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# INVESTIGATION OF BRIDGE DECK PROTECTION SYSTEMS

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16. Abstract

This study evaluated the effectiveness of various protection systems used for rehabilitation of existing salt contaminated bridge decks. Bridges selected for this study were on Routes I-29 and I-35 in the North Kansas City, Missouri area having similar environmental and high traffic conditions, and, with one exception, built from 1954 to 1958.

Protection systems placed and tested included a Stratfull design type cathodic protection; low slump and latex modified concrete wearing surfaces; sheet types Protecto Wrap M-400A and Heavy Duty Bituthene; and liquid types Gacoflex UWM-2811, and Superseal 4000LT membrane systems. All protective systems were overlaid with asphaltic concrete except for low slump and latex modified concrete. Each protection system was constructed on two bridge decks during the 1976-1977 construction season.

Each of the protective systems provided a relatively maintenance free overlay for a five to eight year period. Rutting and shoving of the asphaltic concrete was minor but was the predominant problem with membranes and cathodic protection systems. Low slump and latex modified concrete overlays provided the smoothest riding surfaces. Membrane systems protected the deck concrete from ingress of chloride ions. Concrete overlays did not prevent ingress of chloride ions but did slow the amount and depth of penetration with time.

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FHWA STUDY NO. 76-2

Prepared By

MISSOURI HIGHWAY AND TRANSPORTATION DEPARTMENT

DIVISION OF MATERIALS AND RESEARCH

DECEMBER, 1988

In Cooperation With

U. S. DEPARTMENT OF TRANSPORTATION

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

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# INTRODUCTION

## PROBLEM

Corrosion of reinforcing steel in concrete bridge decks has been accelerated by increasing use of de-icers. Increasing concentrations of chloride ion around the reinforcing steel has enhanced rapid growth of corrosion products which ultimately causes loss of concrete on the surface of the bridge decks. Repair cost has accelerated causing severe budgetary problems. Solutions to abate or stop the corrosion deterioration of existing bridge decks and to prevent corrosion deterioration of future structures are needed.

## HISTORY

The Missouri Highway and Transportation Department, on identification of a problem with bridge deck deterioration due to scaling and spalling, and evaluating possible future maintenance costs, began in 1955 to place bituminous and aggregate seal coats on bridge decks. This application was to seal the immediate surface of the concrete and the structural cracks to prevent further deterioration.

Construction specifications for new construction were changed in 1959 to help cope with deterioration problems. From observed defects in existing structures, more restrictive limitations on the shale or shaley stone contents of the coarse aggregate were imposed. Design changes increased cover to two inches above the top reinforcing steel and established

limitation on the maximum air temperature during a concrete deck pour of 90 degrees F.

In 1960, further restrictions were placed on fresh concrete properties by specifying a four inch maximum slump and entrained air content of 4 to 7%. Application of double boiled linseed oil to the surface of the concrete deck and parapet walls of new structures was also specified after a given curing period and before opening to traffic. One application of double boiled linseed oil was required each year thereafter, for a period of five years.

In 1970, because of the theory of corrosion due to salt intrusion, the use of several proprietary waterproofing membrane systems to protect new and existing bridge decks was initiated. These liquid and sheet type membranes were normally thicker in application rate than the seal coats and were protected from traffic abrasion with a two inch asphaltic concrete overlay system.

In 1973, experimental use of epoxy coated reinforcing steel was initiated for new bridge construction. The coating, an electro-static heat treat process, was designed to protect the reinforcing steel from the corrosive environment. Handling and placing procedures were improved during the construction of experimental installations. Epoxy coated reinforcing steel has subsequently been specified for new reinforced concrete bridge decks.

In 1975, cathodic protection was placed on a pair of twin box girder bridges. The design of the system, done inhouse, was

a copy of the original Stratfull[2] design which used pie shaped cast iron primary anodes with coke breeze asphaltic concrete as secondary anode. Missouri has subsequently engaged in active use of cathodic protection since 1984.

In 1976, low slump concrete and latex modified mortar overlays were used to rehabilitate existing bridge decks. Shortly thereafter the latex modified mortar was re-designed to the present latex modified concrete overlay. During the same period of time, the cover on the top reinforcing steel in the new reinforced concrete bridge decks was increased to a total of 3 inches. A new concrete mix design (B-2) for bridge decks was designed with 7.75 bags of cement per cubic yard at a maximum water-cement ratio of 0.40 to increase density and reduce permeability of the concrete to help retard chloride penetration.

The above historical sketch of the Missouri Highway and Transportation Department's efforts to find acceptable rehabilitation methods for existing bridge decks and to design preventative measures into new construction to prevent further corrosion deterioration has been productive.

## THEORY

Basic consideration of the above problem would dictate elimination of de-icers. Short of this solution, a method to render the chloride ions ineffective must be developed. Numerous reports have offered laboratory and field research results on the effectiveness of many protection systems to stop

corrosion deterioration of bridge decks. Many questions, however, have been raised about the true performance of protection systems based on the data and test methods used. Ultimate evaluation of a protection system should be from field performance records. Many forms of deterioration can occur to a protection system, but it is the continued corrosion of the reinforcing steel attributable to failure of the protection system that is important in this research investigation.

The theory which was pursued by Missouri in the formulation of this research project was primarily directed to existing structures which were considered as structurally rehabilitatible. Removal of the deteriorated concrete in delaminated areas, cleaning the remaining concrete surface, and placing a protection system appeared to be the most economical measure to extend the life of existing decks. This study was designed to evaluate several protection systems that were being utilized within the State of Missouri, and to include the new proposed concrete overlay designs that had not previously been used in Missouri.

## OBJECTIVE

The objective of this study was to determine the effectiveness of seven protection systems which may be applied to the surface of concrete bridge decks to either eliminate or retard the corrosion process. The 7 protection systems used on 14 bridges in the North Kansas City area were:

1. Cathodic Protection - Bridges L-701 and L-702
2. Low Slump Concrete - Bridges L-501 SB and L-642

3. Dow Latex Modified Concrete - Bridges L-759 SB and L-641
4. Protecto Wrap M-400A w/Protection Sheet (sheet type) - Bridges L-501 NB and L-759 NB
5. Heavy Duty Bituthene (sheet type) - Bridges A-1613 and L-719
6. Gacoflex UWM-2811 (liquid type) - Bridges L-720 and L-721
7. Superseal 4000LT (liquid type) - Bridges L-563 and L-571

All of these structures carried main line traffic on either Route I-29 or I-35 as shown in Figure 1. The heavy traffic afforded by the location of the test bridges was considered essential to obtain deterioration rate data to establish protection system performance in the least amount of time possible. Performance under those conditions was considered harsh and should give indication of expected performance in the lighter traffic areas.

## RESEARCH APPROACH

All structures selected for use in this study were located in close proximity and were all placed under the same contract to eliminate as many extraneous variables as possible. Each phase of the rehabilitation and construction program was observed and recorded. Tests during the construction period were performed at the completion of each phase of work which were considered to best reflect any changes in the condition of the deck or to test the characteristics of applied protection

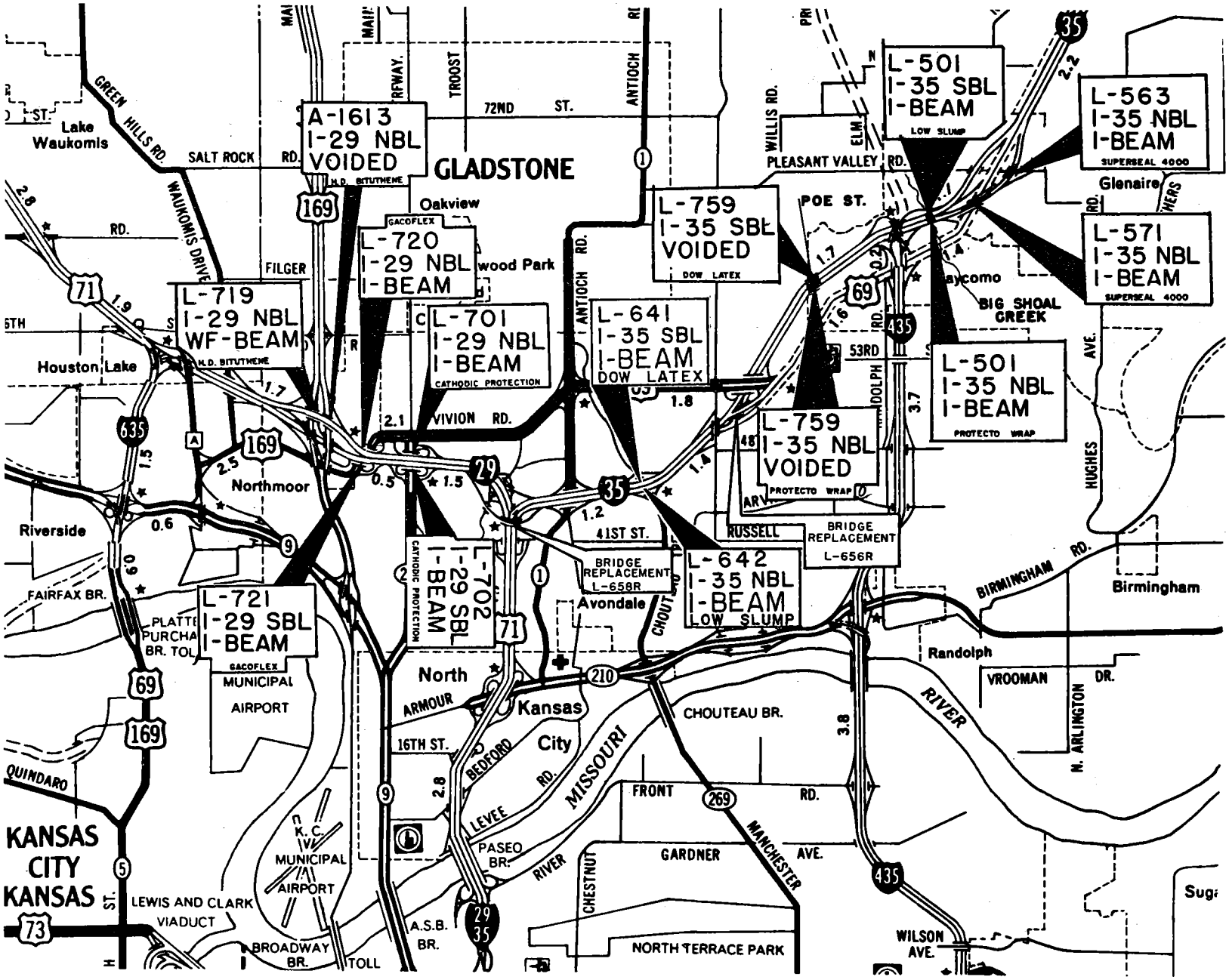



Figure 1 - Location of Bridge Sites Used for Evaluation Testing and Relative Products Used on Each Bridge Deck

systems. Subsequent testing annually was to develop a record of the relative performance of the protection systems with age and traffic loading. Observation of any maintenance performed on these protection systems was duly recorded and reasons for such determined.

Evaluation of the construction sequence was used to consider specification applicability and to determine if changes were needed to insure proper handling of the products. Evaluation of these protection systems was to be based on the physical test results as well as observation of the general overall performance.

## CONCLUSIONS AND RECOMMENDATIONS

Based on field observations and test results after an eight year period, the following conclusions and trends appear warranted.

1. Each of the protective systems provided a relatively maintenance free overlay for a five to eight year period.

2. Low slump and latex modified concrete overlays provided the smoothest riding surface.

3. Low slump and latex modified concrete did not prevent chloride ion penetration within the overlay. However, the overlays appeared to have slowed down the process of chloride ions penetrating deeper into the overlay and eventually to the original deck concrete.

4. Each of the liquid and sheet type membranes prevented additional chloride ion penetration into the original deck concrete.

5. Cathodic protection system (Stratfull design type) - Distresses noted in the asphaltic concrete surface were not considered to be caused by disruptive forces within the concrete deck, therefore, cathodic protection appeared to be performing satisfactorily. Distresses were identified as cracking, rutting, and minor shoving of the asphaltic concrete surface. That distress could be attributed to debonding of one or both asphaltic concrete courses, stripping of porphyry coarse aggregate near the bottom of the asphaltic concrete surface course, or a slightly unstable coke breeze asphaltic concrete layer. Evaluation of the copper-copper sulfate and zinc (coated

and uncoated) half cells indicated copper-copper sulfate was more sensitive to changes in environment of the system.

6. Low slump concrete - Surface cracking was considered to be the major cause of concern. Cores drilled from the concrete overlay indicated cracks were generally full depth of the overlay regardless of the surface crack width. Minor areas of patching were required. Less than four percent of each deck area surveyed indicated delaminations. Delaminations were the result of debonding of the overlay over the patched concrete deck and fracture planes.

7. Latex modified concrete - Surface cracking was considered to be the major cause of concern. Cores drilled from the latex modified concrete overlay indicated cracks were generally full depth of the overlay regardless of the surface crack width. Minor areas of patching was required. Less than ten percent of each deck area surveyed indicated delaminations. Delaminations were the result of debonding of the overlay over the patched concrete deck and fracture planes.

8. Sheet types Protecto Wrap M-400A and Heavy Duty Bituthene Membranes - Based on "waterproofing" ability, the membranes failed. Resistance scans dropped sharply after the first year of service and remained low for the remaining seven years of the study. Based on chloride ion content, the membrane systems provided the protection sought. Minor cracking, patching, and rutting occurred. Delaminations of deck areas surveyed ranged from 1 to 18 percent. Delaminations could have been the result of debonding of one or more layers of the membrane system and/or stripping of the porphyry coarse

aggregate near the bottom of the asphaltic concrete surface course. Some fracture planes were detected in the decks with Heavy Duty Bituthene.

9. Liquid types Gacoflex UWM-2811 and Superseal 4000LT membranes - Based on "waterproofing" ability, the membranes failed. Resistance scans dropped sharply after the first year of service and remained low for the remaining seven years of the study. Based on chloride ion content, the membrane systems provided the protection sought. Minor cracking, patching, and rutting occurred. Delamination of deck areas surveyed ranged from 21 to 75 percent. Delaminations could have been the result of debonding of one or more layers of the membrane system and/or stripping of the porphyry coarse aggregate near the bottom of the asphaltic concrete surface course. Some fracture planes were detected in the decks with Superseal 4000LT.

10. Predictability of chloride ion concentration from electrical potential values would be subject to large error and therefore unacceptable.

11. All liquid and sheet type membrane systems had effectively stabilized chloride ion concentrations at levels existing prior to placement of the systems. Chloride ion concentration had undergone some redistribution in the concrete overlays.

12. Generally, all protective systems, except cathodic protection, indicated stable or decreasing electrical potentials in the "active corrosion" range of voltages more negative than -0.35 volts.

13. A rapid in situ field chloride ion determination method was evaluated with the method used in AASHTO T260. Results between the two methods were not significant.

## IMPLEMENTATION

This study provided a concentrated effort to evaluate specification requirements, construction procedures, and serviceability of the overlay systems tested.

Specifications for handling and placing each of the bridge deck protection systems and construction procedures were evaluated during the actual construction phase of this study. Basically, the manufacturers suggested procedures were followed and no particular outstanding problems were noted. However, numerous notes were added to future specifications for purposes of clarification of intent or procedure.

Serviceability of the overlay systems as discussed in this report has given the department a systematic evaluation of various bridge deck protection systems. Even though all of these systems may have some problems associated with cracking or deterioration of the overlay materials, protection of the original deck appears to have been achieved. Frequency of maintenance operations to maintain a particular system in place has a great bearing on acceptability. Therefore, the implementation of the conclusions and recommendations relating to each individual system has generally been accepted and has influenced the use of these systems within the Missouri highway system. Concrete overlays are now being used more extensively in Missouri than any other rehabilitation type overlay system.

Additional studies were initiated because of observations made from this investigation. A study was conducted on low

slump and latex modified concrete overlays to determine how extensive the overlay cracking problem was. This resulted in increased thickness of the overlays to prevent most of the cracking problems. Another study was conducted into the mix design of the porphyry asphaltic concrete overlays to study the stripping of the aggregate. This study caused a redesign of the asphaltic concrete mix to better control this problem by addition of a minimum of one percent hydrated lime, by weight of total mix.

In general, the Missouri Highway and Transportation Department has undergone many design changes in bridge deck rehabilitation since the beginning of this project. As specific aspects of a particular system are considered, subsequent designs may reflect changes due to reported field evaluations. Presently, only the liquid applied membranes are used, if used at all. Concrete overlays (low slump and latex) are used extensively in rehabilitation and some new construction. The 7.75 bag concrete mix design (B-2) is now the standard for bridge deck concrete on new or replacement contracts. Cathodic protection has been used extensively on bridges requiring rehabilitation in sensitive and heavy traffic areas. Advances in technology and product concepts have caused cathodic protection to be a viable asset to rehabilitation rather than costly replacement.

# RESEARCH DATA AND TEST METHODS

## SELECTION AND LOCATION OF TEST SITE

During the planning phase of this study, liquid and sheet type membrane bridge deck protection systems were being placed on both new and rehabilitated bridge decks. However, with the specification change to use a denser concrete mix design, epoxy coated reinforcing steel in the top mat and the increased depth of concrete cover on all new construction, such protection systems would be used exclusively on existing rehabilitated bridge decks. Therefore, the bridge decks considered for use in this investigation were existing bridges which were in some need of repair and generally had chloride ion contents sufficiently high enough to promote corrosion.

Selection of the North Kansas City, Missouri area on Routes I-29 and I-35, Figure 1, satisfied the above criteria and also provided for all systems to be placed in similar environmental and traffic load conditions. Specific characteristics of the bridges selected and the associated traffic data per bridge are shown in Table 1.

## CONSTRUCTION OF PROTECTION SYSTEMS

Each bridge selected in this study was evaluated for its condition immediately prior to removal of deteriorated concrete and fracture plane areas. Testing to establish the condition of the reinforced concrete decks before rehabilitation work began, consisted of fracture plane, potential scan, surface profile,

Table 1 - Summary of Characteristics of Bridges

| Bridge No. | Lane | Width(1) (Feet) | Length(2) (Feet) | Bridge Type(3) | ADT(4) | Year(5) Built | Design Load |
|---|---|---|---|---|---|---|---|
| **Cathodic Protection** | | | | | | | |
| L-701 | NB | 30 | 182 | I-BM | 25300 | 1957 | S20 |
| L-702 | SB | 42 | 182 | I-BM | 25300 | 1957 | S20 |
| **Low Slump Concrete Wearing Surface** | | | | | | | |
| L-501 | SB | 30 | 207 | I-BM | 16200 | 1958 | S20 |
| L-642 | NB | 28 | 149 | I-BM | 14400 | 1954 | S20 |
| **Latex Concrete Wearing Surface** | | | | | | | |
| L-641 | SB | 28 | 149 | I-BM | 12500 | 1954 | S20 |
| L-759 | SB | 40 | 133 | VSLB | 13400 | 1958 | H15 |
| **Protecto Wrap M-400A (Sheet Membrane)** | | | | | | | |
| L-501 | NB | 30 | 207 | I-BM | 15400 | 1958 | S20 |
| L-759 | NB | 40 | 133 | VSLB | 12300 | 1958 | H15 |
| **Heavy Duty Bituthene (Sheet Membrane)** | | | | | | | |
| A-1613 | NB | 37 | 155 | VSLB | 27900 | 1965 | S20 |
| L-719 | NB | 30 | 295 | I-BM | 27900 | 1957 | S20 |
| **Gacoflex UWM-2811 (Liquid Membrane)** | | | | | | | |
| L-720 | SB | 42 | 245 | I-BM | 27500 | 1957 | S20 |
| L-721 | NB | 30 | 282 | I-BM | 27900 | 1957 | S20 |
| **Superseal 4000LT (Liquid Membrane)** | | | | | | | |
| L-563 | NB | 32 | 152 | I-BM | 15400 | 1958 | S20 |
| L-571 | NB | 30 | 317 | I-BM | 15400 | 1958 | S20 |

(1) Width in feet from curb to curb.
(2) Length in feet along centerline from abutment to abutment.
(3) Bridge types shown are:
I-BM is a concrete deck on an I-Beam stringer system.
VSLB is a thick concrete deck with hollow fiber tubes which is termed a voided slab bridge.
(4) ADT (Average Daily Traffic) is expressed as total traffic on all lanes on the structure as per last inventory 1980.
(5) Date of construction of original structure.

laboratory and field chloride ion testing and an underdeck profile study. Tabulation of the results of this survey are shown in Table 2.

During rehabilitation of the decks, specific locations of the patched areas and whether the patch was half-sole or full depth were recorded. Corrosometers were placed in a chloride laden concrete patch (2 pounds per cubic yard equivalent) at the level of the top reinforcing steel to monitor the corrosion activity under the membranes. After repair and immediately prior to placement of the membrane or overlay system, a final fracture plane, potential scan, and resistance survey was made. Tabulation of these results are shown in Table 3.

During placement of these bridge deck protection systems, specific notes were maintained on ease of placement, uniformity of coverage, specific locations of cover sheeting, and other information which was considered to have bearing on the ultimate performance of the system. Results of this information gathering is discussed in the following section of this report entitled, Observation of Placement of Protection Systems.

After completion of the membrane or overlay system and prior to opening to traffic, the decks were again surveyed for fracture plane, potential scan, and resistance scan to provide the zero point for future annual evaluations and comparisons. Tabulation of these results are shown in Table 4.

The results of these tests were used as a basis of analysis for performance of the protection systems during the four annual observations.

Table 2 - Condition of Bridge Decks Before Repairs Were Made By Contractor

Part A - Electrical Potential Scan

| Bridge | Lane | No. of Samples | Percent of Sample Within Potential Range (Negative Voltage) 0-0.10 | 0.11-0.20 | 0.21-0.30 | 0.31-0.40 | 0.41-0.50 | 0.51-0.60 | 0.61-0.70 | 0.71-0.80 | 0.81-0.90 | )0.91 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Cathodic Protection** | | | | | | | | | | | | |
| L-701R | NB | 450 | 0 | 4.5 | 39.3 | 36.4 | 14.9 | 4.9 | | | | |
| L-702R | SB | 630 | 7.0 | 45.5 | 31.4 | 12.9 | 3.2 | | | | | |
| **Low Slump Concrete Wearing Surface** | | | | | | | | | | | | |
| L-501R | SB | 512 | 13.2 | 67.2 | 17.0 | 1.8 | 0.8 | | | | | |
| L-642R | NB | 147(1) | 4.1 | 30.6 | 10.2 | 14.3 | 21.8 | 19.0 | | | | |
| **Latex Concrete Wearing Surface** | | | | | | | | | | | | |
| L-641R | SB | 147(1) | 2.0 | 28.0 | 13.6 | 10.2 | 15.6 | 23.1 | 7.5 | | | |
| L-759R | SB | 430 | 0.5 | 40.9 | 51.4 | 5.8 | 1.2 | 0.2 | | | | |
| **Protecto Wrap M-400A (Sheet Membrane)** | | | | | | | | | | | | |
| L-501R | NB | 514 | 12.2 | 67.7 | 16.4 | 2.7 | 1.0 | | | | | |
| L-759R | NB | 433 | 1.4 | 46.8 | 40.9 | 10.2 | 0.7 | | | | | |
| **Heavy Duty Bituthene Membrane (Sheet Membrane)** | | | | | | | | | | | | |
| A-1613R | NB | 463 | 0.4 | 34.1 | 53.6 | 10.4 | 1.5 | | | | | |
| L-719R | NB | 725 | 5.5 | 79.0 | 12.7 | 2.1 | 0.7 | | | | | |
| **Gacoflex UWM-2811 (Liquid Membrane)** | | | | | | | | | | | | |
| L-720R | SB | 479 | 1.6 | 86.3 | 9.8 | 2.0 | 0.3 | | | | | |
| L-721R | NB | 690 | 0 | 67.8 | 26.6 | 4.6 | 1.0 | | | | | |
| **Superseal 4000LT (Liquid Membrane)** | | | | | | | | | | | | |
| L-563R | NB | 379 | 30.4 | 58.0 | 9.5 | 1.6 | 0.5 | | | | | |
| L-571R | NB | 794 | 0.8 | 9.6 | 27.4 | 26.4 | 27.7 | 13.0 | 1.1 | | | |

(1) Tested driving lane only because of AC overlay.

Table 2 (Continued)

Part B - Chloride Determinations

| Bridge | Lane | No. of Samples | Average Chloride Ion Content (Pounds Per Cubic Yard of Concrete) 1/4-3/4 | 3/4-1 1/4 | 1 1/4-1 3/4 | 1 3/4-2 1/4 | 2 1/4-2 3/4 | 2 3/4-3 1/4 | Clear Depth of Steel(2) (Avg.) |
|---|---|---|---|---|---|---|---|---|---|
| Cathodic Protection | | | | | | | | | |
| L-701R | NB | 16 | 10.76 | 6.12 | 3.16 | 1.41 | 0.62 | 0.27 | 1 1/2" |
| L-702R | SB | 24 | 7.81 | 4.90 | 2.75 | 1.17 | 0.49 | 0.25 | 1 1/2" |
| Low Slump Concrete Wearing Surface | | | | | | | | | |
| L-501R | SB | 16 | 5.00 | 1.74 | 0.49 | 0.28 | 0.21 | 0.20 | 1 1/2" |
| L-642R | NB | 12 | 6.52 | 5.32 | 4.39 | 2.76 | 2.28 | 1.67 | 1 1/2" |
| Latex Concrete Wearing Surface | | | | | | | | | |
| L-641R | SB | 12 | 5.67 | 5.04 | 4.12 | 3.09 | 2.36 | 1.96 | 1 1/2" |
| L-759R | SB | 20 | 5.89 | 2.46 | 0.63 | 0.25 | 0.20 | 0.20 | 1 3/4" |
| Protecto Wrap M-400A (Sheet Membrane) | | | | | | | | | |
| L-501R | NB | 16 | 3.40 | 1.66 | 0.70 | 0.26 | 0.21 | 0.20 | 1 1/2" |
| L-759R | NB | 16 | 6.20 | 2.88 | 1.00 | 0.48 | 0.28 | 0.20 | 1 3/4" |
| Heavy Duty Bituthene Membrane (Sheet Membrane) | | | | | | | | | |
| A-1613R | NB | 12 | 8.62 | 5.45 | 3.11 | 1.39 | 0.74 | 0.36 | 2 1/2" |
| L-719R | NB | 24 | 6.58 | 3.32 | 1.16 | 0.47 | 0.32 | 0.28 | 1 1/2" |
| Gacoflex UWM-2811 (Liquid Membrane) | | | | | | | | | |
| L-720R | SB | 30 | 5.81 | 3.51 | 1.16 | 0.46 | 0.27 | 0.22 | 1 1/4" |
| L-721R | NB | 24 | 6.71 | 3.90 | 1.61 | 0.59 | 0.26 | 0.20 | 1 1/4" |
| Superseal 4000LT (Liquid Membrane) | | | | | | | | | |
| L-563R | NB | 12 | 6.03 | 2.39 | 0.44 | 0.27 | 0.20 | 0.20 | 1 1/2" |
| L-571R | NB | 24 | 5.86 | 3.13 | 1.64 | 0.82 | 0.65 | 0.48 | 1 3/4" |

(2) Original deck construction design.

Table 2 (Continued)

Part C - Physical Condition of Concrete Deck By Visual Observation

| Bridge | Lane | Delamination By Delamtect: Total Ft. Trace | Delamination By Delamtect: Percent 2-5 Dev. | Delamination By Delamtect: Percent >5 Dev. | Total Area of Survey (Sq.Ft.) | Patching: Partial Depth (% Area) | Patching: Full Depth (% Area) | Surface Profile: Spalling (% Area) | Surface Profile: Scale (% Area) | Surface Profile: Cracking Avg. No. Cracks/Grid | Underdeck Survey: Area(3) Efflor. (% Est.) | Underdeck Survey: Cracks(4) With Efflor. | Underdeck Survey: Cracks(4) Without Efflor. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Cathodic Protection** | | | | | | | | | | | | | |
| L-701R | NB | 6808.1 | 2.66 | 1.88 | 5374.80 | 1.77 | 0 | 0 | 0 | 0.34 | 0 | 0.2 | 6.0 |
| L-702R | SB | 9316.3 | 0.83 | 0.12 | 7524.72 | 0 | 0 | 0 | | 0.48 | 0 | 1.0 | 5.0 |
| **Low Slump Concrete Wearing Surface** | | | | | | | | | | | | | |
| L-501R | SB | 6571.5 | 0.43 | 0.12 | 6160.80 | 0 | 0 | 0 | 0 | 0.56 | 0.1 | 1.0 | 0.1 |
| L-642R | NB | 4398.3 | 7.40 | 6.92 | 4105.08 | 9.26(5) | 0(5) | 0(5) | 0.67(5) | 0.36 | 13.0 | 0 | 0 |
| **Latex Concrete Wearing Surface** | | | | | | | | | | | | | |
| L-641R | SB | 4710.1 | 7.85 | 4.90 | 4121.40 | 0.54(5) | 0(5) | 0(5) | 3.28(5) | 0.32 | 20.0 | 0.1 | 0.5 |
| L-759R | SB | 6365.3 | 1.09 | 0.38 | 5304.40 | 0.20 | 0 | 0.01 | 0 | 0.18 | 0 | 0.2 | 0.2 |
| **Protecto Wrap M-400A (Sheet Membrane)** | | | | | | | | | | | | | |
| L-501R | NB | 6571.5 | 3.69 | 0.79 | 6160.80 | 0.01 | 0 | 0.01 | 0 | 0.91 | 0 | 2.0 | 0.5 |
| L-759R | NB | 6630.5 | 4.25 | 0.73 | 5304.40 | 0.62 | 0 | 0 | 0 | 0.25 | 0 | 0 | 0.2 |
| **Heavy Duty Bituthene Membrane (Sheet Membrane)** | | | | | | | | | | | | | |
| A-1613R | NB | 6493.2 | 0.68 | 0.26 | 5797.50 | 0 | 0 | 0 | 0 | 0.50 | 0 | 0 | 0.5 |
| L-719R | NB | 10021.5 | 2.28 | 0.56 | 8842.50 | 0.01 | 0 | 0.01 | 0 | 0.89 | 0.02 | 1.0 | 0.5 |
| **Gacoflex UWM-2811 (Liquid Membrane)** | | | | | | | | | | | | | |
| L-720R | SB | 13212.2 | 0.49 | 0.13 | 10276.14 | 0 | 0 | 0.01 | 0 | 0.34 | 0 | 0.1 | 3.0 |
| L-721R | NB | 10508.1 | 1.17 | 0.15 | 8295.90 | 0 | 0 | 0.02 | 0 | 0.45 | 0 | 0.5 | 2.0 |
| **Superseal 4000LT (Liquid Membrane)** | | | | | | | | | | | | | |
| L-563R | NB | 5426.6 | 5.90 | 1.66 | 4522.20 | 0.06 | 0 | 1.00 | 0 | 0.38 | 0 | 1.0 | 3.0 |
| L-571R | NB | 10901.6(6) | 8.66 | 7.20 | 9498.00 | 30.36 | 0 | 1.00 | 0 | 1.27 | 5.0 | 1.0 | 1.0 |

(3) Estimated because no dimensions shown or possible.
(4) Cracking estimates based on visual rating of 0 for no cracking to 10 for complete coverage of deck area with visual cracks respectively.
(5) Estimated after scarification and AC overlay removal and cracking could not be determined.
(6) One span of passing lane on deck was omitted because of construction equipment on deck.

Table 3 - Condition of Bridge Decks After Repairs Were Made But Prior to Placement of Protective System

Part A - Electrical Potential Scan

| Bridge | Lane | No. of Samples | Percent of Sample Within Potential Range (Negative Voltage) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 0-0.10 | 0.11-0.20 | 0.21-0.30 | 0.31-0.40 | 0.41-0.50 | 0.51-0.60 | 0.61-0.70 | 0.71-0.80 | 0.81-0.90 | )0.91 |
| **Cathodic Protection** | | | | | | | | | | | | |
| L-701R | NB | 450 | 0 | 4.9 | 43.3 | 37.9 | 11.4 | 2.5 | | | | |
| L-702R | SB | 630 | 0.2 | 48.1 | 34.6 | 15.2 | 1.7 | 0.2 | | | | |
| **Low Slump Concrete Wearing Surface** | | | | | | | | | | | | |
| L-501R | SB | 512(1) | 10.3 | 77.1 | 10.8 | 1.6 | 0.2 | | | | | |
| L-642R | NB | 329(1) | 7.0 | 17.0 | 16.1 | 33.4 | 24.3 | 2.2 | | | | |
| **Latex Concrete Wearing Surface** | | | | | | | | | | | | |
| L-641R | SB | 330(1) | 7.0 | 26.7 | 18.5 | 15.4 | 24.5 | 7.9 | | | | |
| L-759R | SB | 430(1) | 9.3 | 62.1 | 22.8 | 5.3 | 0.5 | | | | | |
| **Protecto Wrap M-400A (Sheet Membrane)** | | | | | | | | | | | | |
| L-501R | NB | 514 | 24.7 | 57.6 | 15.3 | 1.8 | 0.6 | | | | | |
| L-759R | NB | 433 | 0.7 | 44.4 | 45.0 | 9.0 | 0.7 | 0.2 | | | | |
| **Heavy Duty Bituthene Membrane (Sheet Membrane)** | | | | | | | | | | | | |
| A-1613R | NB | 463 | 1.9 | 36.3 | 52.5 | 8.2 | 1.1 | | | | | |
| L-719R | NB | 725 | 5.5 | 77.4 | 14.0 | 2.5 | 0.6 | | | | | |
| **Gacoflex UWM-2811 (Liquid Membrane)** | | | | | | | | | | | | |
| L-720R | SB | (2) | (2) | | | | | | | | | |
| L-721R | NB | 690 | 0.3 | 65.2 | 29.0 | 4.7 | 0.8 | | | | | |
| **Superseal 4000LT (Liquid Membrane)** | | | | | | | | | | | | |
| L-563R | NB | 379 | 25.8 | 54.0 | 17.9 | 1.8 | 0.5 | | | | | |
| L-571R | NB | 794 | 0.9 | 7.3 | 37.4 | 40.8 | 12.0 | 1.6 | | | | |

(1) Data taken after scarification.
(2) No potential scan made because only minor repairs were made.

Table 3 (Continued)

Part B - Resistance Scan

| Bridge | Lane | No. of Samples | Percent of Sample in Resistance Range (ohms) 0-500 | 501-1K | 1.01K-1.5K | 1.51K-10K | 10.01K-100K | 100.01K-1M | )1M |
|---|---|---|---|---|---|---|---|---|---|
| **Cathodic Protection** | | | | | | | | | |
| L-701R | NB | (3) | | | | | | | |
| L-702R | SB | (3) | | | | | | | |
| **Low Slump Concrete Wearing Surface** | | | | | | | | | |
| L-501R | SB | 128(4) | 53.9 | 25.0 | 11.7 | 9.4 | | | |
| L-642R | NB | 82(4) | 81.7 | 9.8 | 2.4 | 6.1 | | | |
| **Latex Concrete Wearing Surface** | | | | | | | | | |
| L-641R | SB | 83(4) | 74.7 | 9.7 | 7.2 | 8.4 | | | |
| L-759R | SB | 108(4) | 84.3 | 12.9 | 2.8 | | | | |
| **Protecto Wrap M-400A (Sheet Membrane)** | | | | | | | | | |
| L-501R | NB | 128 | 36.0 | 19.6 | 6.2 | 38.2 | | | |
| L-759R | NB | 108 | 38.0 | 38.0 | 15.7 | 8.3 | | | |
| **Heavy Duty Bituthene Membrane (Sheet Membrane)** | | | | | | | | | |
| A-1613R | NB | 116 | 62.1 | 15.5 | 4.3 | 15.5 | 2.6 | | |
| L-719R | NB | 181 | 32.0 | 61.4 | 6.6 | | | | |
| **Gacoflex UWM-2811 (Liquid Membrane)** | | | | | | | | | |
| L-720R | SB | 209 | 43.5 | 42.1 | 12.0 | 2.4 | | | |
| L-721R | NB | 173 | 45.1 | 54.9 | | | | | |
| **Superseal 4000LT (Liquid Membrane)** | | | | | | | | | |
| L-563R | NB | 95 | 12.6 | 45.2 | 22.1 | 20.1 | | | |
| L-571R | NB | 198 | 74.8 | 15.2 | 5.0 | 5.00 | | | |

(3) No resistance tests performed on these structures.
(4) Data taken after scarification.

Table 3 (Continued)

Part C - Physical Condition of Concrete Deck by Visual Observation

| Bridge | Lane | Delamination By Delamtect: Total Ln. Ft. Trace | Percent 2-5 Dev. | Percent )5 Dev. | Total Area of Survey (Sq.Ft.) | Patching: Partial Depth (% Area) | Full Depth (% Area) | Surface Profile(5): Spalling (% Area) | Scale (% Area) | Cracking Avg. No. Cracks/Grid | Underdeck Survey: Area(6) Efflor. (% Est.) | Cracks(7) With Efflor. | Cracks(7) Without Efflor. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Cathodic Protection** | | | | | | | | | | | | | |
| L-701R | NB(5) | 2866.6 | 6.45 | 0.40 | 5374.80 | 8.85 | 0 | 0 | 0 | NA | 0 | 0.2 | 6.0 |
| L-702R | SB(5) | 8958.0 | 0.51 | 0.04 | 7524.72 | 0.96 | 0 | 0 | 0 | NA | 0 | 1.0 | 5.0 |
| **Low Slump Concrete Wearing Surface** | | | | | | | | | | | | | |
| L-501R | SB(5) | 7393.0 | 0.39 | 0.03 | 6160.80 | 0.17 | 0 | 0 | 0 | NA | 0.1 | 1.0 | 0.1 |
| L-642R | NB(5) | 2052.5 | 4.38 | 3.93 | 4105.08 | 16.31 | 33.99 | 0 | 0 | NA | 0.5 | 0 | 0 |
| **Latex Concrete Wearing Surface** | | | | | | | | | | | | | |
| L-641R | SB(5) | 2355.0 | 4.63 | 5.50 | 4121.4 | 17.32 | 29.55 | 0 | 0 | 0.32 | 4.0 | 0 | 0.4 |
| L-759R | SB(5) | 6365.3 | 0.78 | 0.03 | 5304.40 | 1.97 | 0 | 0 | 0 | 0.18 | 0 | 0.2 | 0.2 |
| **Protecto Wrap M-400A (Sheet Membrane)** | | | | | | | | | | | | | |
| L-501R | NB | 6982.2 | 5.11 | 0.08 | 6160.80 | 2.37 | 0 | 0 | 0 | 0.91 | 0 | 2.0 | 0.5 |
| L-759R | NB | 6630.5 | 3.81 | 0.38 | 5304.40 | 1.58 | 0 | 0 | 0 | 0.25 | 0 | 0 | 0.2 |
| **Heavy Duty Bituthene (Sheet Membrane)** | | | | | | | | | | | | | |
| A-1613R | NB | 7116.2 | 0.13 | 0.03 | 5797.50 | 1.21 | 0 | 0 | 0 | 0.50 | 0 | 0 | 0.5 |
| L-719R | NB | 10611.0 | 0.72 | 0.06 | 8842.50 | 1.28 | 0 | 0 | 0 | 0.89 | 0.02 | 1.0 | 0.5 |
| **Gacoflex UWM-2811 (Liquid Membrane)** | | | | | | | | | | | | | |
| L-720R | SB | (8) | (8) | (8) | 10276.14 | 0.22 | 0 | 0 | 0 | 0.34 | 0 | 0.1 | 3.0 |
| L-721R | NB | 9402.0 | 0.89 | 0.06 | 8295.90 | 0.79 | 0 | 0 | 0 | 0.45 | 0 | 0.5 | 2.0 |
| **Superseal 4000LT (Liquid Membrane)** | | | | | | | | | | | | | |
| L-563R | NB | 2411.8 | 3.34 | 0.29 | 4522.20 | 3.57 | 0 | 0 | 0 | 0.38 | 0 | 1.0 | 3.0 |
| L-571R | NB | 11397.6 | 0.67 | 0.12 | 9498.00 | 27.35 | 16.34 | 0 | 0 | 1.27 | 2.5 | 1.0 | 1.0 |

(5) Observation on original or scarified surface as applicable.
(6) Estimated because no dimensions shown or possible.
(7) Cracking estimates based on visual rating of 0 for no cracking to 10 for complete coverage of deck area with visual cracks respectively.
(8) No fracture plane survey made because only minor repairs required.

Table 4 - Condition of Bridge Decks After Placement of Protection System

Part A - Electrical Potential Scan

| Bridge | Lane | No. of Samples | Percent of Sample Within Potential Range (Negative Voltage) 0-0.10 | 0.11-0.20 | 0.21-0.30 | 0.31-0.40 | 0.41-0.50 | 0.51-0.60 | 0.61-0.70 | 0.71-0.80 | 0.81-0.90 | >0.91 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Cathodic Protection** | | | | | | | | | | | | |
| L-701R | NB | 450 | 3.8 | 37.5 | 50.9 | 7.8 | | | | | | |
| L-702R | SB | 630 | 20.8 | 53.7 | 22.2 | 2.7 | 0.6 | | | | | |
| **Low Slump Concrete Wearing Surface** | | | | | | | | | | | | |
| L-501R | SB | 512 | 2.8 | 57.1 | 36.9 | 2.8 | 0.2 | 0.0 | 0.2 | | | |
| L-642R | NB | 329 | 0 | 0.9 | 46.5 | 47.1 | 4.9 | 0.6 | | | | |
| **Latex Concrete Wearing Surface** | | | | | | | | | | | | |
| L-641R | SB | 330 | 0 | 8.5 | 53.4 | 32.4 | 5.7 | | | | | |
| L=759R | SB | 430 | 3.7 | 73.5 | 18.9 | 3.9 | | | | | | |
| **Protecto Wrap M-400A (Sheet Membrane)** | | | | | | | | | | | | |
| L-501R | NB | 128(1) | 100.0 | | | | | | | | | |
| L-759R | NB | 108(1) | 100.0 | | | | | | | | | |
| **Heavy Duty Bituthene (Sheet Membrane)** | | | | | | | | | | | | |
| A-1613R | NB | 69(2) | 94.2 | 2.9 | 1.5 | 1.4 | | | | | | |
| L-719R | NB | 103(2) | 89.3 | 6.8 | 0.0 | 1.0 | 0.0 | 1.0 | 1.0 | 0.9 | | |
| **Gacoflex UWM-2811 (Liquid Membrane)** | | | | | | | | | | | | |
| L-720R | SB | 209(1) | 70.8 | 16.3 | 10.0 | 1.4 | 0.0 | 0.0 | 0.0 | 0.5 | 0.5 | 0.5 |
| L-721R | NB | 115(2) | 97.5 | 0.9 | 0.0 | 0.0 | 0.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.85 |
| **Superseal 4000LT (Liquid Membrane)** | | | | | | | | | | | | |
| L-563R | NB | 94(1) | 85.1 | 8.6 | 4.2 | 1.1 | 1.0 | | | | | |
| L-571R | NB | 199(1) | 84.9 | 6.0 | 0.5 | 7.1 | 1.5 | | | | | |

(1) Spot checked in both lanes. Used staggered 6 ft. by 8 ft. grid.
(2) Spot checked in the passing lane only. Used staggered 6 ft. by 8 ft. grid.

Table 4 (Continued)

Part B - Resistance Scan

| Bridge | Lane | No. of Samples | Percent of Sample in Resistance Range (ohms) 0-500 | 501-1K | 1.01K-1.5K | 1.51K-10K | 10.01K-100K | 100.01K-1M | >1M |
|---|---|---|---|---|---|---|---|---|---|
| **Cathodic Protection** | | | | | | | | | |
| L-701R | NB | (3) | | | | | | | |
| L-702R | SB | (3) | | | | | | | |
| **Low Slump Concrete Wearing Surface** | | | | | | | | | |
| L-501R | SB | 128 | 100.0 | | | | | | |
| L-642R | NB | 82 | 100.0 | | | | | | |
| **Latex Concrete Wearing Surface** | | | | | | | | | |
| L-641R | SB | 83 | 100.0 | | | | | | |
| L-759R | SB | 108 | 100.0 | | | | | | |
| **Protecto Wrap M-400A (Sheet Membrane)** | | | | | | | | | |
| L-501R | NB | 128 | 0 | 0 | 0 | 0 | 4.0 | 6.2 | 89.8 |
| L-759R | NB | 108 | 0 | 0 | 0 | 0 | 0 | 10.8 | 89.2 |
| **Heavy Duty Bituthene (Sheet Membrane)** | | | | | | | | | |
| A-1613R | NB | 116 | 0 | 0 | 0 | 0 | 0.9 | 0 | 99.1 |
| L-719R | NB | 181 | 0 | 0 | 0 | 0 | 1.1 | 4.9 | 94.0 |
| **Gacoflex UWM-2811 (Liquid Membrane)** | | | | | | | | | |
| L-720R | SB | 209 | 0 | 0 | 0 | 0 | 4.8 | 7.6 | 87.6 |
| L-721R | NB | 173 | 0 | 0 | 0 | 0 | 1.1 | 0.6 | 98.3 |
| **Superseal 4000LT (Liquid Membrane)** | | | | | | | | | |
| L-563R | NB | 95 | 0 | 0 | 0 | 1.0 | 7.4 | 2.1 | 89.5 |
| L-571R | NB | 198 | 0 | 0 | 0 | 8.6 | 0.5 | 12.6 | 78.3 |

(3) No resistance survey taken on these decks.

