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EXPERIMENTAL COST EFFECTIVE RECONSTRUCTION OF BRIDGE DECKS

AN INTERIM REPORT

JULY 1981

BY

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16. Abstract

This report presents the results of an evaluation of the initial period of performance of experimental reconstruction systems designed to effectuate an economic extension of the life of bridge decks in which salt contaminated concrete has been left in place. To date, four structures have been restored by this design alternate, employing sheet-type membranes as the protective measure against continued deck deterioration. The field evaluation included visual inspection and performance testing immediately after installation and at a time-in-service ranging from two to three years. Testing included measurement of electrical potential and electrical resistance between the steel reinforcement and the deck surface. Electrical potential measurements are interpreted as indicating the presence of active corrosion, resulting from accumulation of deicing salts at the level of the top mat of reinforcing steel in an amount sufficient to permit corrosion at a destructive rate(1). The measurement of electrical resistance is interpreted as indicating the effectiveness of the membrane-pavement system in preventing penetration by water and deicing salts. All membrane systems were judged to have performed satisfactorily during this initial evaluation period.

Due to the limited time in service of these installations and only isolated incidence of premature failure, no attempt was made in this report to draw conclusions with respect to their ability to achieve the desired goal. It is hoped that monitoring efforts thru the duration of the study will yield more definitive information in this regard.

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1.0 CONCLUSIONS

1 The four membrane-pavement systems studied have performed satisfactorily during this initial period of evaluation.

Isolated areas on Sites 1, 2 and 4 exhibited some premature deterioration of the asphalt overlay and protective membrane affecting less than 1% of total deck areas. However, these areas were repaired and have shown no apparent adverse effect on the overall integrity of the protective systems

2. The level of corrosion activity as determined by the half-cell potential technique appears to be unrelated to the apparent performance of the membrane-pavement system as determined by electrical resistance.

The results of the half-cell potential surveys strongly suggest a trend toward a decrease in corrosion activity within the subject structures.

The results of the electrical resistance survey provide no definitive information at this time.

2.0 RECOMMENDATIONS

1. For future studies of this type, the employment of a non-destructive test method for rapid, local, in-situ determination of chloride content would be a valuable addition to the currently used battery of performance testing methods. Research by others, as well as results in this study indicate that half-cell potential measurements, indicating the general level of corrosion activity at the time of measurements, are directly related to chloride concentration in the concrete at the rebar level. This relationship should prove especially useful in the interpretation of potential measurements within the "uncertain" zone and thus in the early detection of possible trends in performance. The nuclear prototype

"Chloride-in-Bridge-Deck Analyzer" currently being developed by the FHWA[8] appears to be the most promising candidate for this testing.

2. A stratified grid similar to that used for potential measurements should be employed for the collection of resistance measurements to allow for an analysis of measurements by location (i.e., curb line, 5 feet from curb, 10 feet from curb, etc.) This might also be useful in determining the source of the intrusion of water and or salts (i.e., through or around the membrane)

3. An alternative patching material (to Octocrete) is suggested for use in the repair of existing concrete decks. Although the cause of the patching failures cited in this report is believed to be chiefly the result of unfavorable working conditions, recent reports of poor field performance of Octocrete by our maintenance forces warrant the employment of an improved patching material.

Based on the results of recent laboratory and field testing by the Department the following products are recommended as the most viable alternatives for general purpose patching:

Product	Producer
Set-45	Set Products
Sika Set Mortar	Sika Chemical Corporation
Darex 240	W.R. Grace & Co.

3.0 INTRODUCTION

3.1 Problem Statement

There is presently insufficient information available to adequately predict the extent to which bridge deck restoration methods, applied to decks in which salt contamination is allowed to remain in situ, will achieve the desired goal of an economic extension of the life of the structure.

3.2 Objectives

The objectives of this research are to determine under what circumstances the Experimental Cost Effective Systems approach is a viable alternative to an extensive reconstruction of deteriorated bridge decks and to determine the relative economics of those rehabilitation procedures which prove successful.

The intent of this report is to provide an account of the performance of protective membranes installed on four of the structures (Appendix A) thus far selected for this study. At this writing the time in service of these installations ranged from two to three years.

3.3 Background

Premature deterioration of bridge decks is recognized as a major problem, both nationally and in New Jersey. The costs involved in maintaining or restoring these structures to a serviceable condition are substantial. It has been concluded the primary cause of bridge deck deterioration is the accelerated corrosion of reinforcing steel in the presence of deicing chemicals. The reinforcement steel in new or reconstructed concrete bridge decks thus must be protected from the intrusion of salt if such premature or continued deterioration is to be avoided.

A variety of alternate measures have been employed for protecting bridge deck steel from corrosion, including use of specially coated reinforcing bars, internal waterproofing. protective membranes, and increased depth of cover. Many of these protective measures are the subject of ongoing New Jersey research projects.

FHWA guidelines[2] require that as a prerequisite to employing any of these protective measures in a federally-funded permanent deck restoration, all concrete in highly chloride-contaminated areas and/or areas of active rebar corrosion must be removed. As an alternate to such full-scale, permanent restorations, the FHWA guidelines provide for another category of federally-participating bridge deck rehabilitation measures identified as "Experimental Cost Effective Reconstruction". The objective of this latter category of reconstruction is to achieve a minimum 10 to 15 years extension of the life of the deck. This design alternative allows salt-contaminated deck concrete to be left in place.

As indicated by the title, the efficacy of the "Experimental Cost Effective Systems" category of deck restorations is not completely established. The relative effectiveness of this concept will be determined by the collection and analysis of data on the preexisting condition and subsequent durability service history of decks restored by this design alternate, as well as an analysis of the relative economics of various successful alternate methods.

4.0 STUDY PROCEDURES

Evaluative and restoration activities for the subject structures included an evaluation of the existing condition and extent of deterioration, removal of all obviously deteriorated concrete, reparation as necessary for the protective system selected; system installation and the initial and follow-up non-destructive performance testing of the system.

The pre-restoration deck condition appraisals involved the determination of the location and degree of reinforcing steel corrosion by the use of half-cell corrosion detection equipment, delamination detection with the appropriate equipment to determine the location of areas of unsound concrete, chloride analyses to provide a quantitative measure of chloride ion content of the concrete at various levels in the deck, determination of areas with inadequate concrete cover over the reinforcing steel by use of the appropriate equipment, and subjective visual assessments.

Preliminary repair work generally entailed the stripping of old asphalt down to the existing deck, sampling for chloride analyses[3] removal of unsound concrete and patching with Octocrete. In at least one instance (Route N.J. 35), Class B concrete was used as an alternate patching material because the faster setting time of the Octocrete made it very difficult to use when large quantities of patching mix were required. This operation was followed by a deck surface preparation (sweeping, then application of tack coat or primer), installation of the sheet type protective membrane and finally, placement of a 1-1/2 to 2 inch bituminous wearing surface.

Initial performance test data were then collected employing the half-cell corrosion detection equipment cited earlier and an electrical method for measuring the waterproofing effectiveness of membrane pavement systems when applied to concrete bridge decks. This data will serve as base measurements for bi-annual resurveys through 1982.

