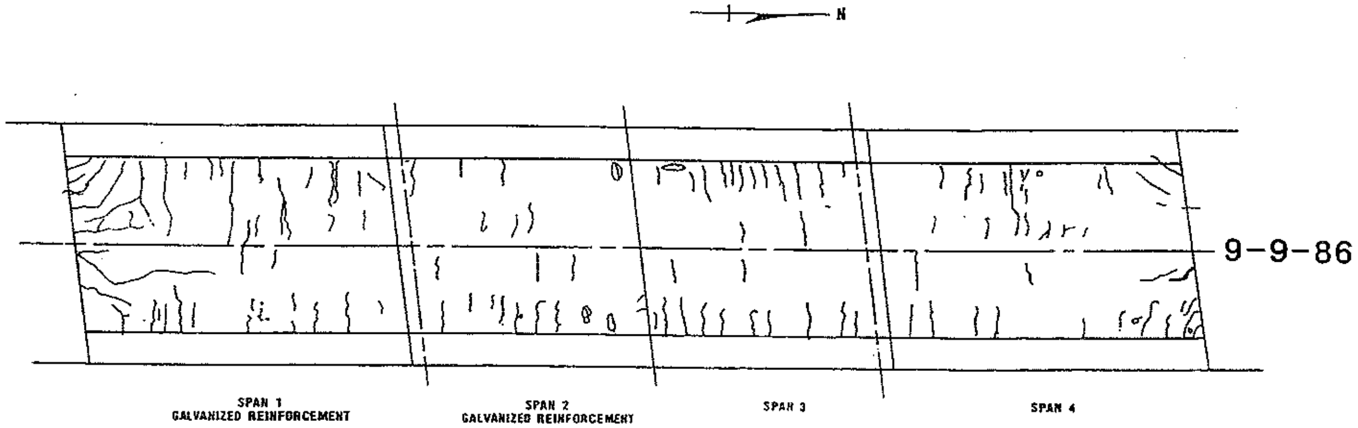


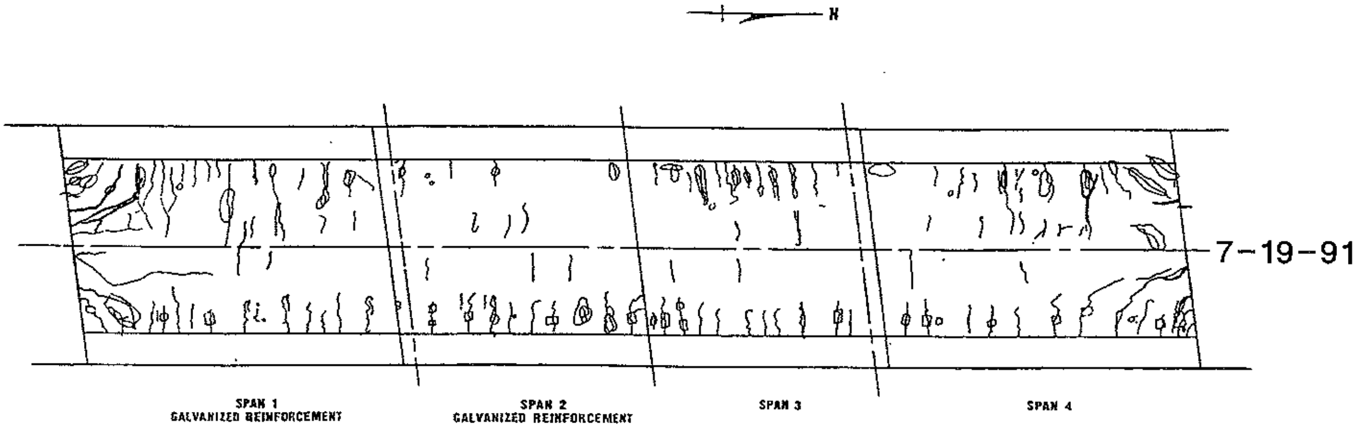
S14 of 82123
SCHAEFER RD. over JEFFRIES FREEWAY (I-96)