Table 4 (Continued)

Part C - Physical Condition of Deck Surface by Visual Observation

| Bridge | Lane | Delamination By Delamtect: Total Ft. Trace | Percent 2-5 Dev. | Percent >5 Dev. | Total Area of Survey (Sq.Ft.) | Patching: Partial Depth (% Area) | Patching: Full Depth (% Area) | Surface Profile(4): Spalling (% Area) | Surface Profile(4): Scale (% Area) | Surface Profile(4): Cracking Avg. No. Cracks/Grid | Underdeck Survey: Area(5) Efflor (% Est.) | Underdeck Survey: Cracks(6) With Efflor. | Underdeck Survey: Cracks(6) Without Efflor. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Cathodic Protection** | | | | | | | | | | | | | |
| L-701R | NB | 6808.1 | 8.03 | 0.93 | 5374.80 | 0 | 0 | 0 | 0 | 0 | 0 | 0.2 | 6.0 |
| L-702R | SB | 9674.6 | 1.14 | 0.17 | 7524.72 | 0 | 0 | 0 | 0 | 0 | 0 | 1.0 | 5.0 |
| **Low Slump Concrete Wearing Surface** | | | | | | | | | | | | | |
| L-501R | SB | 7803.7 | 0.13 | 0.01 | 6160.80 | 0 | 0 | 0 | 0 | 0 | 0.1 | 1.0 | 0.1 |
| L-642R | NB | 4984.7 | 0 | 0 | 4105.08 | 0 | 0 | 0 | 0 | 0 | 0.5 | 0 | 0 |
| **Latex Concrete Wearing Surface** | | | | | | | | | | | | | |
| L-641R | SB | 5004.5 | 0.16 | 0 | 4121.4 | 0 | 0 | 0 | 0 | 0 | 4.0 | 0 | 0.4 |
| L-759R | SB | 6630.5 | 0.20 | 0.09 | 5304.40 | 0 | 0 | 0 | 0 | 0 | 0 | 0.2 | 0.2 |
| **Protecto Wrap M-400A (Sheet Membrane)** | | | | | | | | | | | | | |
| L-501R | NB | 7393.0 | 1.67 | 0.21 | 6160.80 | 0 | 0 | 0 | 0 | 0 | 0 | 2.0 | 0.5 |
| L-759R | NB | 6630.5 | 0.81 | 0.02 | 5304.40 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.2 |
| **Heavy Duty Membrane (Sheet Membrane)** | | | | | | | | | | | | | |
| A-1613R | NB | 6802.4 | 21.17 | 61.75 | 5797.50 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.5 |
| L-719R | NB | 11200.5 | 23.54 | 30.38 | 8842.50 | 0 | 0 | 0 | 0 | 0 | 0.02 | 1.0 | 0.5 |
| **Gacoflex UWM-2811 (Liquid Membrane)** | | | | | | | | | | | | | |
| L-720R | SB | 12722.8 | 19.21 | 27.89 | 10276.14 | 0 | 0 | 0 | 0 | 0 | 0 | 0.1 | 3.0 |
| L-721R | NB | 10508.1 | 19.00 | 17.14 | 8295.90 | 0 | 0 | 0 | 0 | 0 | 0 | 0.5 | 2.0 |
| **Superseal 4000LT (Liquid Membrane)** | | | | | | | | | | | | | |
| L-563R | NB | 5426.6 | 1.74 | 0.05 | 4522.20 | 0 | 0 | 0 | 0 | 0 | 0 | 1.0 | 3.0 |
| L-571R | NB | 12030.8 | 4.54 | 0.68 | 9498.00 | 0 | 0 | 0 | 0 | 0 | 2.5 | 1.0 | 1.0 |

(4) Observation on new surface before opening to traffic.
(5) Estimated because no dimensions shown or possible.
(6) Cracking estimates based on visual rating of 0 for no cracking to 10 for complete coverage of deck area with visual cracks respectively.

## OBSERVATION OF PLACEMENT OF PROTECTION SYSTEMS

### GENERAL

Construction was initiated in the spring of 1977 and completed in December, 1977. A minimum of one lane of traffic was maintained on each bridge during repair and placement of the membrane or overlay, therefore, all systems were placed in a two stage construction sequence.

Corrosometer probes, used to detect corrosion activity, were placed in the concrete decks at the depth of the top most reinforcing steel with a 2 pound per cubic yard chloride ion bearing concrete backfill. The probes register consecutively higher readings on a CK-3 meter as it corrodes. Placement in the backfill was done in such a manner to insure that the probes were isolated from the steel rebars, however, provision was made whereby the probe could be grounded to the reinforcing steel by a remote receptacle. One corrosometer probe was placed in each traffic lane at or near the centerline of the lane on each structure. Exception to this procedure was on the cathodic protection structures where additional corrosometer probes were placed in the decks to monitor specific locations.

Observations made during construction helped to modify existing specifications to clarify intent or to make application of the system easier. Outline of these observations would consist of many pages of discussion as well as having to reproduce the specifications for each protection system.

Therefore, for brevity, the following descriptions and discussions of application of the various protection systems will be general.

## CATHODIC PROTECTION

The cathodic protection system used in this evaluation was designed by department personnel. Plans and specifications are shown in the Appendix to this report. Bridges which were selected for application of this cathodic protection system were on tangents and of equal length, however, one was 2 lanes wide and the other was 3 lanes wide. The difference in width afforded the opportunity to study the effective areas of influence of the anodes and the ultimate ability of the cathodic system to cover variable widths.

Anodes were placed at a twenty foot spacing in the curb lines. The remainder of the length was divided equally between the last anodes on each end of the bridge. Anodes were placed directly opposite each other with regard to both curb lines. This arrangement afforded a study of placing anodes in a square grid arrangement with 20 foot longitudinal by either 28 or 40 foot transverse spacings.

Equipment was provided in this study to monitor each anode and half cell placed on the decks. Anodes were a high grade chromium silicon steel which would give a low rate of loss due to corrosion per year.

Half cells permanently placed in the concrete decks for monitoring potential levels were of three types: copper-copper

sulfate solid state and zinc with and without encapsulation in a proprietary backfill material. Results from these half cells will be compared to determine if one particular type is more reliable than the others.

Number 8 stranded, copper, Haylar fluoropolymer covered wire was used to connect anodes, half cells, and grounds with rectifiers and read-out devices. Haylar covering was specified because it had a high resistance to heat and deformation which was necessary because of the temperature of asphaltic coke breeze mixture. Silicon rectifiers were manufactured by RIO Engineering Co., Houston, Texas. Voltage to each anode was varied by rheostats placed in each anode supply line. Each bridge had a separate rectifier for independent cathodic protection operation.

The electrolyte used to distribute the current density across the concrete surface was constructed with coke breeze as the aggregate in an asphaltic concrete mixture. The coke breeze material had a high carbon content arranged in a crystal lattice configuration which enabled the material to be a good electrical conductor. The coke breeze asphaltic concrete was placed using conventional asphaltic paving equipment and techniques.

Coke breeze asphaltic concrete was placed at temperatures ranging from 175$^{o}$F to 275$^{o}$F at the paver. Best compaction was obtained with batches which were on the cooler side of specification limits. The coke breeze electrolyte layer was covered with a special asphaltic concrete surface course

consisting of crushed porphyry aggregate for protection and a riding surface.

The cathodic protection systems were activated in November, 1977 by a representative of Cathodic Protection Service, Tulsa, Oklahoma. The parameter used for establishing the current density necessary to assure protection of the reinforcing steel was a -0.30 volt shift from the original half cell value.

## LOW SLUMP CONCRETE WEARING SURFACE

Low slump concrete used in this evaluation was similar to the Iowa Low Slump design which had been in use for bridge deck resurfacing for some time. Materials used to construct low slump concrete wearing surface on this project were: crushed porphyry coarse aggregate, Kansas River sand fine aggregate, Type I cement from Missouri Portland Cement Company, AD-AIRE air entraining agent, and Plastocrete 161 water reducing agent.

A mobile continuous mixer was used for the first time in Missouri for placing overlay concrete. Material stockpiles were located a short distance from the bridge site. The mixer trucks were loaded at the stockpile site and traveled to the bridge sites for calibration. The procedure was determined to be satisfactory as no problem arose due to uniformity of aggregate feed. Each vehicle containing the various materials was calibrated individually.

Traffic, maintained on the bridges during reconstruction, did not present a particular problem for application of the

wearing surface, however, cracking did develop in the wearing surface of one of the structures at a very early age.

## LATEX MODIFIED CONCRETE WEARING SURFACE

The latex concrete overlay used in this evaluation was designed primarily from the Dow Chemical Company's specifications. Material used to construct the latex modified concrete wearing surfaces on this project were: Meramec River Gravel coarse aggregate, Meramec River sand fine aggregate, Type I cement from Missouri Portland Cement Company, and Latex Emulsion Admixture, Modifier A, from Dow Chemical Company. A mobile continuous mixer was used to mix the overlay concrete. Calibration procedures were identical to that for the low slump concrete.

Construction of the concrete wearing surfaces for latex was completed by placing one lane at a time while maintaining traffic through the project. The traffic itself, as discussed previously for the low slump construction, did not cause construction problems, however, transverse cracking did occur in the wearing surfaces at a very early age. The wearing surface placed in the first stage of construction was observed to have transverse cracking before construction of the second stage.

## PROTECTO WRAP M-400A

One of two types of sheet membranes used in this evaluation was Protecto Wrap M-400A system. This system consisted of a cold-applied pre-formed reinforced coal tar and synthetic resin

membrane of approximately 70 mils thickness, applied over a Protecto Wrap #80 primer. The membrane, once in place, was primed with a Protecto Wrap PS Primer and asphaltic-impregnated roofing sheets of at least 65 pound grade placed over the entire surface. Roofing sheets should be precut before placing on membrane to prevent damage to membrane. Terminal edges of the membranes were then sealed with a Protecto Wrap CA-1609H mastic material. A special asphaltic concrete consisting of crushed porphyry aggregate was placed over the membrane system.

The Protecto Wrap system was completed one lane at a time while maintaining traffic on the bridges. The only adverse effect of construction of the membrane system one lane at a time was the inability to protect with any great success, the exposed edge of the membrane during concrete deck repair in the second lane of construction. Weathering, debris, traffic, and construction equipment were factors which accumulatively caused deterioration of exposed membrane. Without a good edge of previously placed membranes available to continue placement of second lane of construction, the effectiveness of the membrane system could be diminished.

## HEAVY DUTY BITUTHENE

The second of the two types of sheet membranes used in this evaluation was the Heavy Duty Bituthene system. This system consisted of a cold-applied pre-formed self-adhering membrane incorporating a woven polypropylene mesh embedded between a layer of self-adhesive rubberized asphalt and a non-tacky

bituminous compound, total thickness of 65 mil minimum. The membrane was applied to the deck with a primer and terminal edges of the membrane were sealed with a mastic material as recommended by the manufacturer. A special asphaltic concrete consisting of crushed porphyry aggregate was placed over the membrane system.

The Heavy Duty Bituthene system was completed by closing one lane at a time and maintaining traffic on the bridge. Again, the edge of the previously placed membrane was very difficult to protect from damage during repairs made in the second lane of construction. Without a good edge of the previously placed membrane available to continue placement of the second lane of construction, effectiveness of the membrane could be diminished.

This membrane was applied without roofing paper protection sheets, therefore, the surface of the membrane was visible prior to covering with a wearing surface. As a result, the membrane was observed to have large blisters under the membrane when left overnight or for several days without the wearing surface in place. Blisters would appear to decrease in size during the day and reappear larger in size the next morning. Puncturing the blisters and forcing the membrane back in place, then applying a patch of Heavy Duty Bituthene over the puncture proved successful to eliminate the blisters.

This membrane had a pre-tacked top surface to accept the asphaltic concrete wearing surface. This pre-tacked surface was very slippery when exposed to the sun a sufficient length of

time to become warm. Paving in the late afternoon on a hot sunny day is difficult, especially, if the bridge is on a significant grade or superelevation. Damage to the membrane is less apt to occur if paving is done during the coolest part of the day.

GACOFLEX UWM-2811

One of the two types of liquid membranes used in this evaluation was Gacoflex UWM-2811 system. This system consisted of a two-component, cold-applied, elastomeric polyurethane applied to the concrete deck as a liquid coating and an asphalt-impregnated roofing sheet, 55 pound grade or heavier, laid over the liquid coating. A special asphaltic concrete consisting of crushed porphyry aggregate was placed over the membrane system.

The Gacoflex system was completed by closing one lane at a time and maintaining traffic on the bridge. The only adverse effect of construction of the membrane system one lane at a time was the inability to protect, with any great success, the exposed edge of the membrane during concrete deck repair of the second lane of construction. Weathering, debris, traffic, and construction equipment were factors which accumulatively caused deterioration of the exposed membrane. Roofing paper should be precut before placing on membrane to prevent damage to membrane. Without a good edge of the previously placed membrane and roofing paper available to continue the placement of the second lane of construction, effectiveness of the membrane system could be diminished.

The two-component elastomeric polyurethane materials consists of Part H and Part U which were pre-packaged in exact ratio for mixing. Part H was packaged in a 5-gallon type container with a molded insert in the top portion to hold the pre-packaged Part U. Part U was packaged in a rectangular 1/2 gallon metal can with a small 1 inch screw top opening. This metal can design caused some problem in ability to get all the Part U component into the mix. Thus, the contractor was required to cut the bottom out of the metal can before mixing the Part U into the Part H mixture to ensure all the available material was used.

When a membrane is applied to a concrete deck surface, bubbling will usually occur because of air trying to escape from the concrete pores. To alleviate this problem, the deck was first primed with a mixture of no more than 1 part solvent to 2 parts of the Gacoflex membrane. The solvent content was varied within the 1:2 ratio depending on daily temperature and cloud cover.

SUPERSEAL 4000LT

The second of the two types of liquid membranes used in this evaluation was Superseal 4000LT. This system consisted of a single component, hot-applied, polymer type elastomer applied to the deck as a liquid coating and an asphaltic-impregnated roofing paper of 65 pound grade laid over the liquid coating.

Superseal 4000LT system was also completed by placing one lane at time because traffic required the use of the remainder

of the structures during reconstruction. The edge of the membrane was very difficult to protect from damage during the concrete deck repairs made in the second lane of construction, the same as with the Gacoflex membrane.

Of importance also is the necessity of keeping all extra construction traffic off of the membranes until the wearing surface is placed. During the construction of one lane of the Superseal system, the contractor who was placing the asphaltic concrete tapers at each end of the bridges, tried to place the tapers before the wearing surface on the membrane was placed. A finish roller operator proceeded to run across the roofing paper to get to the other end of the bridge and in doing so caused considerable damage by pressing large particles, rock or debris, on the surface of the roofing paper through the membrane system. The damage was extensive and required considerable time and expense to repair. This damage and required repair was not a fault of the membrane system but rather the sequence of operations.

Handling of Superseal 4000LT membrane after heating to the desired temperature and drawing from the double boiler heater must be quick. The "open time" on the heated membrane after taking it out of the double boiler is very short. Application to a cold deck surface further reduces "open time" as does cooler air temperature. Generally "open time" from the heater to final squeegee pass was less than 1 minute and the placement of the roofing paper was within 1 minute after final squeegee pass. Therefore, the closer the heater to the operation, the

more time there is available to work the material to proper thickness. Excessive thickness will give a spongy layer of material which will yield under heavy traffic usage thus leading to failure of the wearing surface. Spray application may eliminate some of the problem with open time, however, roofing paper operation will have to be quick to get adherence. Roofing paper must be precut before placing on membrane to prevent damage to the membrane.

## ANNUAL FIELD OBSERVATION AND TEST DATA

All bridges in this study were surveyed before and after concrete deck repair and after placement of the various protection systems. Thereafter, surveys were made for four consecutive years. A final survey was made in 1984. These surveys included delamination profile, potential scan, resistance scan, surface profile, and underdeck profile observations. **Delamination is defined in this report as the general term used to indicate a hollowness detected by tapping the existing surface of the overlay protection system. Possible failure mechanisms causing delamination are separation between layers of membrane materials or the asphaltic overlay, debonding of the overlay from the concrete deck, and/or fracture plane within the concrete deck. Data must be so interpreted as used in this report.**

Data obtained from these surveys is presented in Table 5, Parts A through N. Each part of the table represents the applicable test data for the individual protection system placed on a respective bridge deck.

These data will be used extensively in the discussion which follows.

## Table 5 - Summary of Observations for Analysis of Protection Systems

### Part A, Bridge No. L-701R, Cathodic Protection System

a. Potential Scan

| Year | No. of Samples | Electrical Potential (Negative Voltage) 0-.10 | .11-.20 | .21-.30 | .31-.40 | .41-.50 | .51-.60 | .61-.70 | .71-.80 | .81-.90 | ).91 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Before | 450 | 0.0 | 4.5 | 39.3 | 36.4 | 14.9 | 4.9 | | | | |
| After | 450 | 0.0 | 4.9 | 43.3 | 37.9 | 11.4 | 2.5 | | | | |
| 1977 | 450 | 3.8 | 37.5 | 50.9 | 7.8 | | | | | | |

b. Cathodic System Activated (Current On)

| Year | Samples | Electrical Potential (Negative Voltage) 0-.50 | .51-1.00 | 1.01-1.50 | 1.51-2.00 | 2.01-2.50 | 2.51-3.00 | 3.01-3.50 | 3.51-4.00 | 4.01-4.50 | )4.51 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1977 | 450 | 0.0 | 1.8 | 6.7 | 9.6 | 42.8 | 33.9 | 1.6 | 1.6 | 0.0 | 2.0 |
| 1978 | 450 | 14.2 | 71.9 | 9.7 | 1.6 | 0.7 | 0.7 | 0.7 | 0.5 | | |
| 1979 | 450 | 8.0 | 74.4 | 13.5 | 0.0 | 0.2 | 1.4 | 1.8 | 0.7 | | |
| 1980(1) | 225 | 1.3 | 68.6 | 24.0 | 2.2 | 0.4 | 0.0 | 0.0 | 0.4 | 1.3 | 1.8 |
| 1981 | 450 | 28.8 | 42.4 | 22.4 | 3.6 | 0.5 | 0.5 | 0.7 | 0.9 | 0.2 | |
| 1984 | 450 | 0.2 | 3.8 | 12.7 | 20.2 | 14.2 | 14.0 | 12.9 | 6.9 | 5.3 | 9.80 |

Cathodic System Polar Volt (Differential between ON and OFF, instantaneous)

| Year | No. of Samples | Electrical Potential (Negative Voltage) 0-.10 | .11-.20 | .21-.30 | .31-.40 | .41-.50 | .51-.60 | .61-.70 | .71-.80 | .81-.90 | ).91 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1977 | 450 | 8.7 | 18.9 | 51.9 | 15.6 | 2.5 | 0.2 | 0.2 | 2.0 | | |
| 1978(2) | | | | | | | | | | | |
| 1979 | 450 | 63.9 | 14.0 | 5.8 | 3.8 | 3.6 | 3.1 | 1.1 | 0.9 | 0.0 | 3.8 |
| 1980(1) | 225 | 81.0 | 7.6 | 2.2 | 4.0 | 0.4 | 0.4 | 0.0 | 0.0 | 0.0 | 4.4 |
| 1981 | 450 | 65.5 | 17.3 | 7.1 | 3.6 | 2.0 | 1.1 | 0.0 | 0.2 | 0.5 | 2.7 |
| 1984 | 450 | 0.0 | 6.2 | 12.9 | 9.1 | 9.3 | 6.0 | 6.2 | 4.2 | 3.8 | 42.3 |

| Year | c. Delamination(3) Ln. Ft. | % | d. Surface Profile (Patching) Sq. Ft. | % | Cracking (Cr/Grid) | e. Underdeck "E" (Area Only) Sq. Ft. | % |
|---|---|---|---|---|---|---|---|
| Before | 129.0 | 1.89 | 95.2 | 1.77 | 0.34 | 9.5 | 0.15 |
| After | 10.0(1) | 0.40(1) | 475.5(1) | 8.85(1) | — | 9.5 | 0.15 |
| 1977 | 63.5 | 0.93 | 0 | 0 | 0 | 9.5 | 0.15 |
| 1978 | 310.0 | 4.55 | 0 | 0 | 0 | 9.5 | 0.15 |
| 1979 | 58.5 | 0.86 | 0 | 0 | 0.43 | 9.5 | 0.15 |
| 1980 | 961.7(1) | 28.3(1) | 0 | 0 | 0.97(1) | 11.5 | 0.18 |
| 1981 | 6808.1 | 100.0 | 0 | 0 | 1.21 | 11.5 | 0.18 |
| 1984 | 6808.1 | 100.0 | 0 | 0 | 1.56 | 27.0 | 0.43 |

(1) Only one stage of construction tested, calculated on that area surveyed only.
(2) No test made on either stage of construction because of polar volt test equipment malfunction.
(3) Delamination is shown as total lineal feet of delamination found per year in the area surveyed.

Table 5 (Continued) - Summary of Observations for Analysis of Protection Systems

Part B, Bridge No. L-702R, Cathodic Protection System

a. Potential Scan

| Year | No. of Samples | Electrical Potential (Negative Voltage) 0-.10 | .11-.20 | .21-.30 | .31-.40 | .41-.50 | .51-.60 | .61-.70 | .71-.80 | .81-.90 | ).91 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Before | 630 | 7.0 | 45.5 | 31.4 | 12.9 | 3.2 | | | | | |
| After | 630 | 0.2 | 48.1 | 34.6 | 15.2 | 1.7 | 0.2 | | | | |
| 1977 | 630 | 20.8 | 53.7 | 22.2 | 2.7 | 0.6 | | | | | |

b. Cathodic System Activated (Current On)

| Year | No. of Samples | Electrical Potential (Negative Voltage) 0-.50 | .51-1.00 | 1.01-1.50 | 1.51-2.00 | 2.01-2.50 | 2.51-3.00 | 3.01-3.50 | 3.51-4.00 | 4.01-4.50 | )4.51 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1977 | 630 | 0.0 | 0.0 | 1.1 | 2.7 | 15.7 | 13.8 | 13.2 | 13.5 | 14.9 | 25.1 |
| 1978 | 630 | 62.9 | 29.2 | 6.4 | 1.0 | 0.2 | 0.3 | | | | |
| 1979 | 630 | 47.4 | 42.1 | 7.6 | 1.1 | 0.3 | 0.5 | 1.0 | | | |
| 1980(1) | 405 | 52.4 | 42.4 | 1.5 | 2.2 | 0.3 | 0.0 | 0.0 | 0.3 | 0.3 | 0.6 |
| 1981 | 630 | 20.9 | 49.4 | 14.3 | 6.5 | 3.3 | 1.4 | 0.9 | 0.3 | 0.8 | 2.2 |
| 1984 | 630 | 3.3 | 29.3 | 36.4 | 12.5 | 7.5 | 4.1 | 2.2 | 1.1 | 1.4 | 2.2 |

Cathodic System Polar Volt (Differential between ON and OFF, instantaneous)

| Year | No. of Samples | Electrical Potential (Negative Voltage) 0-.10 | .11-.20 | .21-.30 | .31-.40 | .41-.50 | .51-.60 | .61-.70 | .71-.80 | .81-.90 | ).91 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1977 | 630 | 0.2 | 0.0 | 0.0 | 0.3 | 0.3 | 0.5 | 1.7 | 1.2 | 1.3 | 94.5 |
| 1978 | 369 | 1.9 | 11.4 | 16.3 | 26.4 | 22.0 | 8.6 | 3.8 | 3.0 | 2.2 | 4.4 |
| 1979 | 630 | 75.0 | 9.6 | 2.7 | 3.6 | 1.6 | 2.7 | 1.1 | 1.1 | 0.6 | 2.0 |
| 1980(1) | 405 | 87.2 | 5.7 | 1.7 | 0.3 | 1.7 | 0.7 | 0.7 | 0.5 | 0.0 | 1.5 |
| 1981 | 630 | 1.7 | 70.1 | 9.2 | 3.5 | 2.2 | 1.9 | 2.1 | 1.7 | 0.2 | 7.4 |
| 1984 | 630 | 5.7 | 44.7 | 16.2 | 5.9 | 4.8 | 4.3 | 2.4 | 2.7 | 1.6 | 11.7 |

| Year | c. Delamination(2) Ln. Ft. | % | d. Surface Profile (Patching) Sq. Ft. | % | Cracking (Cr/Grid) | e. Underdeck "E" (Area Only) Sq. Ft. | % |
|---|---|---|---|---|---|---|---|
| Before | 11.0 | 0.12 | 0 | 0 | 0.48 | 6.5 | 0.08 |
| After | 4.0 | 0.04 | 72.07 | 0.96 | -- | 4.0 | 0.05 |
| 1977 | 16.5 | 0.17 | 0 | 0 | 0 | 4.0 | 0.05 |
| 1978 | 171.5 | 1.77 | 0 | 0 | 0 | 4.0 | 0.05 |
| 1979 | 73.5 | 0.76 | 0 | 0 | 0.18 | 7.2 | 0.09 |
| 1980 | 122.3(1) | 1.26(1) | 0 | 0 | 0.60(1) | 7.2 | 0.09 |
| 1981 | 9674.6 | 100.0 | 0 | 0 | 0.79 | 7.2 | 0.09 |
| 1984 | 9674.6 | 100.0 | 0 | 0 | 1.07 | 7.2 | 0.09 |

(1) Only one stage of construction tested.
(2) Delamination is shown as total lineal feet of delamination found per year in the area surveyed.

Table 5 (Continued) - Summary of Observations for Analysis of Protection Systems

Part C, Bridge No. L-501R SB, Low Slump Concrete Wearing Surface

a. Potential Scan (% of readings)

| Year | No. of Samples | Electrical Potential (Negative Voltage) 0-.10 | .11-.20 | .21-.30 | .31-.40 | .41-.50 | .51-.60 | .61-.70 | .71-.80 | .81-.90 | ).91 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Before | 512 | 13.2 | 67.2 | 17.0 | 1.8 | 0.8 | | | | | |
| After(3) | 512 | 10.3 | 77.1 | 10.8 | 1.6 | 0.2 | | | | | |
| 1977 | 512 | 2.8 | 57.1 | 36.9 | 2.8 | 0.2 | 0 | 0.2 | | | |
| 1978 | 512 | 2.6 | 45.5 | 36.0 | 14.5 | 1.2 | 0.2 | | | | |
| 1979 | 512 | 0 | 41.7 | 46.1 | 10.8 | 1.0 | 0.4 | | | | |
| 1980(1) | 255 | 0 | 43.1 | 49.0 | 7.1 | 0.8 | | | | | |
| 1981 | 512 | 8.0 | 65.6 | 24.1 | 1.9 | 0.4 | | | | | |
| 1984 | 512 | 6.0 | 60.7 | 27.0 | 5.5 | 0.4 | 0.4 | | | | |

b. Resistance Scan (% of readings)

| Year | No. of Samples | Resistance (ohms) 0-500 | 501-1K | )1K-1.5K | )1.5K-10K | )10K-100K | )100K-1M | )1M |
|---|---|---|---|---|---|---|---|---|
| Before | No Test | | | | | | | |
| After(3) | 128 | 53.9 | 25.0 | 11.7 | 9.4 | | | |
| 1977 | 128 | 100.0 | | | | | | |
| 1978 | 128 | 13.3 | 86.7 | | | | | |
| 1979 | 9 | 0 | 90.0 | 0 | 10.0 | | | |
| 1980(1) | 5 | 100.0 | | | | | | |
| 1981 | 9 | 0 | 20.0 | 67.5 | 12.5 | | | |
| 1984 | 9 | 44.5 | 22.2 | 33.3 | | | | |

| Year | c. Delamination(4) Ln. Ft. | % | d. Surface Profile (Patching) Sq. Ft. | % | Cracking (Cr/Grid) | e. Underdeck "E" (Area Only) Sq. Ft. | % |
|---|---|---|---|---|---|---|---|
| Before | 9.5 | 0.12 | 0 | 0 | 0.56 | 317.6 | 4.60 |
| After | 2.0 | 0.03 | 10.6 | 0.17 | — | 317.6 | 4.60 |
| 1977 | 1.0 | 0.01 | 0 | 0 | 0 | 317.6 | 4.60 |
| 1978 | 0 | 0 | 0 | 0 | 1.33 | 317.6 | 4.60 |
| 1979 | 0 | 0 | 0 | 0 | 1.65 | 317.6 | 4.60 |
| 1980 | 7.33(1) | 0.09(1) | 38.75(2) | 0.63 | 1.96(1) | 325.0 | 4.71 |
| 1981 | 21.00 | 0.27 | 38.75 | 0.63 | 2.05 | 325.0 | 4.71 |
| 1984 | 89.36 | 1.14 | 46.92 | 0.76 | 2.12 | 325.0 | 4.71 |

(1) Only one stage of construction tested.
(2) Patch placed by maintenance at north expansion joint because of loose angleiron.
(3) Data taken after scarification.
(4) Delamination is shown as total lineal feet of delamination found per year in the area surveyed.

Table 5 (Continued) - Summary of Observations for Analysis of Protection Systems

Part D, Bridge No. L-642R, Low Slump Concrete Wearing Surface

a. Potential Scan (% of readings)

| Year | No. of Samples | Electrical Potential (Negative Voltage) 0-.10 | .11-.20 | .21-.30 | .31-.40 | .41-.50 | .51-.60 | .61-.70 | .71-.80 | .81-.90 | ).91 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Before(1) | 147 | 4.1 | 30.6 | 10.2 | 14.3 | 21.8 | 19.0 | | | | |
| After(2) | 329 | 7.0 | 17.0 | 16.1 | 33.4 | 24.3 | 2.2 | | | | |
| 1977 | 329 | 0 | 0.9 | 46.5 | 47.1 | 4.9 | 0.6 | | | | |
| 1978 | 329 | 0 | 11.8 | 36.8 | 42.8 | 8.2 | 0.4 | | | | |
| 1979 | 329 | 0 | 23.4 | 30.4 | 41.3 | 4.6 | 0.3 | | | | |
| 1980(1) | 184 | 2.2 | 35.3 | 43.0 | 17.4 | 2.1 | | | | | |
| 1981 | 329 | 5.5 | 37.4 | 41.0 | 14.0 | 2.1 | | | | | |
| 1984 | 329 | 26.4 | 52.4 | 17.6 | 3.0 | 0.6 | | | | | |

b. Resistance Scan (% of readings)

| Year | No. of Samples | Resistance (ohms) 0-500 | 501-1K | )1K-1.5K | )1.5K-10K | )10K-100K | )100K-1M | )1M |
|---|---|---|---|---|---|---|---|---|
| Before | No Test | | | | | | | |
| After(2) | 82 | 81.7 | 9.8 | 2.4 | 6.1 | | | |
| 1977 | 82 | 100.0 | | | | | | |
| 1978 | 82 | 100.0 | | | | | | |
| 1979 | 12 | 0 | 100.0 | | | | | |
| 1980(1) | 7 | 0 | 100.0 | | | | | |
| 1981 | 12 | 6.4 | 19.4 | 0 | 61.3 | 12.9 | | |
| 1984 | 12 | 0 | 8.3 | 41.7 | 50.0 | | | |

| Year | c. Delamination(3) Ln. Ft. | % | d. Surface Profile (Patching) Sq. Ft. | % | Cracking (Cr/Grid) | e. Underdeck "E" (Area Only) Sq. Ft. | % |
|---|---|---|---|---|---|---|---|
| Before | 345.0 | 6.92 | 380.1 | 9.26 | 0.36 | 819.50 | 16.68 |
| After | 98.0(1) | 3.93(1) | 2065.0 | 50.30 | -- | 150.50 | 3.06 |
| 1977 | 0 | 0 | 0 | 0 | 0 | 160.50 | 3.27 |
| 1978 | 0 | 0 | 0 | 0 | 0.70 | 160.50 | 3.27 |
| 1979 | 9.0 | 0.18 | 0 | 0 | 1.38 | 160.50 | 3.27 |
| 1980 | 7.49(1) | 0.15(1) | 0 | 0 | 1.77(1) | 160.50 | 3.27 |
| 1981 | 126.46 | 2.54 | 0 | 0 | 1.77 | 160.50 | 3.27 |
| 1984 | 191.69 | 3.84 | 0 | 0 | 1.92 | 160.50 | 3.27 |

(1) Only one stage of construction tested.
(2) Data taken after scarification.
(3) Delamination is shown as total lineal feet of delamination found per year in the area surveyed.

Table 5 (Continued) - Summary of Observations for Analysis of Protection Systems

Part E, Bridge No. L-641R, Latex Modified Concrete Wearing Surface

a. Potential Scan (% of readings)

| Year | No. of Samples | Electrical Potential (Negative Voltage) 0-.10 | .11-.20 | .21-.30 | .31-.40 | .41-.50 | .51-.60 | .61-.70 | .71-.80 | .81-.90 | ).91 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Before(1) | 147 | 2.0 | 28.0 | 13.6 | 10.2 | 15.6 | 23.1 | 7.5 | | | |
| After(3) | 330 | 7.0 | 26.7 | 18.5 | 15.4 | 24.5 | 7.9 | | | | |
| 1977 | 330 | 0 | 8.5 | 53.4 | 32.4 | 5.7 | | | | | |
| 1978 | 330 | 0 | 19.4 | 40.1 | 32.7 | 7.2 | 0.6 | | | | |
| 1979 | 330 | 2.1 | 26.4 | 42.4 | 23.0 | 6.1 | | | | | |
| 1980(1) | 183 | 2.2 | 29.5 | 47.5 | 19.2 | 1.6 | | | | | |
| 1981 | 330 | 3.7 | 32.7 | 48.8 | 13.6 | 1.2 | | | | | |
| 1984 | 330 | 3.0 | 37.9 | 40.0 | 16.4 | 2.1 | 0.6 | | | | |

b. Resistance Scan (% of readings)

| Year | No. of Samples | Resistance (ohms) 0-500 | 501-1K | )1K-1.5K | )1.5K-10K | )10K-100K | )100K-1M | )1M |
|---|---|---|---|---|---|---|---|---|
| Before | No Test | | | | | | | |
| After(3) | 83 | 74.7 | 9.7 | 7.2 | 8.4 | | | |
| 1977 | 83 | 100.0 | | | | | | |
| 1978 | 83 | 85.6 | 14.4 | | | | | |
| 1979 | 8 | 25.0 | 75.0 | | | | | |
| 1980(1) | 5 | 0 | 60.0 | 40.0 | | | | |
| 1981 | 8 | 0 | 0 | 87.5 | 37.5 | 12.5 | | |
| 1984 | 8 | 0 | 37.5 | 37.5 | 25.0 | | | |

| Year | c. Delamination(4) Ln. Ft. | % | d. Surface Profile (Patching) Sq. Ft. | % | Cracking (Cr/Grid) | e. Underdeck "E" (Area Only) Sq. Ft. | % |
|---|---|---|---|---|---|---|---|
| Before | 245.0 | 4.90 | 22.4 | 0.54 | 0.32 | 972.6 | 19.72 |
| After | 137.5(1) | 5.5(1) | 1931.7 | 46.87 | -- | 477.9 | 9.69 |
| 1977 | 0 | 0 | 0 | 0 | 0 | 477.9 | 9.69 |
| 1978 | 5.0 | 0.10 | 1.06(2) | 0.02(2) | 0.26 | 477.9 | 9.69 |
| 1979 | 13.5 | 0.27 | 1.06 | 0.02 | 0.85 | 477.9 | 9.69 |
| 1980 | 0.3(1) | 0.01(1) | 1.06 | 0.02 | 1.66 | 477.9 | 9.69 |
| 1981 | 90.1 | 1.80 | 1.06 | 0.02 | 1.80 | 477.9 | 9.69 |
| 1984 | 458.1 | 9.15 | 1.06 | 0.02 | 2.09 | 477.9 | 9.69 |

(1) Only one stage of construction tested.
(2) Patches placed by contractor in footprints near end of bridge.
(3) Data taken after scarification.
(4) Delamination is shown as total lineal feet of delamination found per year in the area surveyed.

Table 5 (Continued) - Summary of Observations for Analysis of Protection Systems

Part F, Bridge No. L-759R SB, Latex Modified Concrete Wearing Surface

a. Potential Scan (% of readings)

| Year | No. of Samples | Electrical Potential (Negative Voltage) 0-.10 | .11-.20 | .21-.30 | .31-.40 | .41-.50 | .51-.60 | .61-.70 | .71-.80 | .81-.90 | ).91 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Before | 430 | 0.5 | 40.9 | 51.4 | 5.8 | 1.2 | 0.2 | | | | |
| After(2) | 430 | 9.3 | 62.1 | 22.8 | 5.3 | 0.5 | | | | | |
| 1977 | 430 | 3.7 | 73.5 | 18.9 | 3.9 | | | | | | |
| 1978 | 430 | 0 | 13.3 | 63.0 | 21.2 | 2.5 | | | | | |
| 1979 | 430 | 0 | 24.7 | 64.2 | 10.9 | 0.2 | | | | | |
| 1980(1) | 231 | 3.0 | 65.8 | 26.5 | 4.7 | | | | | | |
| 1981 | 430 | 1.6 | 56.8 | 36.9 | 3.3 | 1.4 | | | | | |
| 1984 | 430 | 1.4 | 68.9 | 26.7 | 3.0 | | | | | | |

b. Resistance Scan (% of readings)

| Year | No. of Samples | Resistance (ohms) 0-500 | 501-1K | )1K-1.5K | )1.5K-10K | )10K-100K | )100K-1M | )1M |
|---|---|---|---|---|---|---|---|---|
| Before | | | | | | | | |
| After(2) | 108 | 84.3 | 12.9 | 2.8 | | | | |
| 1977 | 108 | 100.0 | | | | | | |
| 1978 | 108 | 100.0 | | | | | | |
| 1979 | 8 | 12.5 | 87.5 | | | | | |
| 1980(1) | 4 | 100.0 | | | | | | |
| 1981 | 8 | 0 | 100.0 | | | | | |
| 1984 | 8 | 0 | 12.5 | 87.5 | | | | |

| Year | c. Delamination(3) Ln. Ft. | % | d. Surface Profile (Patching) Sq. Ft. | % | Cracking (Cr/Grid) | e. Underdeck "E" (Area Only) Sq. Ft. | % |
|---|---|---|---|---|---|---|---|
| Before | 25.5 | 0.38 | 10.6 | 0.20 | 0.18 | 0 | 0 |
| After | 2.0 | 0.03 | 104.7 | 1.97 | -- | 0 | 0 |
| 1977 | 6.0 | 0.09 | 0 | 0 | 0 | 0 | 0 |
| 1978 | 1.0 | 0.02 | 0 | 0 | 0.01 | 0 | 0 |
| 1979 | 29.0 | 0.44 | 0 | 0 | 0.68 | 0 | 0 |
| 1980 | 27.54(1) | 0.83(1) | 0 | 0 | 0.62(1) | 0 | 0 |
| 1981 | 77.15 | 1.16 | 0 | 0 | 1.11 | 0 | 0 |
| 1984 | 389.75 | 5.88 | 0 | 0 | 1.82 | 0 | 0 |

(1) Only one stage of construction tested.
(2) Data taken after scarification.
(3) Delamination is shown as total lineal feet of delamination found per year in the area surveyed.

Table 5 (Continued) - Summary of Observations for Analysis of Protection Systems

Part G, Bridge No. L-501R NB, Protecto Wrap Membrane System

a. Potential Scan (% of readings)

| Year | No. of Samples | Electrical Potential (Negative Voltage) 0-.10 | .11-.20 | .21-.30 | .31-.40 | .41-.50 | .51-.60 | .61-.70 | .71-.80 | .81-.90 | ).91 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Before | 514 | 12.2 | 67.7 | 16.4 | 2.7 | 1.0 | | | | | |
| After | 514 | 24.7 | 57.6 | 15.3 | 1.8 | 0.6 | | | | | |
| 1977(2) | 128 | 100.0 | | | | | | | | | |
| 1978 | 514 | 18.8 | 14.2 | 50.2 | 12.1 | 2.7 | 0.4 | 0.6 | 0.4 | 0.2 | 0.4 |
| 1979 | 514 | 23.0 | 33.8 | 34.2 | 5.6 | 1.0 | 0.8 | 1.0 | 0.4 | 0 | 0.2 |
| 1980(1) | 257 | 4.3 | 21.0 | 47.8 | 20.6 | 2.7 | 2.0 | 1.2 | 0 | 0.4 | 0 |
| 1981 | 514 | 19.6 | 30.3 | 31.4 | 13.8 | 3.1 | 1.4 | 0.2 | 0.2 | | |
| 1984 | 514 | 13.6 | 30.4 | 43.1 | 7.6 | 3.1 | 1.4 | 0.6 | 0 | 0.2 | |

b. Resistance Scan (% of readings)

| Year | No. of Samples | Resistance (ohms) 0-500 | 501-1K | )1K-1.5K | )1.5K-10K | )10K-100K | )100K-1M | )1M |
|---|---|---|---|---|---|---|---|---|
| Before | No Test | | | | | | | |
| After | 128 | 36.0 | 19.6 | 6.2 | 38.2 | | | |
| 1977 | 128 | 0 | 0 | 0 | 0 | 4.0 | 6.2 | 89.8 |
| 1978 | 128 | 0 | 0 | 1.6 | 43.0 | 23.4 | 15.6 | 16.4 |
| 1979 | 128 | 0 | 0 | 3.1 | 50.1 | 16.4 | 7.8 | 22.6 |
| 1980(1) | 64 | 0 | 1.6 | 0 | 79.6 | 15.6 | 1.6 | 1.6 |
| 1981 | 128 | 0 | 0.8 | 2.3 | 64.8 | 13.3 | 9.4 | 9.4 |
| 1984 | 128 | 0 | 0 | 3.1 | 64.0 | 14.1 | 9.4 | 9.4 |

| Year | c. Delamination(3) Ln. Ft. | % | d. Surface Profile (Patching) Sq. Ft. | % | Cracking (Cr/Grid) | e. Underdeck "E" (Area Only) Sq. Ft. | % |
|---|---|---|---|---|---|---|---|
| Before | 61.5 | 0.79 | 0.8 | 0.01 | 0.91 | 290 | 4.20 |
| After | 6.5 | 0.08 | 146.3 | 2.37 | -- | 290 | 4.20 |
| 1977 | 16.5 | 0.21 | 0 | 0 | 0 | 290 | 4.20 |
| 1978 | 78.0(1) | 2.00(1) | 0 | 0 | 0 | 298.5 | 4.33 |
| 1979 | 1781.5 | 22.83 | 0 | 0 | 0.44 | 298.5 | 4.33 |
| 1980 | 1083.5(1) | 27.77(2) | 0 | 0 | 0.06(1) | 298.5 | 4.33 |
| 1981 | 967.9 | 12.40 | 0 | 0 | 0.62 | 300.5 | 4.36 |
| 1984 | 1237.9 | 15.86 | 0 | 0 | 1.09 | 300.5 | 4.36 |

(1) Only one stage of construction tested.
(2) Spot checked in both lanes. Used staggered 6 ft. by 8 ft. grid.
(3) Delamination is shown as total lineal feet of delamination found per year in the area surveyed.

Table 5 (Continued) - Summary of Observations for Analysis of Protection Systems

Part H, Bridge No. L-759R NB, Protecto Wrap Membrane System

a. Potential Scan (% of readings)

| Year | No. of Samples | Electrical Potential (Negative Voltage) 0-.10 | .11-.20 | .21-.30 | .31-.40 | .41-.50 | .51-.60 | .61-.70 | .71-.80 | .81-.90 | ).91 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Before | 433 | 1.4 | 46.8 | 40.9 | 10.2 | 0.7 | | | | | |
| After | 433 | 0.7 | 44.4 | 45.0 | 9.0 | 0.7 | 0.2 | | | | |
| 1977(2) | 108 | 100.0 | | | | | | | | | |
| 1978 | 433 | 37.2 | 18.7 | 30.9 | 9.9 | 2.8 | 0.5 | | | | |
| 1979 | 433 | 15.0 | 25.1 | 37.0 | 13.9 | 6.2 | 2.1 | 0.7 | | | |
| 1980(1) | 233 | 31.8 | 10.3 | 34.3 | 17.2 | 6.4 | | | | | |
| 1981 | 433 | 16.2 | 43.2 | 26.1 | 10.6 | 3.9 | | | | | |
| 1984 | 433 | 34.6 | 29.6 | 28.6 | 6.7 | 0.5 | | | | | |

b. Resistance Scan (% of readings)

| Year | No. of Samples | Resistance (ohms) 0-500 | 501-1K | )1K-1.5K | )1.5K-10K | )10K-100K | )100K-1M | )1M |
|---|---|---|---|---|---|---|---|---|
| Before | No Test | | | | | | | |
| After | 108 | 38.0 | 38.0 | 15.7 | 8.3 | | | |
| 1977 | 108 | 0 | 0 | 0 | 0 | 0 | 10.8 | 89.2 |
| 1978 | 108 | 0 | 0 | 0 | 2.8 | 49.1 | 12.0 | 36.1 |
| 1979 | 108 | 0 | 0 | 0 | 13.9 | 30.5 | 20.4 | 35.2 |
| 1980(1) | 58 | 0 | 0 | 0 | 24.1 | 46.5 | 3.5 | 25.9 |
| 1981 | 108 | 0 | 0 | 0 | 15.7 | 20.4 | 21.3 | 42.6 |
| 1984 | 108 | 0 | 0 | 0 | 25.0 | 40.8 | 12.0 | 22.2 |

| Year | c. Delamination(3) Ln. Ft. | % | d. Surface Profile (Patching) Sq. Ft. | % | Cracking (Cr/Grid) | e. Underdeck "E" (Area Only) Sq. Ft. | % |
|---|---|---|---|---|---|---|---|
| Before | 48.5 | 0.73 | 32.9 | 0.62 | 0.25 | 0 | 0 |
| After | 25.0 | 0.38 | 84.1 | 1.58 | -- | 0 | 0 |
| 1977 | 10.5 | 0.02 | 0 | 0 | 0 | 0 | 0 |
| 1978 | 14.0 | 0.21 | 0 | 0 | 0 | 0 | 0 |
| 1979 | 39.0 | 0.59 | 0 | 0 | 0.12 | 0 | 0 |
| 1980 | 72.63(1) | 2.03(1) | 0 | 0 | 0.07(1) | 0 | 0 |
| 1981 | 56.10 | 0.85 | 0 | 0 | 0.25 | 0 | 0 |
| 1984 | 1008.81 | 15.21 | 0 | 0 | 0.68 | 0 | 0 |

(1) Only one stage of construction tested.
(2) Spot checked in both lanes. Used staggered 6 ft. by 8 ft. grid.
(3) Delamination is shown as total lineal feet of delamination found per year in the area surveyed.