5.0 SYSTEMS UNDER TEST

While this study was not designed to evaluate protective systems on an individual product basis, some detailed information about the sheet-type membranes selected for use on the subject structures is provided in this section.

Membrane No. 1: Royston Bridge Membrane No. 10

Supplier:	Royston
Composition:	Heat-modified bituminous resin composition with inner layers of open-weave, fiberglass mesh and polyester top surface.
Thickness:	80 mils
Size:	4-ft x 50-ft rolls
Primer:	Royston Bridge Membrane Primer 713, synthetic rubber and resin based formulation in an organic solvent system.
Coverage:	0.1 gal/sq.yd.
Current(1978) Cost:	$6.00/sq.yd., in-place (includes cost of wearing course).

Membrane No. 2: Heavy-Duty Bituthene

Supplier:	W.R. Grace Co.
Composition:	High strength woven mesh embedded between a layer of self-adhesive rubberized asphalt and non-tacky bituminous compound.
Thickness:	80 mils
Size:	3-ft x 50-ft rolls
Primer:	Bituthene Primer, 75% solvent with 25% rubberized asphalt.
Coverage:	0.02 - 0.04 gal/sq.yd.
Current(1978) Cost:	$15.00/sq.yd., in-place (includes cost of wearing course).

6.0 METHODS OF EVALUATION

Beginning immediately after restoration a bi-annual performance evaluation schedule for the test structures was initiated employing the following techniques as recommended in FHWA guidelines.

6.1 Physical Condition Survey

A visual inspection to determine general deck condition noting evidence of deterioration of the asphalt overlay and/or protective membrane

6.2 Electrical Potential Survey

This method, adopted as a standard test by ASTM(4) in 1977, covers the estimation of the electrical half cell potential of reinforcing steel in concrete, for the purpose of determining the corrosion activity of the reinforcing steel. A diagram detailing the equipment used and basic test arrangement is shown in Appendix B. Measurements are taken by placing the porous tip of the copper sulfate electrode in contact with the deck surface and measuring the electrical potential with a high-impedance voltmeter. To minimize large errors in measurement, contact resistance is reduced by use of a sponge soaked in an electrical contact solution and placed between the electrode and deck surface. Measurements are taken utilizing a grid pattern over the surface being investigated. Ideally, the grid spacing should not be greater than the minimum spacing of the reinforcing bars (see Appendix C for diagram of typical grid pattern). With respect to interpretation of results, potential values greater than -0.35 volts indicate a greater than 90 percent probability that corrosion is occurring in that area at the time of measurement. Values between -0.20 and -0.35 are in an area where corrosion activity is uncertain. Values less -0.20 indicate a greater than 90 percent probability that no corrosion is occurring at that time and location. In relation to the Cu/CuSO4 reference electrodes the potential of the rebar is almost always active and thus, more active corrosion gives a more negative potential (e.g. -0.35 > -0.20). However, for clarity, the sign of the potential will be disregarded with data presented herein. Using this convention of a numerically larger value signifies a more active potential.

This technique has served as a very useful tool in detecting areas of corrosion or potential corrosion even prior to any visible indication of distress. However, while the validity of the electrical potential technique has been verified by a number of researchers, caution must be exercised in the interpretation of the data[5].

6.3 Electrical Resistance Survey

This nondestructive method covers the measurement of the waterproofing effectiveness of membrane pavement systems when applied to concrete bridge decks. The basic concept involves measuring (with an ohmmeter) the gross electrical resistance between an electrode placed on the saturated top surface of the membrane and the mat of reinforcing steel to which it has been electrically connected (see Appendix D for diagram of test arrangement). Readings are interpreted to indicate variation in the imperviousness of the membrane and the relative degree of wetness condition of the underlying concrete surface. The degree of wetness is inversely proportional to the resistance reading. In particular, based on criteria developed by California researchers Spellman & Stratfull[6], observed resistances of 500,000 ohms and over are an indication of excellent performance; 500,000 to 100,000 are considered questionable performance, while reading below 100,000 indicate poor performance.

7.0 RESULTS AND DISCUSSION

7.1 Condition Evaluation of Existing Structures

After limited field condition surveys were conducted to identify structural inadequacies and the degree of deicing chemical contamination, the bridge decks were subjected to a detailed field appraisal. A summary of these appraisals is provided in Appendix E.

Application of condition survey criteria developed by the FHWA (Appendix F) detailed field appraisals resulted in the following classification of the subject structures.

Site No.	Bridge Identification	Condition Classification
1	Route U.S. 22, Eastbound Viaduct over Liberty Street and Lehigh Valley R.R. Structure No. 2004-153	Category 3 - Light to No Active Corrosion
2	Bloy Street over Route U.S. 22 Structure No. 2004-152	Category 1 - Extensive Active Corrosion
3	Route U.S. 22 over the Elizabeth River Structure No. 2004-151	Category 2 - Moderate Active Corrosion
4	Route N.J.35 over the Navesink River Structure No. 1312-154	Category 1 - Extensive Active Corrosion

7.2 Condition Evaluation of Experimental Systems

Visual inspection to determine the general deck condition of the subject bridges at the end of this initial evaluation period revealed some deterioration of the membrane pavement systems on the two structures carrying Route U.S. 22 and the Route N.J. 35 bridge over the Navesink River

As noted in Appendix G, early signs of distress occurred in the form of alligator cracking after the installations had been in service for approximately 20 months. This condition rapidly worsened, resulting in the breaking up of the asphalt overlay and tearing of the protective membrane in three isolated areas on the Liberty Street structure, one area on the bridge over the Elizabeth River (westbound roadway) and one on the southerly most span of the bridge over the Navesink River

Further investigations of the affected area (Route 22 bridges) revealed that the displaced materials (principally, Octocrete patching) had an efflorescent coating. Because of the concentrated state of this salt-based coating, it is believed to be the result of numerous deicing salts applications during one of the most severe winters in this region.* Unfortunately, no information is available at this time with respect to the total amount of deicing salts applied at these locations during the period in question or the composition of the coating.

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*1978-79: 14 snowstorms resulting in approximately 52 inches of precipitation (See reference 7).

The Octocrete material recovered from the affected areas is believed to have come from deteriorated patches in the existing concrete deck. The failure of the patching effort and subsequent localized failure of the overlay and membrane may, in part, be attributed to a patching operation under adverse weather (rain) and traffic conditions during the preliminary repair work. With respect to the former, the presence of water in excess of the mix proportion has been reported to adversely affect the bonding ability of Octocrete. The operation on the viaduct-type structure over Liberty Street was further complicated by a "bouncing" action of the deck apparently induced by heavy traffic flow in lanes adjacent to the work area. It is believed that the cohesiveness of the patching material was detrimentally affected, as its components appeared to separate due to the resultant vibrations.

These isolated problem areas were subsequently repaired and have exhibited no significant adverse affect on the overall integrity of membrane-pavement systems.