D



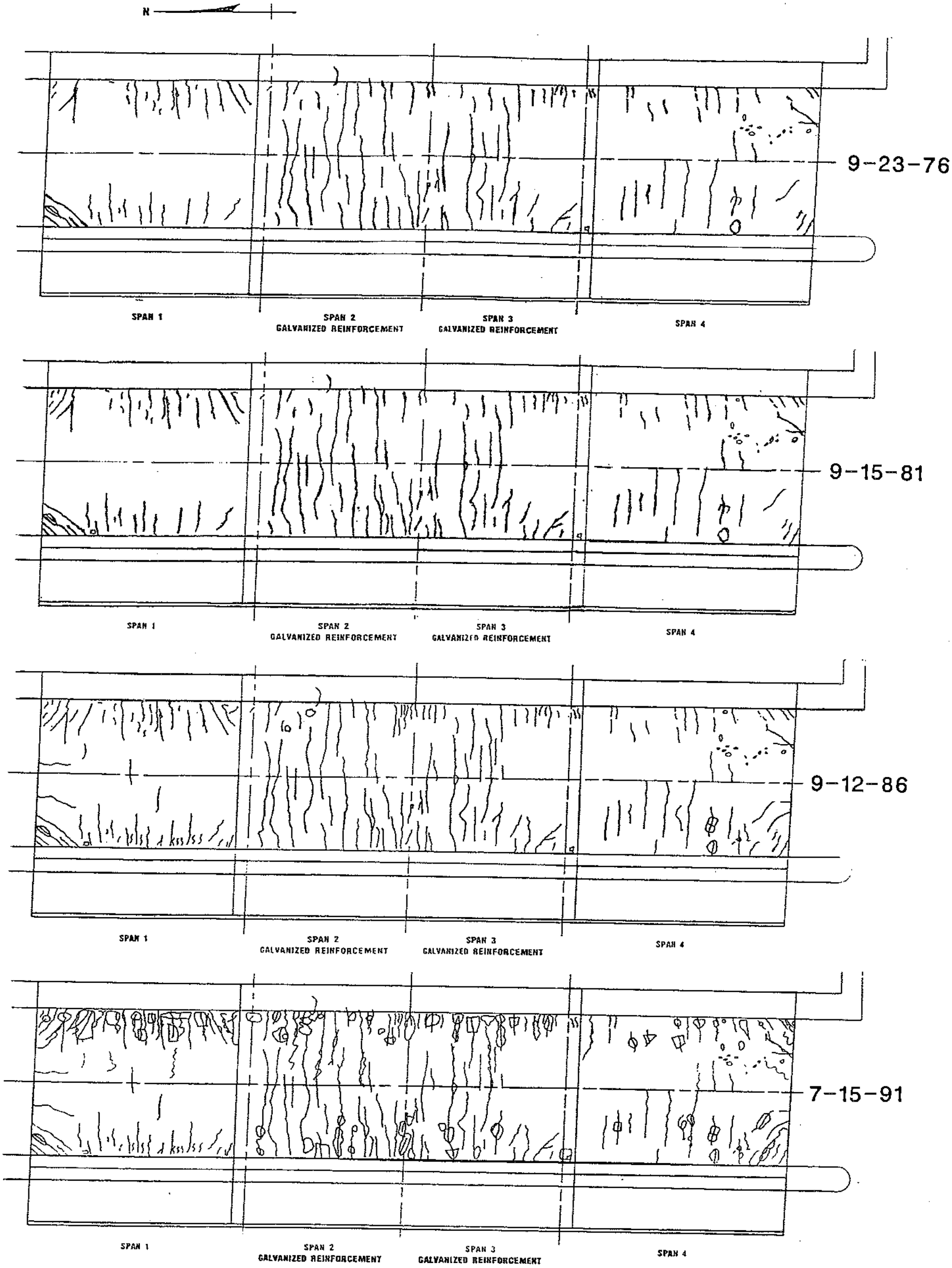






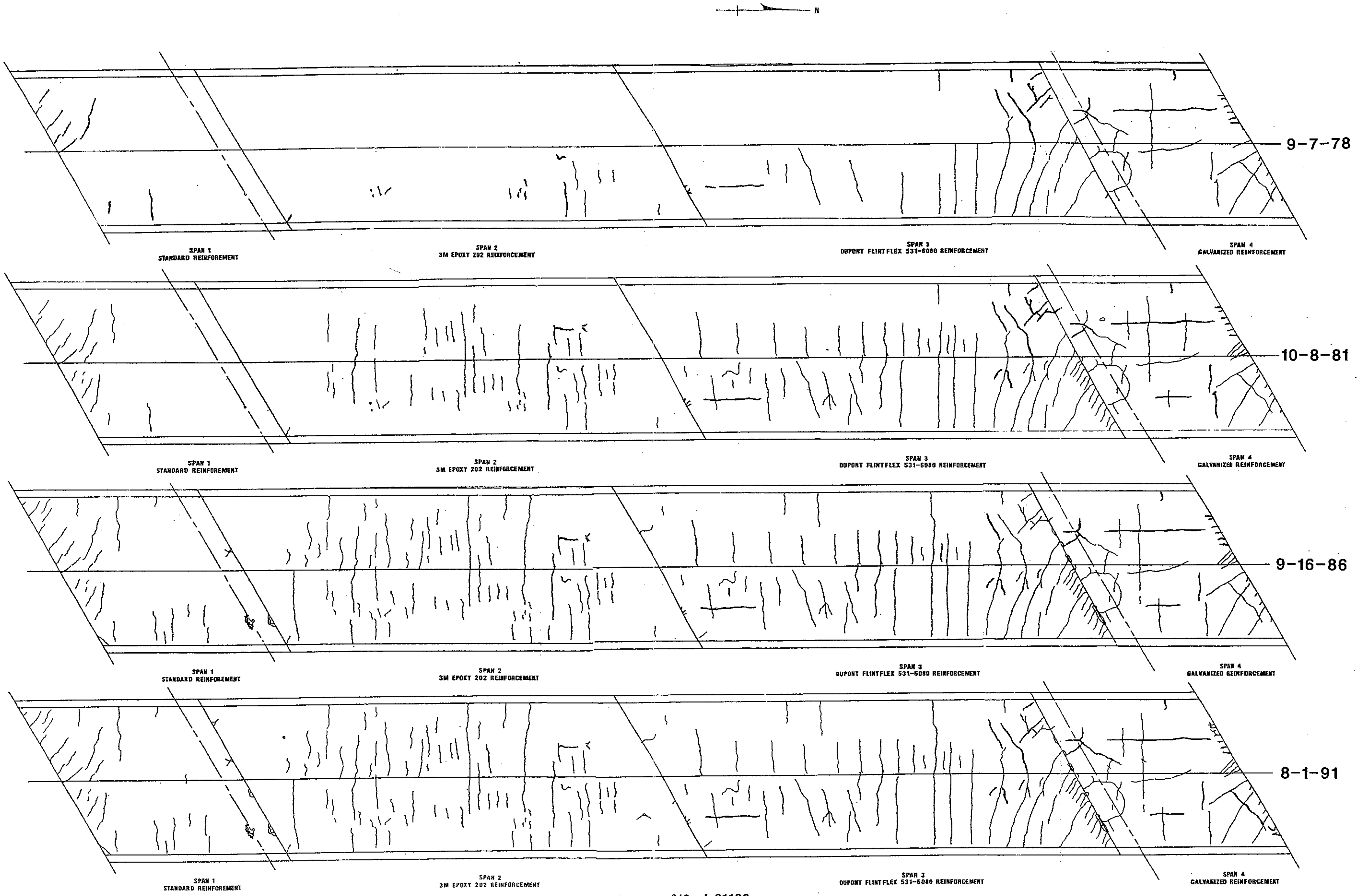
S17 of 82123
MEYERS AVE. over JEFFRIES FREEWAY (I-96)