Table 5 (Continued) - Summary of Observations for Analysis of Protection Systems

Part I, Bridge No.A-1613R, Heavy Duty Bituthene

a. Potential Scan (% of readings)

| Year | No. of Samples | Electrical Potential (Negative Voltage) 0-.10 | .11-.20 | .21-.30 | .31-.40 | .41-.50 | .51-.60 | .61-.70 | .71-.80 | .81-.90 | ).91 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Before | 463 | 0.4 | 34.1 | 53.6 | 10.4 | 1.5 | | | | | |
| After | 463 | 1.9 | 36.3 | 52.5 | 8.2 | 1.1 | | | | | |
| 1977(1) | 69 | 94.2 | 2.9 | 1.5 | 1.4 | | | | | | |
| 1978 | 463 | 15.1 | 25.7 | 48.8 | 8.4 | 1.2 | 0.4 | 0.2 | 0.0 | 0.2 | |
| 1979 | 463 | 4.8 | 56.6 | 31.7 | 5.8 | 1.1 | | | | | |
| 1980(1) | 194 | 0 | 57,2 | 36.6 | 6.2 | | | | | | |
| 1981 | 463 | 21.2 | 50.5 | 26.1 | 2.2 | | | | | | |
| 1984 | 463 | 12.5 | 47.1 | 32.0 | 4.3 | 3.9 | 0.2 | | | | |

b. Resistance Scan (% of readings)

| Year | No. of Samples | Resistance (ohms) 0-500 | 501-1K | )1K-1.5K | )1.5K-10K | )10K-100K | )100K-1M | )1M |
|---|---|---|---|---|---|---|---|---|
| Before | No Test | | | | | | | |
| After | 116 | 62.1 | 15.5 | 4.3 | 15.5 | 2.6 | | |
| 1977 | 116 | 0 | 0 | 0 | 0 | 0.9 | 0 | 99.1 |
| 1978 | 116 | 0 | 15.5 | 0.9 | 55.2 | 14.6 | 6.0 | 7.8 |
| 1979 | 116 | 0 | 0 | 1.7 | 56.9 | 31.9 | 8.6 | 0.9 |
| 1980(1) | 49 | 0 | 0 | 4.1 | 71.4 | 20.4 | 4.1 | 0 |
| 1981 | 116 | 0 | 0 | 0 | 53.5 | 33.6 | 6.0 | 6.9 |
| 1984 | 116 | 0 | 0 | 0.7 | 46.7 | 29.3 | 11.2 | 12.1 |

| Year | c. Delamination(2) Ln. Ft. | % | d. Surface Profile (Patching) Sq. Ft. | % | Cracking (Cr/Grid) | e. Underdeck "E" (Area Only) Sq. Ft. | % |
|---|---|---|---|---|---|---|---|
| Before | 18.5 | 0.26 | 0 | 0 | 0.50 | 0 | 0 |
| After | 2.0 | 0.03 | 70.4 | 1.21 | — | 0 | 0 |
| 1977 | 4391.5 | 61.75 | 0 | 0 | 0 | 0 | 0 |
| 1978 | 2796.0 | 39.32 | 0 | 0 | 0.02 | 0 | 0 |
| 1979 | 19.0 | 0.27 | 0 | 0 | 0.12 | 0 | 0 |
| 1980 | 545.5(1) | 7.67(1) | 0 | 0 | 0.24(1) | 0 | 0 |
| 1981 | 311.5 | 4.38 | 0 | 0 | 0.42 | 0 | 0 |
| 1984 | 1251.7 | 17.60 | 45.4 | 0.78 | 0.86 | 0 | 0 |

(1) Only one stage of construction tested.

(2) Delamination is shown as total lineal feet of delamination found per year in the area surveyed.

Table 5 (Continued) - Summary of Observations for Analysis of Protection Systems

Part J, Bridge No. L-719R, Heavy Duty Bituthene

a. Potential Scan (% of readings)

| Year | No. of Samples | Electrical Potential (Negative Voltage) 0-.10 | .11-.20 | .21-.30 | .31-.40 | .41-.50 | .51-.60 | .61-.70 | .71-.80 | .81-.90 | ).91 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Before | 725 | 5.5 | 79.0 | 12.7 | 2.1 | 0.7 | | | | | |
| After | 725 | 5.5 | 77.4 | 14.0 | 2.5 | 0.6 | | | | | |
| 1977(1) | 103 | 89.3 | 6.8 | 0 | 1.0 | 0 | 1.0 | 1.0 | 0.9 | | |
| 1978 | 725 | 12.0 | 66.0 | 12.5 | 4.4 | 4.3 | 0.3 | 0.3 | 0 | 0.2 | |
| 1979 | 725 | 19.0 | 63.6 | 12.4 | 3.2 | 0.7 | 0.2 | 0.7 | 0 | 0.2 | |
| 1980(1) | 358 | 27.4 | 66.5 | 4.2 | 1.1 | 0 | 0.8 | | | | |
| 1981 | 725 | 64.9 | 24.4 | 6.6 | 2.6 | 0.7 | 0.6 | 0 | 0.2 | | |
| 1984 | 725 | 44.4 | 43.4 | 9.2 | 1.9 | 0.4 | 0.3 | 0.4 | | | |

b. Resistance Scan (% of readings)

| Year | No. of Samples | Resistance (ohms) 0-500 | 501-1K | )1K-1.5K | )1.5K-10K | )10K-100K | )100K-1M | )1M |
|---|---|---|---|---|---|---|---|---|
| Before | No Test | | | | | | | |
| After | 181 | 32.0 | 61.4 | 6.6 | | | | |
| 1977 | 181 | 0 | 0 | 0 | 0 | 1.1 | 4.9 | 94.0 |
| 1978(1) | 157 | 0 | 3.8 | 0 | 73.3 | 21.0 | 1.3 | 0.6 |
| 1979 | 181 | 0.6 | 1.1 | 2.2 | 56.9 | 35.9 | 3.3 | |
| 1980(1) | 89 | 0 | 0 | 0 | 49.5 | 43.8 | 5.6 | 1.1 |
| 1981 | 181 | 0 | 0 | 0.5 | 48.6 | 38.7 | 10.5 | 1.7 |
| 1984 | 181 | 0 | 0 | 0 | 39.2 | 38.7 | 15.5 | 6.6 |

| Year | c. Delamination(2) Ln. Ft. | % | d. Surface Profile (Patching) Sq. Ft. | % | Cracking (Cr/Grid) | e. Underdeck "E" (Area Only) Sq. Ft. | % |
|---|---|---|---|---|---|---|---|
| Before | 63.0 | 0.56 | 0.4 | 0.01 | 0.89 | 18.2 | 0.18 |
| After | 7.0 | 0.06 | 113.1 | 1.28 | -- | 18.2 | 0.18 |
| 1977 | 3403.0 | 30.38 | 0 | 0 | 0 | 18.2 | 0.18 |
| 1978 | 652.5 | 5.82 | 0 | 0 | 0 | 18.2 | 0.18 |
| 1979 | 207.5 | 1.85 | 0 | 0 | 0.06 | 18.2 | 0.18 |
| 1980 | 189.6(1) | 3.38(1) | 0 | 0 | 0.15(1) | 18.2 | 0.18 |
| 1981 | 178.7 | 1.60 | 0 | 0 | 0.60 | 18.2 | 0.18 |
| 1984 | 89.1 | 1.01 | 1.2 | 0.01 | 1.22 | 24.2 | 0.23 |

(1) Only one stage of construction tested.
(2) Delamination is shown as total lineal feet of delamination found per year in the area surveyed.

Table 5 (Continued) - Summary of Observations for Analysis of Protection Systems

Part K, Bridge No. L-720R, Gacoflex UWM-2811 Membrane System

a. Potential Scan (% of readings)

| Year | No. of Samples | Electrical Potential (Negative Voltage) 0-.10 | .11-.20 | .21-.30 | .31-.40 | .41-.50 | .51-.60 | .61-.70 | .71-.80 | .81-.90 | ).91 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Before | 479 | 1.6 | 86.3 | 9.8 | 2.0 | 0.3 | | | | | |
| After | No Test | | | | | | | | | | |
| 1977(4) | 209 | 70.8 | 16.3 | 10.0 | 1.4 | 0 | 0 | 0 | 0.5 | 0.5 | 0.5 |
| 1978 | 835 | 6.6 | 69.5 | 17.4 | 3.0 | 1.5 | 0.9 | 0.8 | 0.2 | 0.1 | |
| 1979 | 835 | 9.0 | 76.0 | 8.9 | 2.1 | 2.0 | 1.2 | 0.7 | 0.1 | | |
| 1980(1) | 299 | 20.7 | 70.3 | 4.3 | 2.0 | 0.7 | 1.4 | 0.6 | | | |
| 1981 | 835 | 48.6 | 43.6 | 4.4 | 0.9 | 1.3 | 0.8 | 0.4 | | | |
| 1984 | 835 | 34.1 | 57.0 | 5.7 | 1.3 | 1.0 | 0.4 | 0.5 | | | |

b. Resistance Scan (% of readings)

| Year | No. of Samples | Resistance (ohms) 0-500 | 501-1K | )1K-1.5K | )1.5K-10K | )10K-100K | )100K-1M | )1M |
|---|---|---|---|---|---|---|---|---|
| Before | No Test | | | | | | | |
| After | 209 | 43.5 | 42.1 | 12.0 | 2.4 | | | |
| 1977 | 209 | 0 | 0 | 0 | 0 | 4.8 | 7.6 | 87.6 |
| 1978 | 209 | 1.4 | 9.6 | 12.4 | 56.5 | 14.4 | 1.9 | 3.8 |
| 1979 | 209 | 0 | 4.3 | 13.9 | 56.0 | 16.3 | 7.1 | 2.4 |
| 1980(1) | 75 | 0 | 0 | 24.0 | 73.3 | 2.7 | | |
| 1981 | 209 | 0 | 1.9 | 4.8 | 59.8 | 21.1 | 8.6 | 3.8 |
| 1984 | 209 | 0 | 9.1 | 15.3 | 37.3 | 18.2 | 10.5 | 9.6 |

| Year | c. Delamination(5) Ln. Ft. | % | d. Surface Profile (Patching) Sq. Ft. | % | Cracking (Cr/Grid) | e. Underdeck "E" (Area Only) Sq. Ft. | % |
|---|---|---|---|---|---|---|---|
| Before | 17.0 | 0.13 | 0 | 0 | 0.34 | 0 | 0 |
| After | (2) | (2) | 22.5 | 0.22 | — | 0 | 0 |
| 1977 | 3685.5 | 27.89 | 0 | 0 | 0 | 0 | 0 |
| 1978 | 329.0 | 2.49 | 40.42 | 0.39 | 0.11 | 0 | 0 |
| 1979 | 328.5 | 2.49 | 137.50(3) | 1.34 | 0.12 | 0 | 0 |
| 1980 | 2668.5(1) | 20.20(1) | 137.50 | 1.34 | 0.26(1) | 1.0 | 0.01 |
| 1981 | 1015.6 | 7.69 | 137.50 | 1.34 | 0.40 | 1.0 | 0.01 |
| 1984 | 2730.1 | 20.66 | 137.50 | 1.34 | 0.98 | 1.0 | 0.01 |

(1) Only one stage of construction tested.
(2) No potential scan made because only minor repairs were made.
(3) Permanent patch replaced by contractor due to potholes developed during winter 1977.
(4) Spot checked in both lanes. Used staggered 6 ft. by 8 ft. grid.
(5) Delamination is shown as total lineal feet of delamination found per year in the area surveyed.

Table 5 (Continued) - Summary of Observations for Analysis of Protection Systems

Part L, Bridge No. L-721R, Gacoflex UWM-2811 Membrane System

a. Potential Scan (% of readings)

| Year | No. of Samples | Electrical Potential (Negative Voltage) 0-.10 | .11-.20 | .21-.30 | .31-.40 | .41-.50 | .51-.60 | .61-.70 | .71-.80 | .81-.90 | ).91 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Before | 690 | 0.0 | 67.8 | 26.6 | 4.6 | 1.0 | | | | | |
| After | 690 | 0.3 | 65.2 | 29.0 | 4.7 | 0.8 | | | | | |
| 1977(1) | 115 | 97.5 | 0.9 | 0 | 0 | 0 | 0.8 | 0 | 0 | 0 | 0.8 |
| 1978 | 690 | 10.7 | 64.1 | 20.5 | 1.7 | 1.8 | 0.3 | 0.2 | | | |
| 1979 | 690 | 15.4 | 65.5 | 14.5 | 2.9 | 1.0 | 0.4 | 0.1 | 0.2 | | |
| 1980(1) | 345 | 53.3 | 37.4 | 7.5 | 1.5 | 0.3 | | | | | |
| 1981 | 690 | 45.6 | 42.4 | 8.8 | 1.7 | 0.8 | 0.3 | 0.2 | 0.2 | | |
| 1984 | 690 | 25.8 | 59.1 | 9.8 | 3.6 | 1.2 | 0.1 | 0.4 | | | |

b. Resistance Scan (% of readings)

| Year | No. of Samples | Resistance (ohms) 0-500 | 501-1K | )1K-1.5K | )1.5K-10K | )10K-100K | )100K-1M | )1M |
|---|---|---|---|---|---|---|---|---|
| Before | No Test | | | | | | | |
| After | 173 | 45.1 | 54.9 | | | | | |
| 1977 | 173 | 0 | 0 | 0 | 0 | 1.1 | 0.6 | 98.3 |
| 1978 | 173 | 0.6 | 28.9 | 1.1 | 49.7 | 16.2 | 3.5 | |
| 1979 | 173 | 0 | 0 | 4.6 | 69.4 | 17.9 | 5.2 | 2.9 |
| 1980(1) | 87 | 0 | 10.3 | 13.8 | 50.6 | 25.3 | | |
| 1981 | 173 | 0 | 0 | 1.8 | 57.2 | 33.5 | 7.5 | |
| 1984 | 173 | 0 | 1.2 | 6.4 | 2.6 | 20.2 | 12.7 | 6.9 |

| Year | c. Delamination(3) Ln. Ft. | % | d. Surface Profile (Patching) Sq. Ft. | % | Cracking (Cr/Grid) | e. Underdeck "E" (Area Only) Sq. Ft. | % |
|---|---|---|---|---|---|---|---|
| Before | 16.0 | 0.15 | 0 | 0 | 0.45 | 0 | 0 |
| After | 6.0 | 0.06 | 65.6 | 0.79 | -- | 0 | 0 |
| 1977 | 1801.5 | 17.14 | 0 | 0 | 0 | 0 | 0 |
| 1978 | 1696.5 | 16.14 | 58.31(2) | 0.7 | 0 | 0 | 0 |
| 1979 | 692.0 | 6.58 | 58.31 | 0.7 | 0.01 | 0 | 0 |
| 1980 | 1079.5(1) | 10.27(1) | 58.31 | 0.70 | 0.03(1) | 0 | 0 |
| 1981 | 879.2 | 8.37 | 58.31 | 0.70 | 0.47 | 0 | 0 |
| 1984 | 2084.2 | 19.83 | 374.0 | 4.51 | 0.84 | 0 | 0 |

(1) Only one stage of construction tested.
(2) Permanent patch placed by contractor due to potholes developed during winter of 1977.
(3) Delamination is shown as total lineal feet of delamination found per year in the area surveyed.

Table 5 (Continued) - Summary of Observations for Analysis of Protection Systems

Part M, Bridge No. L-563R, Superseal 4000LT Membrane System

a. Potential Scan (% of readings)

| Year | No. of Samples | Electrical Potential (Negative Voltage) 0-.10 | .11-.20 | .21-.30 | .31-.40 | .41-.50 | .51-.60 | .61-.70 | .71-.80 | .81-.90 | ).91 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Before | 379 | 0.4 | 58.0 | 9.5 | 1.6 | 0.5 | | | | | |
| After | 379 | 5.8 | 54.0 | 17.9 | 1.8 | 0.5 | | | | | |
| 1977(2) | 94 | 85.1 | 8.6 | 4.2 | 1.1 | 1.0 | | | | | |
| 1978 | 379 | 10.5 | 29.0 | 47.0 | 12.7 | 0.8 | | | | | |
| 1979 | 379 | 24.3 | 54.3 | 18.5 | 2.9 | | | | | | |
| 1980(1) | 189 | 19.6 | 17,5 | 7.4 | 0.5 | | | | | | |
| 1981 | 379 | 72.8 | 20.3 | 5.8 | 0.8 | 0.3 | | | | | |
| 1984 | 379 | 41.2 | 47.0 | 8.2 | 1.2 | 0.5 | 1.3 | | | | |

b. Resistance Scan (% of readings)

| Year | No. of Samples | Resistance (ohms) 0-500 | 501-1K | )1K-1.5K | )1.5K-10K | )10K-100K | )100K-1M | )1M |
|---|---|---|---|---|---|---|---|---|
| Before | No Test | | | | | | | |
| After | 95 | 12.6 | 45.2 | 22.1 | 20.1 | | | |
| 1977 | 95 | 0 | 0 | 0 | 1.0 | 7.4 | 2.4 | 89.5 |
| 1978 | 95 | 0 | 1.1 | 0 | 33.7 | 41.0 | 20.0 | 4.2 |
| 1979 | 95 | 0 | 0 | 0 | 45.3 | 28.4 | 15.8 | 10.5 |
| 1980(1) | 47 | 0 | 0 | 0 | 76.6 | 8.5 | 10.6 | 4.3 |
| 1981 | 95 | 0 | 0 | 0 | 61.1 | 31.5 | 3.2 | 4.2 |
| 1984 | 95 | 0 | 1.0 | 3.2 | 48.5 | 29.5 | 16.8 | 1.0 |

| Year | c. Delamination(4) Ln. Ft. | % | d. Surface Profile (Patching) Sq. Ft. | % | Cracking (Cr/Grid) | e. Underdeck "E" (Area Only) Sq. Ft. | % |
|---|---|---|---|---|---|---|---|
| Before | 95.0 | 1.66 | 2.7 | 0.06 | 0.38 | 20.0 | 0.39 |
| After | 7.5(1) | 0.29(1) | 161.4 | 3.57 | — | 20.0 | 0.39 |
| 1977 | 3.0 | 0.05 | 0 | 0 | 0 | 20.0 | 0.39 |
| 1978 | 12.0 | 0.21 | 0 | 0 | 0.01 | 20.0 | 0.39 |
| 1979 | 1856.0 | 32.40 | 0 | 0 | 0.15 | 20.0 | 0.39 |
| 1980 | 1606.4(1) | 28.04(1) | 0 | 0 | 0.15(1) | 20.0 | 0.39 |
| 1981 | 886.5 | 15.48 | 0 | 0 | 0.41 | 20.0 | 0.39 |
| 1984 | 1320.6 | 23.06 | 112.4(3) | 2.48 | 0.77 | 20.0 | 0.39 |

(1) Only one stage of construction tested.
(2) Spot checked in both lanes. Used staggered 6 ft. by 8 ft. grid.
(3) Full depth deck repairs included in this patching was 15.25 sq. ft. or 0.30% of area.
(4) Delamination is shown as total lineal feet of delamination found per year in the area surveyed.

Table 5 (Continued) - Summary of Observations for Analysis of Protection Systems

Part N, Bridge No. L-571R, Superseal 4000LT Membrane System

a. Potential Scan (% of readings)

| Year | No. of Samples | Electrical Potential (Negative Voltage) 0-.10 | .11-.20 | .21-.30 | .31-.40 | .41-.50 | .51-.60 | .61-.70 | .71-.80 | .81-.90 | ).91 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Before | 794 | 0.8 | 9.6 | 21.4 | 26.4 | 27.7 | 13.0 | 1.1 | | | |
| After | 794 | 0.9 | 7.3 | 37.4 | 40.8 | 12.0 | 1.6 | | | | |
| 1977(3) | 199 | 84.9 | 6.0 | 0.5 | 7.1 | 1.5 | | | | | |
| 1978 | 794 | 16.6 | 13.0 | 27.6 | 34.1 | 6.0 | 1.1 | 0.0 | 0.6 | 0.1 | |
| 1979 | 794 | 11.3 | 22.0 | 42.9 | 17.7 | 3.2 | 1.7 | 0.9 | 0.2 | 0.1 | |
| 1980(1) | 390 | 15.1 | 30.0 | 43.9 | 7.7 | 1.5 | 1.8 | | | | |
| 1981 | 794 | 14.3 | 31.5 | 38.3 | 11.1 | 2.5 | 1.3 | 0.5 | 0.5 | 0 | 0.2 |
| 1984 | 794 | 14.4 | 19.4 | 32.7 | 20.1 | 7.9 | 3.1 | 2.1 | 0.2 | 0 | 0.1 |

b. Resistance Scan (% of readings)

| Year | No. of Samples | Resistance (ohms) 0-500 | 501-1K | )1K-1.5K | )1.5K-10K | )10K-100K | )100K-1M | )1M |
|---|---|---|---|---|---|---|---|---|
| Before | | | | | | | | |
| After | 198 | 74.8 | 15.2 | 5.0 | 5.0 | | | |
| 1977 | 198 | 0 | 0 | 0 | 8.6 | 0.5 | 12.6 | 78.3 |
| 1978 | 198 | 0 | 0.5 | 0 | 49.5 | 31.3 | 12.1 | 6.6 |
| 1979 | 198 | 0 | 2.0 | 14.7 | 47.4 | 20.2 | 5.1 | 10.6 |
| 1980(1) | 97 | 0 | 0 | 15.5 | 50.5 | 15.5 | 1.0 | 17.5 |
| 1981 | 198 | 0.5 | 6.1 | 6.6 | 68.7 | 12.1 | 2.5 | 3.5 |
| 1984 | 198 | 0 | 1.5 | 7.6 | 51.5 | 24.2 | 8.6 | 6.6 |

| Year | c. Delamination(5) Ln. Ft. | % | d. Surface Profile (Patching) Sq. Ft. | % | Cracking (Cr/Grid) | e. Underdeck "E" (Area Only) Sq. Ft. | % |
|---|---|---|---|---|---|---|---|
| Before | 866.0 | 7.20 | 2884.0 | 30.36 | 1.27 | 494.2 | 4.65 |
| After | 14.5 | 0.12 | 4150.0 | 43.69 | -- | 494.2 | 4.65 |
| 1977 | 81.5 | 0.68 | 0 | 0 | 0 | 494.2 | 4.65 |
| 1978 | 921.5 | 7.66 | 62.9(2) | 0.66(2) | 0.01 | 539.5 | 5.07 |
| 1979 | 1830.0 | 15.21 | 62.9 | 0.66 | 0.08 | 539.5 | 5.07 |
| 1980 | 5521.0(1) | 45.89(1) | 62.9 | 0.66 | 0.43(1) | 539.5 | 5.07 |
| 1981 | 3807.7 | 31.65 | 62.9 | 0.66 | 0.77 | 539.5 | 5.07 |
| 1984 | 9110.8 | 75.73 | 249.0(4) | 2.62 | 1.67 | 539.5 | 5.07 |

(1) Only one stage of construction tested.
(2) Permanent patch placed by contractor due to potholes developed during winter 1977.
(3) Spot checked in both lanes. Used staggered 6 ft. by 8 ft. grid.
(4) Full depth deck repairs included in this patching was 123.75 sq. ft. or 1.16% of area.
(5) Delamination is shown as total lineal feet of delamination found per year in the area surveyed.

# INTERPRETATION OF TEST DATA

## GENERAL APPROACH TO ANALYSIS

The performance analysis and discussion of these bridge deck protection systems will be based on test data presented in the preceding section of this report. The discussion is supplemented with photographs and graphs when appropriate.

## CHLORIDE ION DETERMINATION

Chloride ion penetration analysis was included in the testing procedures on these bridges to determine the effectiveness of the membrane system to control further chloride ion intrusion. Chloride ion test locations were established on the deck surface during the initial condition survey. These test locations were selected on the basis that no delamination, underdeck efflorescence, or patching was present in the immediate area.

In conjunction with this chloride ion testing program, two additional analyses were incorporated for informational purposes. First, the specific location of the chloride ion samples were chosen to correspond to a range of electrical potential readings. Each chloride ion sample was obtained at the grid location relative to a given potential reading to obtain data to analyze the relationship of potential reading with chloride ion concentration.

Second, also incorporated with the initial chloride ion sampling, a corresponding in situ chloride ion determination was

made. These analyses will be discussed first and then the analyses of chloride ion intrusion after placement of the membrane will follow.

## ELECTRICAL POTENTIAL READING RELATIVE TO CHLORIDE ION CONCENTRATION

Chloride ion content of the deck concrete was determined for each 1/2 inch increment of depth from 1/4 inch to 4 1/4 inches by AASHTO Method T 260. The top 1/4 inch of the concrete was discarded. Each of the eight lifts (A through H) for each sample location was tested separately for its chloride ion content. Thus, with the electrical potential reading at each chloride ion sample location, a simple linear regression analyses was run to determine if association existed. Table 6 is the product of the regression analyses made by accumulating all data for the fourteen bridges for each lift of chloride ion sample.

The number of pairs of values (N) is noted as a decreasing value as the depth increases. This is a result of not drilling to the depth indicated because of coming in contact with reinforcing steel or having to discontinue taking the sample due to weather or traffic conditions. However, the number of samples for each lift was quite sufficient to establish relationships.

The significance tests show that chloride ion contents at all lifts were significantly related to the electrical potential readings. However, as noted in Figures 2 and 3, which represent chloride ion sample lifts A and C, as examples, have very large

Table 6 - Simple Linear Regression Results for Electrical Potential Vs. Chloride Ion Concentration

| Lift | (Inches) | N | b | a | $r^2$ | r | $S_{y.x}$ | CV% | 95% Signif. |
|---|---|---|---|---|---|---|---|---|---|
| A | 1/4-3/4 | 258 | 9.854 | 4.23 | 0.08 | 0.28 | 3.37 | 52.1 | Yes |
| B | 3/4-1 1/4 | 258 | 10.094 | 1.35 | 0.14 | 0.37 | 2.55 | 70.2 | Yes |
| C | 1 1/4-1 3/4 | 257 | 9.908 | -0.50 | 0.25 | 0.50 | 1.74 | 100.1 | Yes |
| D | 1 3/4-2 1/4 | 255 | 6.409 | -0.59 | 0.28 | 0.53 | 1.03 | 120.2 | Yes |
| E | 2 1/4-2 3/4 | 254 | 4.908 | -0.56 | 0.31 | 0.56 | 0.74 | 133.2 | Yes |
| F | 2 3/4-3 1/4 | 240 | 3.818 | -0.46 | 0.22 | 0.47 | 0.73 | 175.9 | Yes |
| G | 3 1/4-3 3/4 | 234 | 4.440 | -0.65 | 0.26 | 0.51 | 0.75 | 201.2 | Yes |
| H | 3 3/4-4 1/4 | 226 | 3.890 | -0.56 | 0.26 | 0.51 | 0.64 | 197.3 | Yes |

Figure 2 - Analysis of Chloride Ion Concentration at 1/4 to 3/4" Depth With Electrical Potential

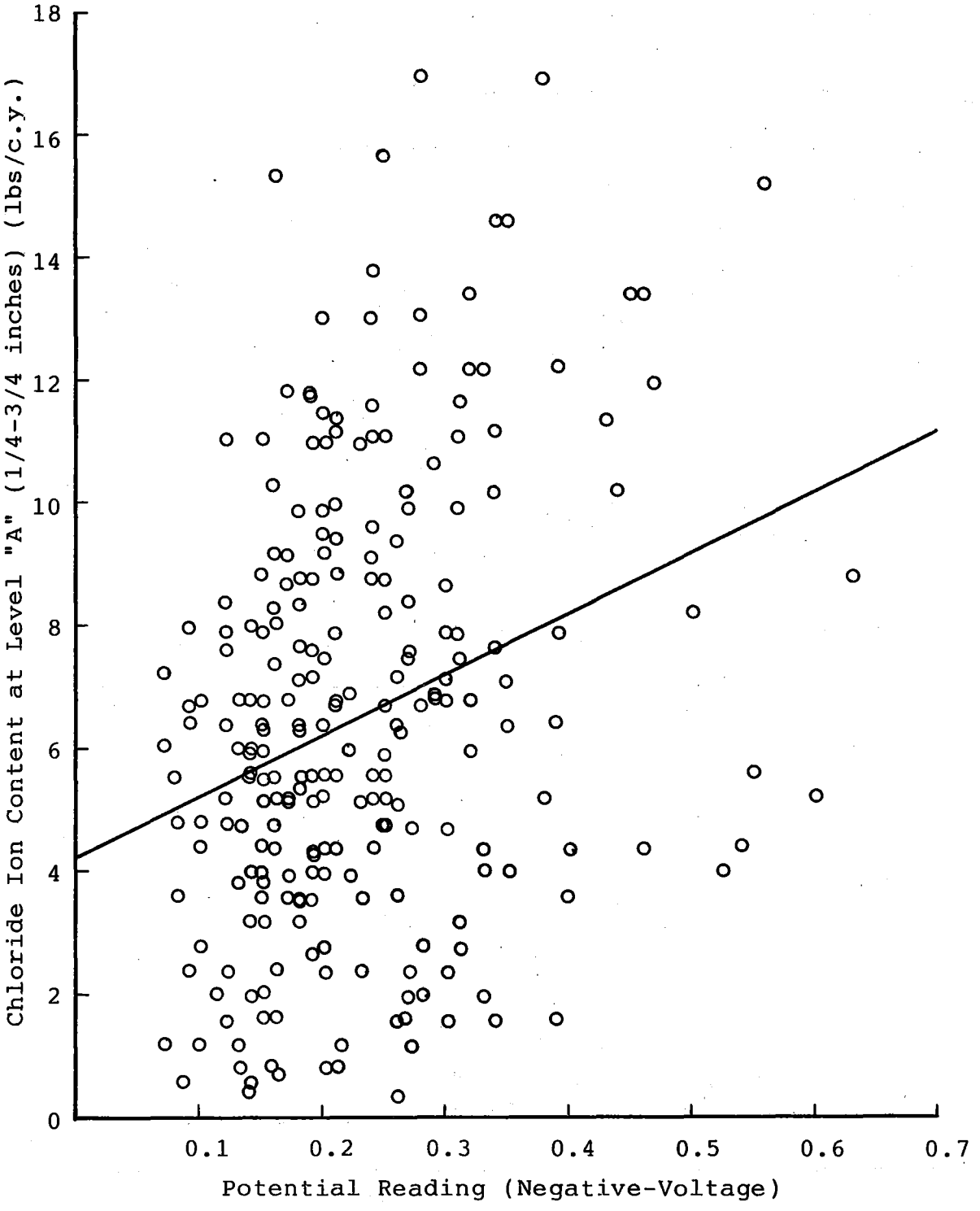
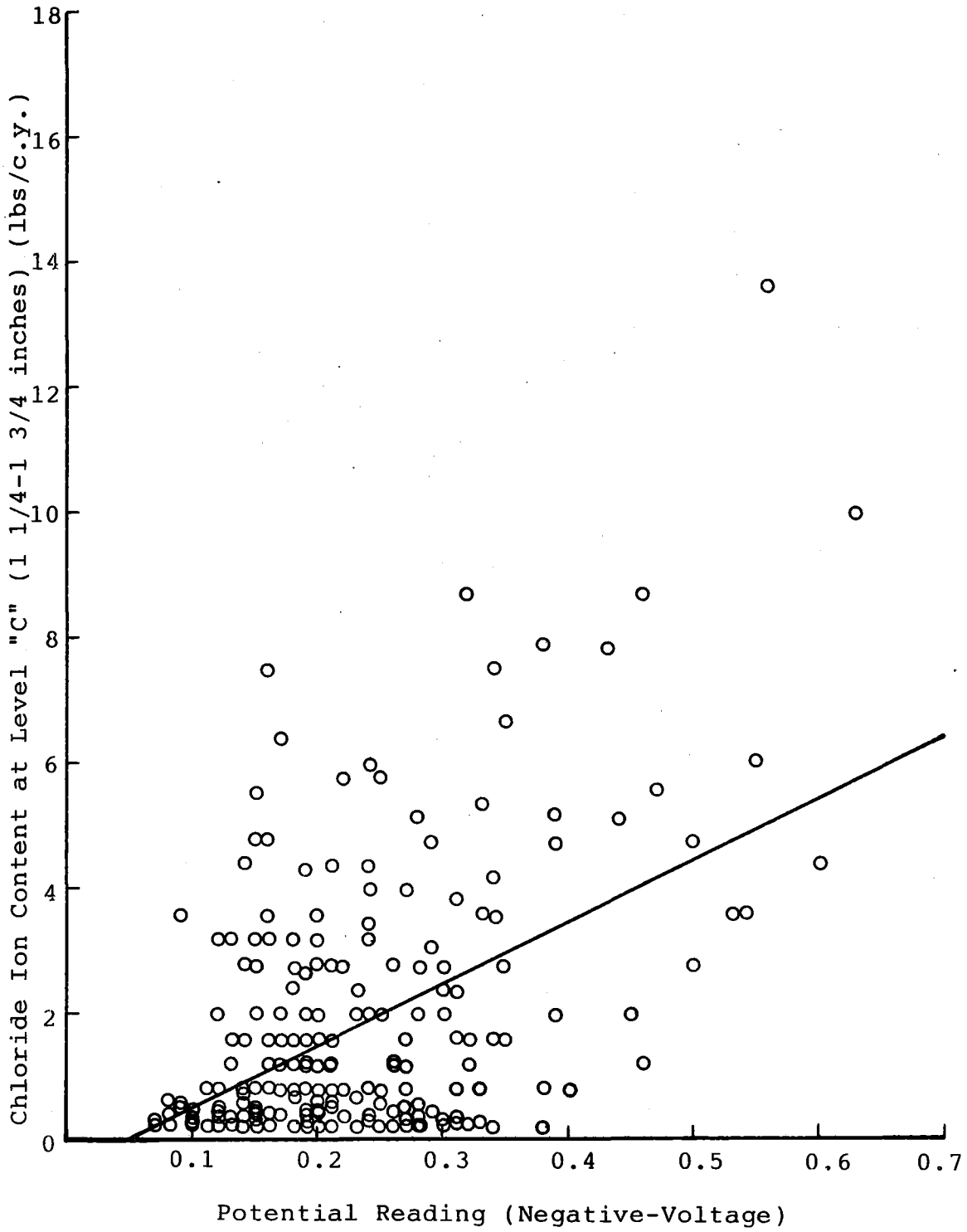


Figure 3 - Analysis of Chloride Ion Concentration at 1 1/4 to 1 3/4" Depth with Electrical Potential

(Represents approximate depth of top reinforcing steel in most bridges in this study.)



distributions of data. This variation is related to in Table 6 through the coefficient of variation (CV%) for all lifts and the implied accompanying errors of estimate. Also, the regression formulas indicate further lack of meaningful relationships because the y axis ordinate becomes negative as shown in Table 6, which is definitely not realistic. If good results were accomplished, the best fit curve would intersect the y axis at approximately 0.20 pounds of chloride ion per cubic yard, which through numerous tests has been determined to be the average chloride ion content for fresh concrete produced in Missouri.

Therefore, based on this large sampling of bridge decks in a very limited area of almost similar environmental conditions, these results indicate the predictability of chloride ion content from observation of the electrical potential scan would be subject to large error and would be unacceptable.

## EVALUATION OF A RAPID IN SITU DETERMINATION OF CHLORIDE ION IN PCC BRIDGE DECKS

Determination of chloride ion content of a powdered sample of portland cement concrete by AASHTO T 260 is time consuming for a laboratory. A report entitled "Rapid In Situ Determination of Chloride Ion in Portland Cement Concrete Bridge Decks" by Garrett L. Morrison [1] provided a field method for determination of water soluble chloride ion content which was reported to have good correlation with laboratory results. This method utilized a specific chloride ion electrode and a buffer solution which had been placed in a clean dust free hole drilled in the bridge deck. Potential readings from the electrode after

an immersion time of 90 seconds were converted to chloride ion concentration in pounds of chloride ion per cubic yard of concrete.

Incorporation of this in situ chloride ion concentration method afforded a good opportunity to evaluate its merits for utilization as a substitute for the laboratory method. Chloride ion samples were removed in 3/4 inch increments from a special test hole. The field in situ chloride ion analysis was then made in the same hole after each lift was removed. Only two horizons were used in this correlation. One at 1/4" to 1" and the other at 1" to 1 3/4". Method of performing the in situ chloride ion test was similar to that described in the report by Morrison [1].

Each bridge deck used in this investigation was tested for in situ chloride ion content by taking a minimum of six individual samples per deck. Therefore, a total of 200 samples from the two horizons were available for this analysis.

Twelve samples were omitted from the population because the concrete in the upper portion of the decks were in very poor condition. When the asphaltic concrete overlay which existed on these decks was removed, a considerable amount of moisture and debris was observed at the surface of the concrete. This moisture and debris continued to drain and crumble into the hole interfering with the in situ chloride ion test. The remaining 188 samples were used to determine if a statistical significance existed between in situ chloride ion results and laboratory

potentiometric titration of the concrete removed from the test hole.

Figure 4 exhibits the 188 samples for both horizons shown as chloride ion per cubic yard of concrete as determined by laboratory potentiometric titration as a function of the uncorrected in situ electrode reading. Attempts were made to satisfy the relationship by either a linear or quadratic curve of best fit using all 188 points. Electrode potentials were used in the uncorrected state, corrected for standardization of the probe immediately prior to test only, and corrected for temperature of the buffer solution and standardization of the probe in combination.

Coefficient of variations from the above analyses indicated none of the above correlations would represent the relationship with less than a 39% or 40% error based on a quadratic or a linear analysis respectively. Corresponding coefficients of determination were 0.49 and 0.46 respectively. The best relationship derived from this data was with uncorrected electrode readings in the 1/4" to 1" horizon. Table 7 shows overall results of relationships for the two best fit curves and uncorrected and corrected electrode readings.

In situ chloride ion determination method used in this analysis did not yield results at the 95% significance level desired. However, the method does provide a base from which modification could enhance the quality of results. Potential readings from the chloride ion specific probe in this field study were in the range of 60 to 140 mV. Figure 5 is a

Figure 4 - Halide Electrode Potential (Uncorrected) with Standard Laboratory Chloride Content Determination (Potentiometric Titration)

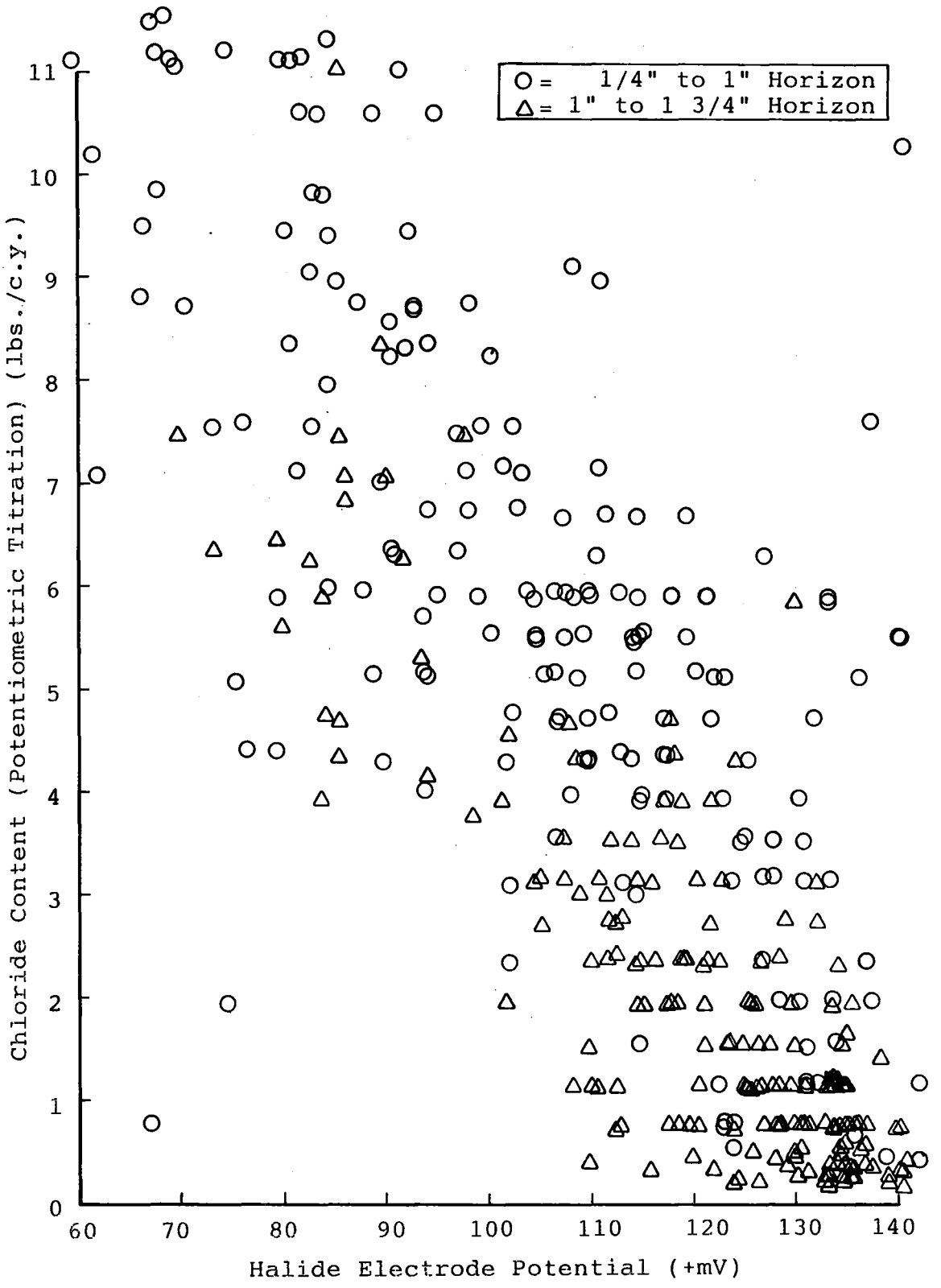


Table 7 - Correlation of Field Electrode Values With Laboratory Chloride Ion Content as Determined by Potentiometric Titration

| Correlation | Horizon | Coefficient of Determination | Correlation Coefficient | Average Chloride Ion Content (lbs./c.y.) | Standard Error of Estimate | Percent Error | Number of Pairs of Data |
|---|---|---|---|---|---|---|---|
| **Part A - Uncorrected Field Electrode Value** | | | | | | | |
| Linear | 1/4"-1" | 0.46 | 0.67 | 5.7 | 2.3 | 40.4 | 188 |
| Quadratic | 1/4"-1" | 0.49 | 0.70 | 5.7 | 2.2 | 38.6 | 188 |
| Linear | 1"-1 3/4" | 0.63 | 0.79 | 2.1 | 1.2 | 57.1 | 188 |
| Quadratic | 1"-1 3/4" | 0.64 | 0.80 | 2.1 | 1.2 | 57.1 | 188 |
| **Part B - Corrected Field Electrode Value for Calibration with 1 x $10^{-3}$ M Chloride Solution** | | | | | | | |
| Linear | 1/4"-1" | 0.44 | 0.67 | 5.7 | 2.3 | 40.4 | 188 |
| Quadratic | 1/4"-1" | 0.47 | 0.69 | 5.7 | 2.3 | 40.4 | 188 |
| Linear | 1"-1 3/4" | 0.63 | 0.80 | 2.1 | 1.2 | 57.1 | 188 |
| Quadratic | 1"-1 3/4" | 0.67 | 0.82 | 2.1 | 1.1 | 52.4 | 188 |
| **Part C - Corrected Field Electrode Value for Calibration with 1 x $10^{-3}$ Chloride Solution and Temperature of Buffer Solution** | | | | | | | |
| Linear | 1/4"-1" | 0.32 | 0.56 | 5.7 | 2.6 | 45.6 | 188 |
| Quadratic | 1/4"-1" | 0.33 | 0.57 | 5.7 | 2.6 | 45.6 | 188 |
| Linear | 1"-1 3/4" | 0.56 | 0.75 | 2.1 | 1.3 | 61.9 | 188 |
| Quadratic | 1"-1 3/4" | 0.66 | 0.81 | 2.1 | 1.2 | 57.1 | 188 |

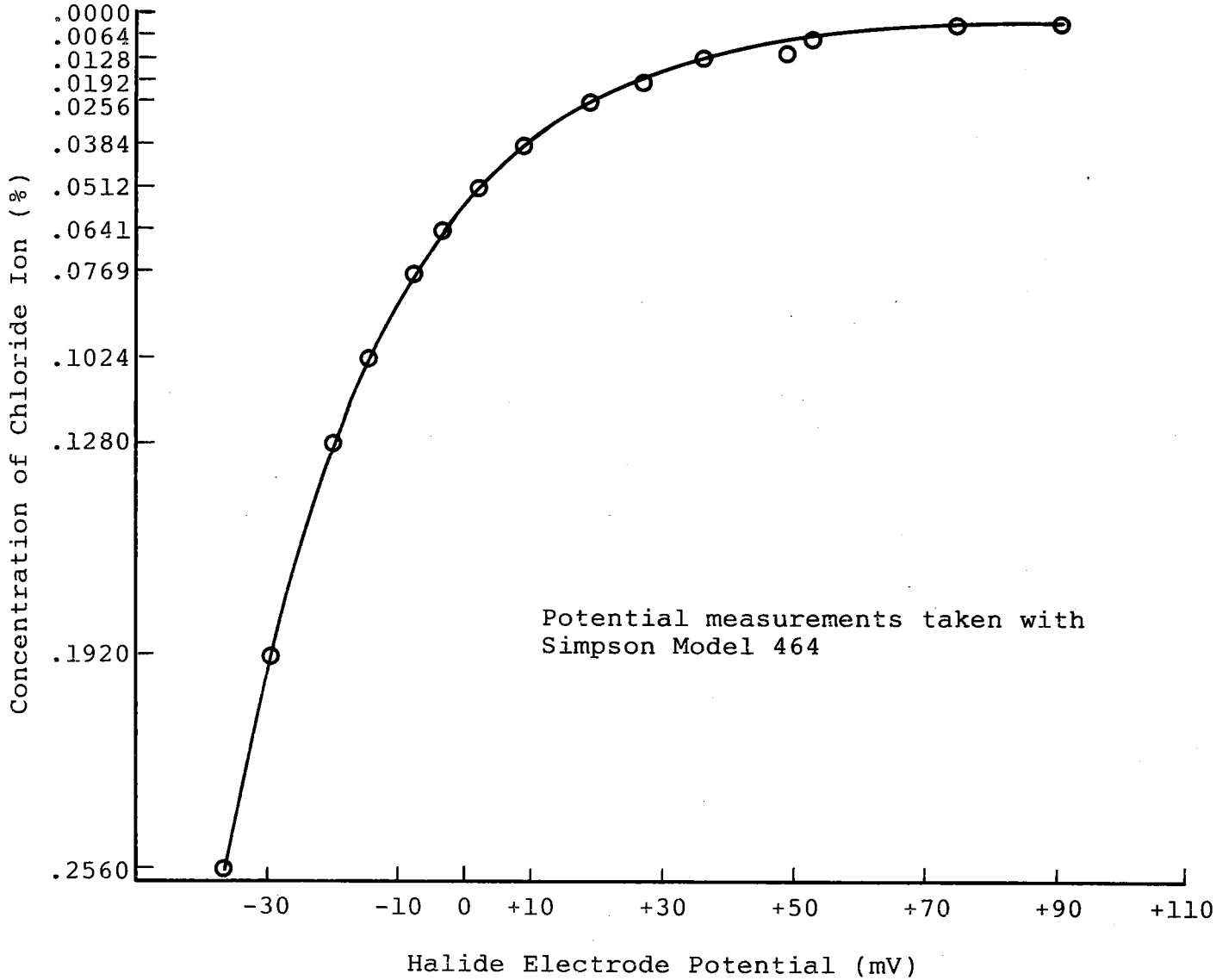



Figure 5 - Calibration of Halide Electrode
Model 96-17 (Combination Chloride)

laboratory calibration curve for the electrode used in this evaluation. Slope of this curve for this observed range of potential readings approached zero. If the buffer solution would be modified to cause the electrode sensitivity to occur within -30 to 50 mV range, the quality of the results may be greatly enhanced.