7.3 Performance Testing Evaluation

A summary of the results of electrical potential and resistance measurements collected on these experimental systems is presented in tabulation on Page 12. For more ready interpretation, the tabulated data is presented in Figures 1, 1A, 2 and 3 in the form of bar charts. Figures 1 and 1A present a percentile distribution of the combined results systems) of the respective test methods, while Figure 4 gives a distribution of results by the proportion of potential measurements in the active corrosion zone by structure and location (i.e., curb line, 5 feet curb, 10 feet from curb). By plotting the change in proportion of measurements occurring in this category for individual deck and location it is

ELECTRICAL MEASUREMENTS OF MEMBRANE-TREATED DECKS

Site No.	Date Tested	Months In Service When Tested	Total Number of Half Cell Measurement	Mean, Volts	Half Cell Potential Percentiles, Volts (% of Measurements with Cited Potential) <0.20V	0.02 to 0.35V	>0.35V	Total Number of Resistance Measurements	Median KΩ	Resistance Percentiles (% of Measurements with Cited Resistance) >500KΩ	500 to 100KΩ	<100KΩ
1	4-78	Before Repair, t_{-1}	276	.18	70	30	0					
	8-78	New, t_0	276	.11	68	32	0	50	495,000	48	28	24
	10-80	26, t_1	276	.08	74	21	5	50	4,000,000	54	14	32
2	10-77	Before Repair, t_{-1}	33	.27	30	46	24					
	12-77	New, t_0	33	.10	80	17	3	10	9,200,000	70	30	0
	9-80	33, t_1	33	.02	97	3	0	10	18,200,000	70	20	10
3	4-78	Before Repair, t_{-1}	60	.18	71	27	2					
	8-78	New, t_0	60	.16	55	45	0	5	412,000	40	40	20
	9-80	25, t_1	60	.10	74	23	3	5	568,000	60	20	20
4	7-77	Before Repair, t_{-1}	135	.34	2	60	38					
	12-77	New, t_0	135	.29	18			29	188,000	38	21	41
	8-80	32, t_1	135	.20	44			29	900,000	24	21	55

Figure 1: DISTRIBUTION OF ELECTRICAL RESISTANCE MEASUREMENTS ON MEMBRANE-TREATED DECKS BY LEVEL OF PERFORMANCE.

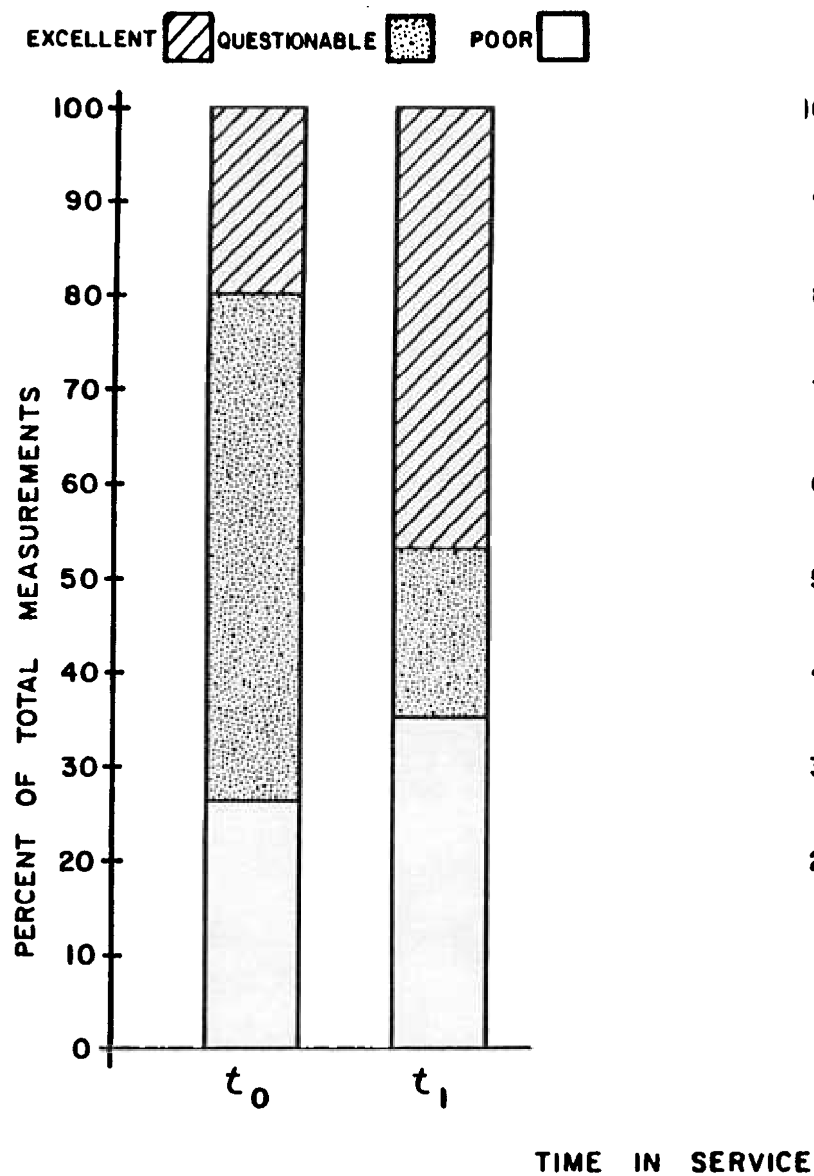
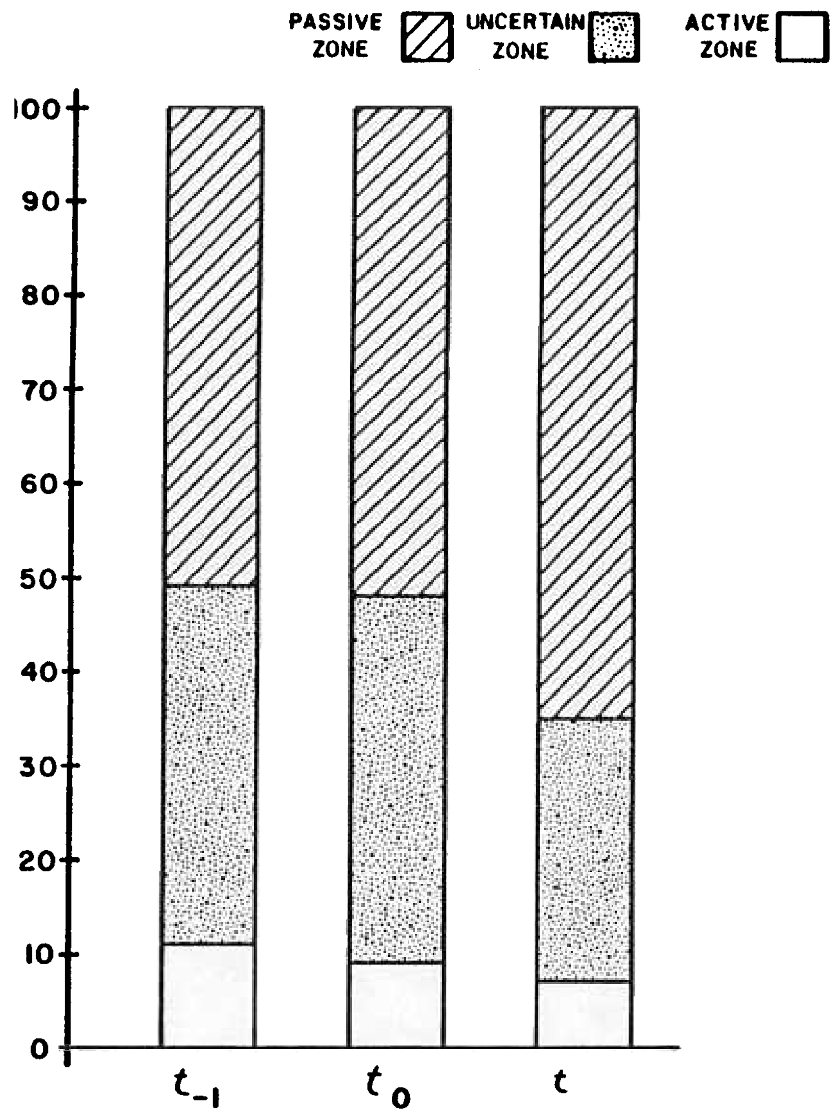