E

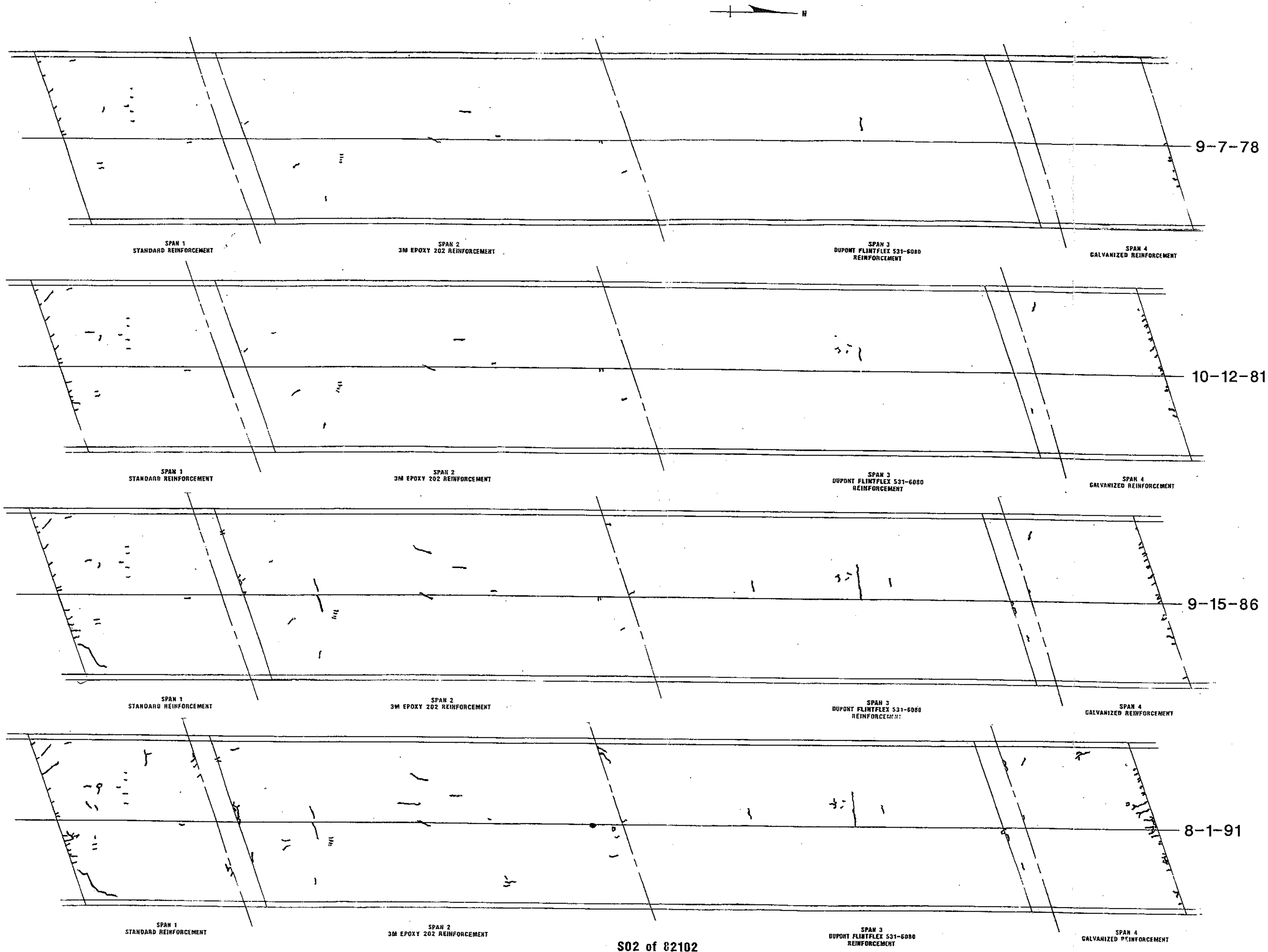


S18 of 23123
WYOMING AVE. over JEFFIERS FREEWAY (I-96)