Study with this method should continue. A fast method of chloride ion content evaluation of bridge deck concretes could be helpful when used in conjunction with rehabilitation of existing salt contaminated bridge decks.

## CHLORIDE ION PENETRATION ANALYSES AFTER MEMBRANE PLACEMENT

Prior to rehabilitation,two bridges, L-641R and L-642R, had an asphaltic concrete overlay and three bridges, A-1613R, L-759R NB, and L-759R SB, were in the original state with bare concrete surface. Remainder of the bridges had a seal coat with porphyry rock chips.

Data in Table 8 shows the relative chloride ion concentration for the bridges used in this investigation prior to rehabilitation. Figure 6 indicates the average chloride ion content for the deck surface conditions mentioned above. Except for the decks having an asphaltic concrete resurfacing, none of the decks had chloride ion concentrations above 2 pounds at the level of the reinforcing steel.

Study of the chloride ion penetration after the membranes had been in place for four and seven years necessitated the destruction of the membrane system at each location where the

Table 8 - Distribution of Average Chloride Ion Content Within and Between Bridges Before Reconstruction

| Bridge | | N(1) | Average Chloride Ion Content (lbs./c.y.) Lift A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|---|---|
| L-701R | NB | 16 | 10.76 | 6.12 | 3.16 | 1.41 | 0.62 | 0.27 | 0.20 | 0.20 |
| L-702R | SB | 24 | 7.81 | 4.90 | 2.75 | 1.17 | 0.49 | 0.25 | 0.35 | 0.23 |
| L-501R | SB | 16 | 5.00 | 1.74 | 0.49 | 0.28 | 0.21 | 0.20 | 0.20 | 0.20 |
| L-642R | | 12 | 6.52 | 5.32 | 4.39 | 2.76 | 2.28 | 1.93 | 1.65 | 1.16 |
| L-641R | | 12 | 5.67 | 5.04 | 4.12 | 3.09 | 2.36 | 1.96 | 1.99 | 1.70 |
| L-759R | SB | 20 | 5.89 | 2.46 | 0.63 | 0.25 | 0.20 | 0.20 | 0.20 | 0.20 |
| L-501R | NB | 16 | 3.40 | 1.66 | 0.70 | 0.26 | 0.21 | 0.20 | 0.20 | 0.20 |
| L-759R | NB | 16 | 6.17 | 2.89 | 1.00 | 0.48 | 0.28 | 0.20 | 0.20 | 0.20 |
| A-1613R | NB | 12 | 8.62 | 5.45 | 3.10 | 1.39 | 0.75 | 0.36 | 0.23 | 0.21 |
| L-719R | NB | 24 | 6.58 | 3.32 | 1.16 | 0.47 | 0.32 | 0.28 | 0.24 | 0.23 |
| L-720R | | 30 | 5.91 | 3.50 | 1.16 | 0.46 | 0.27 | 0.22 | 0.20 | 0.20 |
| L-721R | | 24 | 6.71 | 3.90 | 1.61 | 0.59 | 0.26 | 0.20 | 0.20 | 0.20 |
| L-563R | NB | 12 | 6.03 | 2.39 | 0.44 | 0.27 | 0.20 | 0.20 | 0.20 | 0.20 |
| L-571R | NB | 24 | 5.85 | 3.13 | 1.64 | 0.82 | 0.65 | 0.48 | 0.36 | 0.30 |
| Average of All Bridges | | 258 | 6.49 | 3.70 | 1.88 | 0.98 | 0.65 | 0.50 | 0.46 | 0.39 |

(1) N represents the number of test sites. Lifts from D through H actually had lesser number of samples because of hitting reinforcing steel or having to terminate drilling because of weather or traffic conditions.

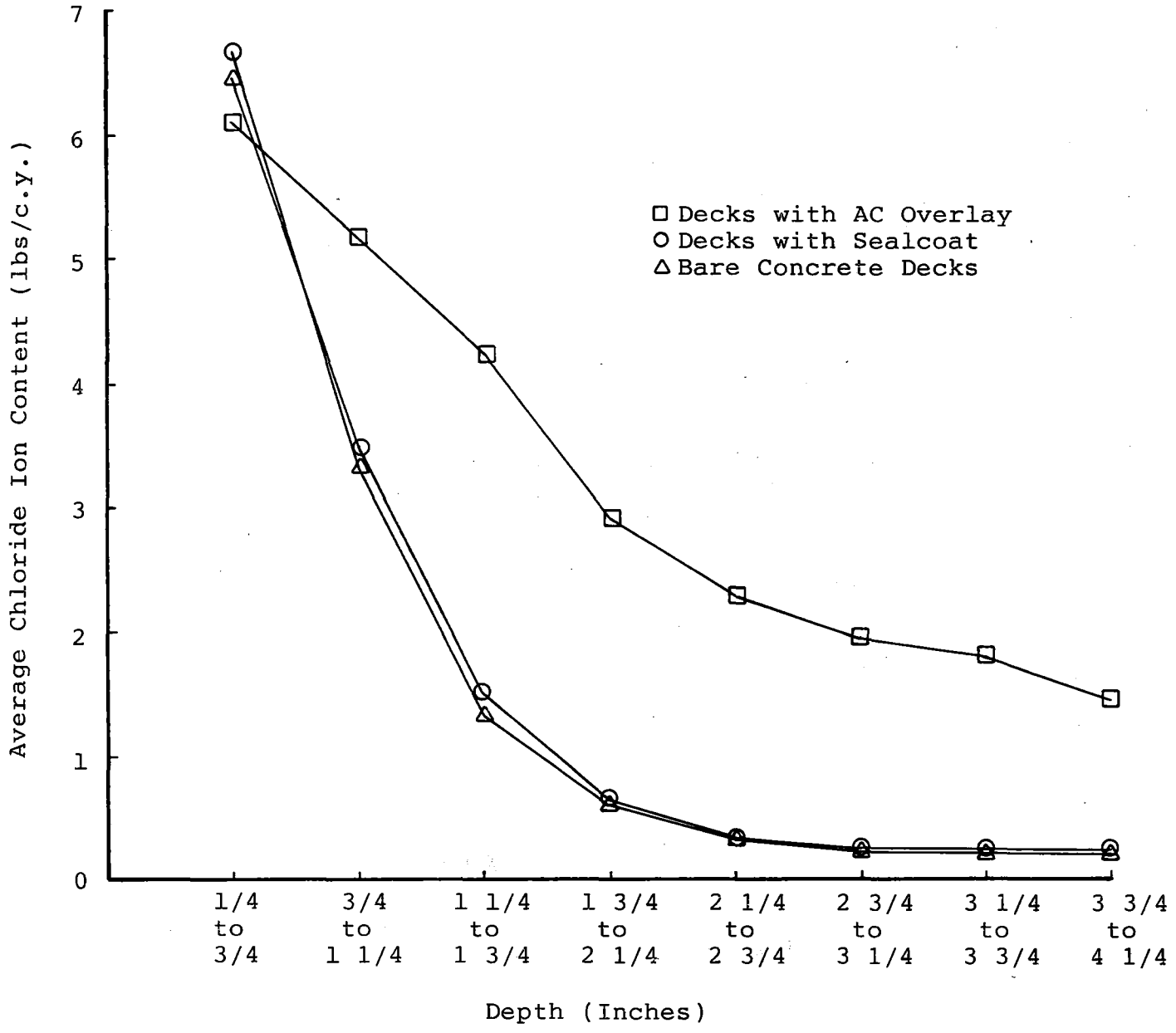



Figure 6 - Average Chloride Ion Content of Concrete Decks with Asphaltic Concrete Overlay, Sealcoat, or No Protection.

chloride ion sample was taken. Therefore, only one-half of the initial sample locations were selected to represent each deck in this analysis. Samples removed in 1981 and 1984 were located as close as possible to the original samples by using the same survey grid layout.

Average chloride ion concentrations for the locations which were chosen for resampling in 1981 and 1984 are shown in Table 9. Graphic illustration of the trends are shown in the relative chloride ion concentrations curves in Figure 7, parts a through g.

Each structure is represented with four chloride ion concentration curves. The first curve is the average of all chloride ion samples taken in 1977 from Table 8. The second curve is the average of the 1977 chloride ion samples selected for retest as shown in Table 9. The third and fourth curves are the average of the resampling in 1981 and 1984 respectively, taken from results also shown in Table 9.

Generally, from parts d through g of Figure 7, the results of this evaluation indicate that for the liquid and sheet waterproofing membrane protection systems, chloride ion concentrations have either remained stable or have been slightly redistributed throughout the depth tested. The exception being the Protecto Wrap membrane which shows a slight overall increase in chloride ion concentration in both bridges. Redistribution has generally resulted in a slight lowering of chloride ion concentration in the top inch or so of the concrete deck and a slight increase in the lower increments.

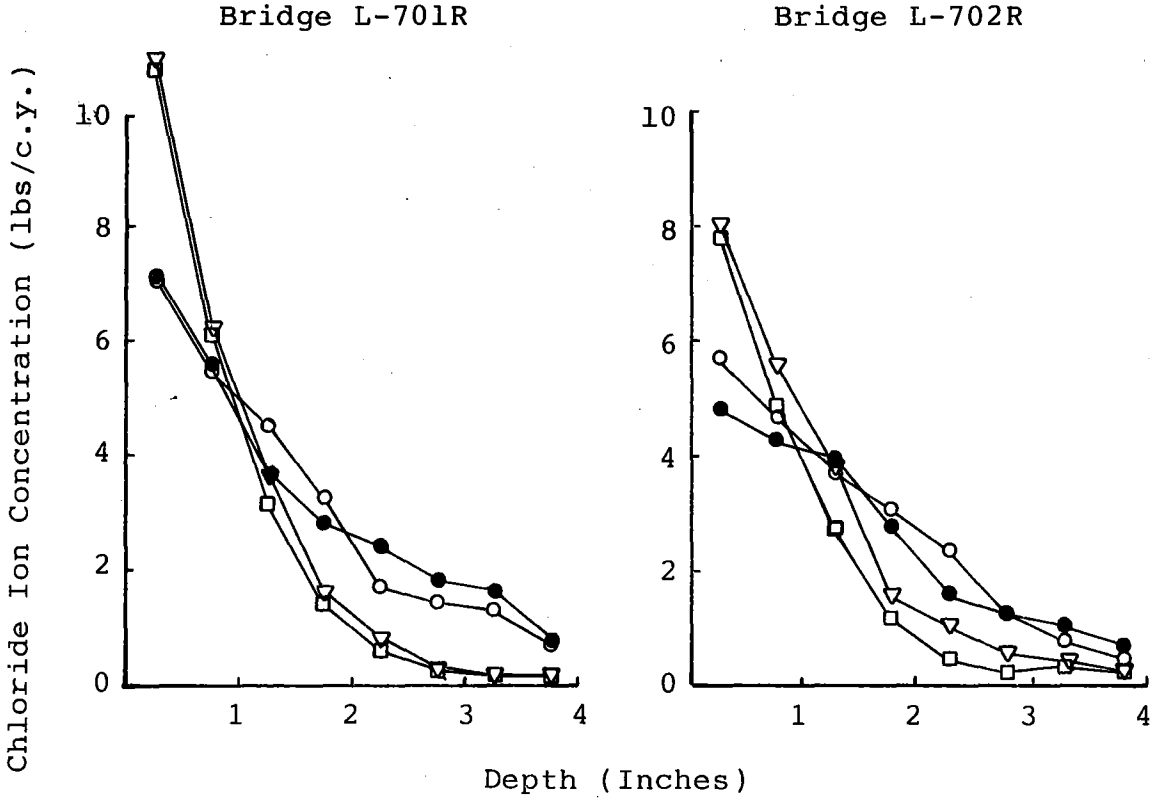
Table 9 - Analysis of Change in Chloride Ion Concentration Resulting After Placing Protection System

| Year | Bridge | | N(1) | Average Chloride Ion Content (lbs./c.y.) Lift A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Cathodic Protection** | | | | | | | | | | | |
| 1977 | L-701R | NB | 8 | 10.96 | 6.24 | 3.64 | 1.66 | 0.82 | 0.32 | 0.20 | 0.20 |
| 1981 | | | 8 | 7.13 | 5.46 | 4.52 | 3.29 | 1.73 | 1.47 | 1.32 | 0.71 |
| 1984 | | | 8 | 7.18 | 5.60 | 3.67 | 2.82 | 2.42 | 1.80 | 1.65 | 0.81 |
| 1977 | L-702R | SB | 12 | 8.06 | 5.60 | 3.78 | 1.58 | 1.01 | 0.59 | 0.49 | 0.30 |
| 1981 | | | 12 | 5.73 | 4.76 | 3.74 | 3.07 | 2.37 | 1.29 | 0.80 | 0.43 |
| 1984 | | | 12 | 4.81 | 4.29 | 3.98 | 2.79 | 1.60 | 1.29 | 1.04 | 0.73 |
| **Low Slump Concrete** | | | | | | | | | | | |
| 1977 | L-501R | SB | 8 | (1) | -- | -- | 4.49 | 1.83 | 0.42 | 0.32 | 0.28 |
| 1981 | | | 8 | 3.06 | 0.73 | 0.35 | 0.85 | 0.84 | 0.57 | 0.42 | 0.31 |
| 1984 | | | 8 | 4.46 | 1.35 | 0.67 | 0.96 | 0.64 | 0.48 | 0.36 | 0.28 |
| 1977 | L-642R | | 8 | (1) | -- | -- | 6.99 | 5.69 | 4.64 | 2.30 | 1.87 |
| 1981 | | | 8 | 3.84 | 0.63 | 0.21 | 0.22 | 0.66 | 1.25 | 1.30 | 1.10 |
| 1984 | | | 8 | 4.59 | 0.62 | 0.18 | 0.22 | 0.66 | 1.12 | 1.06 | 0.80 |
| **Latex Concrete** | | | | | | | | | | | |
| 1977 | L-641R | | 8 | (1) | -- | -- | 5.87 | 4.88 | 4.08 | 3.04 | 2.65 |
| 1981 | | | 8 | 5.41 | 1.01 | 0.24 | 0.64 | 1.22 | 1.17 | 1.20 | 0.73 |
| 1984 | | | 8 | 6.32 | 1.56 | 0.79 | 0.94 | 1.12 | 0.88 | 0.83 | 0.61 |
| 1977 | L-759R | SB | 10 | (1) | -- | -- | 5.90 | 2.83 | 0.80 | 0.29 | 0.20 |
| 1981 | | | 10 | 5.55 | 1.24 | 1.53 | 2.32 | 2.18 | 1.10 | 0.55 | 0.23 |
| 1984 | | | 7 | 7.48 | 3.18 | 2.12 | 2.46 | 1.82 | 1.05 | 0.58 | 0.28 |
| **Protecto Wrap** | | | | | | | | | | | |
| 1977 | L-501R | NB | 8 | 3.75 | 1.67 | 0.88 | 0.24 | 0.20 | 0.20 | 0.20 | 0.20 |
| 1981 | | | 8 | 4.44 | 2.37 | 1.01 | 0.49 | 0.33 | 0.37 | 0.23 | 0.25 |
| 1984 | | | 8 | 5.27 | 2.91 | 1.42 | 0.81 | 0.39 | 0.26 | 0.26 | 0.24 |
| 1977 | L-759R | NB | 9 | 6.36 | 2.81 | 0.83 | 0.33 | 0.22 | 0.20 | 0.20 | 0.20 |
| 1981 | | | 9 | 5.94 | 3.82 | 1.49 | 0.53 | 0.39 | 0.22 | 0.21 | 0.21 |
| 1984 | | | 9 | 6.92 | 5.45 | 3.06 | 1.05 | 0.52 | 0.14 | 0.14 | 0.14 |
| **Heavy Duty Bituthene** | | | | | | | | | | | |
| 1977 | A-1613R | NB | 8 | 8.37 | 5.09 | 2.62 | 1.09 | 0.59 | 0.31 | 0.23 | 0.22 |
| 1981 | | | 8 | 5.99 | 4.56 | 3.38 | 2.19 | 1.63 | 0.93 | 0.55 | 0.44 |
| 1984 | | | 8 | 5.80 | 4.85 | 4.14 | 2.73 | 1.75 | 1.77 | 1.34 | 1.61 |
| 1977 | L-719R | NB | 12 | 6.43 | 3.28 | 1.07 | 0.35 | 0.23 | 0.21 | 0.21 | 0.21 |
| 1981 | | | 12 | 5.87 | 4.01 | 1.69 | 0.62 | 0.34 | 0.24 | 0.22 | 0.20 |
| 1984 | | | 12 | 6.23 | 4.74 | 2.05 | 0.66 | 0.25 | 0.19 | 0.22 | 0.18 |
| **Gacoflex** | | | | | | | | | | | |
| 1977 | L-720R | | 12 | 5.70 | 3.28 | 0.97 | 0.38 | 0.26 | 0.22 | 0.20 | 0.20 |
| 1981 | | | 12 | 5.38 | 3.38 | 1.24 | 0.61 | 0.61 | 0.32 | 0.24 | 0.21 |
| 1984 | | | 10 | 4.76 | 3.97 | 1.91 | 0.69 | 0.32 | 0.22 | 0.22 | 0.20 |
| 1977 | L-721R | | 12 | 6.84 | 3.80 | 1.64 | 0.61 | 0.26 | 0.20 | 0.20 | 0.20 |
| 1981 | | | 12 | 5.60 | 3.64 | 1.56 | 0.67 | 0.36 | 0.26 | 0.23 | 0.21 |
| 1984 | | | 12 | 5.20 | 4.31 | 1.95 | 0.75 | 0.32 | 0.21 | 0.20 | 0.18 |
| **Superseal** | | | | | | | | | | | |
| 1977 | L-563R | NB | 6 | 5.96 | 2.35 | 0.31 | 0.32 | 0.20 | 0.20 | 0.20 | 0.20 |
| 1981 | | | 6 | 4.70 | 2.65 | 1.18 | 0.82 | 0.67 | 0.49 | 0.40 | 0.53 |
| 1984 | | | 6 | 5.04 | 3.12 | 1.92 | 0.81 | 0.44 | 0.31 | 0.19 | 0.19 |
| 1977 | L-571R | NB | 12 | 5.96 | 2.90 | 1.26 | 0.56 | 0.64 | 0.54 | 0.38 | 0.26 |
| 1981 | | | 12 | 2.68 | 2.11 | 1.56 | 0.93 | 0.80 | 0.75 | 0.59 | 0.44 |
| 1984 | | | 12 | 3.33 | 2.27 | 1.38 | 1.18 | 1.08 | 0.79 | 0.69 | 0.47 |

(1) Data missing in these lifts because original surface of deck is now at Level E.

Figure 7 - Chloride Ion Concentration Before and After Protection Systems were Installed.

a. Cathodic Protection System.




Legend (Typical for all parts of Figure 7)

- □ 1977 Full Survey
- ▽ 1977 Partial Survey
- ○ 1981 Partial Survey
- ● 1984 Partial Survey

Figure 7 - Continued

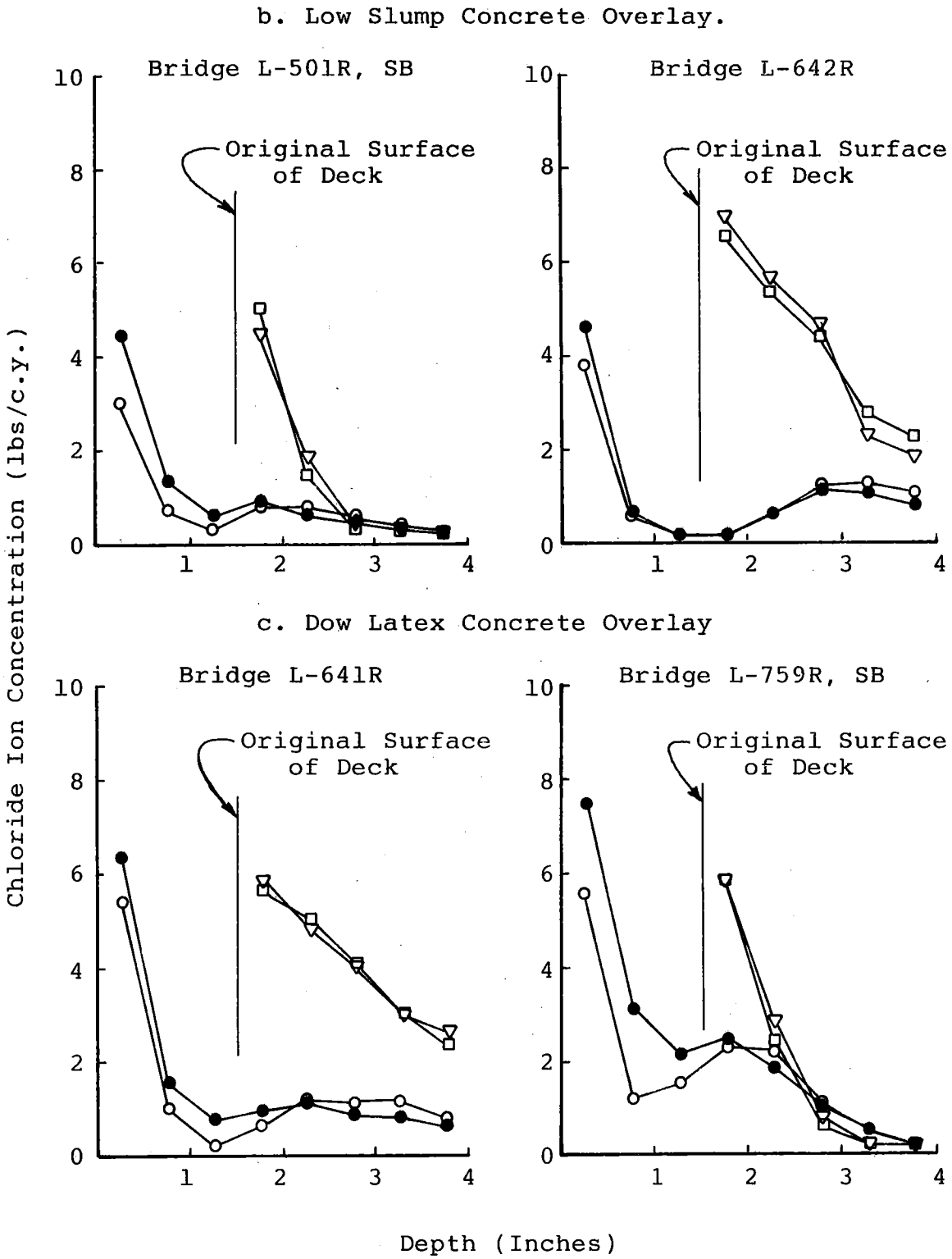


Figure 7 - Continued

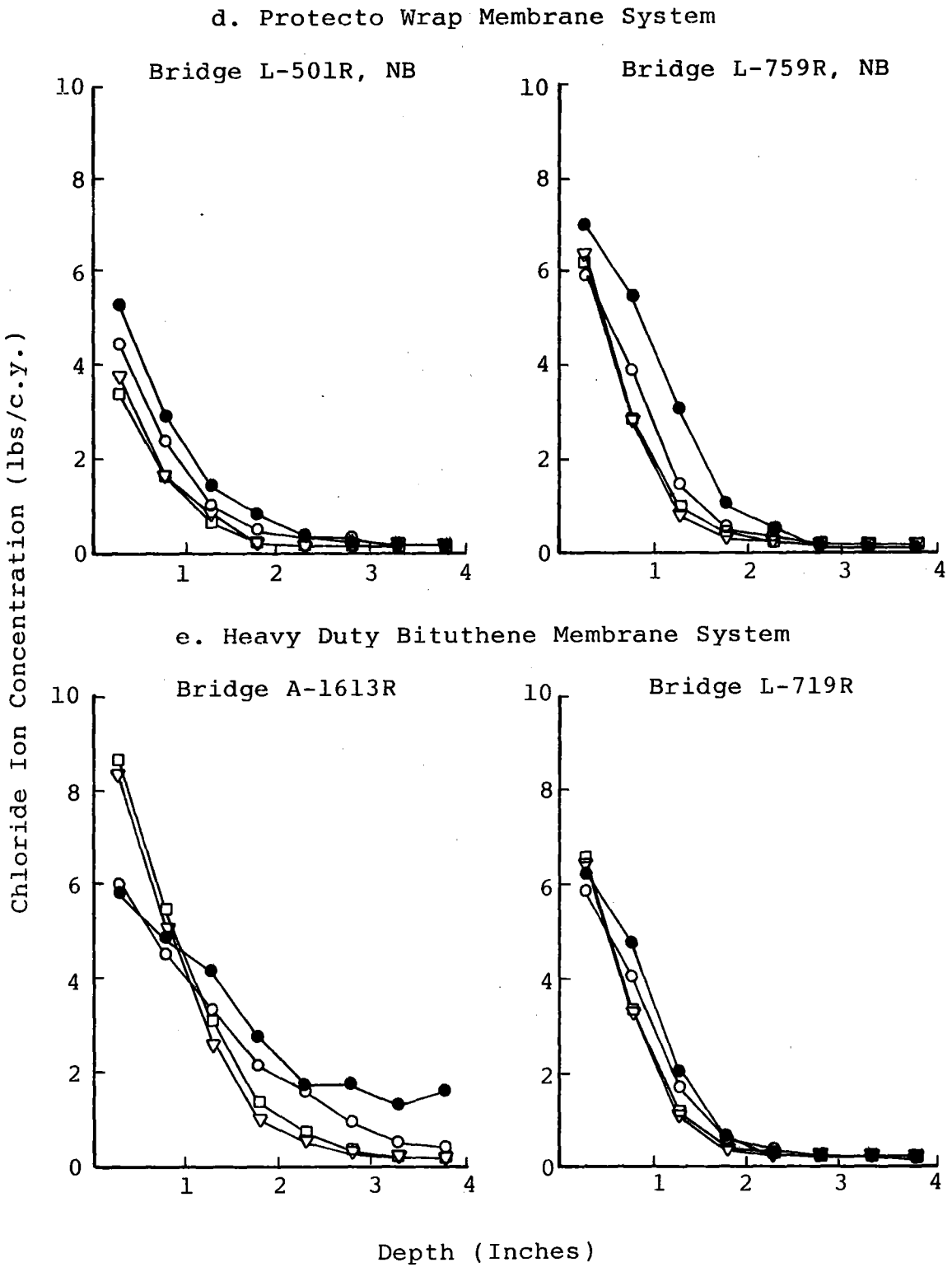
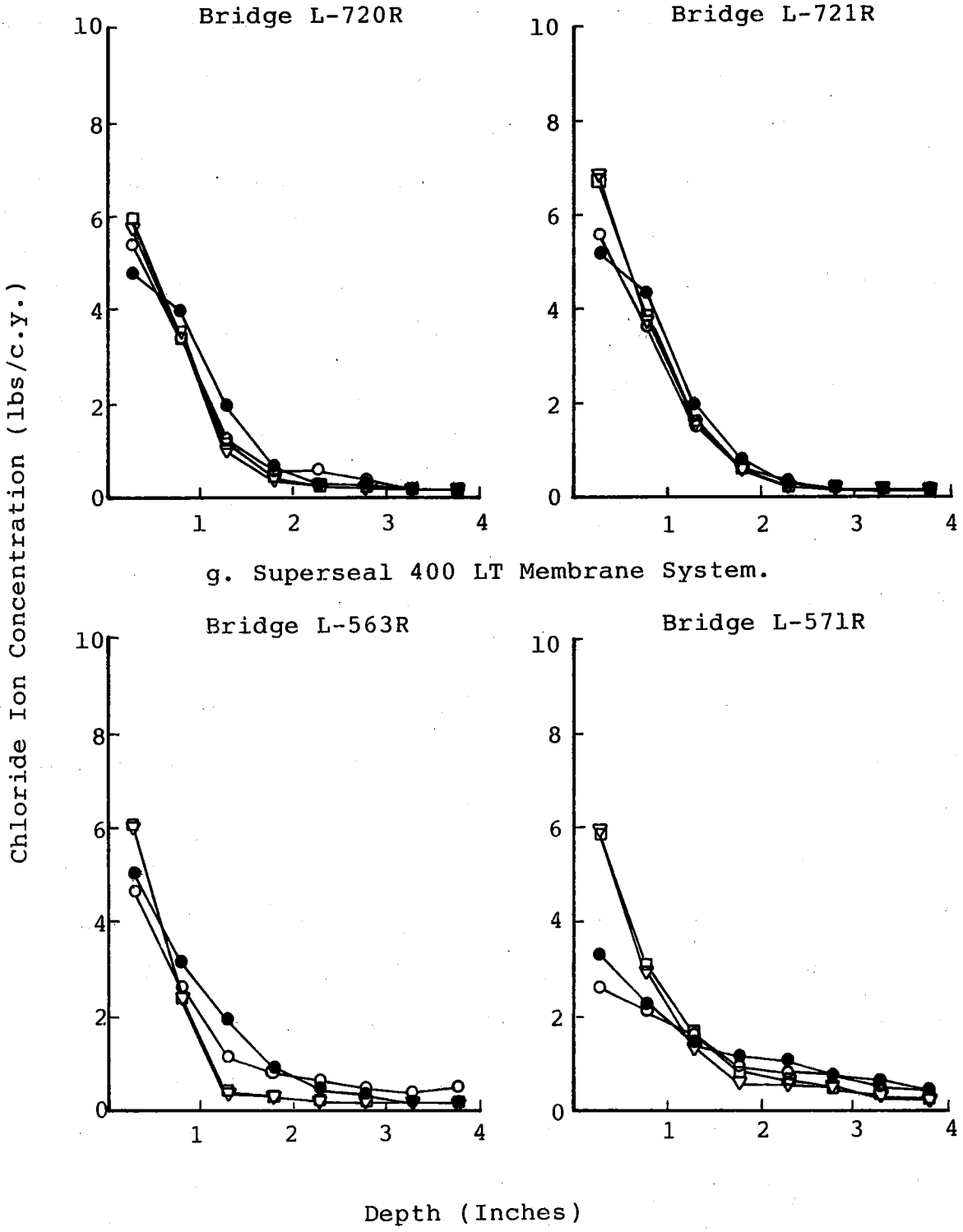


Figure 7 - Continued

f. Gacoflex Membrane System.



Significance of these results is not the concentration levels per se but the fact that the membranes have generally protected the concrete from additional intrusion of chloride ions. These membranes also have apparently prevented moisture absorption by the concrete thus reducing the presence of a mechanism available to the chloride ions to migrate. Essentially, for the liquid and sheet type membrane protection systems, the goal of stabilizing the rate of deterioration based on chloride ion concentration and migration has been achieved.

Observation from parts b and c of Figure 7 indicate that neither of the concrete overlay systems are immune to intrusion of the chloride ions. Results of the 1981 and 1984 surveys indicate high chloride ion concentration in the top 3/4 inch of the concrete overlay which is increasing with time. Two bridges, L-641R and L-642R, were extensively patched during the reconstruction phase of this contract. Sampling in 1981 and 1984 could not be adjusted to completely eliminate these patched areas, therefore, as a result, the lower portion of these data curves reflect a significantly lower average chloride ion content. However, by the significantly lower concentration of chloride ion at the previous original surface of the concrete deck of the other two bridges, the chloride ions have apparently redistributed themselves within the concrete mass. In fact, some chloride ions have apparently moved upwards into the lower portion of the concrete overlays. This also means that moisture is penetrating the concrete overlay to allow for movement of the chloride ions. Such moisture and chloride ion intrusion could

eventually, after working through the overlay system, continue to concentrate in the original concrete deck thereby regenerating the initial problem of corrosion of the reinforcing steel. It appears that the concrete overlay systems have temporarily been successful in stabilizing the rate of deterioration based on chloride ion concentration and migration. Future studies will be conducted to determine how long this trend will persist.

The two cathodic protection bridges were designated as controls for the chloride ion penetration analysis since no membrane is involved in these systems. It was anticipated that with the asphaltic concrete and porous coke breeze-asphaltic mixture on these decks, chloride ions would have the maximum opportunity for penetration. Part a of Figure 7 does not indicate this theory to be absolutely true in all aspects. The top 1 to 1 1/4 inches of the concrete portion of these bridge decks indicate a net loss of chloride ion content since placement of the overlay, whereas, the remainder of the levels show significant increases. The chloride ions appear to have been redistributed from the top portion of the concrete deck. The effect of the cathodic protection systems may have slowed further chloride intrusion because of the attraction of chloride ions to the anode, however, it did not prevent moisture intrusion and apparent redistribution of available chlorides within the concrete decks.

Chloride ion concentration of the original concrete decks since application of the protection systems has generally

followed the assumed behavior patterns. Liquid and sheet type membranes have effectively stabilized the chloride ion concentrations at the levels present during reconstruction and placement of the protection system. The latex modified and the low slump concrete overlay systems have shown chloride ion penetration of the overlay system, however, the rate of penetration may have been slowed. Since two of these bridge decks were extensively repaired prior to placing the concrete overlays, no specific trend is evident with regard to the chloride ion movement in the original concrete. Cathodic protection has not presented a clear indication of the chloride ion condition in the concrete deck. Apparently the chloride ions have redistributed themselves toward the lower depths tested, however, it is not clear if resupply of chloride ions in the top portion of the concrete is occurring.

## ELECTRICAL POTENTIAL SCANS

Use of half-cell voltage potential scans on the surface of an original concrete bridge deck have been widely accepted to determine the level of corrosion activity on the surface of the reinforcing steel. Potential scans made on surfaces other than the surface of the original concrete deck are subject to the possibility of some error. Taking potential measurements through different types of overlay systems could cause error in the assumed location of the potential being measured. Water standing between the layers of products on built up type membranes could cause different lines of least resistance for

the potential readings other than straight down. Variation in density of the overlay and the presence of patching in the immediate area may also cause some variation in the path of least resistance.

In an effort to test the same relative location with the half cell probe in each successive survey, a permanent location was established on the bridge from which all surveys were laid out. A grid of 3 by 4 feet (longitudinal by transverse respectively with the centerline of the bridge) was used to locate the points to take potential measurements.

Table 5 in the Annual Field Observation and Test Data Section of this report gives the potential scan summaries for each individual bridge protection system for each successive test date. Each value in the potential scan is the percentage of potential readings within each specified category of voltage. Changes in environment of the reinforcing steel with time are evident by the changing values noted in the table. A single numerical value to represent the data collected for each respective survey was derived by using a progressive series of reduction factors whereby values would fall within a range of zero to 100. The actual formula which was used is:

$$V_y = A + 0.8B + (0.8)^2C + (0.8)^3D + \ldots + (0.8)^9J$$

Where: V = potential scan summary factor

y = Year of survey

A through J represent the electrical potential percentage values found in Table 5 Sub-part a of each Part A through N, with J representing 0 to -0.10 volt range with A representing the >-0.91 volt range.

Actual range of values for V is 100 if all potential measurements were at the >-0.91 volt level and 13.4 if all potential measurements were at the 0 to -0.10 volt level. A potential value >-0.91 volts may seem high and unrealistic, however, on many occasions values of highly active corrosion areas have been found to be in the -0.8 volt range. The formula used in determining this potential scan summary factor is more sensitive to the higher voltage ranges, therefore, adjustment of this factor up or down indicates that either more or less of the potential readings fell in the higher voltage ranges.

Table 10 represents the potential scan factor (V) values determined by the above method. These values reflect the relative condition of each bridge prior to repairs being made in conjunction with this contract, after repairs were made, and immediately after the protection system was in place as well as successive annual surveys. These results are produced in graphic form in the bar graphs shown in Figure 8.

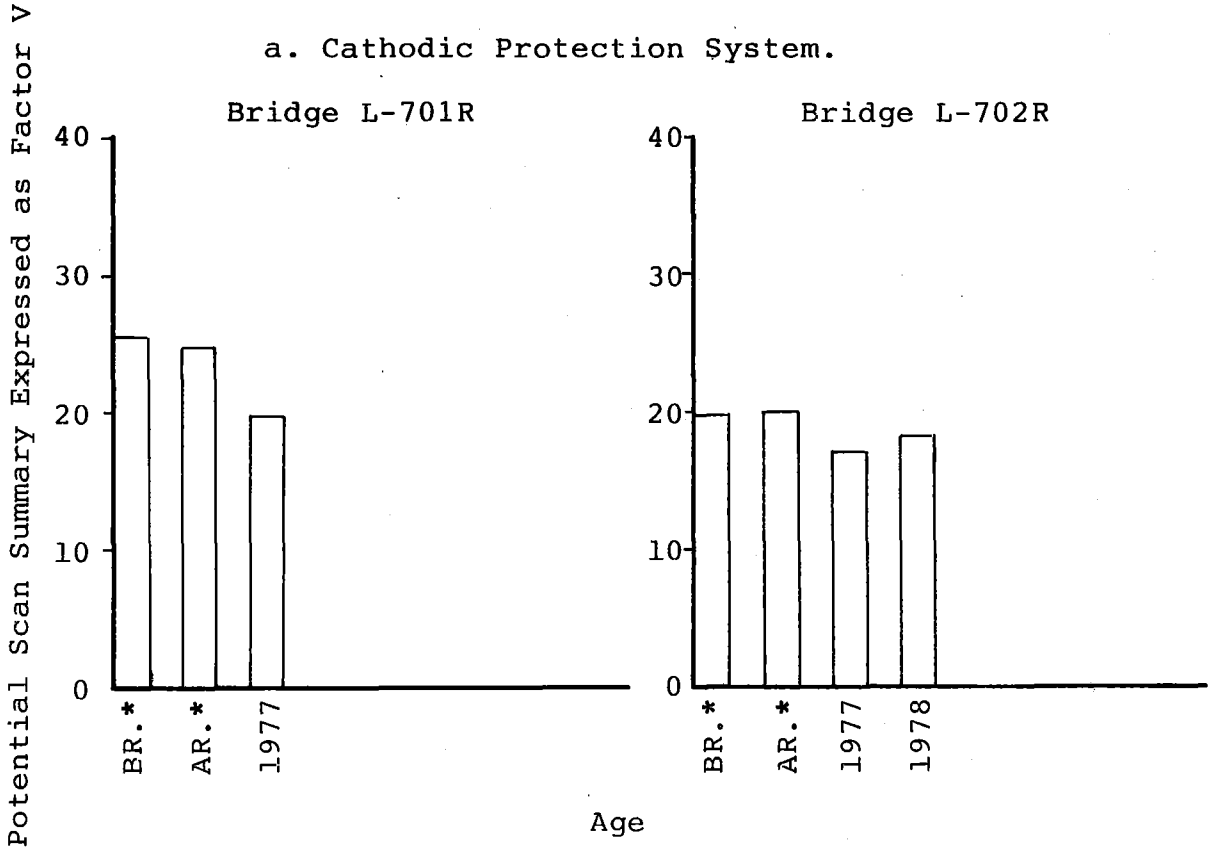
Several of the graphs in Figure 8 show that repairs and patching on these bridges reduced the electrical potential levels. This would be realistic, especially for those bridges having extensive patching operations where the chloride ion laden concrete was removed and the reinforcing steel cleaned. Values shown for 1977 represent the potential level with the protective system in place. Tests in 1977 were made the day following the final placement or curing of the protective system and before traffic had been allowed to use the new surface. This value was considered to be the zero point for evaluation of

Table 10 - Electrical Potential Scan Factor (V)

| Bridge | Before Repair | After Repair | Survey 1977(1) | 1978 | 1979 | 1980 | 1981 | 1984 |
|---|---|---|---|---|---|---|---|---|
| **Cathodic Protection** | | | | | | | | |
| L-701R | 25.47 | 24.60 | 19.54 | (2) | (2) | (2) | (2) | (2) |
| L-702R | 19.80 | 19.99 | 17.14 | 18.23 | (2) | (2) | (2) | (2) |
| **Low Slump Concrete Overlay** | | | | | | | | |
| L-501R SB | 17.36 | 17.08 | 18.62 | 19.83 | 20.00 | 19.65(3) | 17.78 | 18.41 |
| L-642R | 26.52(4) | 24.94 | 24.12 | 23.70 | 22.77 | 20.96(3) | 19.94 | 17.02 |
| **Latex Concrete Overlay** | | | | | | | | |
| L-641R | 28.93(4) | 24.36 | 23.03 | 22.99 | 21.69 | 20.76(3) | 20.25 | 20.40 |
| L-759R SB | 19.71 | 18.09 | 17.86 | 21.88 | 20.56 | 18.86(3) | 18.86 | 18.16 |
| **Protecto Wrap** | | | | | | | | |
| L-501R NB | 17.48 | 16.86 | 13.40(3) | 20.78 | 19.02 | 22.18(3) | 19.74 | 20.03 |
| L-759R | 19.48 | 19.62 | 13.40(3) | 18.08 | 20.72 | 19.80(3) | 18.98 | 17.53 |
| **Heavy Duty Bituthene** | | | | | | | | |
| A-1613R | 20.26 | 19.89 | 14.53(3) | 19.62 | 18.70 | 19.04(3) | 17.38 | 18.79 |
| L-719R | 17.45 | 17.54 | 18.17(3) | 18.28 | 17.48 | 16.34(3) | 15.46 | 16.13 |
| **Gacoflex** | | | | | | | | |
| L-720R | 17.52 | 17.52 | 15.62(3) | 18.50 | 17.97 | 17.28(3) | 15.86 | 16.43 |
| L-721R | 18.51 | 18.58 | 14.04(3) | 17.87 | 17.54 | 15.49(3) | 16.10 | 17.02 |
| **Superseal 4000LT** | | | | | | | | |
| L-563R | 16.40 | 16.92 | 14.35(3) | 19.73 | 17.02 | 16.49(3) | 14.68 | 16.31 |
| L-571R | 28.14 | 24.49 | 14.82(3) | 22.48 | 21.26 | 19.53(3) | 20.18 | 22.48 |

(1) Survey immediately after placing protective system.
(2) No surveys were made with the cathodic protection system off.
(3) Only one stage of construction surveyed, partial survey.
(4) Expanded grid survey made on asphalt overlay.

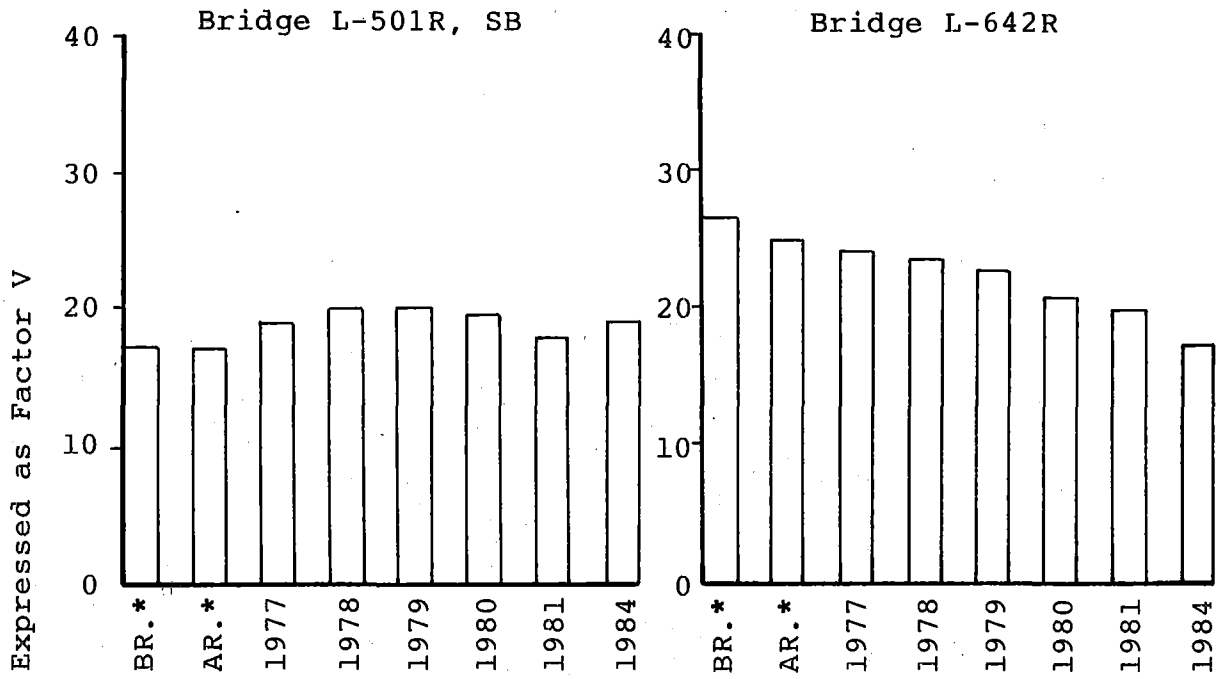
Figure 8 - Potential Scan Surveys Expressed as a Single Numerical Potential Scan Summary Factor.