Figure 1A: DISTRIBUTION OF ELECTRICAL POTENTIAL MEASUREMENTS ON MEMBRANE-TREATED DECKS BY LEVEL OF CORROSION ACTIVITY.



DISTRIBUTION OF ELECTRICAL RESISTANCE ON
INDIVIDUAL MEMBRANE - TREATED DECKS BY LEVEL OF

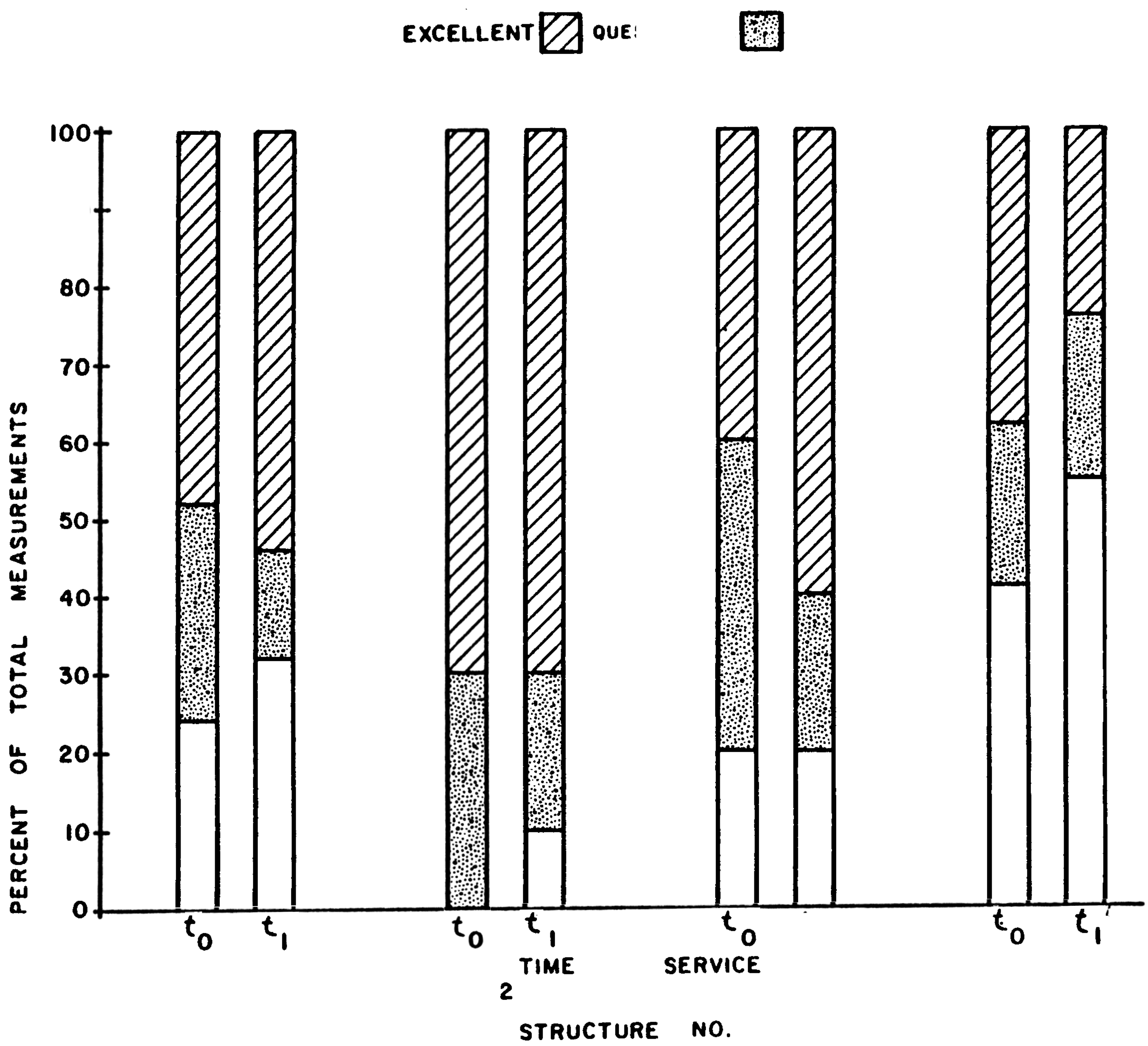


Figure 3: DISTRIBUTION OF ELECTRICAL POTENTIAL MEASUREMENTS ON INDIVIDUAL MEMBRANE TREATED DECKS BY LEVEL OF CORROSION ACTIVITY