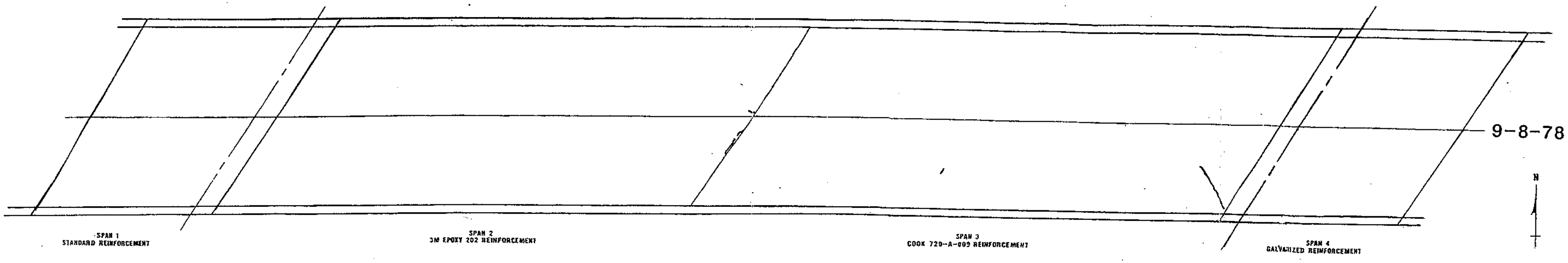
F

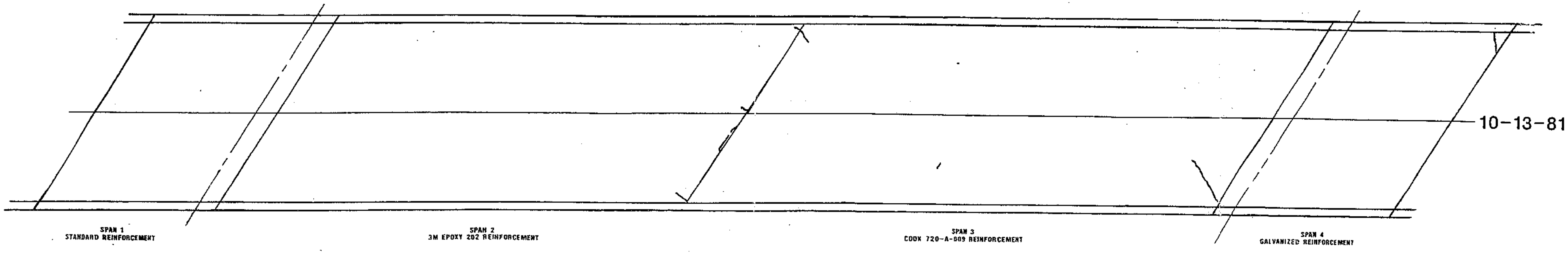


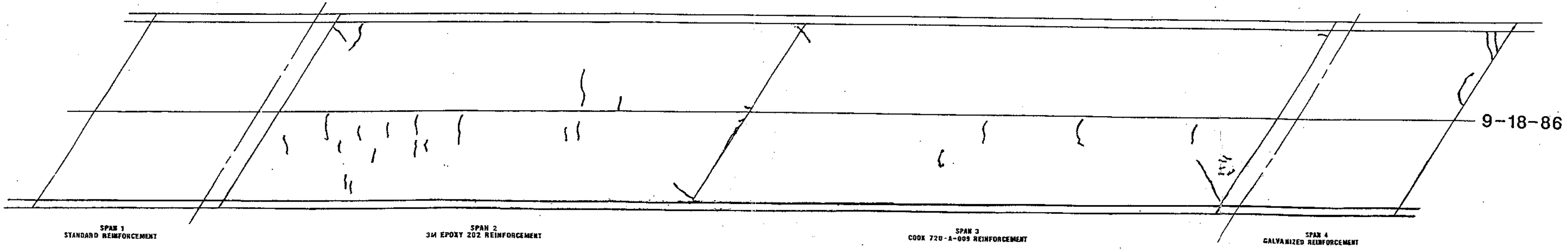
S13 of 81103
CURTIS RD. over M-14

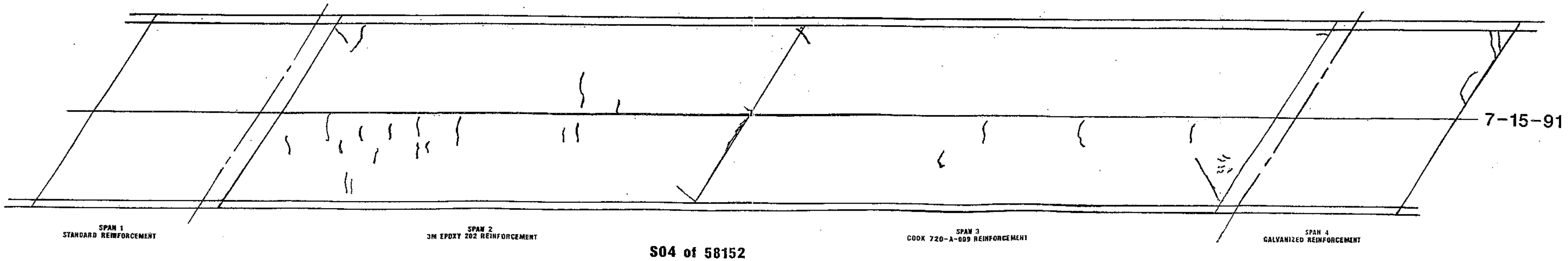


S02 of 82102
NAPIER RD. over M-14









S04 of 58152
POST RD. over I-75