* BR. = Before Repair
AR. = After Repair

Figure 8 - Continued

b. Low Slump Concrete Overlay.

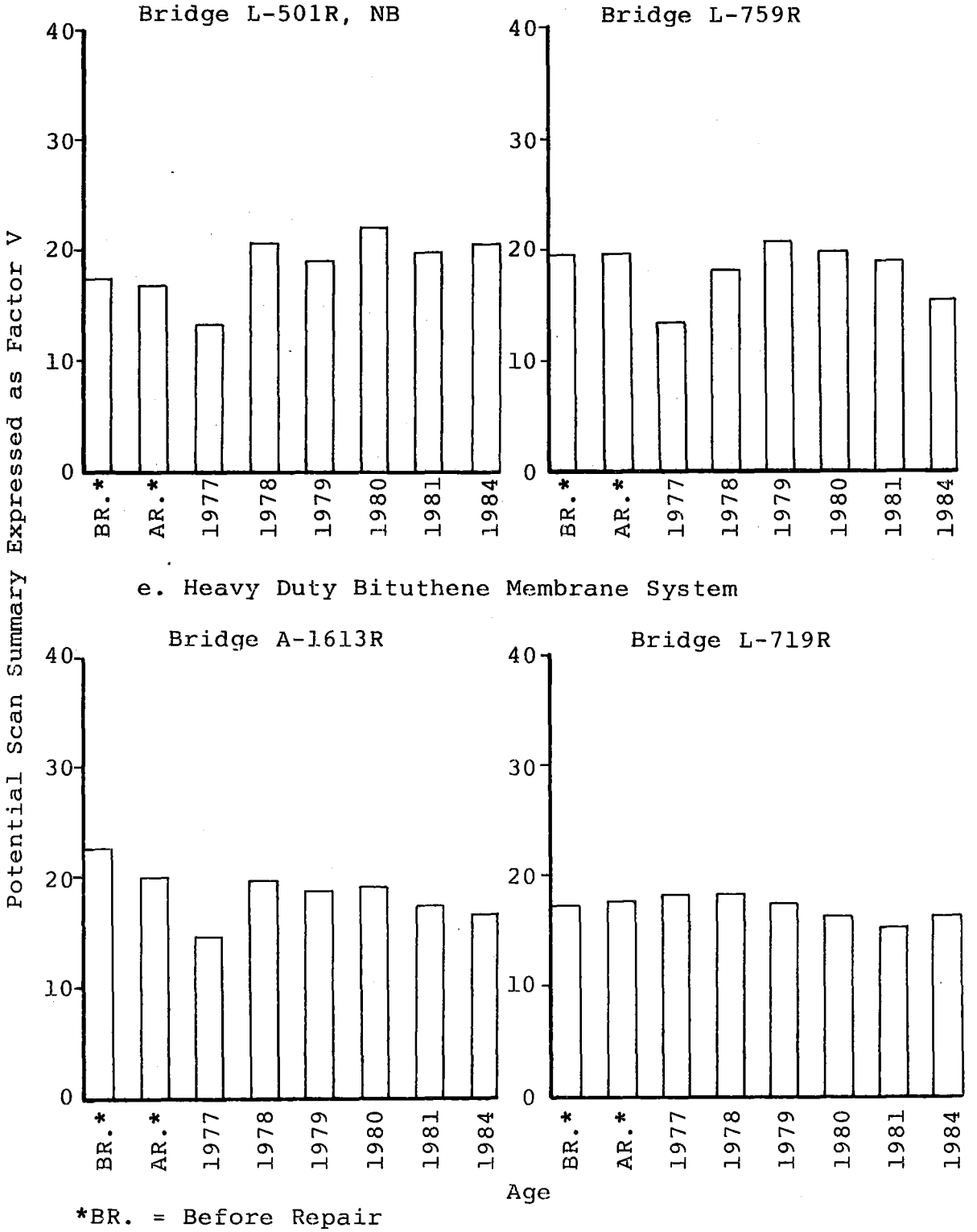



c. Dow Latex Concrete Overlay.

* BR. = Before Repair
AR. = After Repair

Figure 8 - Continued

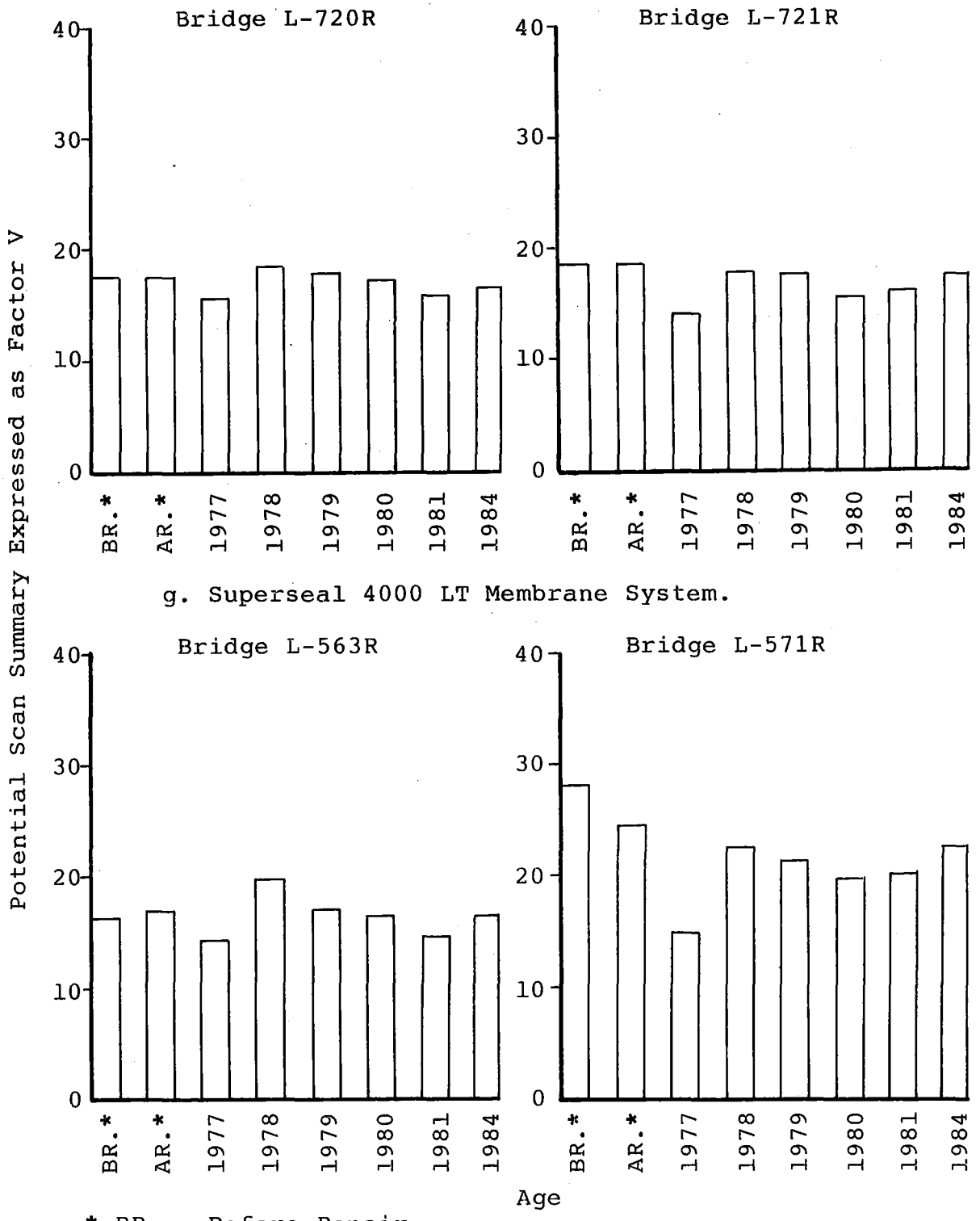
d. Protecto Wrap Membrane System.




*BR. = Before Repair
AR. = After Repair

Figure 8 - Continued

f. Gacoflex Membrane System.




* BR. = Before Repair
AR. = After Repair

the performance of the protection system in terms of voltage potential scans.

Parts d through g, Figure 8, show that except for Bridge L-719R, a significant drop in the potential factor was evident immediately after placement of the liquid and sheet type membrane systems. Bridge L-719R showed an increase in potential factor immediately after placement of the Heavy Duty Bituthene membrane system and a declining factor each year after 1978 until 1984. The other bridges with membrane type protection systems gained in potential factor during the first year or two of service nearly equaling or exceeding the potential value after repair of the bridges. Thereafter, most of the bridges with liquid or sheet type membranes have shown a general trend, with some fluctuations, of decreasing potential factor from the 1978 value. However, none of the bridges have returned to the value observed in 1977 before rehabilitation under this study. Two bridges, L-720R and L-563R, have almost achieved the original zero (1977 after placing membrane) value.

Generally, the voltage potential levels in the concrete decks with the liquid and sheet membrane protection systems have stabilized around the level observed after repair immediately prior to placing the system. This situation could only be brought about as a result of the membrane system affording the concrete protection from further intrusion of chloride ions and moisture. Without mobility, the chloride ions will not be free to migrate to the immediate area around the reinforcing steel to act as a catalyst in the corrosion reactions. These membrane

systems appear to have effectively prevented further deterioration by stabilizing the corrosion potential within the concrete deck with regards to the measured electrical potential levels.

Parts b and c, Figure 8, show potential factors for the two concrete overlay protection systems. Except for Bridge L-501R SB, the 1977 potential factors were below those values observed on the original and repaired deck surveys. During the first year, potential factors were either stable with the 1977 values or slightly higher. Thereafter, all four bridges show a declining trend for potential factors.

Two bridges, L-641R and L-642R, which are identical twin structures, were originally high in potential factors. Both of these bridges had a history of numerous repairs to the concrete deck and had an asphaltic concrete overlay in place prior to reconstruction. Each bridge had a different type of concrete overlay system placed on it for purposes of evaluating the performance of concrete decks. From the observed similarity of the potential factors on these two bridges during the period of this study there appears very little difference in performance of the two types of overlay systems. Performance of the concrete overlay protection systems appear to be satisfactory in terms of stabilizing or reducing the electrical potential levels.

Part a, Figure 8, shows potential factors for the two bridges which were selected for the application of cathodic protection systems. These bridges were also beneficiated in

terms of reduction of potential factors by application of the coke breeze and asphaltic concrete overlay. Since activation of cathodic protection systems, voltage potential measurements have not been made with the system in the completely discharged condition except for L-702R in 1978. Based on observation of other bridges in this study, slight rise in the potential factors appears normal during the first year of operation as the protection system becomes electrically integral with the bridge decks.

Electrical potential measurements made on these various protection systems indicate that generally the trends are for the potential levels to be decreasing. Except for two bridges, all the protection systems showed equal or lower voltage potential levels in 1984 than on the original concrete surface at the beginning of this study in 1977. Bridge L-501R SB, is very near the 1977 level and showing some fluctuation with no specific trend developed. Therefore, at this point in time, based on the voltage potential readings, there is little difference between product performance.

## RESISTANCE SCAN

Resistance scans through membrane systems are normally used to determine the "waterproofness" of the membrane. Many articles have been written which point out deficiencies in the application of results from the resistance test to the actual quality of the product. However, this test remains the predominantly accepted non-destructive measure of a membrane's

resistance to moisture penetration. In the same framework as explained for the potential scans, the resistance scans are subject to error because of the line of least resistance being variable as a result of water between the various layers of the membrane systems.

To insure repeatability of test locations, the same type of grid system as described for the voltage potential scans was used. However, the spacing of the test locations was a 6 by 8 foot staggered grid. Terminology used with these grid systems labeled the longitudinal spacings as "Stations" and transverse spacings as "Lines". Therefore, a staggered grid example would be to test the even numbered lines on Stations 1, 5, 9, and every 4th station thereafter and to test the odd numbered lines on Stations 3, 7, 11, and every 4th station thereafter.

Using the above technique, resistance tests were taken and results were reduced to a resistance factor shown in Table 11. Testing on the cathodic protection bridges was eliminated from this test procedure because "waterproofing" was not a function of that protection system.

Resistance factors shown in Table 11 were calculated in much the same manner as the potential factor. Equation for the calculation of the resistance factor was:

$$R_y = A + 0.8B + (0.8)^2C + \ldots + (0.8)^6G$$

Where: R = Resistance factor

y = Year of survey

A through G represent the percentage values from Table 5, Sub-part b of each Part A through N, with G representing the 0-500 ohm range and A representing the >1M range.

Table 11 - Resistance Scan Factor (R)

| Bridge | After Repair | Survey 1977(1) | 1978 | 1979 | 1980 | 1981 | 1984 |
|---|---|---|---|---|---|---|---|
| **Cathodic Protection** | | | | | | | |
| L-701R | No Tests | | | | | | |
| L-702R | No Tests | | | | | | |
| **Low Slump Concrete Overlay** | | | | | | | |
| L-501R SB | 31.93 | 26.20 | 31.92 | 34.64(2) | 80.00(2) | 40.64(2) | 32.59(2) |
| L-642R | 28.73 | 26.20 | 26.20 | 32.80(2) | 32.80(2) | 47.68(2) | 45.42(2) |
| **Latex Concrete Overlay** | | | | | | | |
| L-641R | 30.00 | 26.20 | 27.15 | 31.15(2) | 36.08(2) | 52.08(2) | 40.48(2) |
| L-759R SB | 27.47 | 26.20 | 26.20 | 31.98(2) | 26.20(2) | 32.80(2) | 39.98(2) |
| **Protecto Wrap** | | | | | | | |
| L-501R NB | 37.96 | 97.32 | 66.53 | 66.26 | 54.14(3) | 59.82 | 59.98 |
| L-759R SB | 33.11 | 97.84 | 78.56 | 78.16 | 70.80(3) | 80.73 | 70.71 |
| **Heavy Duty Bituthene** | | | | | | | |
| A-1613R | 32.72 | 99.68 | 55.66 | 58.02 | 54.57(3) | 60.60 | 64.01 |
| L-719R | 31.23 | 98.62 | 53.86 | 56.17 | 58.96(3) | 59.96 | 63.84 |
| **Gacoflex** | | | | | | | |
| L-720R | 31.35 | 96.75 | 52.06 | 54.29 | 49.10(3) | 57.39 | 58.00 |
| L-721R | 29.82 | 99.48 | 48.70 | 55.93 | 51.14(3) | 57.46 | 59.94 |
| **Superseal 4000LT** | | | | | | | |
| L-563R | 37.48 | 96.43 | 64.06 | 64.51 | 57.44(3) | 58.20 | 59.79 |
| L-571R | 29.19 | 93.10 | 61.82 | 58.56 | 60.43(3) | 53.26 | 58.94 |

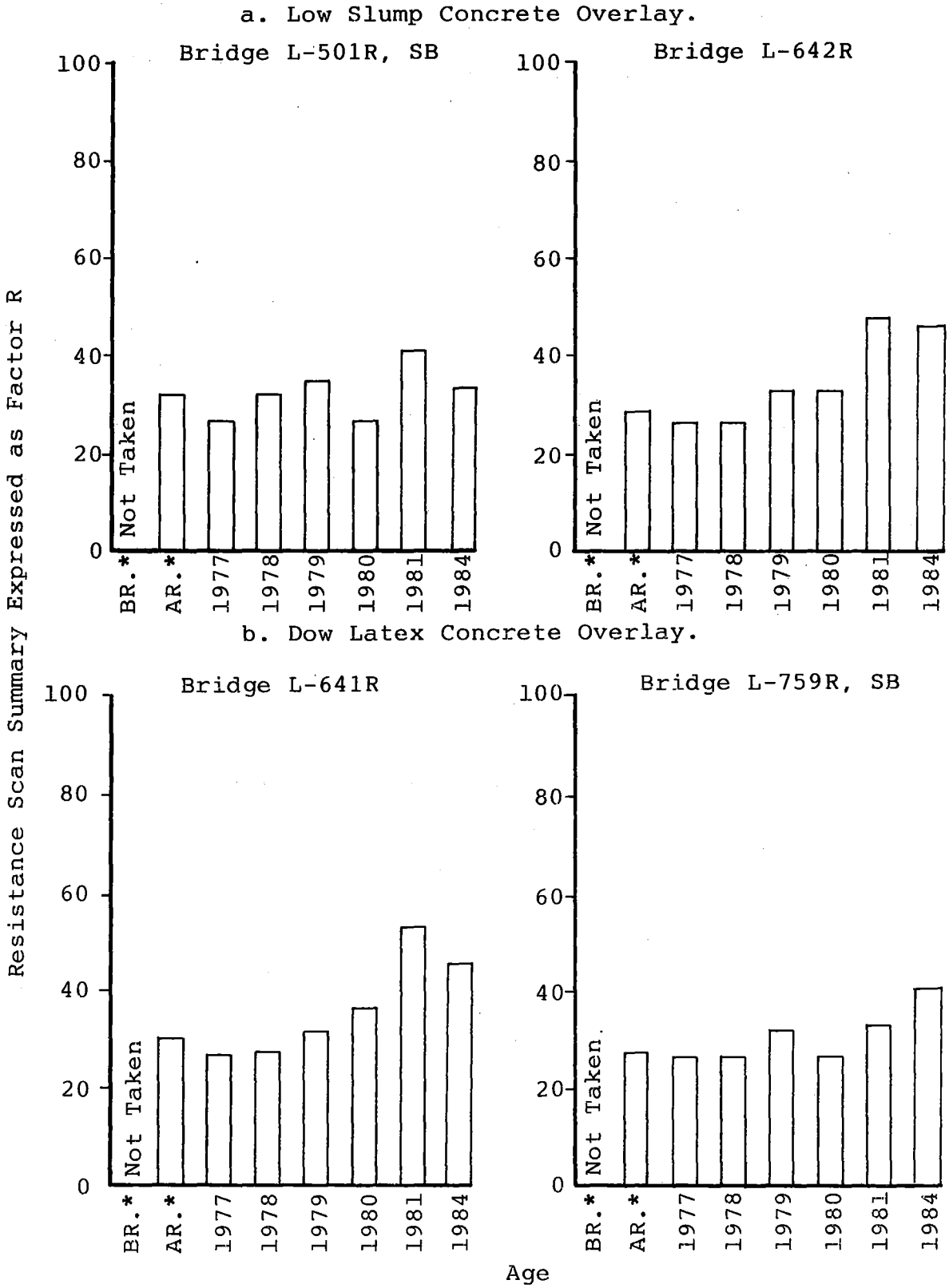
(1) Survey immediately after placing protective system.
(2) Numbers of samples drastically reduced because protection system was not designed as a "waterproofer".
(3) Only one stage of construction tested.

Actual range of values for R was 100 if all resistance measurements were 1M ohms and 26.2 if all resistance measurements were 0-500 ohms. Therefore, as the concrete decks are tested prior to application of a protection system, the resistance factor should be close to 26.2. After application of a protection system resistance factor should approach the maximum of 100.

Figure 9 is a graphical representation of resistance factors shown in Table 11. Parts c through f show results of liquid and sheet type membrane protection systems. Resistance levels immediately after placing these membranes show the desired effect of waterproofing. However, with the first year's service, resistance levels dropped significantly. Thereafter, resistance levels show a fairly stable quality around that which was observed after the first year's service. Generally, interpretation of a drop to a resistance factor of 60 means that less than 15% of the resistance readings are in the preferred range of 1M ohms. A drop to a resistance factor of 75 will show only about 35% of the resistance readings are in the preferred range of 1M ohms. Based on these resistance measurements and preferred objective of "waterproofing" the concrete deck, none of the liquid or sheet membrane systems have proved to be outstanding. Protecto Wrap did have one bridge that out-performed all other membrane systems when considering only resistance criteria.

Parts a and b, Figure 9, show the limited resistance studies of the concrete overlay systems. The results were as

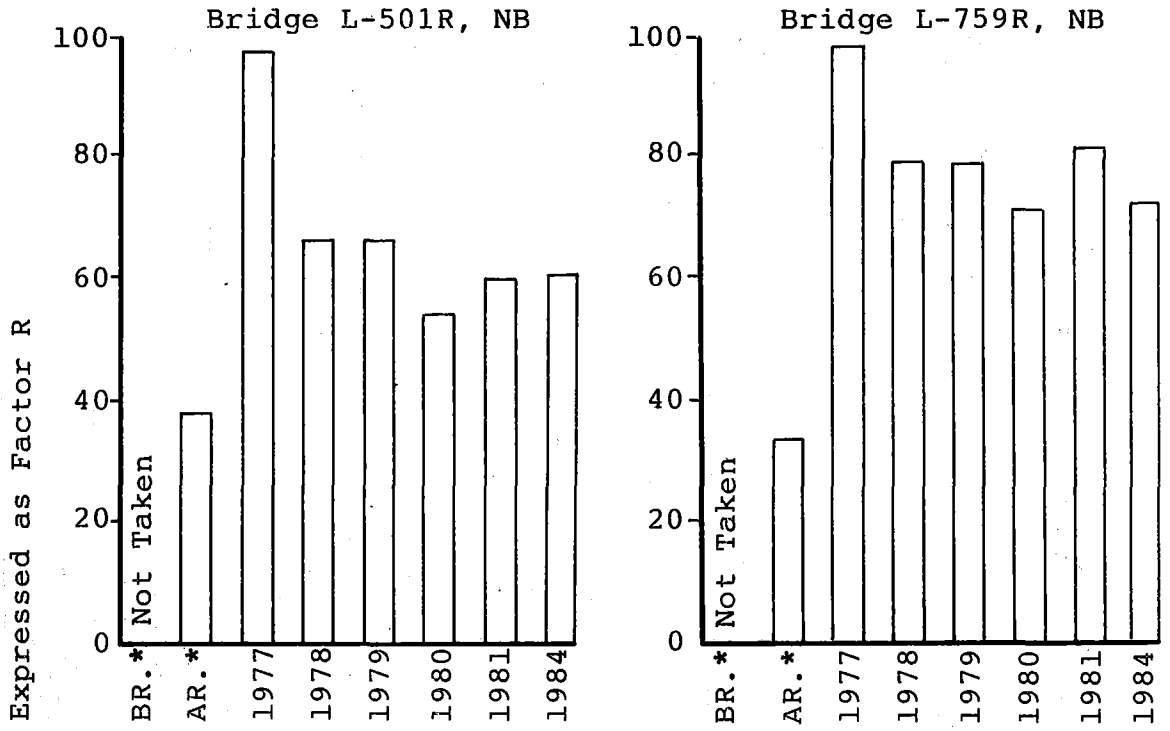
Figure 9 - Resistance Scan Surveys Expressed as a Single Numerical Resistance Scan Summary Factor.



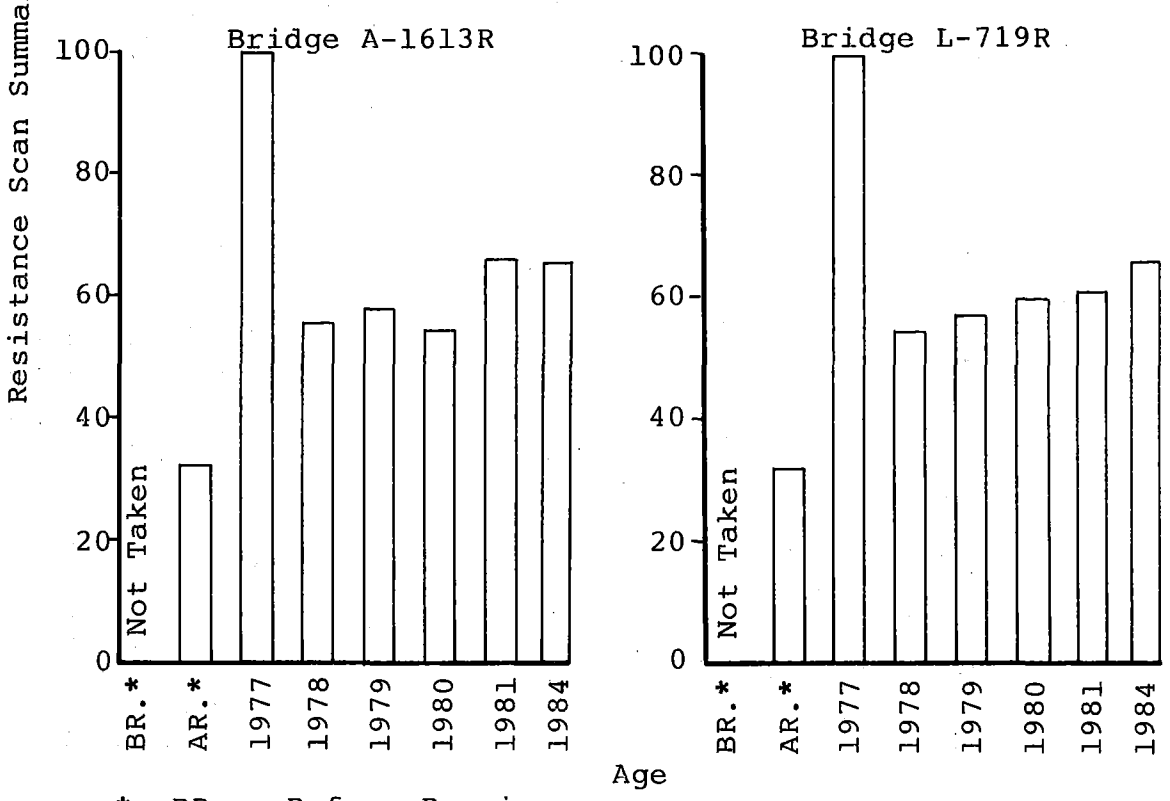

* BR. = Before Repair
AR. = After Repair

Figure 9 - Continued

c. Protecto Wrap Membrane System.



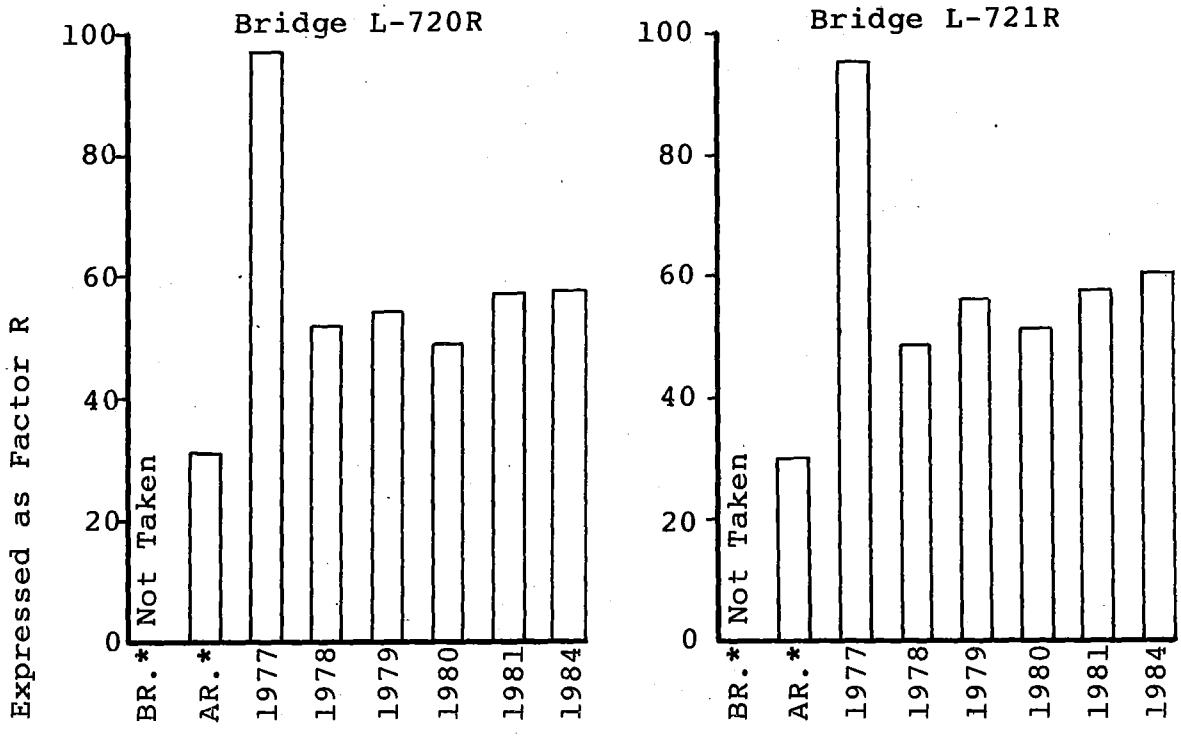

d. Heavy Duty Bituthene Membrane System.



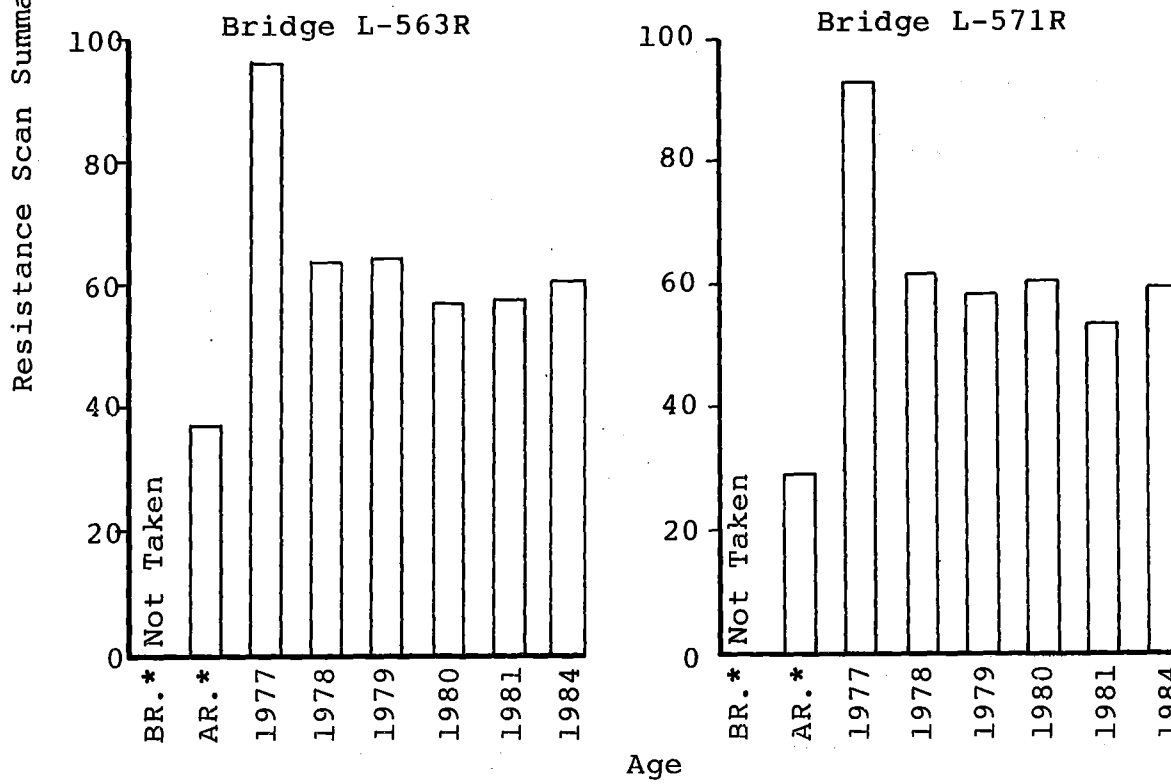

* BR. = Before Repair
AR. = After Repair

Figure 9 - Continued

e. Gacoflex Membrane System.




f. Superseal 4000 LT Membrane System.




* BR. = Before Repair
AR. = After Repair

expected. Concrete overlays are not designed as "waterproofing" systems. Very few readings were taken in or above the 10K ohm range on either of these systems. Continued moisture penetration of these systems may provide mobility to the chloride ions thereby continuing the corrosion process.

Resistance measurements may be a useful tool to determine initial uniformity or quality of a liquid or sheet type membrane protection system, however, resistance measurements do not appear to provide much meaning to the long term quality of the system. Stability of the chloride ions and the apparent decreasing electrical potential levels in these bridges as previously discussed indicate satisfactory performance of these systems.

## DELAMINATION SURVEYS

The SIE Delamtect was used to make all delamination surveys on these bridges. Delamination, as used in this report, means hollowness as determined by Delamtect regardless of origin of hollowness, i.e., fracture plane, debondment, or separation of products comprising the protection system. Fracture plane will be used to define cracking within the original concrete deck caused by rusting of the reinforcing steel. Debonding will be used to define lack of bond between any two layers of the protection system or between the protection system and the original concrete deck surface. Delamination profiles for each of the bridges used in this study were made before repair began, after repairs were completed, after placement of the protection

system, and as surveyed thereafter. The Delamtect was operated such that a longitudinal trace was achieved at nine inch spacing across the deck. Delamination, in terms of percentage of the deck effected, was calculated as the total length of delamtect trace indicating hollowness divided by the total length of traverse. Delamination results shown in Table 5, Sub-part c of Parts A through N, have been summarized in Table 12 for discussion of comparisons.

Delamtect results on anything other than a concrete surface are subject to possible errors. Asphaltic concrete overlays create problems in response levels in the Delamtect. Generally, the deck must be rechecked with a steel rod or hammer and sand method to determine if the response is correct. All Delamtect surveys were checked after the 1977 surveys.

Delaminations come in many forms when discussing membrane or overlay systems. The bonding plane between each step of material application is a possible source of hollowness. The values in Table 12 attest to these problems because of fluctuation from year to year on the observed percent of delamination.

Cathodic protection indicated a uniformly hollow sound in 1981 and 1984. Observations were made from cores which were removed from the protection systems during the 1981 and 1984 survey to verify the existence and the position of the delamination. Generally, there were large areas of little or no bond of the coke breeze to the concrete deck and the asphaltic

Table 12 - Delamination Survey Results In Percent of Deck Area Affected

| Bridge | Delamination(1) - Percent of Area Surveyed: Before Repair | After Repair | Survey 1977(2) | 1978 | 1979 | 1980 | 1981 | 1984 |
|---|---|---|---|---|---|---|---|---|
| **Cathodic Protection** | | | | | | | | |
| L-701R | 1.89 | 0.40(3) | 0.93 | 4.55 | 0.86 | 28.3 (4) | 100.0 | 100.0 |
| L-702R | 0.11 | 0.04 | 0.17 | 1.77 | 0.76 | 1.26 | 100.0 | 100.1 |
| **Low Slump Concrete Overlay** | | | | | | | | |
| L-501R SB | 0.12 | 0.03 | 0.01 | 0 | 0 | 0.09 | 0.27 | 1.14 |
| L-642R | 6.92 | 3.93(4) | 0 | 0 | 0.18 | 0.15(4) | 2.54 | 3.84 |
| **Latex Concrete Overlay** | | | | | | | | |
| L-641R | 4.90 | 5.50(4) | 0 | 0.10 | 0.27 | 0.01(4) | 1.80 | 9.15 |
| L-759R SB | 0.38 | 0.03 | 0.09 | 0.02 | 0.44 | 0.83 | 1.16 | 5.82 |
| **Protecto Wrap** | | | | | | | | |
| L-501R NB | 0.79 | 0.08 | 0.21 | 2.00 | 22.83 | 27.77 | 12.40 | 15.86 |
| L-759R NB | 0.73 | 0.38 | 0.02 | 0.21 | 0.59 | 2.03(4) | 0.85 | 15.21 |
| **Heavy Duty Bituthene** | | | | | | | | |
| A-1613R | 0.26 | 0.03 | 61.75 | 39.32 | 0.27 | 7.67 | 4.38 | 17.60 |
| L-719R | 0.56 | 0.06 | 30.38 | 5.82 | 1.85 | 3.38(4) | 1.60 | 1.01 |
| **Gacoflex** | | | | | | | | |
| L-720R | 0.13 | (5) | 27.89 | 2.49 | 2.49 | 20.20 | 7.69 | 20.66 |
| L-721R | 0.15 | 0.06 | 17.14 | 16.14 | 6.58 | 10.27 | 8.37 | 19.83 |
| **Superseal 4000LT** | | | | | | | | |
| L-563R | 1.66 | 0.29 | 0.05 | 0.21 | 32.40 | 28.04 | 15.48 | 23.06 |
| L-571R | 7.20 | 0.12 | 0.68 | 7.66 | 15.21 | 45.89 | 31.65 | 75.73 |

(1) Delamination means hollowness as determined by Delamtect regardless of origin of hollowness, i.e., fracture plane, debondment, or separation of products of systems.
(2) Survey immediately after placing protection system.
(3) Partial test in one stage of construction only.
(4) Only one stage of construction tested.
(5) No test made.

concrete surface next to the coke breeze showed stripping and generally poor bonding.

Both concrete overlay systems indicated a slight increase in delamination with each successive annual survey. Cores removed in 1981 and 1984 indicate that fracture planes were developing and some debondment, especially at patch areas placed immediately prior to the overlay, was occurring. Latex concrete overlay system showed the largest increase over the 1981-1984 time interval.

Sheet type membrane protection systems presented rather large variations in delaminations between surveys. This is believed to have been a result of the condition of the asphaltic concrete or the sheet membrane and the effects of temperatures on these systems. However, cores were drilled in areas of hollowness on all membrane bridges to determine probable cause.

Sheet type membrane systems were observed to have stripping of the aggregates in the asphaltic concrete overlay at the contact surface with the roofing paper. The Heavy Duty Bituthene membrane was observed in a few cases to have large blisters which apparently developed after being placed on the concrete deck. The membrane, where these voids occurred, appeared to have been effected by heat during placement of asphaltic concrete overlay. Bridges with Heavy Duty Bituthene also presented areas where fracture planes within the concrete deck were observed. Bridge A-1613R was checked by drilling four holes in areas of apparent hollowness. Three of these four observations revealed corroded reinforcing steel and fracture

planes. Bridge L-719R was also checked by drilling four holes in areas of apparent hollowness. Only one area resulted in corroded steel and fracture plane.

Liquid type membrane protection systems were observed to be in much the same condition as the sheet type membrane systems. Asphaltic concrete was observed to have stripping of the aggregate at the bond face with the roofing paper. Roofing paper was generally bonded to the membranes, however, with Superseal membrane, roofing paper was highly saturated with an asphaltic appearing and smelling substance. Source of this substance was not positively determined. The asphaltic concrete was identical in mix design and appearance as the other bridges. The membrane appeared to be in good condition and well bonded to the concrete surface. None of the hollow sounding areas which were checked by core drilling, on the Gacoflex membranes were due to fracture planes. However, for the Superseal systems, one of the five areas tested on L-563R and two of six areas tested on L-571R were observed to be fracture planes in the concrete decks. In each case, corroded reinforcing steel with associated cracking was observed.

Generally, from observations of cores and the data obtained, delamination surveys on overlaid bridge decks do not express with any certainty the condition of either the protection system or original concrete deck. Many forms of deterioration in the membrane system such as stripping of the asphaltic concrete, debondment of any two layers of materials, debondment of the membrane to the concrete deck, or failure of the roofing paper to remain as originally placed will cause a

hollowness to be registered on the Delamtect. Corrosion and fracture planes have in some cases been detected in the hollow-sounding areas on some of the systems. Because of the relatively small number of cores drilled on each bridge, no certainty can be expressed that one system is better than the other based on delamination. The concrete overlays appear to be in good condition based on the relatively low values obtained, however, they are showing increasing percentages of delamination annually.

CORROSOMETER PROBE READINGS

Corrosometers (manufactured by Matcor, Inc.) are precision probes which were placed in the same environment as the reinforcing steel. The corrosometer probe operates on the principal that electrical resistance increases as the cross-sectional area of a metallic conductor decreases. A probe functions as an in situ sensor that accumulates the corrosion history of the environment. Rate of corrosion in Mils Per Year (MPY) may be calculated by the use of the formula:

$$\text{Corrosion Rate(MPY)} = \frac{\text{Instrument Reading}}{\text{Time}} \times 0.365 \times \text{Probe Multiplier}$$

Probes used in this study had probe multipliers of 25, therefore, the constant portion of the equation was reduced to 9.125.

Each bridge deck in this study had one corrosometer probe randomly placed in each traffic lane. The corrosometer probes were located in a wheelpath at the depth of the reinforcing steel. Exception to this was the cathodic protection systems which had two corrosometer probes per traffic lane. Table 13

shows the rate of corrosion for each of the probes in terms of mils loss per year. The corrosion rates were calculated over the longest period possible to show the general trend rather than small incremental fluctuations.

Placement of the corrosometer probes must be considered as being very critical in using this data to evaluate performance of the protection systems. With the sheet and liquid type membrane systems, it is a matter of where the probe was placed with relation to the nearest void in the membrane. From Table 13, there appears to be some areas in just this situation. Of the eight bridges with liquid or sheet type membrane systems, three bridges have one of the corrosometer probes showing a moderate rate of corrosion. All three corrosometer probes were located in the passing lane.

One bridge with the low slump concrete overlay system, Bridge L-501R SB, and one bridge with the latex concrete overlay system, Bridge L-759R SB, also show one corrosometer probe with high corrosion rates. Both probes in this case are located in the driving lane.

The corrosometer probe in Bridge L-759R SB, had a higher corrosion rate than any other probes noted. However, no cracking or delamination was noted in the surveys at the location of this probe.

Four corrosometer probes placed in the cathodic protection bridges showed moderate rates of corrosion. However, three of these probes developed problems rather early in the testing program. Shorts were assumed to have occurred due to breaks in the electrical cables or failure at the junctions of the probe

## Table 13 - Corrosion Rate of Corrosometers

| Bridge No. | Corrosometer No. | First Reading Date | First Reading Value | Last Reading Date | Last Reading Value | Difference Readings | Days | Corrosion Rate (MPY) | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| **Cathodic Protection** | | | | | | | | | |
| L-701R | 1 | 9-30-77 | 107.0 | 12-29-77 | 115.0 | 8.0 | 91 | 0.80 | (1)4-12-78 |
| | 2 | 9-30-77 | 65.0 | 2-11-82 | 82.0 | 17.0 | 1596 | 0.10 | |
| | 3 | 9-30-77 | 77.0 | 2-11-82 | 55.0 | -22.0 | 1596 | -0.12 | |
| | 4 | 9-30-77 | 115.0 | 2-11-82 | 82.0 | -33.0 | 1596 | -0.19 | |
| L-702R | 1 | 9-29-77 | 116.0 | 2-11-82 | 154.0 | 38.0 | 1597 | 0.22 | |
| | 2 | 9-29-77 | 26.0 | 2-11-82 | 20.0 | -6.0 | 1597 | -0.03 | |
| | 3 | 9-29-77 | 36.0 | 2-11-82 | 10.0 | -26.0 | 1597 | -0.14 | |
| | 4 | 9-29-77 | 110.0 | 2-11-82 | 228.0 | 118.0 | 1597 | 0.67 | |
| | 5 | 9-29-77 | 67.0 | 6- 8-78 | 104.0 | 37.0 | 252 | 1.33 | (1)2- 7-79 |
| | 6 | 9-29-77 | 144.0 | 6- 8-78 | 218.0 | 74.0 | 252 | 2.67 | (1)2- 7-79 |
| **Low Slump Concrete** | | | | | | | | | |
| L-501R | 1 | 11-14-77 | 127.5 | 2-18-82 | 248.0 | 120.5 | 1557 | 0.71 | |
| | 2 | 11-14-77 | 48.5 | 2-18-82 | 50.0 | 1.5 | 1557 | 0.01 | |
| L-642R | 1 | 12-15-77 | 67.0 | 5- 4-81 | 104.0 | 37.0 | 1236 | 0.27 | |
| | 2 | 12-15-77 | 117.5 | 5- 4-81 | 135.0 | 17.5 | 1236 | 0.13 | |
| **Latex Concrete Overlay** | | | | | | | | | |
| L-641R | 1 | 12-14-77 | 182.5 | 2-18-82 | 186.0 | 3.5 | 1527 | 0.02 | |
| | 2 | 12-14-77 | 121.0 | 2-18-82 | 88.0 | -33.0 | 1527 | -0.20 | |
| L-759R SB | 1 | 11-14-77 | 95.0 | 2-18-82 | 924.0 | 829.0 | 1557 | 4.86 | |
| | 2 | 11-14-77 | 92.5 | 2-18-82 | 86.0 | -6.5 | 1557 | -0.04 | |
| **Protecto Wrap** | | | | | | | | | |
| L-501R NB | 1 | 11-14-77 | 121.0 | 2-18-82 | 301.0 | 180.0 | 1557 | 1.05 | |
| | 2 | 11-14-77 | 151.0 | 2-18-82 | 143.0 | -8.0 | 1557 | -0.05 | |
| L-759R NB | 1 | 11-14-77 | 74.0 | 2-18-82 | 333.0 | 259.0 | 1557 | 1.52 | |
| | 2 | 11-14-77 | 116.5 | 2-18-82 | 105.0 | -11.5 | 1557 | -0.07 | |
| **Heavy Duty Bituthene** | | | | | | | | | |
| A-1613R | 1 | 9-21-77 | 62.0 | 2-16-82 | 55.0 | -7.0 | 1609 | -0.04 | |
| | 2 | 9-21-77 | 145.0 | 2-16-82 | 141.0 | -4.0 | 1609 | -0.02 | |
| L-719R | 1 | 9-21-77 | 64.0 | 2-16-82 | 108.0 | 44.0 | 1609 | 0.25 | |
| | 2 | 9-21-77 | 146.0 | 2-16-82 | 135.0 | | 1609 | -0.06 | |
| **Gacoflex** | | | | | | | | | |
| L-720R | 1 | 9-21-77 | 0 | 2-16-82 | 57.0 | 57.0 | 1609 | 0.32 | |
| | 2 | 9-21-77 | 104.0 | 2-16-82 | 111.0 | -7.0 | 1609 | -0.04 | |
| L-721R | 1 | 9-21-77 | 52.0 | 2-16-82 | 60.0 | 8.0 | 1609 | 0.04 | |
| | 2 | 9-21-77 | 71.0 | 2-16-82 | 75.0 | 4.0 | 1609 | 0.04 | |
| **Superseal 4000LT** | | | | | | | | | |
| L-563R | 1 | 11-15-77 | 118.0 | 2-17-81 | 122.0 | 4.0 | 1190 | 0.03 | (2)5- 4-81 |
| | 2 | 11-15-77 | 129.5 | 2-18-82 | 122.0 | -7.5 | 1556 | -0.04 | |
| L-571R | 1 | 12-15-77 | 72.5 | 5- 4-81 | 318.0 | 245.5 | 1236 | 1.81 | (3) |
| | 2 | 12-15-77 | 33.0 | 2-18-82 | 19.0 | -14.0 | 1526 | -0.08 | |

(1) Corrosometer shorted out on date shown, water and/or corrosion products in receptacle.
(2) Corrosometer probe was accidently cut by drilling for fracture planes during 1981 survey.
(3) Lock froze on electrical outlet box, no test made in 1982.

or the ground connections. Solidified calcium carbonate products or water was noted in junction receptacles of these probes in the instrumentation cabinet. Corrosion probe number 4 on Bridge L-702R, which had moderate rate of corrosion has been stabilized since the last reading by adjusting the rectifier output to the bridge.