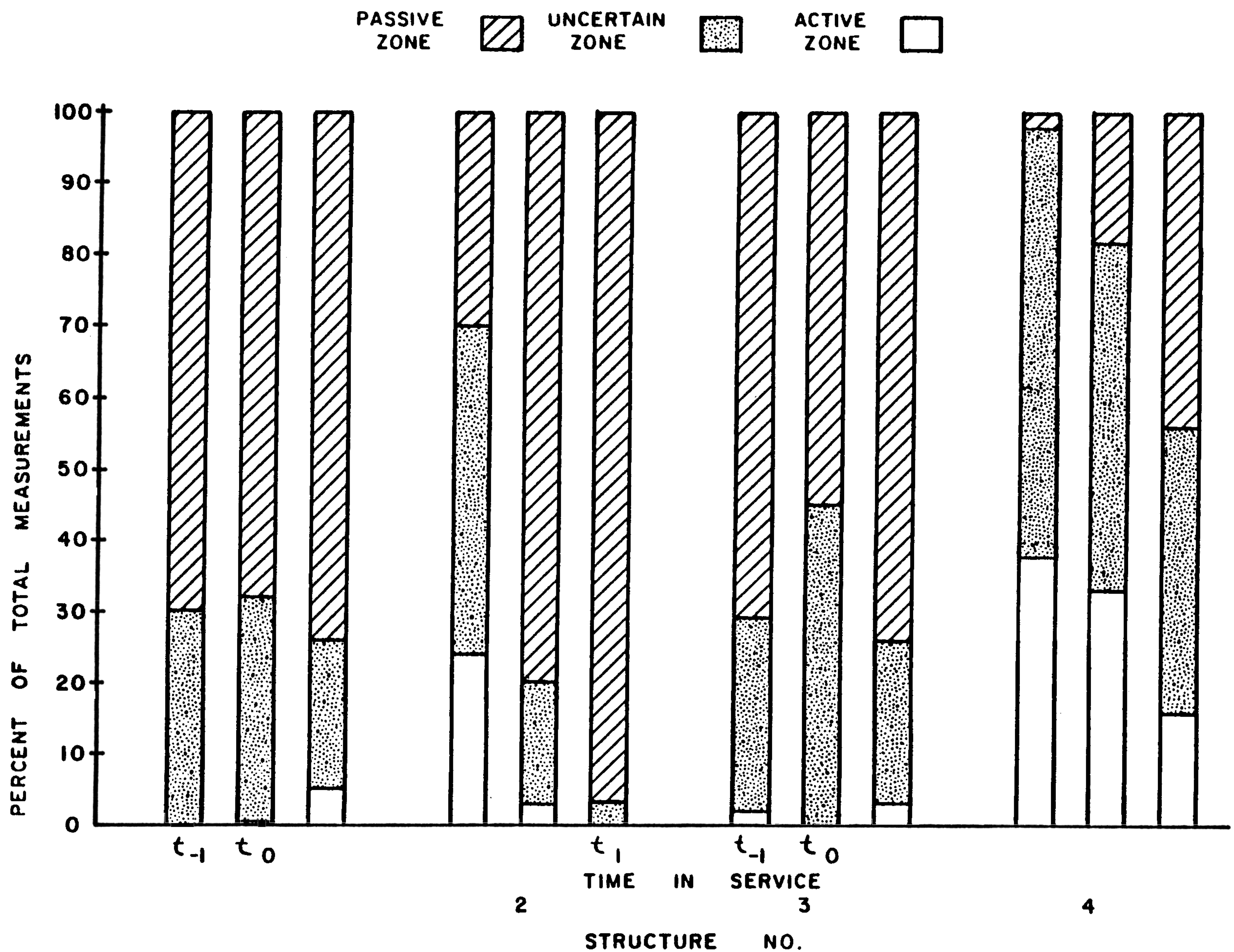
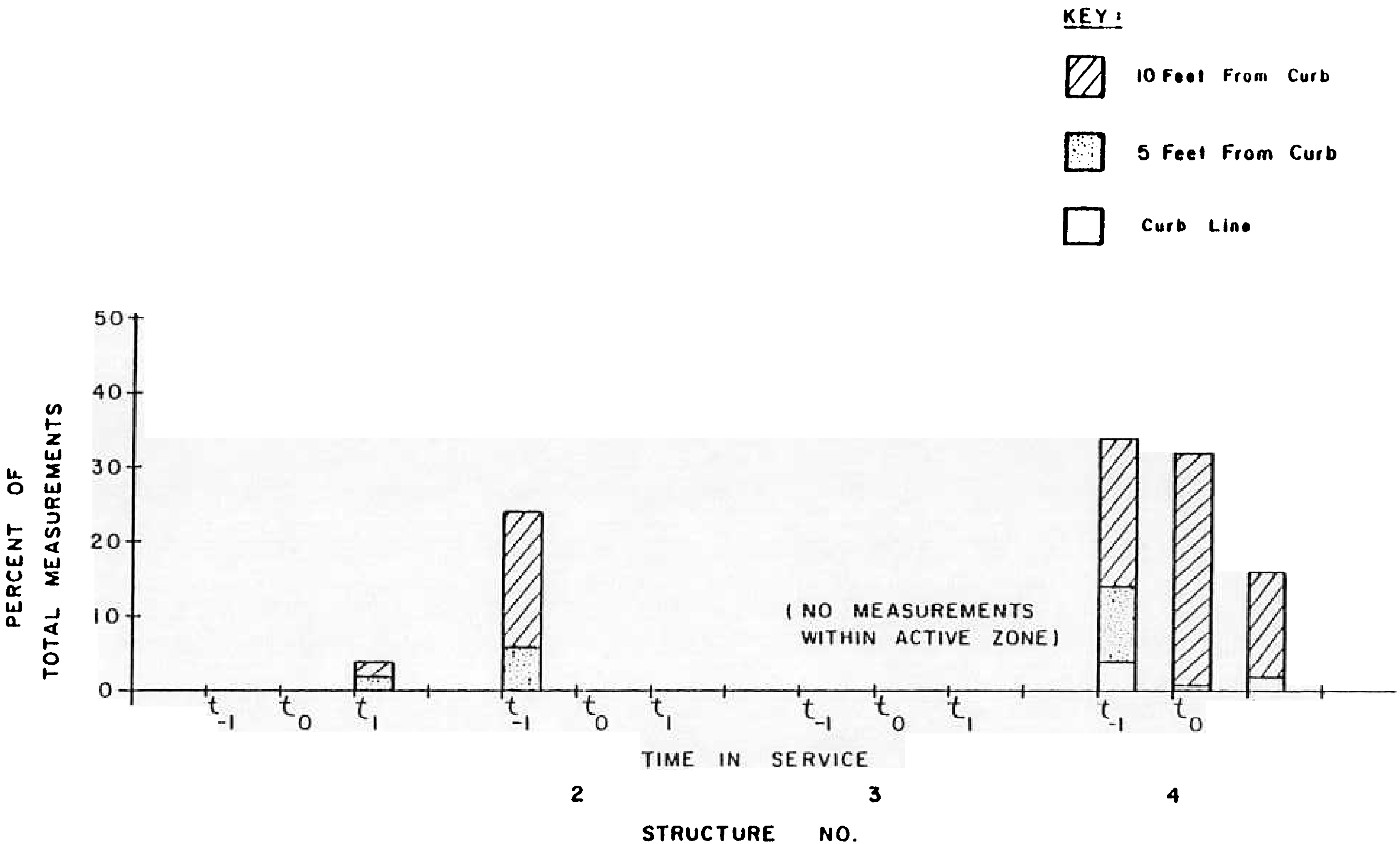


Figure 4: PROPORTION OF HALF CELL POTENTIAL MEASUREMENTS IN THE ACTIVE CORROSION ZONE, BY STRUCTURE AND LOCATION.



hoped that a reasonable judgment of relative condition can be made. The values presented in the tables and figures herein disagree somewhat because of the rounding off technique applied.

The maximum time in service among the subject systems at this evaluation is 33 months. Because this is such a short time in the expected life and there has been only isolated incidence of premature failure, no attempt will be made at this point to draw conclusions with respect to the ability of a particular system to achieve the desired goal. Thus, the interpretation of findings herein are directed toward the detection of possible trends developed during this initial performance period which might be used in predicting future performance.