Rate of corrosion on corrosometer probes must be interpreted as a failure in the protective system if any positive corrosion rates are expressed. Literature from the manufacturer of the corrosometer probes show the effects of corrosion on a particular system the same as a weight loss by coupon in relating the corrosion of the probe to the corrosion occurring in the system. Therefore, from the information in Table 13, no certainty can be derived from the state of corrosion of any bridge reinforcing steel because of the large variability of the results and the relatively small area of the bridge deck that the probe senses.

## SURFACE PROFILE

Surface profile relates to the visual condition of the deck surface with emphasis primarily on cracking and patching. The square feet of patch surface area observed before work commenced under this study, after patching was completed immediately prior to the placement of the protection system, and as surveyed thereafter is shown in Table 5 for each bridge respectively. Numerous areas on some of the decks received extensive repair during the preliminary rehabilitation prior to the protective systems being placed. At the time the protective systems were

placed, the decks were considered to be in good repair. Surface cracking was surveyed before repairs were made. Some cracking could have been eliminated by the halfsole repairs, but was considered insignificant and not resurveyed.

Table 14, shows the cracking noted in each surface profile survey with the final survey in 1984 reduced to a numerical value of number of cracks by grid. As mentioned previously, with the electrical potential scans, a survey grid of 3 by 4 feet was used for control points in the annual surveys. The surface profile data was observed and recorded for each survey using the same grid reference system. Cracking was noted to increase in length and vary in direction as well as to increase in numbers with each successive survey. Therefore, to account for the increasing lengths of cracks, the data was reduced to numerical values by counting the number of cracks within each grid. This data was further reduced to the average number of cracks within a grid or 3 by 4 foot area of the deck for the 1984 survey to give a bases for evaluation which eliminates variable lengths and widths of the bridges.

Based on this analysis procedure, the number of cracks per grid section or 12 square feet of surface area appears to be fairly similar between bridges within each respective protection system except for Superseal. All four of the membrane protective systems show relatively low number of cracks per grid on the average as compared to the concrete overlays systems. The total number of cracks actually counted during the 1981 survey approached the original surface profile survey. Cracks in the asphaltic concrete overlay as shown in this survey, are

## Table 14 - Surface Profile Crack Survey

| Bridge | Before Repair | Total Number of Cracks Survey 1977(1) | 1978 | 1979 | 1980 | 1981 | 1984 | Avg. Cracks Per. Grid 1984 |
|---|---|---|---|---|---|---|---|---|
| **Cathodic Protection** | | | | | | | | |
| L-701R | 172 | 0 | 0 | 216 | 246(2) | 611 | 791 | 1.56 |
| L-702R | 330 | 0 | 0 | 122 | 206(2) | 543 | 738 | 1.07 |
| **Low Slump Concrete Overlay** | | | | | | | | |
| L-501R SB | 321 | 0 | 767 | 953 | 565(2) | 1183 | 1221 | 2.12 |
| L-642R | 133 | 0 | 258 | 512 | 327(2) | 658 | 711 | 1.92 |
| **Latex Concrete Overlay** | | | | | | | | |
| L-641R | 120 | 0 | 96 | 316 | 308(2) | 672 | 779 | 2.09 |
| L-759R | 84 | 0 | 5 | 324 | 148(2) | 533 | 874 | 1.82 |
| **Protecto Wrap** | | | | | | | | |
| L-501R NB | 527 | 0 | 0 | 257 | 18(2) | 356 | 628 | 1.09 |
| L-759R NB | 117 | 0 | 0 | 54 | 17(2) | 119 | 320 | 0.68 |
| **Heavy Duty Bituthene** | | | | | | | | |
| A-1613R | 254 | 0 | 10 | 59 | 59(2) | 211 | 431 | 0.86 |
| L-719R | 727 | 0 | 0 | 47 | 63(2) | 486 | 992 | 1.22 |
| **Gacoflex** | | | | | | | | |
| L-720R | 319 | 0 | 101 | 115 | 119(2) | 366 | 910 | 0.98 |
| L-721R | 344 | 0 | 0 | 6 | 24 | 356 | 639 | 0.84 |
| **Superseal 4000LT** | | | | | | | | |
| L-563R | 165 | 0 | 4 | 63 | 32(2) | 175 | 330 | 0.77 |
| L-571R | 1161 | 0 | 4 | 78 | 196(2) | 705 | 1525 | 1.67 |

(1) Survey immediately after placing protective system.
(2) Only one stage of construction tested.

not considered to be reflective cracks. Generally, the cracking in the original deck was primarily transverse, whereas, cracks in the asphaltic concrete overlays are longitudinal. Because of this crack pattern, the porphyry asphaltic concrete overlays apparently function as an independent layer of material with the membrane functioning as a stress relief system. Traffic loading on the asphaltic concrete surface has also caused some wheelpath rutting with accompanying longitudinal cracking patterns. Therefore, cracking, per se, in the asphaltic concrete overlay in this study does not appear to be detrimental to the functioning of the membrane.

Cracking within the concrete overlay protective systems is considerably higher than that observed in the membrane protective systems. The rate of cracking is roughly 2 times greater per grid. Total cracking recorded in the 1981 survey in the concrete overlays was 3 to 6 times greater than was originally observed in the concrete surface before scarification. The 1984 survey showed increase in surface cracking, however, at a considerably lesser rate of occurrence than observed between 1980 and 1981.

On February 18, 1982, observation of one of the latex concrete overlay systems following two days of fog, rain, and cloudy weather gave indications of a very alarming concentration of cracking which was not previously observed in the 1981 survey. Figures 10 and 11 are typical of the observed crack pattern. Near the ends of the deck, the cracking normally orientated diagonally with the centerline as shown in Figure 10. Cracking within the interior spans of the bridge normally

orientated longitudinal and perpendicular to the centerline as shown in Figure 11. This crack pattern was the first of its type observed in Missouri concrete overlay systems.

To better understand the cracking observed in the concrete overlays, 4 inch diameter cores were drilled which would be representative of various crack situations. Three categories of cracks were established for the purpose of defining the seriousness of the cracking observed. Large cracks were those which were easily observed from 20 or more feet in distance with a large opening of the crack and the edges of the crack may possibly be rounded from wear. Medium cracks were those which were easily observed from a lesser distance of approximately 10 feet with only slight opening and sharp edges of the crack. Fine cracks were those which were observed from an intense study of the immediate area at a distance of approximately 5 feet with no opening of the crack.

The data thus developed from study of the depth of cracking in each bridge deck is presented in Table 15. Sample photographs of the cores which were observed are presented in Figure 12. These five typical cores are each presented in different views. The first photograph is the top of the core as observed in the surface of the deck. The next two sets of photographs are the sides of the core showing the crack depth. The first set of photographs were made after soaking the cores overnight, therefore, cracks which were not apparent to the naked eye were highlighted. The second set were made from a surface dry condition.

Figure 10 - Diagonal Crack Orientation at the Skewed End Joint of One Latex Concrete Overlay, Passing Lane.

Bridge L-759R

Figure 11 - Perpendicular Crack Orientation in the Interior Spans and Bents of One Latex Concrete Overlay, Passing Lane.

Bridge L-759R

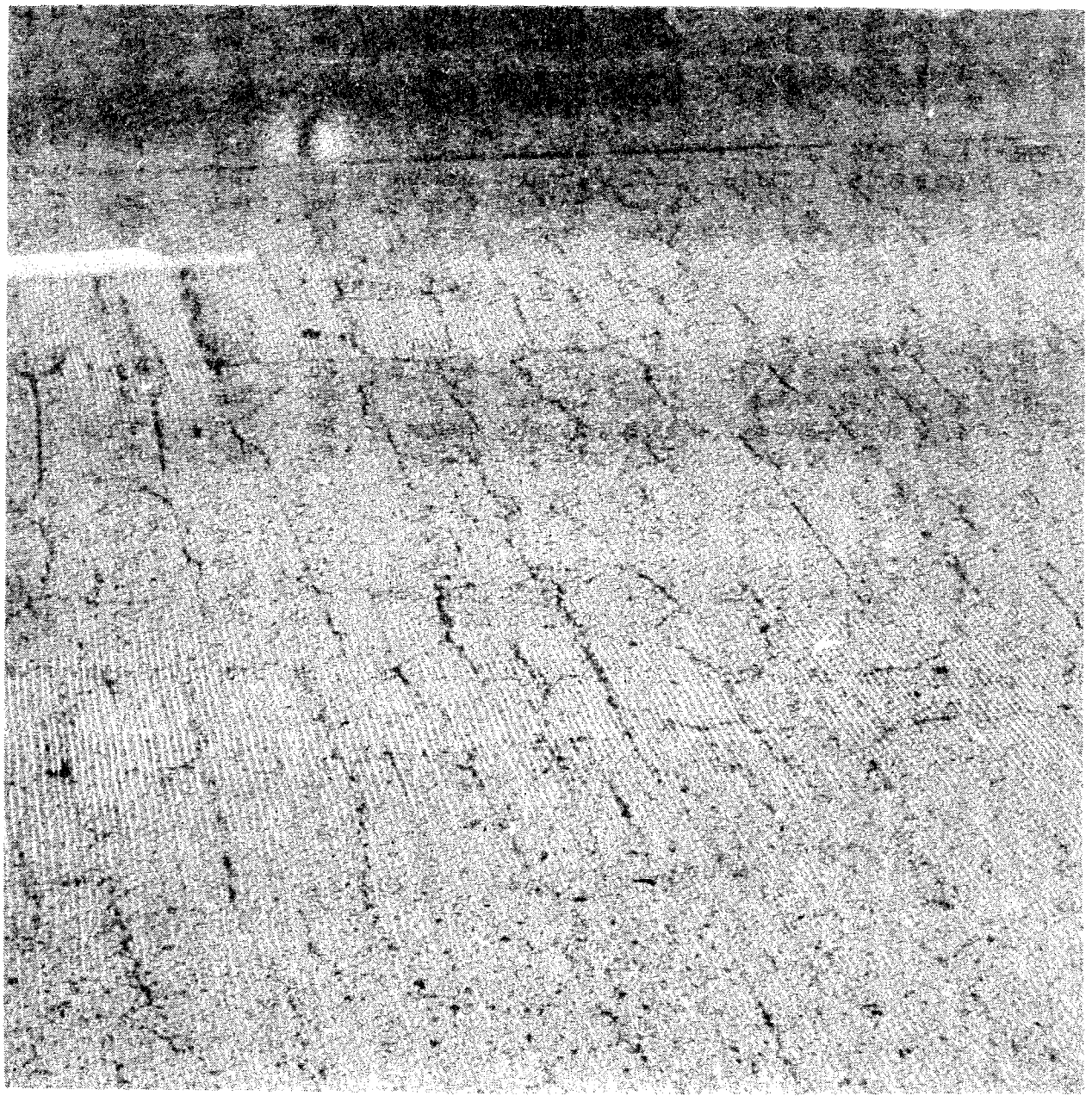


Table 15 - Summary of Observations of Cores Taken to Determine Crack Depth

| Bridge | Core | Depth(Inches) Overlay | Depth(Inches) Steel | Crack First Observed | Crack Orient. | Surface Crack Size | Hollow Area | Steel Rusty | Fracture Plane | Crack Depth (Inches) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | **Latex Concrete Overlay** | | | | | | |
| L-641R | 1 | 1 1/2 | 3 | 1981 | Trans. | Medium | No | Yes | No | 1 1/2 |
| | 2 | 1 5/8 | 3 7/16 | 1981 | Diag. | Fine | No | Yes | No | 1 5/8 |
| | 3 | 2 1/4 | 3 1/8 | 1981 | Trans. | Large | No | Yes | No | 3 1/8 |
| | 4 | 2 5/8 | 4 1/4 | 1979 | Trans. | Large | No | Yes | No | 4 1/4 |
| | 5 | 1 7/8 | NA | 1981 | Longit. | Fine | No | NA | No | 4 11/16 |
| | 6 | 1 7/8 | 3 7/8 | None | Diag. | Fine | No | No | No | 1 |
| L-759R | 1 | 1 7/16 | 2 1/2 | 1979 | Trans. | Large | Yes | Yes | No | 2 1/2 |
| | 2 | 1 3/16 | 1 11/16 | 1980 | Longit. | Medium | No | Yes | Yes | 1 11/16 |
| | 3 | 1 7/16 | 2 7/8 | None | Longit. | Fine | No | Yes | No | 2 7/8 |
| | 4 | 1 1/2 | 3 | None | Trans. | Fine | No | No | No | 1 1/2 |
| | | | | **Low Slump Concrete Overlay** | | | | | | |
| L-501R | 1 | 2 1/8 | 3 3/8 | 1978 | Trans. | Large | No | Yes | No | 2 1/8+ |
| | 2 | 1 15/16 | 3 11/16 | None | Trans. | Medium | No | Yes | No | 1 15/16 |
| | 3 | 2 1/16 | 3 5/8 | 1980 | Longit. | Fine | No | NA | No | 2 1/4 |
| | 4 | 2 3/16 | 3 | 1978 | Trans. | Large | No | Yes | No | 3 |
| | 5 | 2 | 3 3/8 | None | Longit. | Fine | No | NA | No | 2 1/4+ |
| L-642R | 1 | 2 3/8 | 3 11/16 | 1979 | Longit. | Fine | Yes | Yes | Yes | 3 11/16 |
| | 2 | 2 3/8 | 3 7/16 | 1978 | Trans. | Large | No | Yes | No | 3 7/16 |
| | 3 | 2 9/16 | 3 3/4 | 1979 | Longit. | Medium | No | Yes | No | 3 3/4 |
| | 4 | 2 3/8 | 3 11/16 | 1981 | Longit. | Medium | No | No | No | 2 3/8 |
| | 5 | 2 3/4 | NA | 1978 | Trans. | Large | Yes | NA | No | 3+ |

NA - Used in this table means "Not Available" because steel was not encountered in drilling the core.

From the data presented in Table 15, it is apparent that the cracking, except for one core, penetrated the concrete overlay full depth regardless of type of overlay. Approximately one-half of the cores from each overlay type had cracks extending to the depth of the steel which was encountered during drilling. Except for a few cases, the reinforcing steel was corroded at the location where the core was drilled.

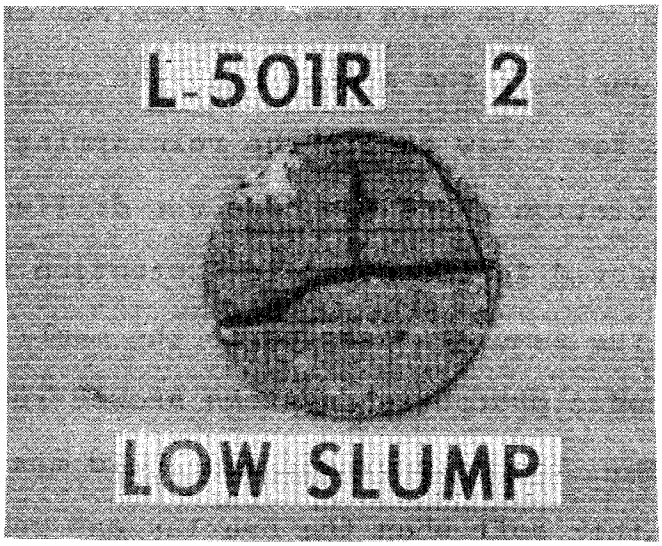
Cracking observed in the cathodic protection systems overlay was much the same as observed in the membrane systems. However, the cathodic protection systems showed rutting more than the membranes. The coke breeze asphaltic mixture was observed to be rather soft when the overlay was removed to take chloride ion samples. Apparently, the stability of the coke breeze asphaltic mixture will influence the performance of the porphyry asphaltic concrete riding surface. Generally, the surface condition of all the protection systems had deteriorated with regard to cracking.

Significant patching of the asphaltic concrete overlay had been required on bridges with membrane systems. One bridge with Heavy Duty Bituthene, both bridges with Gacoflex, and both bridges with Superseal 4000LT membrane systems required patching since final completion of construction. Generally, the patching was required because of breakup and potholing or shoving of the asphaltic concrete overlay. Observation of the materials during removal indicated large areas of stripping of the aggregate, poor bond of the asphaltic concrete to roofing paper, and poor bond of membrane to concrete deck to all be problems in the areas requiring patching. Movement of the asphaltic concrete

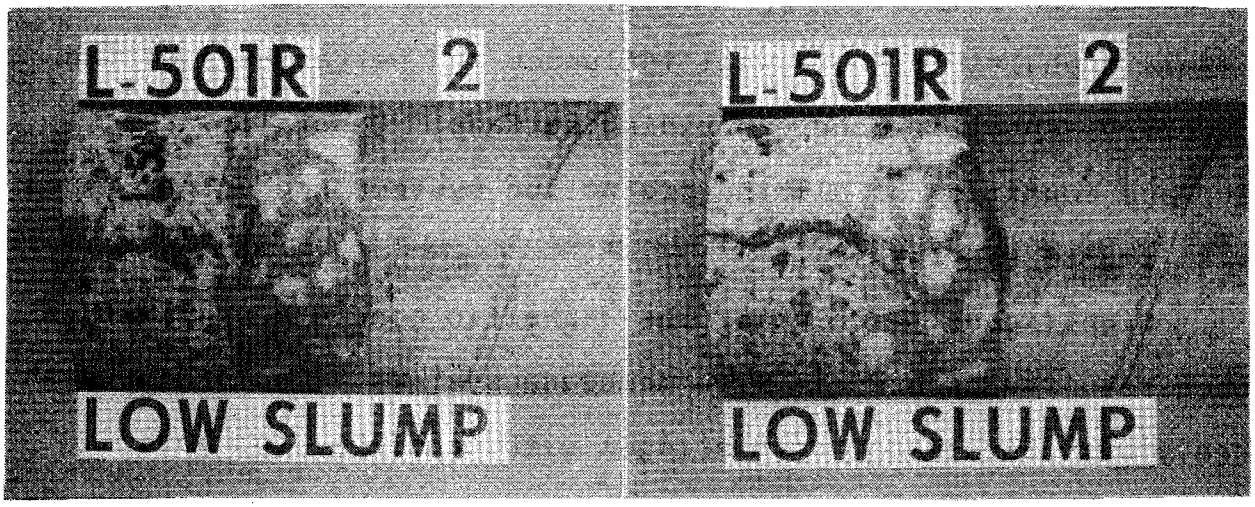
Figure 12 - Five Typical Cores Removed from the Concrete Overlays to Check for Crack Depth.

a. Core No. 2, Bridge L-501R, Low Slump Concrete Overlay

Top of Core




Side, Partially Dry after Soaking Overnight




Same Side, Surface Dry Condition

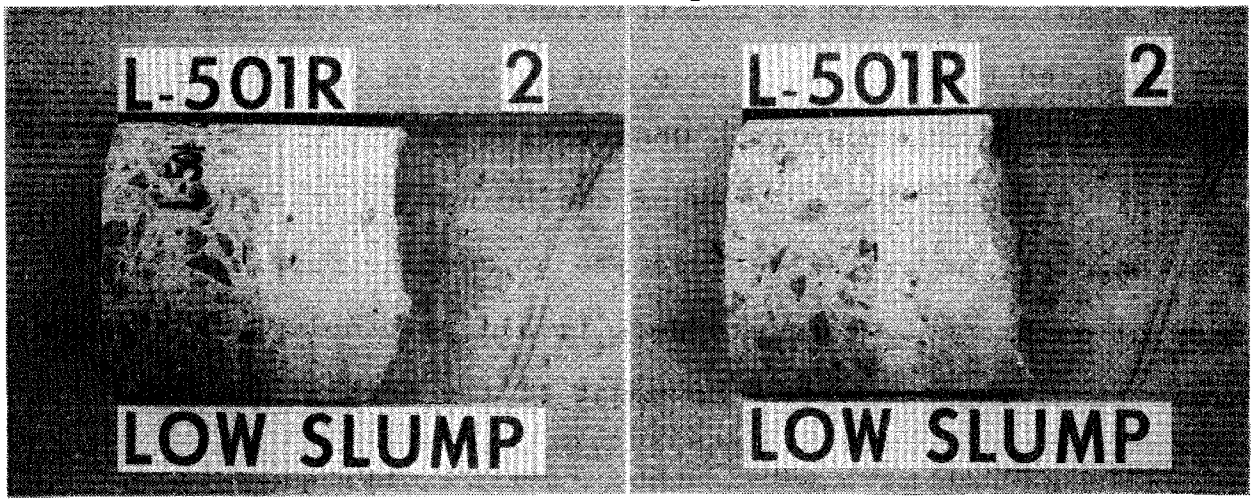
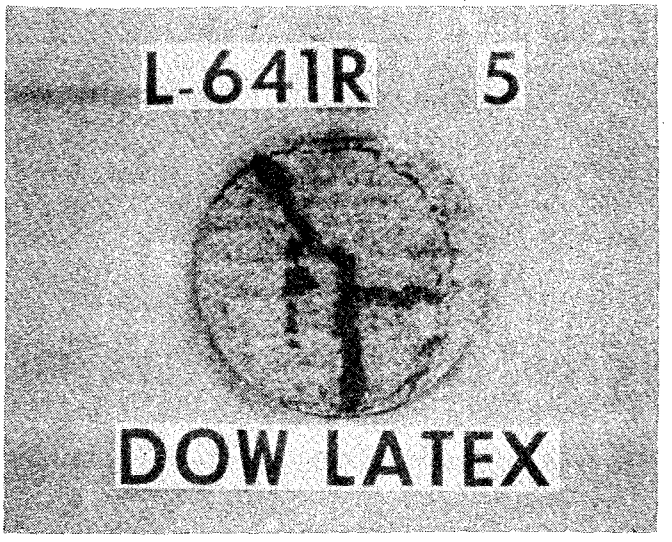


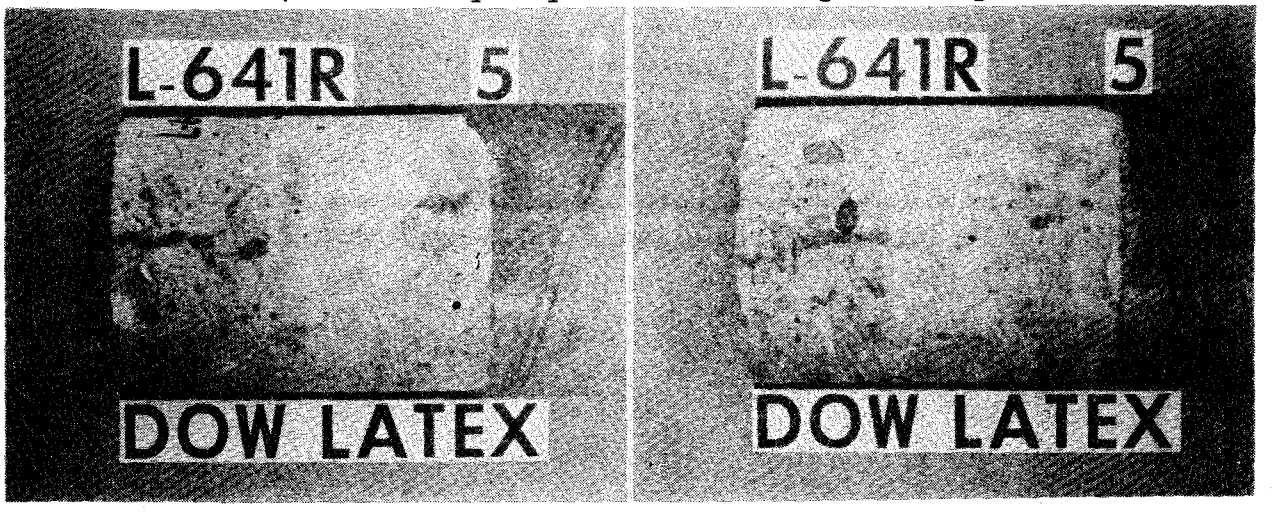
Figure 12 - Continued

b. Core No. 5, Bridge L-641R, Dow Latex Concrete Overlay

Top of Core




Side, Partially Dry after Soaking Overnight




Same Side, Surface Dry Condition

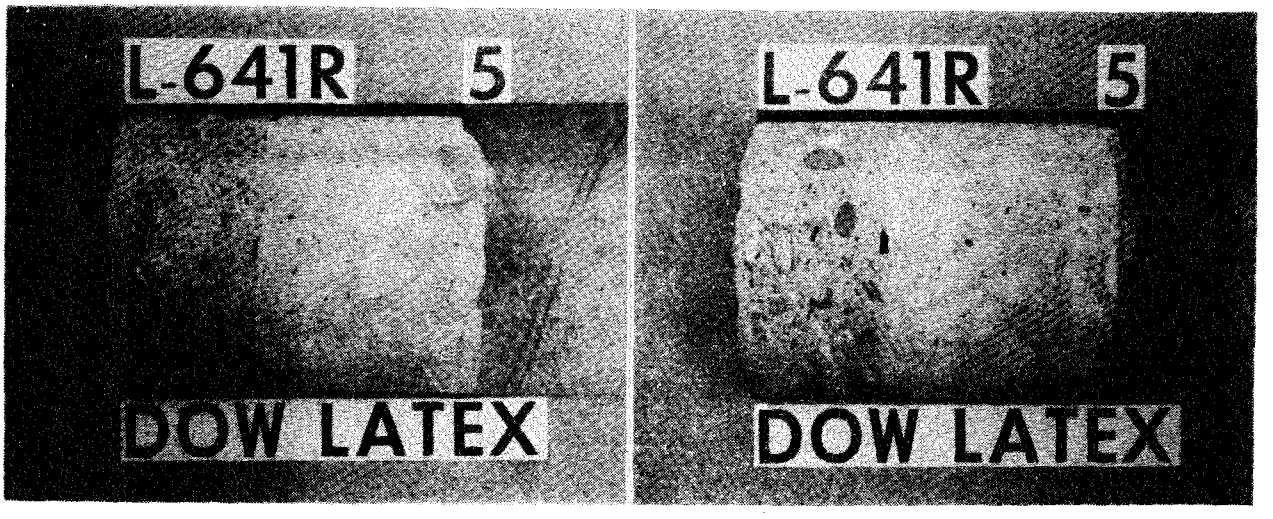
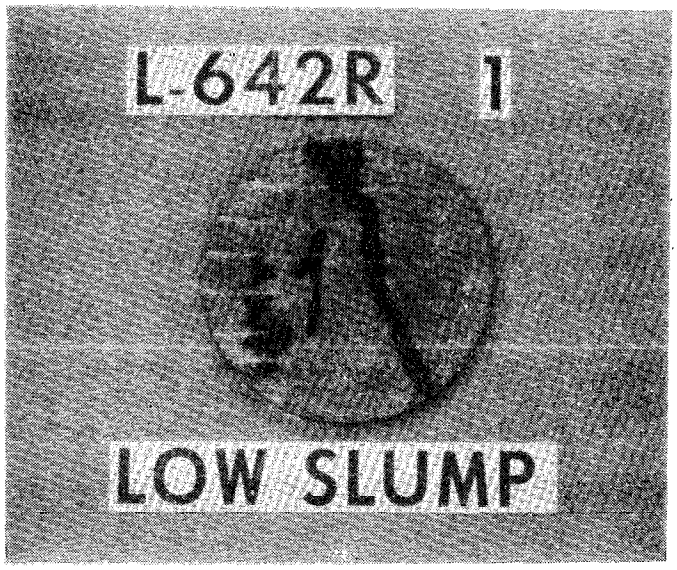


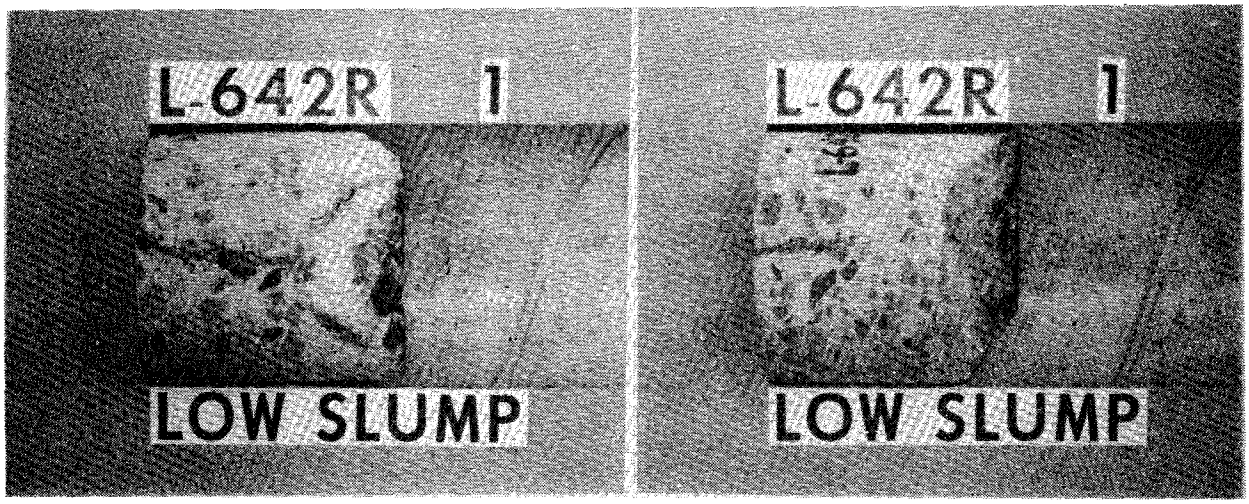
Figure 12 - Continued

C. Core No. 1, Bridge L-642R, Low Slump Concrete Overlay

Top of Core




Side, Partially Dry after Soaking Overnight




Same Side, Surface Dry Condition

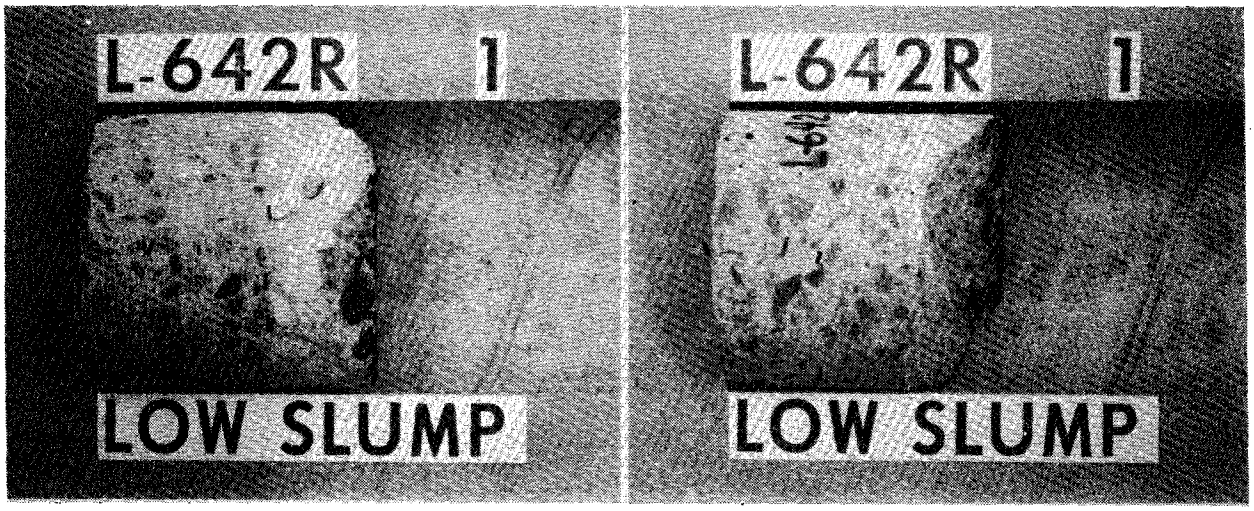
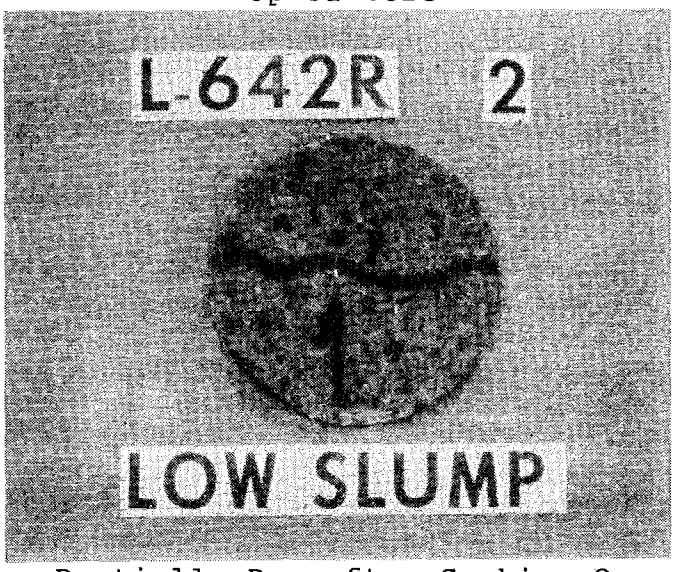


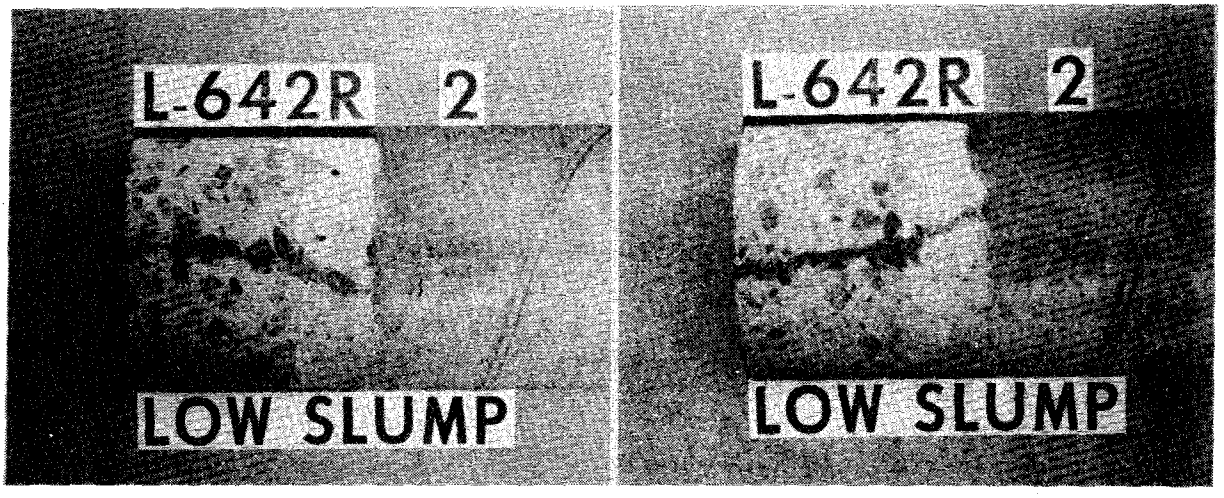
Figure 12 - Continued

d. Core No. 2, Bridge L-642R, Low Slump Concrete Overlay

Top of Core




Side, Partially Dry after Soaking Overnight




Same Side, Surface Dry Condition

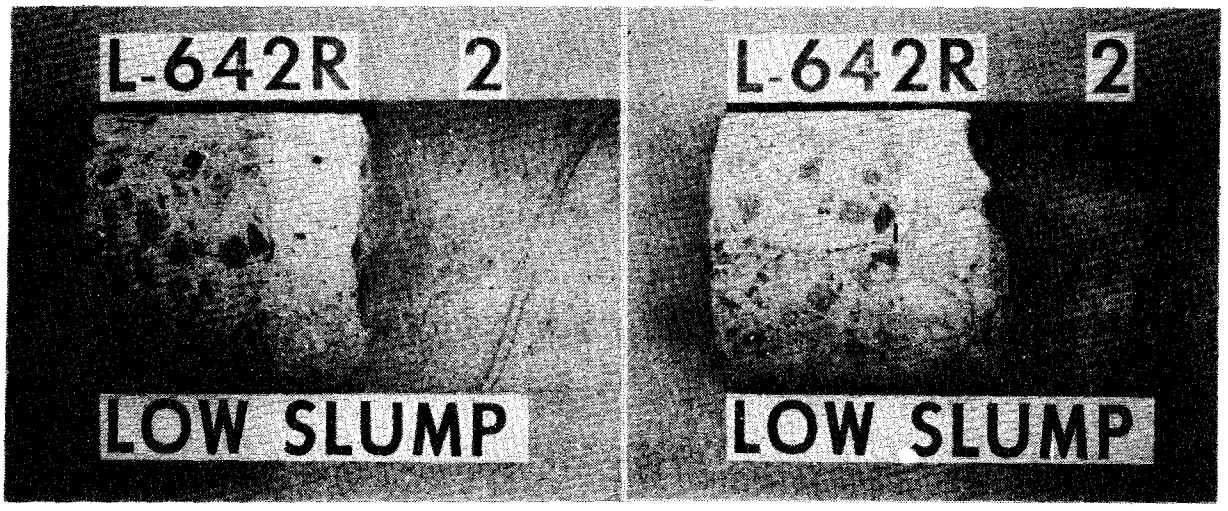
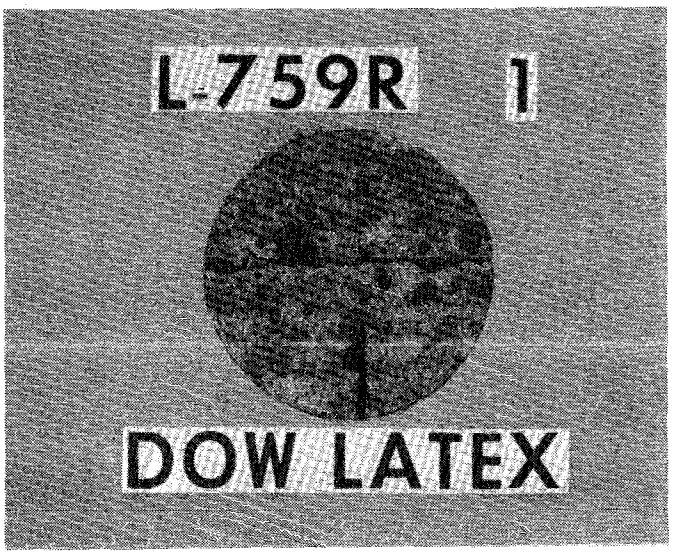


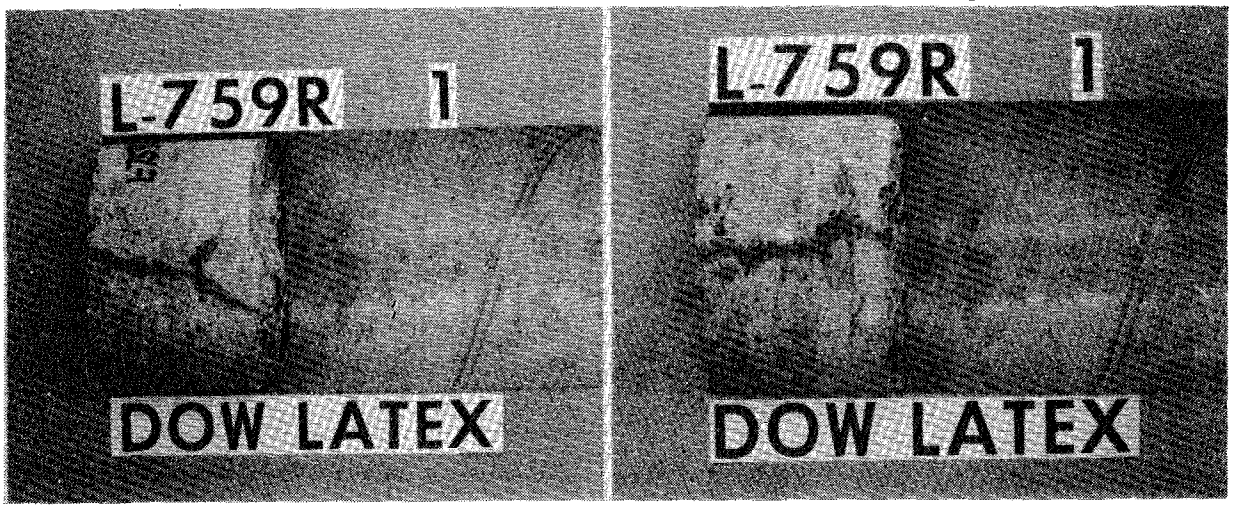
Figure 12 - Continued

e. Core No. 1, Bridge L-759R, Dow Latex Concrete Overlay

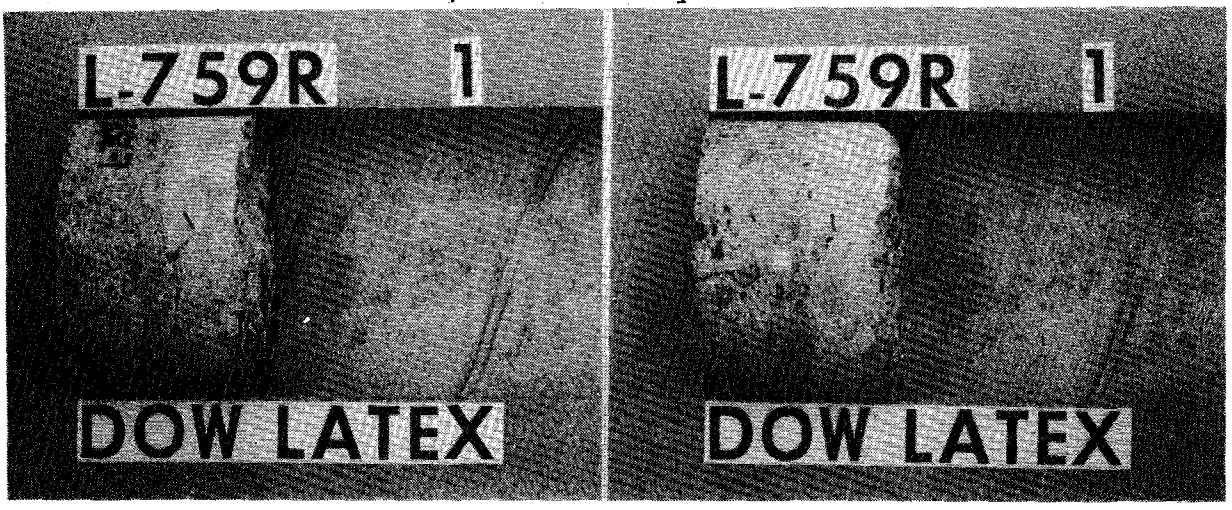
Top of Core




Side, Partially Dry after Soaking Overnight




Same Side, Surface Dry Condition



resulting from any one of these problems could be established as to probable cause of failure, however, many of the cores removed for purposes of taking chloride ion samples did indicate stripping of the aggregate and loss of bond of the asphaltic concrete overlay to be the predominant problem. Effective use of the membrane system, i.e., to pond water to prevent penetration into the deck, naturally will aggravate or precipitate such deterioration. Proper drainage must be incorporated into all membrane system designs.

Maintenance of the membrane systems must be prompt upon identification of a problem. Replacement as soon as possible of any deteriorated membrane must be done to prevent further and more massive deterioration. The damaged membrane system must be replaced to prevent water intrusion under the remaining membrane and continued deterioration. Failure to properly maintain a membrane system will result in mandatory premature replacement of the entire system. None of the membrane systems used in this study stood out as exceptionally better or worse than the others because of patching or required maintenance.

## UNDERDECK SURVEYS

Underdeck surveys were conducted to visually determine areas of the concrete decks which had deteriorated beyond the fracture plane stage. Individual cracks with or without efflorescence was surveyed but not tabulated because cracking, per se, had not been correlated with rate of deterioration of a concrete bridge deck. Efflorescence is normally observed as a whitish deposit along a crack opening on the bottom of the deck.

This deposit has resulted from crystallization or deposition of minerals which have been leached from or carried through the cracks and the water having since evaporated. Multiple full depth cracking within a very limited area will cause the appearance of efflorescence to be uniform over the area and not specifically related to individual cracks. Areas which were observed to be in this state were considered to be extensively deteriorated and should be repaired by replacing the concrete full depth.

Values reported in Table 5, Sub-part e of Part A through N, for the Underdeck "E" surveys was related to the observed areas of efflorescence only. From the tabulated data, only one bridge of the fourteen in this study showed a substantial increase in the square footage of area affected. The area of efflorescence observed on L-571R, which had a Superseal 4000LT membrane protection system, had increased by some 45 square feet. Several other bridges showed between 2 to 20 square feet increase since the placement of the protection system.