7.3.1 Electrical Potential

From an inspection of the distribution of the combined electrical potential data presented in Figure 1A, there appears to be a general trend toward a decrease in the level of corrosion activity within the group of bridges

An analysis of pre-restoration ("t_{-1}") data revealed that approximately 11% of the total measurements indicated the probability that corrosion of reinforcing steel was occurring. Immediately after restoration (time "t_0") this figure dropped slightly to 9%. By the end of the initial performance period ("t_1"= 25 to 33 months), the proportion in the "active" corrosion zone had decreased to approximately 7%. This trend of decreasing corrosion activity is supported by a 20% increase in measurements in the "passive" or "safe" zone and a 30% decrease in the "uncertain" zone since installation of the system.

On an individual basis, Figure 3 shows that data from Structure No. 1 (Liberty St.) and Structure No. 3 (Elizabeth River) follow a trend somewhat different to that of the group as a whole. In these cases the proportion of potentials indicating probable corrosion activity increased from less than 1% to 5% and from 0 to 4% respectively. A further investigation of data from Structure No. 1 indicates that this increase in activity occurred exclusively in Span No. 5 of the structure. Thirteen out of eighty-one or 16% of the measurements taken in this area indicated the presence of active corrosion. It should be noted than Span No. 5--the longest within the structure--was also the only span showing any initial corrosion activity or any visible signs of distress during this evaluation period. An examination of data from Structure No. 3 revealed no apparent explanation for the slight increase in corrosion activity.

In an attempt to detect further trends within the results yielded by this technique, the proportions of measurements in the active corrosion category have been divided by locations (i.e., curbline, 5 feet from the and 10 feet from curb). In the distribution of active corrosion measurements displayed in Figure 4, 66% of the pre-restoration data, 97% of initial and 80% of the follow-up data occurred 10 feet from the curbline. These percentages strongly suggest that the corrosion process tends to be more active in the traffic lane than in the curbline and shoulder areas. This is somewhat surprising in that is is usually at the boundary areas that water and salts intrude.

7.3.2 Electrical Resistance Survey

While an examination of the distribution of the results yielded by this method (see Figures 1 and 2) reveal an apparent increase in the proportion of measurements in the "poor" performance category, any suggestion of a possible trend in this direction cannot be confirmed after only two observations within such a relatively short test period. Therefore, the discussion of these results will be limited to possible sources of measurement variation.

Resistance may be relatively high at the time of the initial reading because of the relative dryness of the parent deck surface at the time or the membrane installation. After installation however, moisture tends to accumulate in the deck thereby reducing electrical resistance to a relatively low level. In the presence of small amounts of moisture, resistance has been reported to remain essentially constant in the "questionable" category. However, an accumulation of moisture and salts in the deck can be expected to cause a substantial and often sudden drop in resistance.

In the case of the subject installations, a 9% overall increase in the proportion of measurements in the "poor" performance category is more than offset by a 27% increase at the "excellent" level. Individually, although structure numbers 2 and 4 do not follow that performance pattern in percentile grading, all of the installations display an increase in the median resistance value, suggesting a drier condition beneath the membrane.

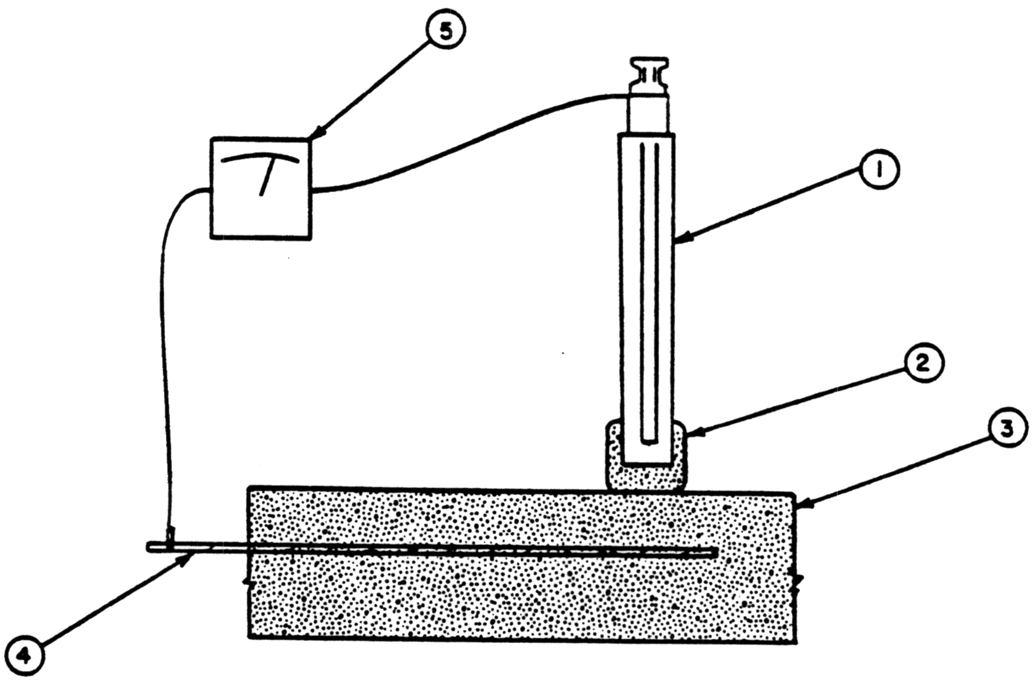
In summary, these factors suggest that the membranes have been at least moderately effective in preventing the further intrusion of water and salts.

APPENDIX A: IDENTIFICATION OF TEST BRIDGES

Site No.	System	Bridge Identification and Location	Approximate Deck Dimensions, Ft.	Construction Problems	Completion Date
1	Royston #10 Waterproofing Membrane (Rolled-on, preformed sheet)	Route U.S. 22, Eastbound Section 13E,14F&15F, Viaduct over Liberty St. and Lehigh Valley R.R., Union County Structure No. 204-153	Spans #1 thru #3: 90x43 Span #4 124x43 Span #5 147x43	(no information available)	November 1977
2	W.R. Grace Waterproofing Membrane (Rolled-on, preformed sheet)	Bloy Street over Route U.S.22,Section 13E, 14F&15F, Union County Structure No. 2004-152	76x44	Intermittent showers during patching operation (is not expected to affect strength of Octocrete patch); overlay was prematurely exposed to traffic causing wear on 2 ft^2 area - was repaired immediately.	December 1977
3	W.R. Grace Waterproofing Membrane (Rolled-on, preformed	Route U.S.22,Section 13E,14F&15F over Elizabeth River Union County Structure No.2004-151	70x40 (Eastbound & Westbound)	None	August 1978
4.	Royston #10 Waterproofing Membrane (Rolled-on, preformed sheet)	Route N.J.35,Section 8H over Navesink River,Monmouth County Structure No.1312-154	77x38 (per span - #4,#8,&#11	Paving operation interrupted by showers; membrane damaged in small area by rubber tire paver; some blistering of membrane occurred after installation; membrane did not adhere well to concrete in some areas.	November 1977

APPENDIX 8

DIAGRAM OF TEST ARRANGEMENT FOR ELECTRICAL POTENTIAL MEASUREMENTS



Copper - Copper Sulfate Half Cell—moved about on deck surface to measure potential of reinforcing steel at various locations.