Significance of this observation is uncertain. Apparently some moisture was being allowed to penetrate the protection system at specific locations. Continuing deterioration evidenced by increasing area efflorescence on the bottom surface of the concrete deck must be considered unacceptable. Of the systems in this study, the following show some increase in area efflorescence: cathodic protection, both bridges; low slump, both bridges; Protecto Wrap, one bridge; Heavy Duty Bituthene, one bridge; Gacoflex, one bridge; and Superseal, one bridge. Basically, the problem appears to be in the curb and parapet

wall overhang area and is rather universal with all protection systems. The curb area being designed as a natural drainage device will be the area which will have the highest probability of being wet. Slow drainage from the asphaltic concrete overlay and cracking along the curbline between the concrete overlay and the parapet structure aggravate the situation.

## CATHODIC PROTECTION

Cathodic protection systems are designed, in principle, to change the electrical potential environment of the reinforcing steel causing it to become cathodic relative to the system. Various designs have emerged from research and industry to provide the anodic polarized systems to create the cathodic environment desired. The system used in this research study was basically similar to the impressed current system designed earlier by R. F. Stratfull [2].

Details of the design of the cathodic protection system for the two bridges in this study are shown in the Appendix. Basically, the cathodic system is all above the surface of the concrete deck except for the zinc half cells, ground connections, and corrosometers. All wiring is located on the surface of the concrete deck. The coke breeze asphaltic mixture used as the electrolyte to distribute the anodic charge on the deck was placed at a thickness of 2 inches. A 2 inch layer of asphaltic concrete with trap rock aggregate provided the riding surface and protection for the coke breeze asphaltic mixture and the cathodic protection system.

Performance of these cathodic protection systems is rather hard to define. As long as proper voltage levels and current flow are maintained over the concrete deck surface by the anodes and coke breeze electrolyte, the reinforcing steel will be protected. Annual surveys indicated that correct voltage levels were generally being maintained. Criteria for protection was a -0.30 volt shift to the half cell embedded in the concrete deck.

A substantial quantity of data was collected during the initial four years of this study from the half cells and anodes placed in these cathodic protection systems. The following discussion is based on trends in the data and the relationships expressed from comparisons of these trends.

During the design phase of this study, various types of half cells were described in the literature. Two types of half cells were used in this study to determine their effectiveness. The solid state copper-copper sulfate and high purity zinc half cells were used. Zinc half cells were used in a coated and uncoated condition. The coating was 75% gypsum, 20% bentonite, and 5% sodium sulfate with a thickness of 0.4 to 0.6 inches. A copper-copper sulfate half cell was placed within one foot and adjacent to each zinc half cell which was placed in the deck. These half cell pairs were to be used for comparison of the types of half cells. During this evaluation, the rectifiers were manually controlled to observe the behavior of the systems.

Initially, the rectifiers were set to cover the -0.30 volt shift at the half cell showing the most requirement. After achieving -0.30 volt polarization shift, the output of the rectifiers were gradually decreased to them keep from

overdriving the systems. Thereafter, the rectifiers were left at a constant setting to allow for study of the environmental changes.

Cathodic protection was applied to two separate bridge decks, however, these bridges were side by side on an interstate system over a city street. One bridge deck, Bridge Number L-701R was 30 feet wide (curb to curb) and the other, Bridge Number L-702R, was 42 feet wide (curb to curb) with a common longitudinal length of 179 feet. The variation gave opportunity to observe the performance of similar cathodic protection systems at two specific widths of bridge decks.

From Bridge L-701R, effects of air temperature on the distribution of the protective current was observed by comparing responses of half cells in the curb lines and the centerline of the bridges. The copper-copper sulfate half cell responses indicated that, generally, as air temperature decreases, the response of the system will be to go more negative in voltage. This follows that as the system becomes cooler and possibly more moist, the resistance to the current flow becomes less. As expected, overall current density near the centerline appears to be less affected by the resulting power fluctuations than density near the curb lines where the anodes were placed.

Protection of the most remote area on the bridge decks was checked by placing half cells in such areas. The most remote area was determined by assuming that the area of influence of each anode was a circular area. Therefore, with the anodes in a square grid layout pattern, the least protected areas would be a somewhat diamond shaped area at the centerpoint of each grid

square or rectangle as the case may be. Halfcells placed in such areas indicated sufficient protection was being afforded these areas.

Comparison of the coated and uncoated zinc and the copper-copper sulfate half cells indicate variation in responses. Generally, the coated zinc cells appear to be overprotected as compared with the -0.30 volt shift response of the accompanying copper-copper sulfate half cells. Uncoated zinc half cells showed a more sturdy response over the same period of time and was more consistent with the response of the copper-copper sulfate half cell.

Generally, from the observations of the half cells on Bridge L-701R, the uncoated zinc half cells show adequate to slightly over adequate protection is being afforded the reinforcing steel. Coated zinc half cells appear to be more variable in the voltage responses and tend to indicate more unstable results. The copper-copper sulfate half cells appear to be more susceptible to location on the deck with regard to anode placement.

Bridge L-702R, the wider of the two bridges, showed the response of both coated and uncoated zinc and copper-copper sulfate half cells placed in the curb line to be similar when comparing the peak to peak voltage fluctuations. However, the copper-copper sulfate half cells showed several readings where the system would not be properly protected. The companion uncoated zinc half cells in the curbline indicated proper protection of the system. Coated zinc half cells in the curb line on the opposite side of the bridge indicated similar

response with the copper-copper sulfate half cells and both indicated proper protection of the system.

Two questions arise when pairs of half cells are observed. First, why is the response to power outages more pronounced for one location than the other, and second, which of the half cells show the correct response. All anodes, being connected to the rectifier output through a common buss, develop the same voltage pressure for the current flow. Some anodes developed better current flow characteristics than others. Apparently, those anodes which are more active than the others will cause higher amplitude variations in the half cells which are close to them. It appears that placement of the half cells remote to the anodes will sense the general environment of the deck and better maintain proper protection. Correct response must be answered when failure occurs to the system and visual observation is made of the concrete deck in the relative locations and the records compared.

With the 42 foot width for Bridge L-702R, half cells were placed at the centerline of the main roadway or 15 feet from the north curb line and at the lane division between the main roadway and the ramp lane or 12 feet from the south curb line. Observation of the copper-copper sulfate half cells indicate somewhat similar patterns of response. Response of the copper-copper sulfate half cells when placed adjacent to coated or uncoated zinc half cells appears to be more erratic than those placed elsewhere. However, response of the copper-copper sulfate half cells appear to agree between the two bridges.

Basically, what all this information yields is a discussion of the variations that may be expected to occur within a cathodic protection system. Relative placement of the half cell with distance to the anodes and the type of half cell used could cause erroneous assumptions as to the level of protection afforded the reinforcing steel. The more sensitive the half cell is to temperature, moisture, and applied power levels from the rectifier the more constant the system will operate. Of course, the assumption with this data is that no adverse changes have occurred to or within the half cells and the readings taken are true with relation to the system. The cathodic protection system on these bridge decks appears to be operating satisfactorily.

## REFERENCES

(1) Morrison, Garrett L., et al, "Rapid In Situ Determination of Chloride Ion In Portland Cement Concrete Bridge Decks", Report No. FHWA-KS-RD-75-2, Kansas Department of Transportation, 1976, 39 pages.

(2) Stratfull, R. F., January, 1974, Interim Report, "Experimental Cathodic Protection of a Bridge Deck", Report No. FHWA-RD-74-31, Federal Highway Administration, 1974, 57 pages.

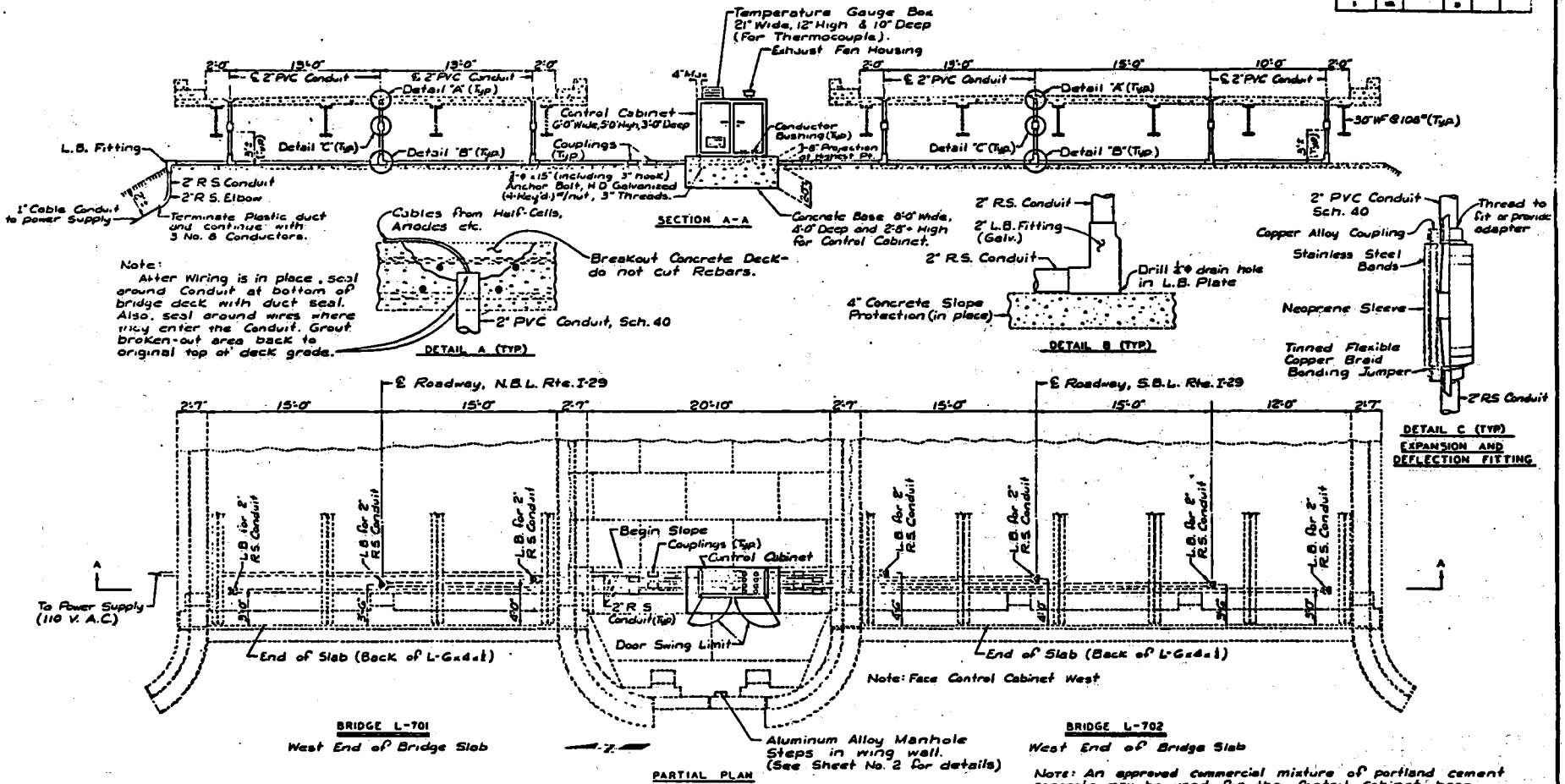
# APPENDIX

## MISSOURI HIGHWAY AND TRANSPORTATION DEPARTMENT

## CATHODIC PROTECTION SYSTEM

## PLANS AND SPECIFICATIONS

# MISSOURI STATE HIGHWAY DEPARTMENT




Note: An approved commercial mixture of portland cement concrete may be used for the Control Cabinet base.

NOTES:

All Conduit shall be Rigid Steel (Galvanized) except as noted.

Strap Conduit to Concrete Slope protection at 3 Ft. centers.

Provide Couplings as required for Rigid Steel Conduit.

Expansion and Deflection Fittings shall be equal to O.Z. Elec. Mfg. Co. Type "DX".

| ESTIMATED QUANTITES | | L-701R | L-702R | TOTAL |
|---|---|---|---|---|
| SPECIAL WORK | L. SUM | — | — | 1 |
| CATHODIC PROTECTION SYSTEM | L. SUM | — | — | 1 |
| PREFORMED COMPRESSION EXPANSION JOINT SEAL 2.5 | LIN. FT. | 60 | 84 | 144 |
| ASPHALT CEMENT (ASPHALTIC CONCRETE) | TON | 9.4 | 13.5 | 22.9 |
| MINERAL AGGREGATE (ASPH. CONC.) COKE BREEZE | TON | 30 | 45 | 75 |
| MINERAL AGGREGATE (ASPH. CONC.) SPECIAL MIXTURE | TON | 62 | 87 | 149 |
| END BENT REPAIR | L. SUM | — | — | 1 |
| REPAIRING CONCRETE DECK (HALF SOLING) | SQ. FT. | 186 | 336 | 522 |
| FULL DEPTH REPAIR | SQ. FT. | 31 | 42 | 73 |

## CATHODIC DECK PROTECTION

BRIDGE: OVER OAK STREET

PROJECT NO. I-29-1 (41) BEG. STA. 44+92.83

JOB NO. J--4 1029 22

DATE: _____

CLAY COUNTY

L-701R

L-702R

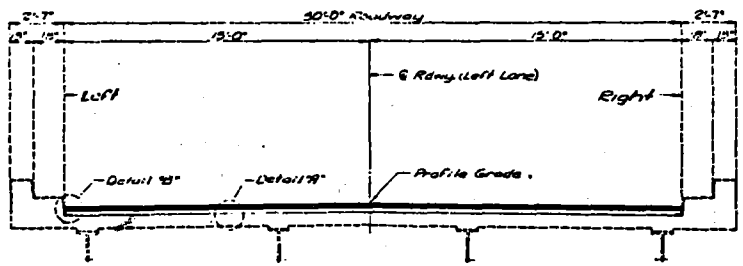
DETAILED DEC. 1975

CHECKED MAY 1976

Note: This drawing is not to scale. Follow dimensions.

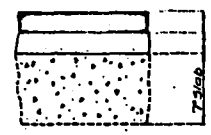
Sheet No. 1 of 10

# SOURI STATE HIGHWAY DEPARTMENT

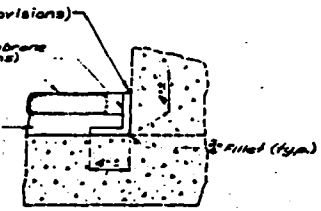



TYPICAL SECTION THRU SPANS
Illustrating Coke Breeze (lower level) and Asphalt Concrete riding surface (upper level)

Note: See tables for specific depth requirments of the Coke Breeze.




DETAIL "A"



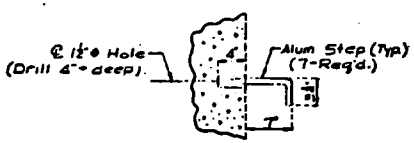

DETAIL "B"

| BILL OF REINFORCING STEEL | | | | |
|---|---|---|---|---|
| NO. | SIZE | MARK | LENGTH | |
| 4 | 6 | H1 | 32'-0" | |
| 58 | 4 | U1 | 2'-5" | U1 |

Note: Total lengths of reinforcing steel are measured along centerline bar to the nearest inch.
Length of H1 bars are figured the total width of the roadway plus 24". The Contractor shall cut at his option and provide 24" lap at splice.
All bending dimensions are out to out.

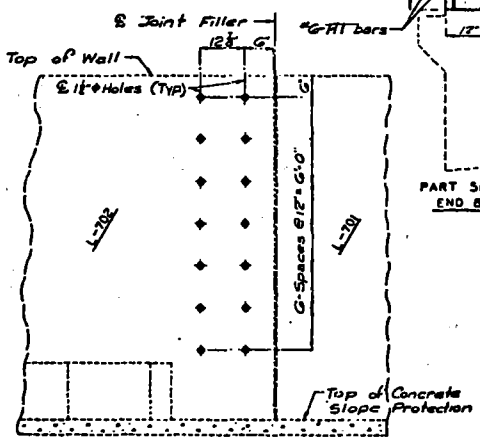
PROFILE GRADES COKE BREEZE AND ASPHALT CONCRETE THICKNESSES REQUIRED

| STATION | PROF. GR. | THICK ASPH CONC. | THICK. COKE BREEZE LEFT | ℄ LANE | RIGHT |
|---|---|---|---|---|---|
| 35+00 | 930.26 | .17 | .18 | .24 | .20 |
| +10 | .38 | .17 | .17 | .26 | .25 |
| +20 | .49 | .17 | .18 | .23 | .19 |
| +30 | .61 | .17 | .21 | .19 | .17 |
| +40 | .72 | .17 | .18 | .21 | .20 |
| +50 | .83 | .17 | .21 | .22 | .21 |
| +60 | .93 | .17 | .19 | .20 | .19 |
| [illegible] | [illegible] | .17 | .18 | .22 | .18 |
| +80 | .14 | .17 | .17 | .19 | .17 |
| +90 | .24 | .17 | .17 | .20 | .17 |
| +00 | .35 | .17 | .17 | .19 | .17 |
| +10 | .45 | .17 | .20 | .21 | .18 |
| +20 | .52 | .17 | .19 | .20 | .19 |
| +30 | .61 | .17 | .20 | .18 | .17 |
| +40 | .69 | .17 | .17 | .18 | .19 |
| +50 | .79 | .17 | .21 | .20 | .18 |
| +60 | .86 | .17 | .17 | .22 | .18 |
| 46+70 | 931.93 | .17 | .17 | .20 | .17 |



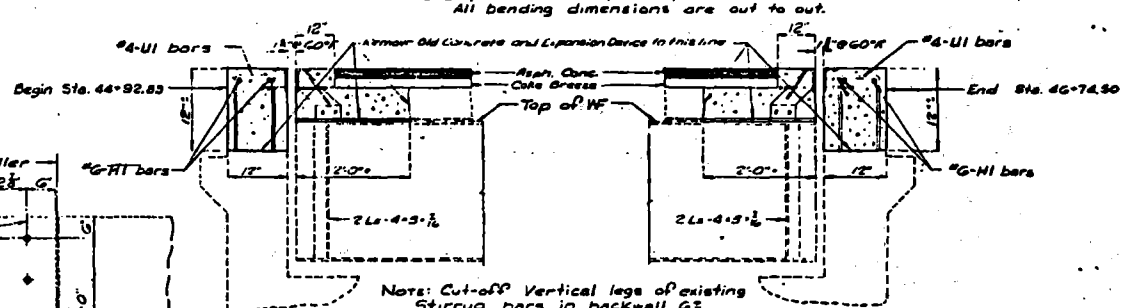

PART SECTION THRU WALL AT STEP

Note: Steps shall be embedded in grout meeting Standard Specification 1066.1.6.




PART ELEVATION OF WING WALL
(VIEW LOOKING WEST)

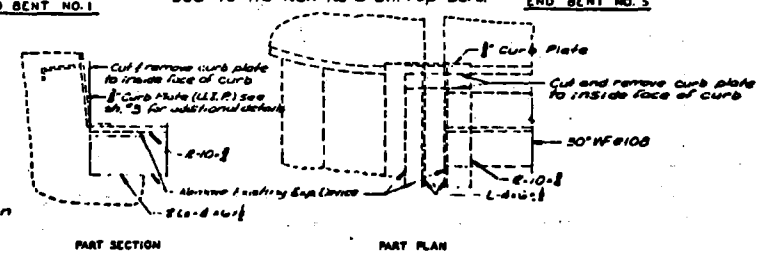
Note: Steps shall be the Alcoa Aluminum Manhole Step, Type 16027B, Aluminum Alloy 6005-T5, A.S.T.M. B221-76.




PART SECTION THRU END BENT NO. 1

PART SECTION THRU END BENT NO. 5

Note: Cut-off Vertical legs of existing Stirrup bars in backwall 6" above Cut-off Concrete line and use to tie New No 4 Stirrup bars.




PART SECTION

PART PLAN

DETAILS OF EXISTING CURB PLATE

Note: Minimum Clearance to Reinforcing Steel shall be 1½".

DETAILED Jan 1976
CHECKED May 1976

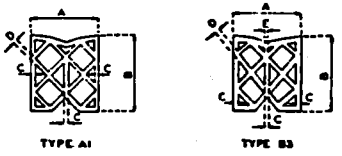
Note: This drawing is not to scale. Follow dimensions.

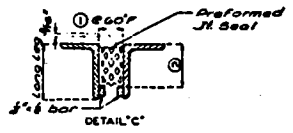
Sheet No. 2 of 10

CLAY COUNTY

L-701 R

# MISSOURI STATE HIGHWAY DEPARTMENT




| TABLE OF TRANSVERSE SEAL TOLERANCES (INCHES) | | | | | |
|---|---|---|---|---|---|
| TYPE | "A" (WIDTH) | "B" (HEIGHT) | "C" (SHELL) | "D" (WEBS) | "E" (B3 ONLY) (SMALL WEBS) |
| A1 OR B3 | 2.500 +0.250 -0.000 | 2.750 +0.125 -0.125 | 0.187 +0.046 -0.013 | 0.093 +0.031 -0.015 | 0.062 +0.031 -0.031 |

| TABLE OF TRANSVERSE SEALS & ARMOR ANGLES | | | | | | |
|---|---|---|---|---|---|---|
| TYPE | GROOVE SIZE AT 60°F. | | SEAL SIZE | | ANGLE SIZE | |
| | ① | ② | WIDTH | HEIGHT | | |
| A1 OR B3 | 1⅛" | 4" | 2½" | 2⅞" | 5x3x⅜ | USE AT BTS. 1 & 5 |

GENERAL NOTES:

Structural Steel for the armored joint of the expansion device shall be fabricated in two sections for construction of approximately ½ the roadway width at a time. The two sections of angles shall be seal welded on the roadway face and down 1" on the vertical leg. True alignment of the angles will be required. The expansion device shall be bent to conform to crown and grade of roadway. The length of angles (curb to curb) shall be determined by field measurement before fabrication.

No. 5 bars for expansion device shall be structural grade.

Approved stud welded anchors or deformed bar anchors (ASTM A496) may be used in lieu of #5 bars shown.

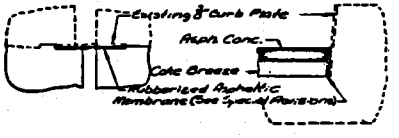
Preformed Compression Joint Seal shall be installed, full roadway width between curb plates.

Payment for furnishing and placing structural steel for expansion device and preformed joint seal shall be made under unit price bid per foot for Expansion Device.

Plan dimensions are based on installation at 60°F.

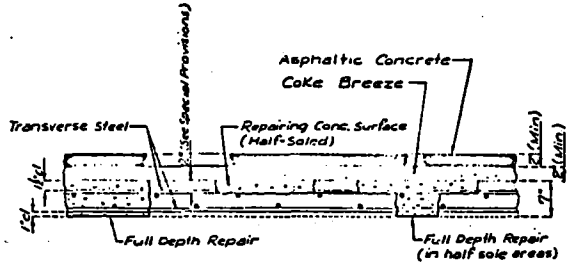
See Special Provisions for the requirements of Compression Joint Seal.

All structural steel shall be A36 and galvanized in accordance with ASTM A-123



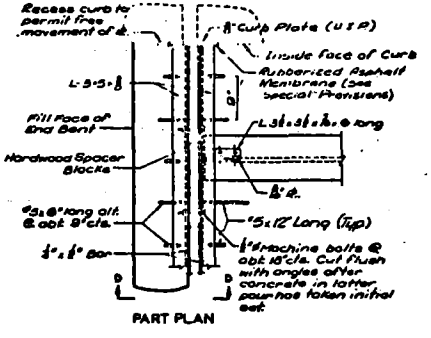

PART PLAN

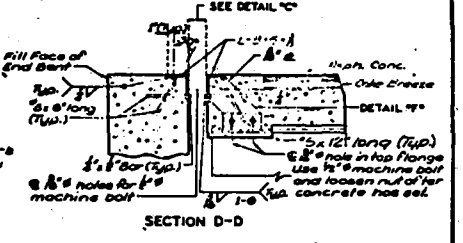
PART SECTION THRU CURB PLATE

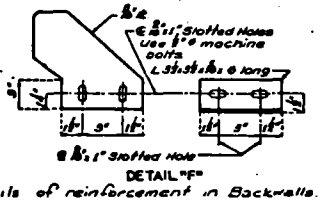



PART CROSS SECTION THRU SLAB

| TABLE OF GROOVE SIZE "①" (INSTALLATION DIMENSIONS) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| TEMP. (°F.) | SEAL WIDTHS | | | | | | | |
| | CONCRETE STRUCTURES | | | | STEEL STRUCTURES | | | |
| | 2½" | 3" | 3½" | 4" | 2½" | 3" | 3½" | 4" |
| -10° | – | – | – | – | 2⅛" | 2⅜" | 3" | 3⅜" |
| 0° | 2⅛" | 2⅜" | 3" | 3⅜" | 2" | 2¼" | 2⅝" | 3¼" |
| +20° | 1⅞" | 2¼" | 2⅝" | 3⅛" | 1⅞" | 2¼" | 2⅝" | 3" |
| +40° | 1⅝" | 2⅛" | 2½" | 2⅞" | 1⅝" | 2⅛" | 2½" | 2⅞" |
| +60° | 1⅜" | 1⅞" | 2¼" | 2⅝" | 1⅜" | 1⅞" | 2¼" | 2⅝" |
| +80° | 1⅜" | 1⅝" | 2" | 2⅜" | 1⅜" | 1⅝" | 2" | 2⅜" |
| +100° | 1¼" | 1⅝" | 1⅞" | 2" | 1¼" | 1⅝" | 1⅞" | 2⅜" |
| +110° | 1⅛" | 1⅜" | 1⅝" | 1⅞" | 1⅛" | 1⅜" | 1⅝" | 2" |
| +120° | – | – | – | – | 1⅛" | 1⅜" | 1⅝" | 1⅞" |




Note: See Sheet No. 2 for details of reinforcement in Backwalls.

## DETAILS AT END BENTS NO. 1 & 5

DETAILED Jan. 1976
CHECKED May 1976

Note: This drawing is not to scale. Follow dimensions.

Sheet No. 3 of 10.

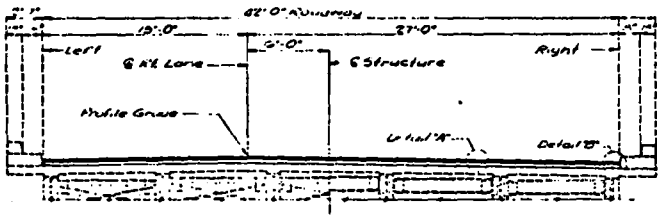
CLAY COUNTY

L-701 R

# MISSOURI STATE HIGHWAY DEPARTMENT

| FED. ROAD DIST. NO. | STATE | FED. AID PROJ. NO. | FISCAL YEAR | SHEET NO. | TOTAL SHEETS |
|---|---|---|---|---|---|
| 5 | MO. | | 19 | | |

Note: See tables for specific depth requirments of the Coke Breeze.

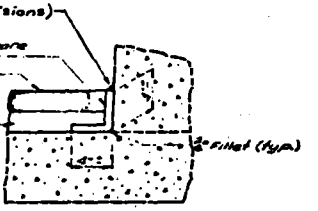



HALF SECTION NEAR INT. BENTS — HALF SECTION SHOWING END DIAPHRAGM

Illustrating Coke Breeze (lower level) and Asphaltic Concrete riding surface (upper level)

DETAIL "A"

| BILL OF REINFORCING STEEL | | | | |
|---|---|---|---|---|
| NO. | SIZE | MARK | LENGTH | |
| 4 | 6 | H2 | 44'-0" | |
| 84 | 4 | U2 | 2'-5" | U2 |



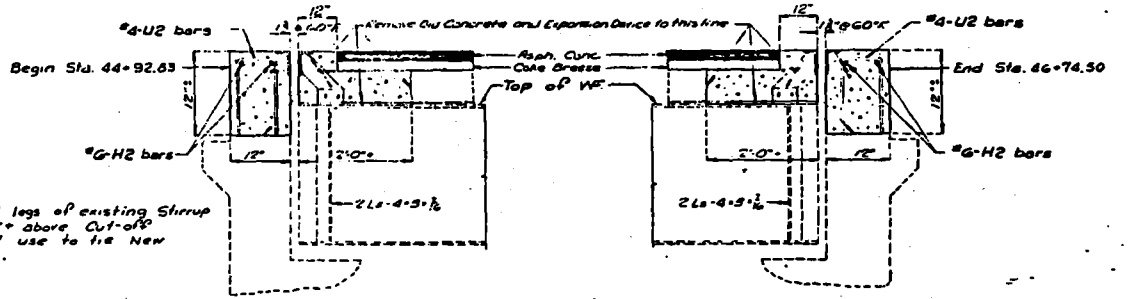

DETAIL "B"

Note: Total lengths of reinforcing steel are measured along centerline bar to the nearest inch.
Length of H2 bars are figured the total width of the roadway plus 24". The Contractor shall cut at his option and provide 24" lap at splice.
All bending dimensions are out to out.

Profile Grades, Coke Breeze and Asph. Conc. thickness req'd.

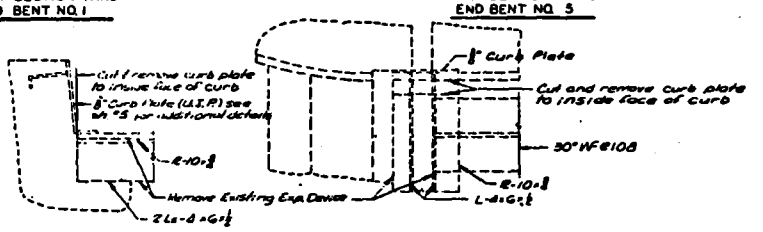
| STATION | PROFILE GRADE | THICK ASPH. CONC. | THICK COKE BREEZE LEFT | ℄ LANE | RIGHT |
|---|---|---|---|---|---|
| 45+10 | [illegible] | .17 | .17 | [illegible] | .17 |
| +10 | .37 | .17 | .18 | [illegible] | .18 |
| +20 | .39 | .17 | .22 | .26 | .18 |
| +30 | .40 | .17 | .20 | .21 | .17 |
| +40 | .71 | .17 | .20 | .27 | .18 |
| +50 | .82 | .17 | .20 | .24 | .18 |
| +60 | .91 | .17 | .17 | .26 | .18 |
| +70 | 931.03 | .17 | .18 | .24 | .18 |
| +80 | .15 | .17 | .17 | .26 | .17 |
| +90 | .23 | .17 | .17 | .22 | .17 |
| 46+00 | .34 | .17 | .17 | [illegible] | .17 |
| +10 | .42 | .17 | .17 | .27 | .17 |
| +20 | .51 | .17 | .17 | .25 | .17 |
| +30 | .60 | .17 | .19 | .26 | .20 |
| +40 | .69 | .17 | .17 | .24 | .17 |
| +50 | .77 | .17 | .17 | .23 | .17 |
| +60 | .85 | .17 | .17 | .22 | .17 |
| 46+70 | 931.93 | .17 | .17 | .28 | .17 |
| | | | | | |

Note: Cut-off Vertical legs of existing Stirrup bars in backwall 6" above Cut-off Concrete line and use to tie New No. 4 stirrup bars.




PART SECTION THRU END BENT NO. 1

PART SECTION THRU END BENT NO. 5




PART SECTION — PART PLAN

DETAILS OF EXISTING CURB PLATE

Note: Minimum Clearance to Reinforcing Steel shall be 1½".

DETAILED JUN 19[illegible]
CHECKED MAY 19[illegible]

Note: This drawing is not to scale. Follow dimensions.

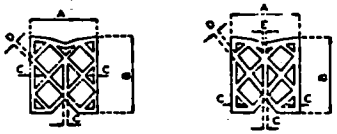
Sheet No. 4 of 10

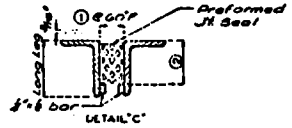
CLAY COUNTY

L-702 R

# MISSOURI STATE HIGHWAY DEPARTMENT

| FED. ROAD DIST. NO. | STATE | FED. AID PROJ. NO. | FISCAL YEARS | SHEET NO. | TOTAL SHEETS |
|---|---|---|---|---|---|
| 5 | MO | | 19 | | |




GENERAL NOTES:

Structural Steel for the armored joint of the expansion device shall be fabricated in two sections for construction of approximately ½ the roadway width at a time. The two sections of angles shall be seal welded on the roadway line and down 1" on the vertical leg. True alignment of the angles will be required. The expansion device shall be bent to conform to crown and grade of roadway. The length of angles (curb to curb) shall be determined by field measurement before fabrication.

No. 5 bars for expansion device shall be structural grade.

Approved stud welded anchors or deformed bar anchors (ASTM A496) may be used in lieu of #5 bars shown.

Preformed Compression Joint Seal shall be installed, full roadway width between curb plates.

Payment for furnishing and placing structural steel for expansion device and preformed joint seal shall be made under unit price bid per foot for Expansion Device.

Plan dimensions are based on installation at 60°F.

See Special Provisions for the requirements of Compression Joint Seal.

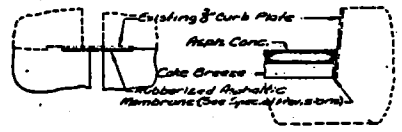
All structural steel shall be A36 and galvanized in accordance with ASTM A-123.

TABLE OF TRANSVERSE SEAL TOLERANCES (INCHES)

| TYPE | "A" (WIDTH) | "B" (HEIGHT) | "C" (SHELL) | "D" (WEBS) | "E" (B3 ONLY) (SMALL WEBS) |
|---|---|---|---|---|---|
| A1 OR B3 | 2.500 +0.250 -0.000 | 2.750 +0.125 -0.125 | 0.187 +0.048 -0.015 | 0.093 +0.031 -0.015 | 0.062 +0.031 -0.031 |

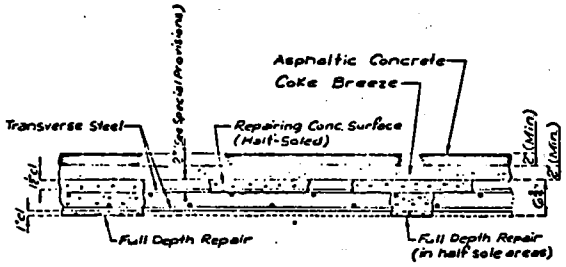
TABLE OF TRANSVERSE SEALS & ARMOR ANGLES

| TYPE | GROOVE SIZE AT 60°F. ① | GROOVE SIZE AT 60°F. ② | SEAL SIZE WIDTH | SEAL SIZE HEIGHT | ANGLE SIZE | |
|---|---|---|---|---|---|---|
| A1 OR B3 | 1⅞" | 4" | 2½" | 2¾" | 3x3x⅜ | Use at Bts. 1 & 5 |




PART PLAN

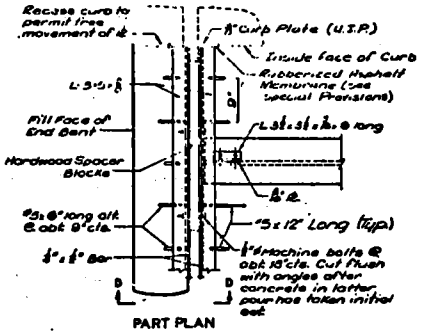
PART SECTION THRU CURB PLATE



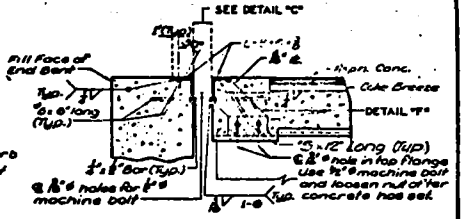

PART CROSS SECTION THRU SLAB

TABLE OF GROOVE SIZE "①" (INSTALLATION DIMENSIONS)

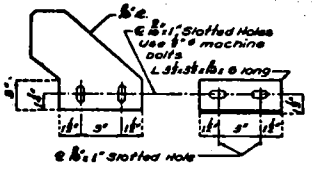
| TEMP. (°F.) | SEAL WIDTHS: CONCRETE STRUCTURES 2½" | 3" | 3½" | 4" | STEEL STRUCTURES 2½" | 3" | 3½" | 4" |
|---|---|---|---|---|---|---|---|---|
| -10° | – | – | – | – | 2 1/16" | 2 7/16" | 3" | 3 7/16" |
| 0° | 2 1/16" | 2 7/16" | 3" | 3 7/16" | 2" | 2 1/32" | 2 7/16" | 3 1/16" |
| +20° | 1 7/16" | 2 1/32" | 2 7/16" | 3 1/16" | 1 7/16" | 2 1/32" | 2 7/16" | 3" |
| +40° | 1 3/16" | 2 1/16" | 2 1/32" | 2 7/16" | 1 3/16" | 2 1/16" | 2 1/16" | 2 7/16" |
| +60° | 1 3/16" | 1 7/16" | 2 1/32" | 2 7/16" | 1 3/16" | 1 7/16" | 2 1/32" | 2 7/16" |
| +80° | 1 1/16" | 1 3/16" | 2" | 2 1/16" | 1 1/16" | 1 3/16" | 2" | 2 1/32" |
| +100° | 1 1/32" | 1 1/16" | 1 3/16" | 2" | 1 1/32" | 1 1/16" | 1 3/16" | 2 1/16" |
| +110° | 1 1/16" | 1 1/16" | 1 1/16" | 1 3/16" | 1 1/32" | 1 1/32" | 1 1/16" | 2" |
| +120° | – | – | – | – | 1 1/16" | 1 1/16" | 1 1/16" | 1 3/16" |




PART PLAN




SECTION D-D




DETAIL "F"

Note: See Sheet No. 4 for details of reinforcement in Backwalls

DETAILS AT END BENTS NO. 1 & 5

DETAILED Jan. 1976
CHECKED MAY 1976

Note: This drawing is not to scale. Follow dimensions.

Sheet No. 5 of 10.

CLAY COUNTY

L-702 R

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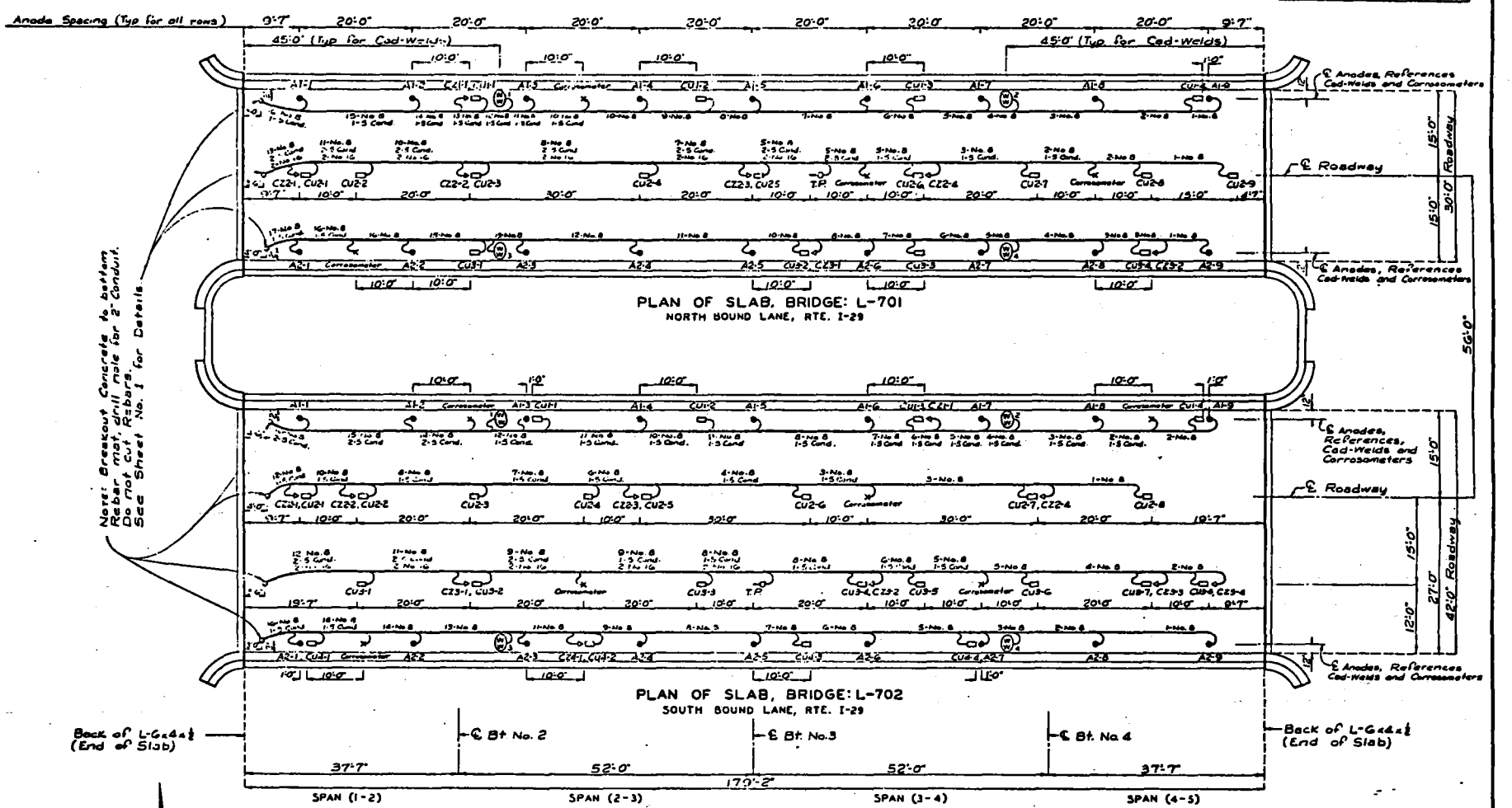
# MISSOURI STATE HIGHWAY DEPARTMENT




Note: See Sheet No. 1 for location of Control Cabinet. See Sheet No. 7 for details of Temp. Probe Anodes and Half Cells.

DETAILED DEC. 1975
CHECKED MAY 1976

Note: This drawing is not to scale, follow dimensions.

Sheet No. 6 of 10

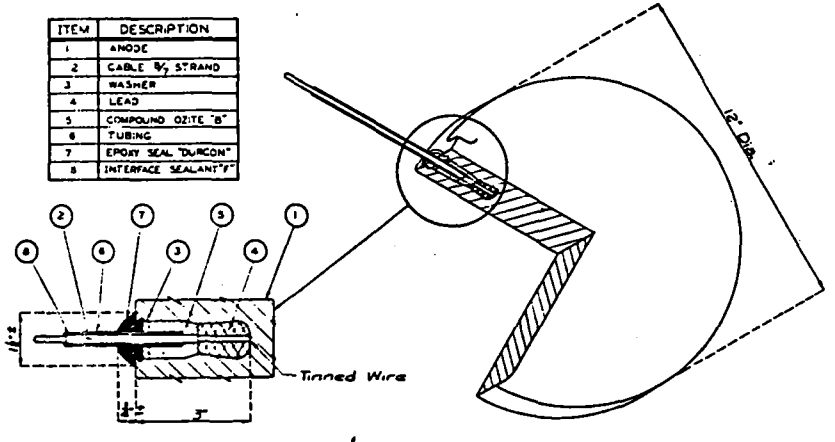
CLAY COUNTY

L-701 R
L-702 R

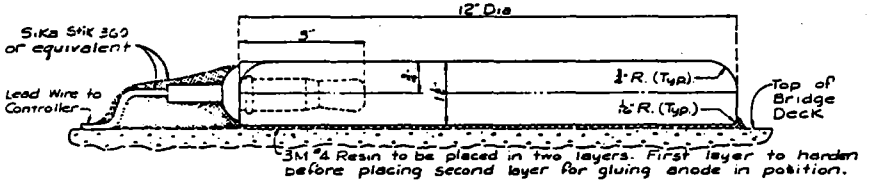
# M. OURI STATE HIGHWAY DEP. MENT

| FED. ROAD DIST. NO. | STATE | FED. AID PROJ. NO. | FISCAL YEAR | SHEET NO. | TOTAL SHEETS |
|---|---|---|---|---|---|
| 5 | MO | | 19 | | |

| ITEM | DESCRIPTION |
|---|---|
| 1 | ANODE |
| 2 | CABLE 6/7 STRAND |
| 3 | WASHER |
| 4 | LEAD |
| 5 | COMPOUND OZITE "B" |
| 6 | TUBING |
| 7 | EPOXY SEAL "DURCON" |
| 8 | INTERFACE SEALANT "F" |

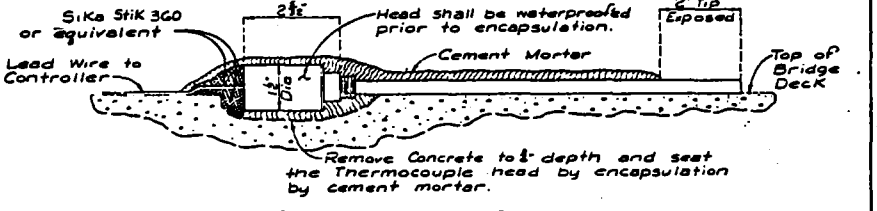



ANODE BY DURIRON CO. INC. DAYTON, OHIO



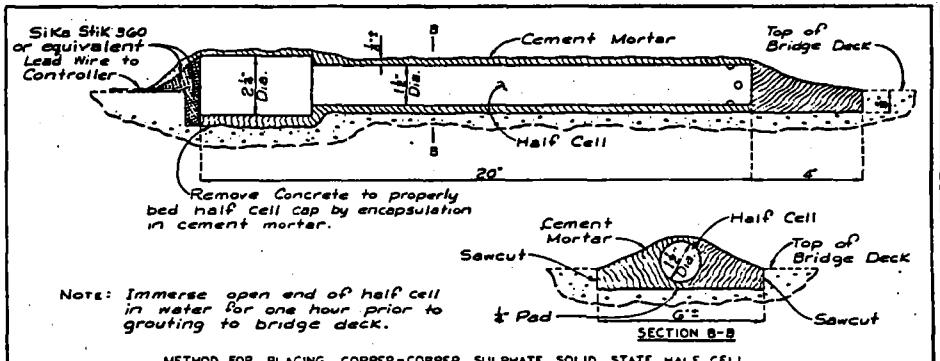

3M #4 Resin to be placed in two layers. First layer to harden before placing second layer for gluing anode in position.

METHOD FOR PLACING ANODE



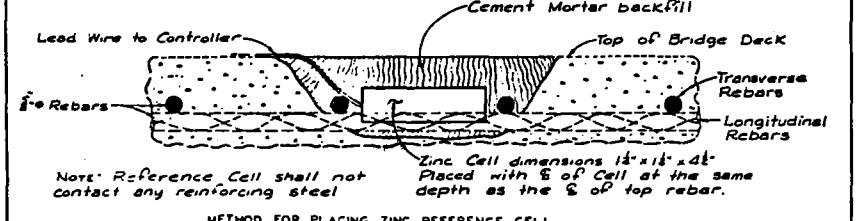

METHOD FOR PLACING THERMOCOUPLE

Thermocouple: Catalog Number 8784-T-3-5-12-1-1-0 (Leeds-Northrup Co.)
Thermocouple Wire: Number 16-56-18, Type TX, Solid.




Note: Immerse open end of half cell in water for one hour prior to grouting to bridge deck.

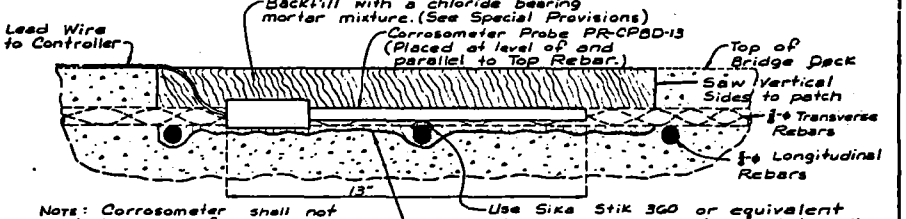
METHOD FOR PLACING COPPER-COPPER SULPHATE SOLID STATE HALF CELL




Note: Reference Cell shall not contact any reinforcing steel

METHOD FOR PLACING ZINC REFERENCE CELL

Note: Cells CZ2-1, CZ2-3 and CZ3-1 on bridge L-701 and cells CZ2-1, CZ2-3, CZ3-1, CZ2-3 and CZ4-1 on bridge L-702 shall be cast in a coating of 75% gypsum, 20% bentonite, 5% sodium sulfate and binder in the factory. This coating shall have a thickness of 0.4 inch minimum and 0.6 maximum. Any cracking observed in this coating shall be repaired and shall be thoroughly dry prior to placement on the deck. All other zinc reference cells shall remain as bare zinc.




Note: Corrosometer shall not contact any reinforcing steel.
Concrete shall be removed to the depth necessary to completely encapsulate the corrosometer probe in chloride bearing mortar.

Use Sika Stik 360 or equivalent where necessary to insulate all reinforcing steel exposed to the chloride bearing mortar.

METHOD FOR PLACING CORROSOMETERS

Note: See Sheet No. 6 for location of Anodes, Thermocouple, Corrosometers and Half Cells.

DETAILED JAN. 1976
CHECKED MAR 1976

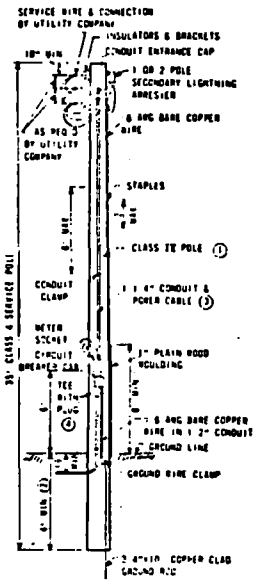
Note: This drawing is not to scale. Follow dimensions.

Sheet No. 7 of 10.

CLAY COUNTY

L-701R
L-702R

# MISSOURI STATE HIGHWAY DEPARTMENT

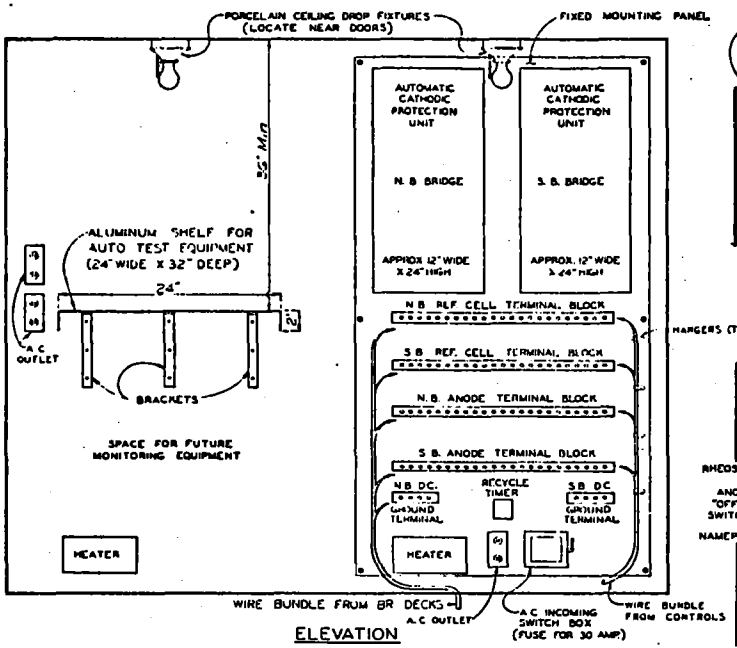



① SERVICE POLE SHALL BE GUYED WHEN SPAN OF SERVICE WIRE EXCEEDS 50 FEET.
② INCREASE 1 FOOT FOR EACH 5 FEET IN LENGTH ABOVE 20 FEET.
③ WHEN POWER SUPPLY ASSEMBLY IS ON A UTILITY COMPANY POLE USE RS CONDUIT AND COIL SERVICE ENTRANCE CABLES AT METER BOX WITH LENGTH SUFFICIENT TO REACH UTILITY COMPANY SECONDARY AND FORM DRIP LOOP
④ TO BE CONNECTED TO CIRCUIT BREAKER CABINET

## POWER SUPPLY ASSEMBLY

NOTE POWER SUPPLY ASSEMBLY SHALL BE MODIFIED TO PROVIDE FOR 110 VOLT SERVICE.

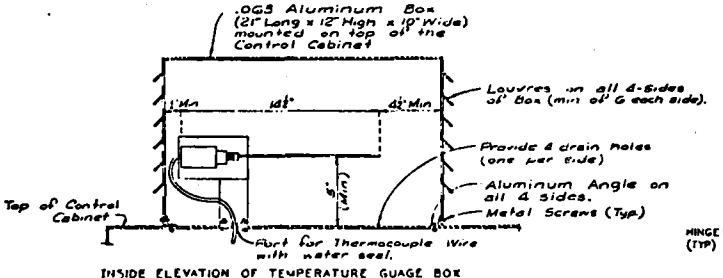
FOR TRENCHING DETAILS SEE STANDARD DRAWING 901.30.




ELEVATION

General Layout for equipment position in Control Cabinet. (Doors and Hinged Panel not shown). (View looking East) See Sheet No 1 for location of Control Cabinet.

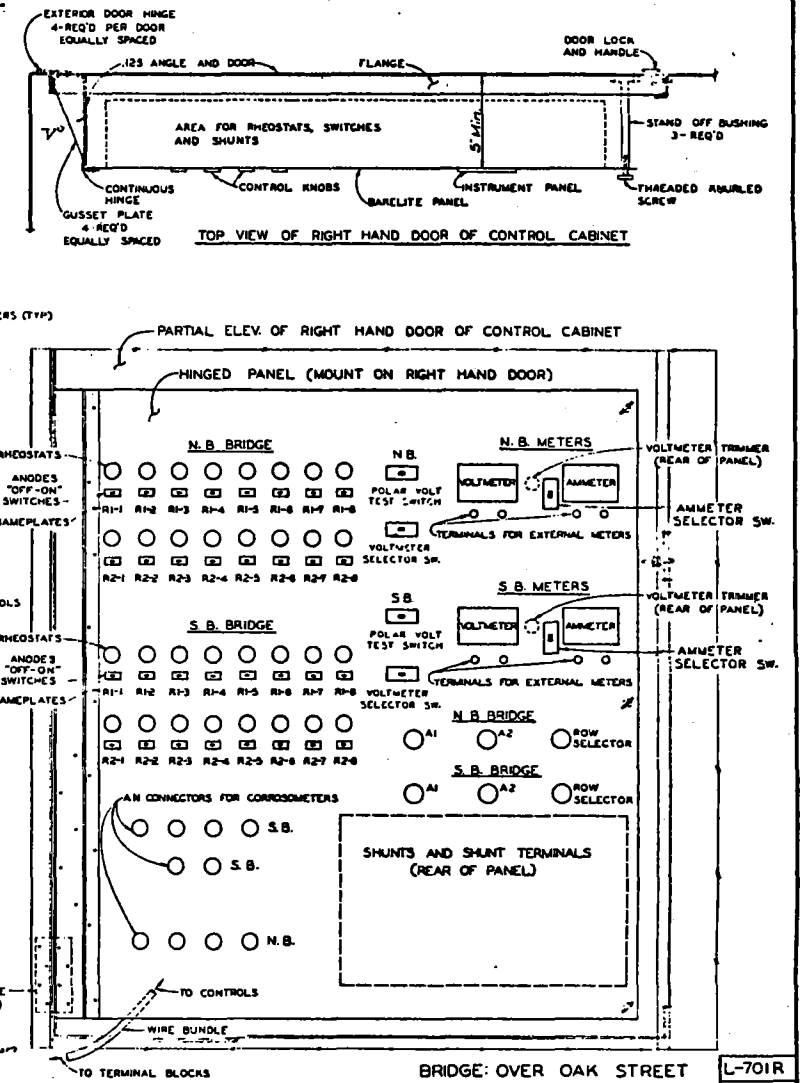
Notes: Provide expanded Wire Caps over Heaters.
Provide adequate space for Wire Bundles.
Provide Aluminum hinged shelf 18" wide x 24" deep on inside of Left Door (Locate approx. 30"± from top of Door.




INSIDE ELEVATION OF TEMPERATURE GUAGE BOX

(View looking East)

See Sheet No 1 for location of Temperature Gauge Box.



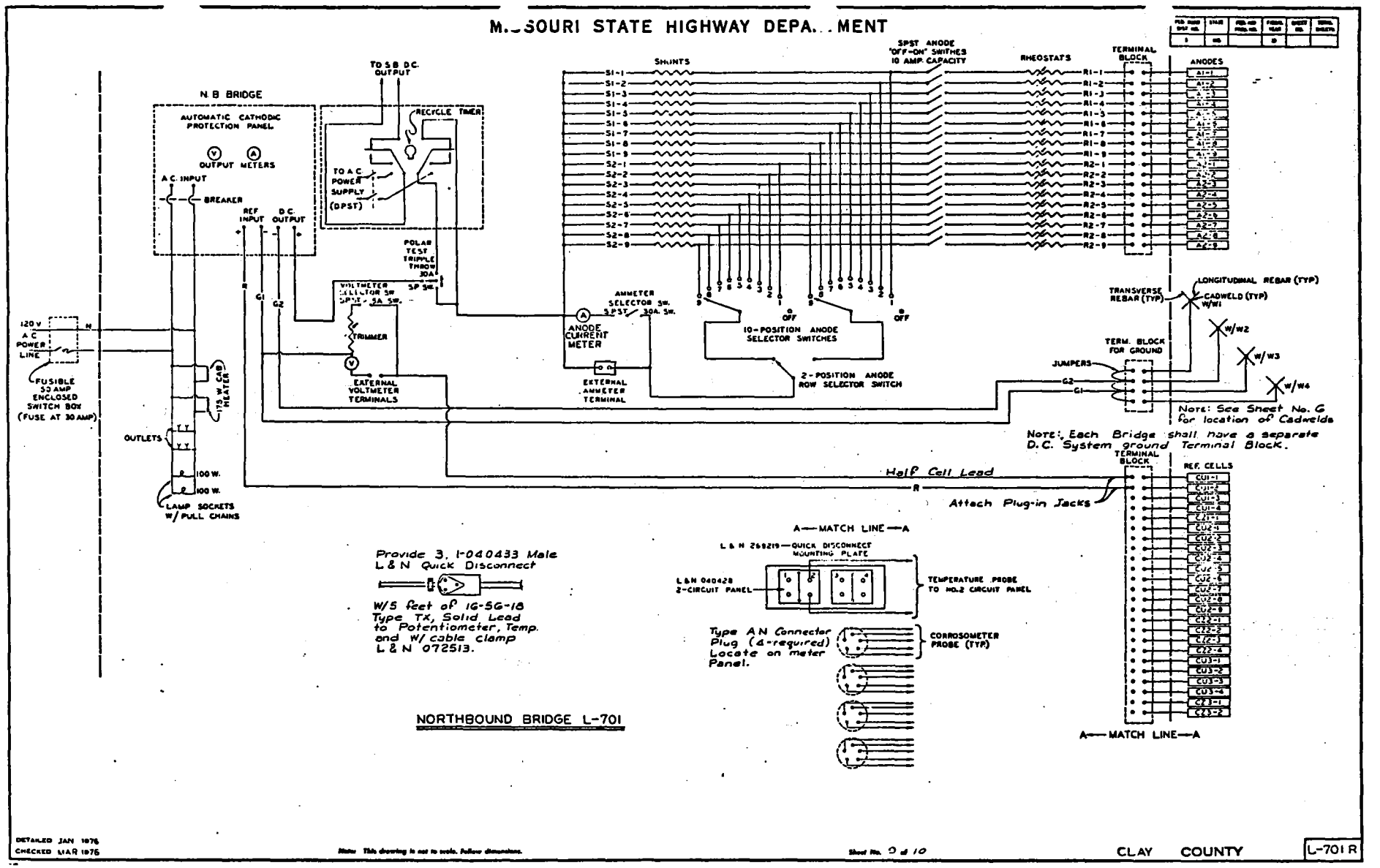

DETAILED JAN 1976
CHECKED MAY 1976

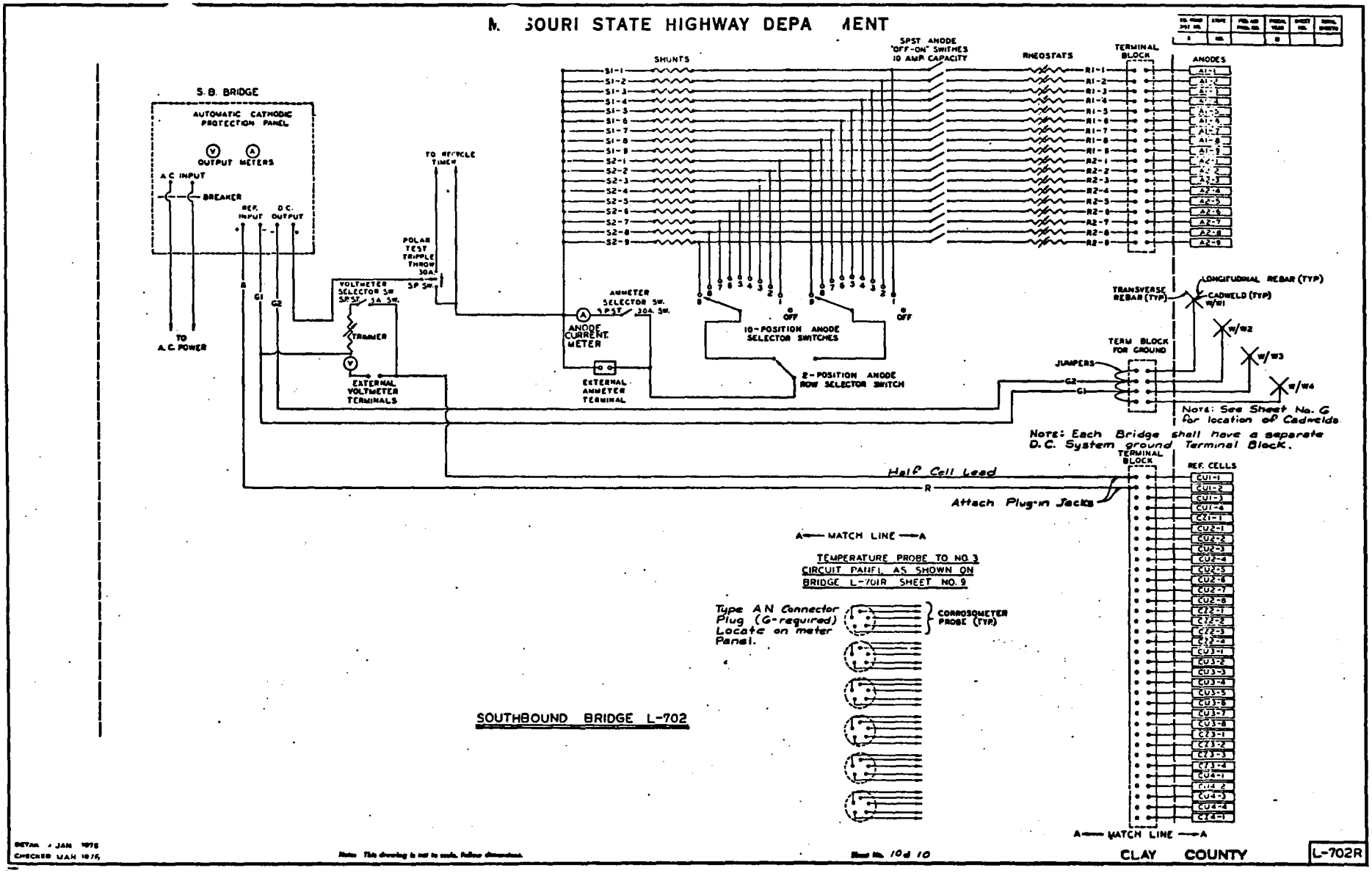
Note: This drawing is not to scale. Follow dimensions.

Sheet No. 8 of 10.

BRIDGE: OVER OAK STREET
CLAY COUNTY

L-701R
L-702R


MISSOURI STATE HIGHWAY DEPARTMENT
N. B. BRIDGE
AUTOMATIC CATHODIC PROTECTION PANEL
OUTPUT METERS
A.C. INPUT
BREAKER
REF INPUT
D.C. OUTPUT
TO S.B. D.C. OUTPUT
RECYCLE TIMER
TO A.C. POWER SUPPLY (DPST)
POLAR TEST TRIPPLE THROW 30A
VOLTMETER SELECTOR SW SPST - 5A SW.
SP SW.
TRIMMER
EXTERNAL VOLTMETER TERMINALS
120 V A.C. POWER LINE
FUSIBLE 50 AMP ENCLOSED SWITCH BOX (FUSE AT 30 AMP)
175 W. CAB HEATER
OUTLETS
100 W.
100 W.
LAMP SOCKETS W/ PULL CHAINS
SHUNTS
SPST ANODE "OFF-ON" SWITHES 10 AMP. CAPACITY
RHEOSTATS
TERMINAL BLOCK
ANODES
AMMETER SELECTOR SW. SPST 30A. SW.
ANODE CURRENT METER
EXTERNAL AMMETER TERMINAL
10-POSITION ANODE SELECTOR SWITCHES
2-POSITION ANODE ROW SELECTOR SWITCH
OFF
TRANSVERSE REBAR (TYP)
LONGITUDINAL REBAR (TYP)
CADWELD (TYP) W/W1
W/W2
W/W3
W/W4
TERM. BLOCK FOR GROUND
JUMPERS
Note: See Sheet No. 6 for location of Cadwelds
Note: Each Bridge shall have a separate D.C. System ground Terminal Block.
Half Cell Lead
Attach Plug-in Jacks
REF. CELLS
A—MATCH LINE—A
L & N 269219—QUICK DISCONNECT MOUNTING PLATE
L & N 040428 2-CIRCUIT PANEL
TEMPERATURE PROBE TO NO. 2 CIRCUIT PANEL
Type A N Connector Plug (4-required) Locate on meter Panel.
CORROSOMETER PROBE (TYP)
Provide 3, 1-040433 Male L & N Quick Disconnect
W/5 feet of 16-SG-18 Type TX, Solid Lead to Potentiometer, Temp. and W/ cable clamp L & N 072513.
NORTHBOUND BRIDGE L-701
DETAILED JAN 1976
CHECKED MAR 1976
Sheet No. 9 of 10
CLAY COUNTY
L-701 R


M. SOURI STATE HIGHWAY DEPA MENT
S. B. BRIDGE
AUTOMATIC CATHODIC PROTECTION PANEL
OUTPUT METERS
A.C. INPUT
BREAKER
REF. INPUT
D.C. OUTPUT
TO A.C. POWER
TO RECYCLE TIMER
POLAR TEST TRIPPLE THROW 30A
SP SW
VOLTMETER SELECTOR SW SPST 3A SW.
TRIMMER
EXTERNAL VOLTMETER TERMINALS
ANOMETER SELECTOR SW. SPST 30A SW.
ANODE CURRENT METER
EXTERNAL AMMETER TERMINAL
SHUNTS
SPST ANODE "OFF-ON" SWITHES 10 AMP CAPACITY
10-POSITION ANODE SELECTOR SWITCHES
2-POSITION ANODE ROW SELECTOR SWITCH
OFF
RHEOSTATS
TERMINAL BLOCK
ANODES
TRANSVERSE REBAR (TYP)
LONGITUDINAL REBAR (TYP)
CADWELD (TYP) W/W1
W/W2
W/W3
W/W4
TERM BLOCK FOR GROUND
JUMPERS
Note: See Sheet No. 6 for location of Cadwelds
Note: Each Bridge shall have a separate D.C. System ground Terminal Block.
Half Cell Lead
Attach Plug-in Jacks
REF. CELLS
A MATCH LINE A
TEMPERATURE PROBE TO NO 3 CIRCUIT PANEL AS SHOWN ON BRIDGE L-701R SHEET NO. 9
Type AN Connector Plug (6-required) Locate on meter Panel.
CORROSOMETER PROBE (TYP)
SOUTHBOUND BRIDGE L-702
CLAY COUNTY
L-702R

EEE SPECIAL WORK - BRIDGES L-701R and L-702R - Project I-IR-29-1(41)

The items of special work consist of the following:

Removing the existing concrete slope protection and excavation necessary for the construction of the concrete base for the control cabinet as shown on the plans.

Constructing concrete base complete in place including anchor bolts and installing conduit. The anchor bolts shall be located by a template supplied by the manufacturer of the control cabinet. Furnish and install aluminum ladder at wingwall as shown on bridge plans.

The entire length of the curb face exposed to the coke breeze asphaltic concrete shall be sealed with a sheet type rubberized asphalt membrane before the tack coat is applied to the deck.

The materials used to seal this curb area shall consist of:

A cold-applied self-adhering membrane incorporating a woven polypropylene mesh embedded between a layer of self-adhesive rubberized asphalt and non-tacky bituminous compound; a primer; and a mastic. The system shall be the Heavy Duty Bituthene Waterproofing Membrane System, a product of Construction Products Division, W. R. Grace and Company.

The sides of the curbs from the junction with the deck to the top of the proposed asphalt wearing surface and approximately four inches onto the deck shall be thoroughly cleaned by the use of air jets, sandblasting, mechanical sweeper, hand brooms, or other approved methods, or as directed by the engineer until this surface area is free of sand, clay, dust, salt deposits, oil or grease deposits, and all loose or foreign matter. The surface of the deck shall be visibly dry prior to and during application.

Inside corners at curb faces shall have a minimum 3/4-inch fillet of concrete grout or epoxy mortar.

Application of the membrane system shall be in strict accordance with the manufacturer's instructions. The contractor shall acquaint himself with the materials specified and their handling characteristics. He shall be thoroughly familiar with the construction procedures recommended by the manufacturer before application of the system. The contractor shall furnish the engineer a copy of the manufacturer's printed instructions for application and construction procedures recommended.

Neither the primer nor the membrane shall be applied when the air temperature or deck temperature is below 40F. The deck shall be surface-dry at the time of application of the primer.

Primer shall be applied uniformly with a brush or roller and worked thoroughly into the concrete surface at an approximate rate of one gallon per 250 to 350 square feet. The primer shall be allowed to dry until tack free (approximately one hour) before applying the membrane. Primer shall only be applied to an area that will be covered with Heavy Duty Bituthene membrane within 24 hours. If the membrane is not placed over the primer within 36 hours or if the surface of the membrane becomes contaminated, the area shall be reprimed. Metal surfaces shall not be primed.

Primer shall be applied to the curb faces from the junction at the curb to the top of the proposed asphalt wearing surface and four inches onto the deck.

After the primer has dried to a tack free condition, the membrane shall be applied to the primed surface area. The membrane shall extend full bridge length.

Special care shall be used at the curb face to insure that the membrane is uniformly adhered to the concrete. The entire membrane shall be free of wrinkles, air bubbles, and other placement defects. In the event bubbles or blisters do form under the membrane, they shall be punctured with a sharp pointed instrument such as an awl and the membrane pressed firmly into contact with the deck. The small puncture opening should be self-sealing, however, openings which are considered to be too large to self-seal shall be patched as directed by the engineer.

The edges of the membrane on the curb faces shall have a troweled bead of mastic applied to insure a seal at the curb face. Any terminating edge of the membrane system shall be sealed in the same manner.

Payment for the above described special work will be made and considered completely covered under the unit price bid, lump sum, for Special Work which price shall include excavation, all materials, disposal, equipment, tools, labor and any other work incidental thereto.

FFF. ELECTRICAL SYSTEM - BRIDGES L-701R and L-702R - Project I-IR-29-1(41)

The cathodic deck protection system for prevention of deck deterioration from reinforcing steel corrosion is required.

The electrical phase of the work shall consist of the installation of anodes, half cells, corrosometers, temperature probe, control cabinet, power supply, conduit system and all associated wiring necessary to make the cathodic protection system function as designed.

The control cabinet and any associated instruments shall be installed and operational prior to beginning of installation of electrical system on the deck.

The contractor shall have a technical representative from an approved cathodic protection consulting firm present on the job during the final inspection of the wiring in the control cabinet and during activation of the systems after completion of the asphaltic concrete overlay and cathodic system. The contractor shall be responsible for notifying the company representative or technical consultant prior to the date of installation or inspection where he is required. The expense of having this representative on the job shall be the contractor's responsibility and no direct payment will be made for this expense.

The control cabinet shall be of 0.125-inch sheet aluminum adequately reinforced, with double doors, with tumbler equipped type locks mounted in door handles. The door shall fit against rain tight rubber gaskets. The door hinges and pins shall be of corrosion resistant metal. The cabinet shall have a thermostatically controlled ventilating fan with exhausting capability, in a water-tight enclosure, of at least 250 c.f.m. installed in the top of the cabinet. The cabinet shall be supplied with a replaceable furnace type fiber glass filter of at least two square foot area mounted behind louvers located in the lower one-fourth of the left door (when facing the cabinet). The cabinet shall be of the size as shown on the plans. The cabinet shall be equipped with two 225-watt thermostatically controlled heaters. The cabinet doors shall be equipped with heavy duty door stops to hold doors open during testing and data gathering periods.

Electrical equipment and materials shall be as follows:

(a) Two 100-watt lamps with individual switches shall be installed in the center front of each door opening in the top of the cabinet.

(b) A 100-foot 3-lead extension cord of 110 volts on a suitable storage reel shall be provided and become part of this system, and remain in the cabinet.

(c) Automatic Cathodic Protection Units shall be RIO Constant Potential Control Model without enclosure.

The rectifier shall be of the selenium type with maximum output of 28 volts DC and 20 amps. The transformer shall be provided with 3 coarse and 6 fine tap adjustments which may be manually set. The units shall operate with any reference within the range of +15 volts and -15 volts.

The units shall employ solid state circuitry for dependable operation and minimum "down time." The units shall be equipped with an automatic current limiter and shall hold potential within $\pm$ 5 millivolts. The units shall be equipped with automatic surge protection and automatic "fail safe" to effect shut down if reference lead wires are broken or if an external electrical surge is induced from the DC side. Each unit shall be equipped with a volt meter and an ammeter to measure output voltage and total current flow.

(d) The rectifier volt meter shall be scaled to read to the nearest 0.2 volts and the ammeter scaled to read to the nearest 0.2 amps.

(e) Annode shunts shall be 0.01 ohm pigtail type meter shunts as manufactured by Holloway, Type RS, 5 Amp, 50 mv. and one end shall be soldered to a common bus bar or bars.

(f) The rheostats shall be 50 ohm, 25 watt, vitreous enamel rheostats, Ohmite Model H with 1-1/2 inch finger grip knob.

(g) A SPST, 10 amp capacity, switch shall be located in line with the rheostats whereby individual anodes may be disconnected from the system at any time desired. These switches shall be flush mounted on the control panel immediately below the rheostat to which it belongs.

(h) Anode selector switches shall be silicon treated ceramic switches with 30 amp, 5 volt DC coin silver contacts, 20° positive index and adjustable stop. They shall have the proper number of sections and positions as shown on the plans. They shall be Allied Electronics Series 747-90___.

(i) Polarization switch shall be an SP Triple Throw, 30 amp capacity, flush mount.

(j) Volt meter shall be a 0-5 microampere, DC suspension type microammeter in series with a resistor so that the scale indicates 0-5 volts. The instrument shall be a Triplett Model No. 320-G. The resistor shall be a miniature 1/4 watt, 0-2 megohm linear taper trimmer control resistor, Allied Electronic Type MLG-26L4, scale divisions to read to 0.2 volts.

(k) Ammeter shall be a 0-15 millivolt DC, suspension type millivoltmeter to indicate 0 to 5 amps with 0.2 amp divisions when connected across a 0.01 ohm shunt, Triplett Model 320-G.

(l) Ammeter selector switch shall be SPST, 30 amps capacity, flush mount.

(m) Meter terminals for external ammeter and volt meter shall be panel-mounted binding posts. The ammeter terminals shall be shorted by a slotted copper bar, Allied Electronics Type DF 31 BC.

(n) Main AC power switch shall be a 50-ampere 120/277 volt AC single pole fusible switch mounted in a metal box with hinged cover with external "on-off" handle. This box shall be surface mounted in the lower portion of the control cabinet. AC power line to the automatic recording equipment shall be grounded.

(o) Convenience outlet shall be a 3-wire, 15-ampere, 125-volt, grounded type, common feed duplex plug outlet in a metal box with metal cover plate. It shall be mounted in the lower portion of the control cabinet. Another electrical outlet shall be mounted next to the shelf in the left side of control cabinet.

(p) Heater resistor shall be a vitreous enameled, 150-ohm, 225-watt power resistor installed in an expanded metal cage. The heater shall be mounted in the lower portion of the control cabinet.

(q) Anode terminal blocks shall be Buchanan sectional or expandable type to accommodate No. 8 conductor on one side and No. 12 conductor on the other. Terminals shall be of the positive clamping type.

(r) Half cell terminal blocks shall be single panel-jack banana type with female outlets on one side spaced 5/8-inch apart and positive clamping lugs to accommodate No. 8 conductor on the other side.

(s) All hook-up wire within the control cabinet shall be No. 12 gauge copper stranded machine tool wire. All conductors shall be marked as shown on the plans. Marking shall be accomplished by the use of adhesive backed plastic or wrap-around cloth type markers.

(t) All No. 8 copper conductors connecting anodes and half cells to terminal blocks shall be Cyprus Wire and Cable 40 mil single extrusion Halar fluoropolymer insulation Type E-CTFE. These conductors shall

also be marked in the manner as set out above before termination in the control cabinet. All conductors shall be tagged permanently with the indentification of the item with which it is associated.

(u) Recycle timers shall be connected to the interrupter bus in the control cabinet. The recycle timer shall be Potter & Brumfield CR Series, No. CR B-48-70180, and mounted in the lower right (when facing the cabinet) portion of the control cabinet. They shall be equipped with on-off switches so they may be placed in service or completely isolated from the circuit and turned off as required.

(v) Three thermocouples shall be installed as follows: One on the northbound bridge (L-701R), and one on the southbound bridge (L-702R), and one on the top of the control cabinet. Installation details are shown on the plans. All leads from the thermocouples shall be marked as set forth above before termination at a terminal block. Lead-in conductors shall be Leeds and Northrup No. 16-56-18, Type TX (Solid). The thermocouples shall be Leeds and Northrup No. 8784-T-3-5-12-1-1-0. All conductors from the probe to the control cabinet shall be continuous without splices. An L & N 269219 Quick Disconnect Mounting Plate with two L & N 040428 2-circuit panels shall be installed in the cabinet and the thermocouple conductors terminated to these panels. Labels shall be affixed to the panels to identify the probes. Three male L & N 040433 Quick Disconnect plugs shall be provided with 5 feet of L & N 16-56-18 lead wire which shall be used with the temperature potentiometer for recording purposes. A cable clamp L & N 072513 shall be used with the male plug. Instrument for temperature readout shall be Leeds and Northrup Model 8692-2, portable type, Catalog No. 8692-2-541. The miniature head on the probe shall be sealed to prevent moisture intrusion, prior to being placed in the mortar mound. The meter shall be made available to the engineer at any time during construction. This instrument shall become the property of the Missouri State Highway Department at the conclusion of this project.

(w) A digital multimeter for testing and calibration purposes shall be furnished as a part of the work. This multimeter shall be a Simpson Model 360 Digital Volt-ohm Multimeter with test lead wires and rechargeable Nickel-Cadium batteries and shall be made available to the engineer at any time during construction. This instrument shall become the property of the Missouri State Highway Department at the conclusion of this project.

(x) Name plates shall be firmly affixed to identify various components of the control panels.

| Name Plate Location | Inscription |
|---|---|
| Ammeter | 0-5 Amperes |
| Voltmeter | 0-1.5 Volts |
| Polarization Voltage Push Button | Polar Volt Test |
| Rheostats N.B. Bridge | R1-1 Through R1-8 |
| Rheostats N.B. Bridge | R2-1 Through R2-8 |
| Rheostats S.B. Bridge | R1-1 Through R1-8 |
| Rheostats S.B. Bridge | R2-1 Through R2-8 |
| Anode Row Selector Switch N.B. | Anode Row 1 & 2 |
| Anode Row Selector Switch S.B. | Anode Row 1 & 2 |
| Anode Selector Switch N.B. | Anode 1-1 Through Anode 1-8 |
| Anode Selector Switch N.B. | Anode 2-1 Through Anode 2-8 |

| | |
|---|---|
| Anode Selector Switch S.B. | Anode 1-1 Through Anode 1-8 |
| Anode Selector Switch S.B. | Anode 2-1 Through Anode 2-8 |

In addition, the ground terminals and the half cell plug-in terminals shall be numbered to coincide with the correct ground or half cell.

(y) Anodes shall be of the size and shape as shown on the plans. Each anode shall be equipped with an insulated pigtail lead conductor approximately 3 feet in length. This lead will be spliced to a No. 8 conductor. The splice shall be of the crimp-on type and dipped in molten non-acid core solder before taping. After electrical splice has been made, it shall be insulated with a minimum of six half-lapped layers of 8 mil, all-weather electrical tape. The taped splice shall then be placed on the concrete surface and sealed with a prefabricated, resin filled splice kit.

(z) The half cells shall be of the number and type as shown on the plans. All copper-copper sulfate half cells shall be placed such that the recording end faces toward the nearest end of the bridge with respect to the transverse centerline of the deck. The zinc half cells shall be placed in the center of a grid space of the top reinforcing steel mat approximately 6 to 12 inches from the recording end of the copper-copper sulfate half cells.

(aa) Half cell electrodes equipped with 3 feet of lead conductor shall be connected to a No. 8 insulated conductor by a crimp-on splice, dipped in molten non-acid core solder, taped and sealed in the same manner as the anodes. After the electrical connection has been made, the half cell shall be mortared to the concrete deck with a grout meeting Section 1066.1.2 of the Standard Specifications.

(bb) At four locations on each bridge deck an insulated copper conductor shall be cad welded to both transverse and longitudinal steel of the top mat reinforcing. After the weld has been completed, it shall be insulated with 3M No. 4 resin and the excavation brought back to original grade with grout meeting the requirements of Section 1066.1.2 of the Standard Specifications. The four locations are shown on the plans by a W/W symbol and are approximately 45 feet from each end of the structure. Distance from the curb of each cad weld shall be approximately 18 inches. The reinforcing steel shall be mechanically cleaned before the splice is made.

The engineer will make the final decision as to the location of all anodes, half cells, and corrosometer probes. The copper-copper sulfate half cells shall be so located that the recording end is directly above a transverse piece of reinforcing steel. The zinc half cells shall be located such that they are not touching any reinforcing steel. The engineer will indicate the location of the reinforcing steel and approve such location as final.

After installation of the anodes and half cells, the engineer will test the electrical connections and continuity of the systems. The engineer will make a comparative survey between the embedded half cell and a portable half cell. A half cell determined to be non-functioning shall be replaced at the contractor's expense. Replaced half cells will be retested.

The corrosometers shall be cleaned on the job site per manufacturer's recommendations. The engineer will check the corrosometers, prior to embedding in the mortar mixture, for proper connection and will establish the initial zero values for each. The corrosometer shall be placed at the depth and with its longitudinal axis parallel with the top reinforcing steel, as shown on the plans. The mortar for embedding corrosometers shall comply with Section 1066.1.2 of the Standard Specifications, however, the water shall contain calcium chloride at the rate of 0.4 pound of Type 2 grade, as specified in Section 1068 of the Standard Specifications, to five (5) gallons of water, with the exception of one corrosometer which will be located on the southbound structure (L-702R), as directed by the engineer. The calcium chloride shall be thoroughly mixed in the water prior to use. Curing of the mortar shall consist of wet burlap or other suitable material for a minimum of 12 hours. The mortar patches shall be air dried a minimum of 48 hours prior to being covered with a seal or membrane system.

The corrosometer connections in the cabinet shall be of the Magna 32135, Type B male with waterproof cap. A ground lead with a Magna 32135, Type B female with waterproof assembly shall be installed but not hooked up until the engineer so directs.

Four corrosometers shall be installed in the northbound structure (L-701R) and six corrosometers shall be installed in the southbound structure, (L-702R), at locations shown on the plans. Installation details are shown on the plans. The corrosometers shall be of the Type PR-CPBD-13, as manufactured by the Magna Corporation, Santa Fe Springs, California. The lead wire shall be Alpha No. 1320 wire. A Model CK-3 Portable Corrosometer meter shall be provided, by the contractor, for monitoring the probes and shall become the property of the Missouri State Highway Department at the completion of the project. The meter shall be made available to the engineer at any time during construction.

The ground block to the corrosometers shall be separate to the cad weld grounds but connected by a No. 8 THHN copper wire loop, that may be removed.

A concrete mortar protection shall be placed around the lead wires where they pass through the parapet wall or deck to allow support and protection during paving.

The engineer will inspect and calibrate the temperature probes prior to their being placed in the mortar mound. The head of the probe shall be waterproofed prior to placing in the mortar mound.

All conductor cable runs from the cad weld splices, the corrosometers, the thermocouple, the half cells, and the anodes shall be continuous, without splices, to the control cabinet. The conductor shall be laid side by side without crossovers to the exit points on each structure. At approximately 6-foot intervals the conductor or conductors shall be secured to the deck by a 2-inch wide bead of Sika Chemical Corporation's Sika Stix 360 or equivalent. At points where the conductors run transversely to the bridge, planks shall be placed on each side of the conductors to provide protection from construction traffic. Each conductor, where it terminates at either a half cell or an anode, shall be supported and encapsulated with Sika Chemical Corporation's Sika Stix 360 or equivalent to provide protection during the placement of asphaltic concrete.

All conductors of a specific type, i.e. half cell or anode shall be neatly bundled and placed around the terminal boards to allow easy access to any terminal.

The contractor shall notify the engineer after the electrical system has been installed and before placement of the tack coat to allow ample time for testing the electrical system and making a voltage survey of the bridge deck. The contractor shall make adjustments or repairs as directed by the engineer.

The tack coat shall be uniformly distributed by hand or spray machine and shall not be applied to the anodes, recording end of half cells or temperature probes.

All products that are used on these structures will be checked by the Central Laboratory, Jefferson City, Missouri, for their conductive quality if materials other than those specified herein are used.

The working day following placement of the coke breeze asphaltic concrete, the engineer will make voltage and polarization tests on the overlay. All traffic shall be kept off the coke breeze asphaltic concrete until the wearing surface is placed.

Upon completion of the asphaltic concrete overlay and after the cathodic system is completed, the system shall be activiated by the contractor. The engineer will make such tests as necessary to determine satisfactory operation of the system. If the system does not operate properly, repairs shall be made by the contractor, at his expense. The technical representative previously required shall be present during the activation and testing of the system and during repair, if repairs are necessary.

Payment for the above described work will be made and considered completely covered under the unit price bid, lump sum for Cathodic Protection System, which price shall include all materials, including conduit and junction boxes, rubberized asphalt membrane, control cabinet, equipment, tools, labor, and any work incidental to complete the system.

## GGG. COKE BREEZE ASPHALTIC CONCRETE - Bridges L-701R & L-702R, Project I-IR-29-1(41)

Coke breeze asphaltic concrete, except as hereinafter provided, shall conform to the applicable requirements for Asphaltic Concrete Pavement of Section 403 of the Standard Specifications, 1973 Edition and its supplements.

Sec. 403.1 Delete this section and substitute the following:

"403.1 Description. The coke breeze asphaltic concrete shall consist of a mixture of coke breeze and asphalt cement prepared in a stationary plant. The mixture shall be placed as the first course over the concrete deck in coformity with the lines, grades, thickness and typical cross sections shown on the plans, or established by the engineer. The mixture shall be placed in one course with a minimum thickness of 2 inches and a maximum thickness of approximately 3 inches."

403.2 Delete this section and substitute the following:

"All materials shall conform to Division 1000, Materials Details, and specifically as follows:

| Item | Section |
|---|---|
| Asphalt Cement (60-70 or 85-100 Penetration) | 1015.5 |
| Fine Aggregate | 1002.2.1 |
| Mineral Filler | 1002.3 |

The source of coke breeze shall be approved by the engineer. Coke breeze shall be commercial quality as defined in ASTM Designation D 121. If petroleum coke is used, it shall be calcined, and may require fine aggregate and mineral filler and less asphalt than shown in Section 403.3.1 as amended in this specification. The mixture of coke breeze and asphalt cement shall show satisfactory cohesion when tested in accordance with ASTM D 1075-75. The engineer will designate the grade of asphalt cement".

403.3.1 Delete this section and substitute the following:

"The coke breeze and asphalt cement shall be combined in such proportions that the composition by weight of the finished mix is within the following range."

| Coke Breeze Asphaltic Concrete Mixture | Percent Min. | Max |
|---|---|---|
| Passing 1/2 inch sieve | 100 | |
| Passing 1/2 inch sieve, retained on 3/8 inch sieve | 0 | 25 |
| Passing 3/8 inch sieve, retained on No. 4 sieve | 0 | 45 |
| Passing No. 4 sieve, retained on No. 10 sieve | 7 | 45 |
| Passing No. 10 sieve, retained on No. 40 sieve | 7 | 50 |
| Passing No. 40 sieve, retained on No. 80 sieve | 3 | 20 |
| Passing No. 80 sieve, retained on No. 200 sieve | 3 | 18 |
| Passing No. 200 sieve | 0 | 10 |
| Asphalt Cement | 15 | 20 |

403.3.2 Delete this section.

403.3.3 Delete the sixth sentence in this section.

403.3.4 Delete this section and substitute the following:

The engineer may make adjustments in the mix formula submitted by the contractor. The percentage of asphalt will be selected by the engineer. Approved mixtures, when compacted and tested in the laboratory in accordance with ASTM D 1074-75 shall have a stability of not less than 300 pounds per square inch.

403.3.5 Delete this section.

403.3.6 Delete this section and substitute the following:

"Gradation Control. In producing mixtures for the project, the plant shall be so operated that no intentional deviations from the job-mix formula are made except as specifically authorized by the engineer.

The gradation of the aggregates will be determined from samples taken from the hot bins."

403.3.7 Delete this section.

403.5.5 Add the following to the end of this section:

The temperature of the aggregates shall not exceed 275F. The contractor's attention is directed to the characteristic features of the coke breeze material. It heats rapidly and is highly absorbent.

403.5.6 Delete this section and substitute the following:

"Screens. Separation of coke breeze into sizes will not be required."

403.5.12.5 Add the following to the end of this section:

(d) The unit weight per volume of the coke breeze mixture will be reduced from that normally encountered when natural aggregates are used. It will be necessary that this differential in unit weight per volume be considered in establishing batch weights for this mixture.

403.5.13.4 Add the following to the end of this section:

(c) The unit weight per volume of the coke breeze mixture will be reduced from that normally encountered when natural aggregates are used. It will be necessary that this differential in unit weight per volume be considered in establishing the production rate for this mixture.

403.5.18 Delete this section and substitute the following:

"Rollers. All rollers or other equipment used to compact the coke breeze mixture shall be in satisfactory working condition. All rollers shall be capable of reversing without backlash and steel wheel rollers shall be equipped with scrapers. Rollers shall have a system for moistening each wheel or roll. The following types of rollers shall be provided:

(1) Initial Rolling. Four ton to five ton three wheel roller or two wheel tandem-type roller.

(2) Final Rolling. Not less than 10 ton two or three wheel tandem-type roller."

403.6 In the first sentence delete "40F" and substitute "50F".

403.7 Delete the last sentence of this section and substitute the following: "The final mixture shall not exceed 275 F when discharged from the pugmill."

403.11.4 Delete this section and substitute the following:

"Rolling shall be continued until there is no visible evidence of further consolidation and until all roller marks are eliminated. At least two complete coverages shall be made with the initial and two complete coverages made with the final rollers. No density tests samples will be taken except as directed by the engineer."

Payment will be made under:

Item 403-60.00 Asphalt Cement (Asphaltic Concrete), per ton

Item 403-99.95 Mineral Aggregate (Asphaltic Concrete), Coke Breeze Asphaltic Concrete per ton.

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