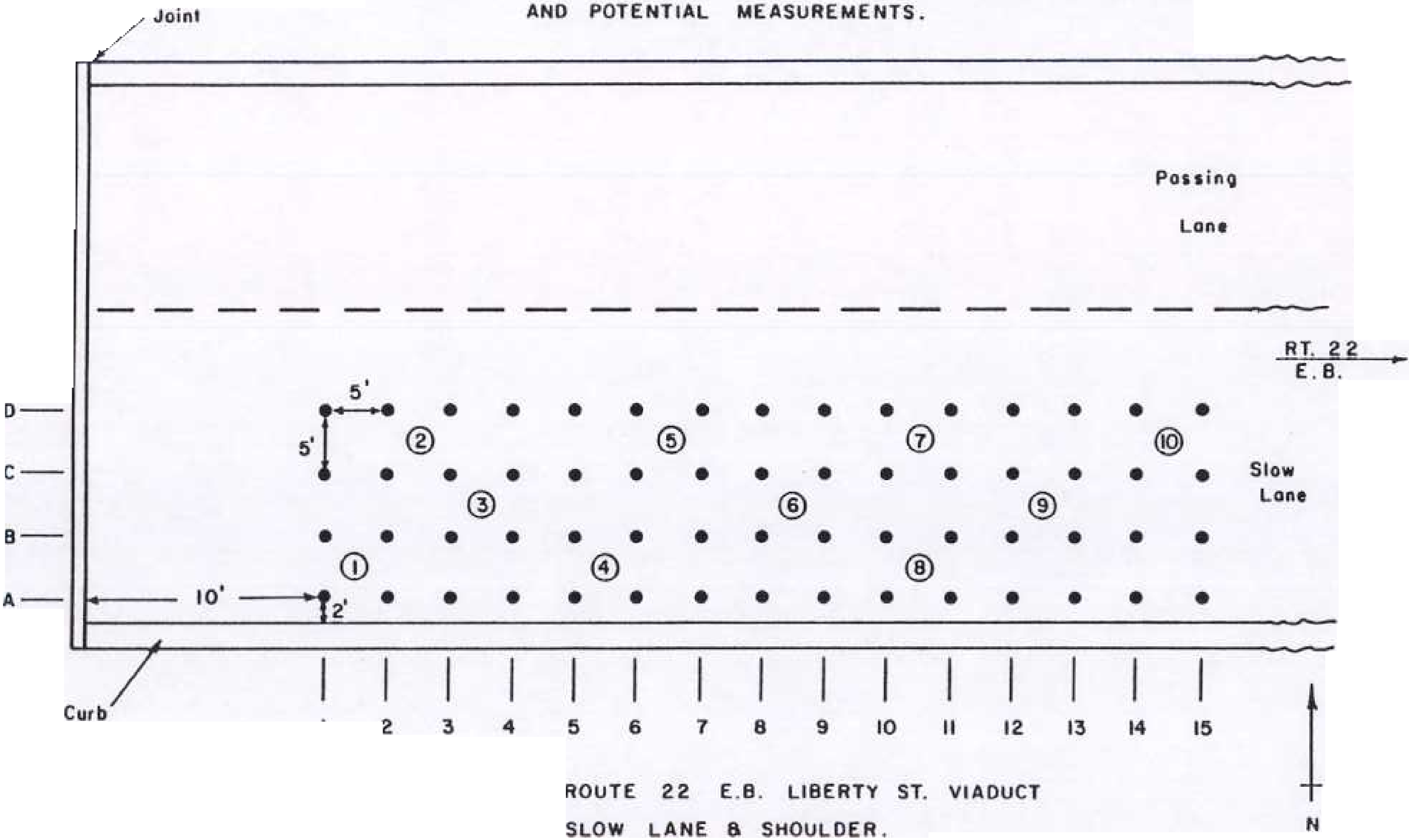
Electrical Junction Device—sponge prewetted with low electrical resistance contact solution

Concrete

Reinforcing steel

(5) Voltmeter

APPENDIX C: TYPICAL GRID LAYOUT FOR ELECTRICAL RESISTANCE AND POTENTIAL MEASUREMENTS.



ROUTE 22 E.B. LIBERTY ST. VIADUCT

SLOW LANE & SHOULDER.

SPANS 1, 2 & 3

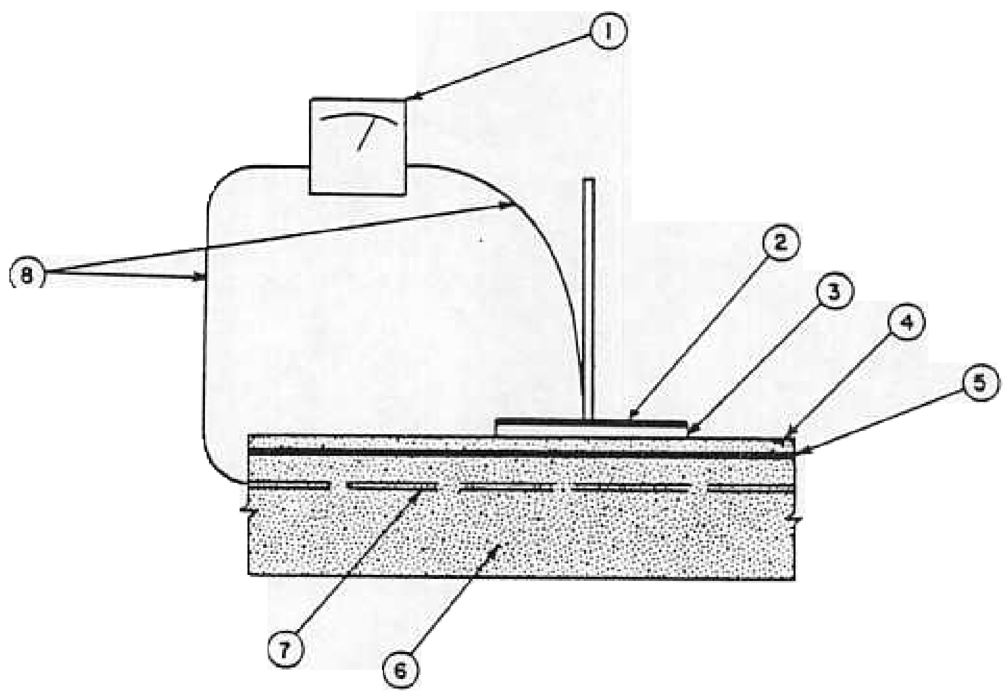
MEASUREMENTS TAKEN 8/15/78

O = Resistance Measurement Locations

● = Half-Cell " "

APPENDIX D

DIAGRAM OF TEST ARRANGEMENT FOR ELECTRICAL RESISTANCE MEASUREMENTS



(1) Ohmmeter, 20,000 ohms per volt rating

(2) Copper (or aluminium) plate, 12 in. x 12 in. x 1/8 in

(3) Polyurethane sponge, 12 in. x 12 in. x 1/2 in. to be attached to the copper plate with rubber bands or other suitable means — when assembled, this apparatus is called the probe.

(4) Bituminous pavement surface

(5) Waterproofing membrane

(6) Concrete bridge deck

(7) Reinforcing steel mat

(8) No. 18 insulated wire, Belden test probe wire or equivalent; two spools, minimum length, 125 ft.

APPENDIX E: RESULTS OF EXISTING CONDITION SURVEY AND APPRAISAL EVALUATION

BRIDGE IDENTIFICATION AND LOCATION	VISUAL ASSESSMENT	CHLORIDE CONTENT, lb/yd^3	CONCRETE COVER, IN.	ELECTRICAL POTENTIAL, VOLTS	DELAMINATION
Route U.S. 22 Eastbound Section 13E, 14F and 15F Viaduct over Liberty St. and Lehigh Valley R.R. Union County Structure No.2004-153	Generally fair condition; slight scaling and spalling over 5-10% of deck.	$\bar{x}$ = 0.82 No samples over 2.0 lb/yd^3 remove or replace thresh old.	$\bar{x}$ = 1.65 86% of measurements below 2 in. minimum.	Less than 1%>0.35	Slight to moderate over approximately 10% of deck area.
Bloy St. over Route U.S.22, Section 13E, 14F, and 15F Union County Structure No. 2004-152	Poor condition; moderate to severe scaling and spalling over 30% of deck; some exposed rebars.	$\bar{x}$ = 2.41 83% for samples over threshold.	$\bar{x}$ = 1.44 80% below minimum.	24%>0.35	Slight to moderate over 10-15% of deck area.
Route U.S.22, Section 13E, 14F and 15F over Elizabeth River Union County Structure No. 2004-151	Generally good condition; no visible deterioration in westbound roadway; slight spalling and very small area of exposed re-bars in the eastbound roadway.	$\bar{x}$ = 3.39 40% of samples over threshold.	$\bar{x}$ = 1.44 100% below minimum	2%>0.35	Slight
Route N.J.35 Section 8H over Navesink River Monmouth Co. Structure No. 1312-154 (Spans 4, 8, 11 only)	Moderate to severe scaling and spalling with patches over 60% of deck; some exposed rebars.	$\bar{x}$ = 8.00 100% of samples over threshold.	$\bar{x}$ = 2.15 41% below minimum.	38%>0.35	Moderate over 15% of deck area.

APPENDIX F: FHWA BRIDGE DECK CONDITION CATEGORY CLASSIFICATION

(FHWA PROGRAM MANUAL, TRANSMITTAL 188)

Category 1 - Extensive Active Corrosion 5 percent or over of the deck visibility spalled, OR 40 percent or over of the deck area having deteriorated and/or contaminated concrete or active rebar corrosion as indicated by a summation of non-duplicating areas consisting of the following 1) spalls, (2) delaminations, (3) electrical potentials over 0.35 volts (CSE), and (4) chloride content samples greater than 2 pounds of chloride per CY of concrete as determined by 10 random samples of the deck area excluding the area of spalls, delaminations and potentials over 0.35 volts.

Category 2 - Moderate Active Corrosion 0 to 5 percent of the deck visibly spalled, OR 5 to 40 percent of the deck area having deteriorated and/or contaminated concrete or active rebar corrosion as indicated by a summation of nonduplicating areas consisting of the following: (1) spalls, (2) delaminations, (3) electrical potentials over 0.35 volts (CSE), and (4) chloride content samples greater than 2 pounds of chloride per CY of concrete as determined by 10 random samples of the deck area excluding the area of spalls, delaminations and potentials over 0.35 volts.

Category 3 - Light to No Active Corrosion, No visible spalls, OR 0 to 5 percent of the deck area having deteriorated and/or contaminated concrete or active rebar corrosion as indicated by a summation of nonduplicating areas consisting of the following: (1) delaminations, (2) electrical potentials over 0.35 volts (CSR), and (3) chloride content samples greater than 2 pounds of chloride per CY of concrete as determined by 10 random samples of the deck area excluding the area of spalls, delaminations and potentials over 0.35 volts.

APPENDIX G: RESULTS OF FOLLOW-UP PERFORMANCE TESTING EVALUATION

BRIDGE IDENTIFICATION AND LOCATION	PROTECTIVE SYSTEM	MONTHS IN SERVICE WHEN TESTED	VISUAL ASSESSMENT	ELECTRICAL POTENTIAL, VOLTS	RESISTANCE
Route U.S. 22, Eastbound Section 13E, 14F and 15F, Viaduct over Liberty St. and Lehigh Valley R.R., Union County Structure No. 2004-153	Membrane No. 1	26	Alligatoring developed after 18 months in service resulting in overlay and membrane failure in 3 locations. Total area affected, approximately 28 ft^2 or less than 1% of the total deck area.	5% > 0.35	32% > 100
Bloy St. over Route U.S. 22, Section 13E, 14F and 15F, Union County Structure No. 2004-152	Membrane No. 2	33	No signs of distress	0% > 0.35	10% > 100
Route U.S. 22, Section 13E, 14F and 15F over Elizabeth River, Union County Structure No. 2004-151	Membrane No. 2	25	Alligatoring developed after 20 months in service resulting in overlay and membrane failure in one location. The affected area measured approximately 20 ft^2 or less than 1% of the total deck area.	3% > 0.35	20% > 100
Route N.J. 35, Section 8H over Navesink River, Monmouth Co. Structure No. 1312-154 (Spans 4, 8 and 11 only).	Membrane No. 1	32	Alligatoring developed after 20 months in service resulting in overlay and membrane failure in one location (Span No. 12). The affected area measured approximately 2 ft^2 or less than 1% of the total deck area.	16% > 0.35	55% > 100

APPENDIX H: REFERENCES

1) "Waterproofing Membranes for Bridge Deck Rehabilitation", Research Report 52, N.Y.S.D.O.T., May 1977.

2) Section 2, Subsection 7, FHWA Transmittal 188, April 1976.

3) Berman, Horace A., "Determination of Chloride in Hardened Portland Cement Paste, Mortar and Concrete", Interim Report No. FHWA-RD-72-12, FHWA, September 1972.

4) ASTM C876-77, Standard Test Method for "Half Cell Potentials of Reinforcing Steel in Concrete".

5) Ellis, William J. and Bianchetti, Ronald L., "State-of-the-Art Report, Corrosion Control and Repair of Concrete Bridge Structures", NCHRP Project No. 12-19, April 1979. Chamberlain, W.P., Irwin, Richard J. and Amsler, Duane E.

6) Spellman, D.L. and Stratfull, R.F., "An Electrical Method for Evaluating Bridge Deck Coatings", Highway Research Record 357, Highway Research Board, 1971.

7) Local Climatological Data Summary, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Winter 1978-79

8) Rhodes, Stout, Siebers and Schindler, "In Situ Determination of the Chloride Content of Portland Cement Concrete Bridge Decks" Report No FHWA/RD-80/030, FHWA, August 1980.