REPORT NO. CDOH-P&R-R-77-8

EVALUATION OF BRIDGE DECK
REPAIR AND PROTECTIVE SYSTEMS

Herbert N. Swanson
Denis E. Donnelly
Colorado Division of Highways
4201 East Arkansas Avenue
Denver, Colorado 80222

Interim Report
December 1977

Prepared in cooperation with the
U. S. Department of Transportation
Federal Highway Administration

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-CO-RD-77-8		

4. Title and Subtitle EVALUATION OF BRIDGE DECK REPAIR AND PROTECTIVE SYSTEMS	5. Report Date December 1977 6. Performing Organization Code
7. Author(s) Herbert N. Swanson, Denis E. Donnelly	8. Performing Organization Report No. CDOH-P&R-R-77-8
9. Performing Organization Name and Address Colorado Division of Highways Planning and Research Branch 4201 East Arkansas Avenue Denver, Colorado 80222	10. Work Unit No. (TRAIS) 11. Contract or Grant No. 1475
12. Sponsoring Agency Name and Address State Department of Highways 4201 East Arkansas Avenue Denver, Colorado 80222	13. Type of Report and Period Covered Interim - 2 Years 14. Sponsoring Agency Code

15. Supplementary Notes

Prepared in cooperation with the U. S. Department of Transportation, Federal Highway Administration.

16. Abstract

This report describes efforts to control bridge deck deterioration in Colorado. A follow up testing program to determine the degree of continued effectiveness of waterproofing membranes has been underway since 1974. Results to date show that the most important factor is how well a membrane is placed. Several projects in Colorado have employed the use of Latex Modified Concrete as a surface wearing and protective course. Recent inspections of latex modified bridge decks indicate that some significant cracking is beginning to take place. Chlorides are entering these cracks and steel corrosion may be in progress at these points.

Considerable time may be required, however, to determine if the corrosion progresses laterally and the true value of this design.

17. Key Words	18. Distribution Statement
Waterproofing membranes, monomer, asphalt overlay, bridge decks, chloride concentration, concrete, corrosion, deterioration, electrical resistance, half cell, latex modified	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	33	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

TABLE OF CONTENTS

INTRODUCTION

Bridge deck deterioration has become a major problem facing Colorado as well as other states using chloride deicers on bridge decks. Chlorides entering the concrete cause the steel to corrode rapidly. Corroded steel requires much larger volume than the original steel, causing the surface concrete to pop-out. Consequently, large areas of pop-outs and delaminated concrete are responsible for poor riding quality, reduced safety and weakened structure.

Photograph No. 1
Structure No. E-16-HE - Eastbound Over 32nd Avenue shows badly deteriorated bridge deck

In an effort to control this deterioration, Colorado has tried many impervious membranes on new structures. Some membrane systems have been discontinued due to cost and difficulty of application. A few new systems have been added with a follow-up testing program to determine the degree of continued effectiveness of waterproofing membranes underway since 1974.

More recently some badly deteriorated decks have been repaired by cleaning off all delaminated concrete to the level of the top reinforcing steel, sandblasting the rust from the steel and then resurfacing with one of two methods. The first method is to apply a surface layer of quick setting patch cement material covered by an asphalt membrane and an asphalt concrete overlay. A second method is to apply a latex modified concrete wearing course.

A report BRIDGE DECK DETERIORATION IN COLORADO published in January 1976 described equipment and testing procedures. That report also detailed asphalt membrane methods and results to that time.

This report will update the effectiveness of asphalt membrane systems and will describe the latex modified concrete system.

BRIDGE DECK MEMBRANE EVALUATION

Through September, 1977 Colorado has placed 171 waterproofing membranes on its bridges. The yearly breakdown follows:

Year	Number	Type of System (1) Built-Up	(2) Prefabricated	(3) Single Component
1971	14	--	14	--
1972	48	11	20	17
1973	40	7	4	29
1974	12	--	1	11
1975	20	--	--	20
1976	24	--	--	24
1977 (part)	13	--	--	13
	171	18	39	114

Table 1

The Built-Up systems (1) have been phased out. One reason was the difficulty of construction. Built-Up included five layers of coal tar emulsion and two of fiberglass, the layers being placed one at a time. Another problem was the highly toxic nature of the materials. Application required the use of rubber gloves and clothing and protective goggles.

Three types of prefabricated membranes have been used. They are Protecto Wrap, Royston No. 10 and Heavy Duty Bituthene. Protecto Wrap is a laminate of synthetic resin reinforced coal tar and a non-woven synthetic fibrous mat. Royston No. 10 is a laminate of an impregnated fiberglass mesh sandwiched between layers of a bituminous mastic. Heavy Duty Bituthene is a polyethylene film with a rubberized asphalt adhesive on one side.

Prefabricated systems (2) are still allowed but have not been chosen by contractors due to expense and difficulty of placement.

Hot applied Single Component systems have been the only ones selected since 1975 and these have been limited to Superseal 4000, Gilsabind No. 5, and Deckseal No. 50. Superseal 4000 is a elastomeric PVC polymer. Gilsabind No. 5 and Deckseal No. 50 are 25% rubber and 75% asphalt cement with a small amount of extender oil to improve solubility of the rubber in the asphalt.

In the fall of 1974 the Staff Materials Branch established a continuous testing program using the electrical resistance method. The electrical resistance testing is to determine the integrity of water tight systems. The procedure is described in detail in Appendix A. Twenty bridges were selected statewide representing a wide range of system types and environmental conditions. A summary of the results to date is shown on Table 2.

The number of bridges to be continuously retested by the resistance method has been reduced substantially since many of the membranes are no longer in use. In addition, enough data has been collected on systems still in use to reach some conclusions on the effectiveness of the membranes through five years of service. Testing will continue to obtain results on new systems and longer range results on existing systems.

Future plans include drilling through the asphalt and membrane to obtain concrete samples for chloride analysis and to make half-cell measurements. The chloride content and active corrosion as indicated by half-cell potentials can be correlated with membrane resistance measurements to determine if a change in specifications is required.

MEMBRANE EVALUATION CONCLUSIONS

Results to date show that the most important factor in membrane performance is how well it is placed. A well constructed membrane, of any type in any environment, tests well immediately after placement and continues to test well.

Table 2

SAMPLE GROUP OF MEMBRANES

COLORADO DOH MATERIALS LAB LONG RANGE RETESTING PROGRAM

Field Dist.	Str. Number	Location	Year Installed	Type or Brand	Roofing Paper	System*	% Success Fall 1974	% Success Spring 1975	% Success Fall 1975	% Success Fall 1976	% Success Fall 1977
I	F-12-U	W. Frisco/10 mi.	1971	Royston #10	NO	2	69	73	77	65	73
I	F-12-V	W. Frisco WB	1971	Royston #10	NO	2	98	97	97	99	95
I	E-17-HE	SH 128 & I 25 EB	1972	Protecto Wrap	NO	2	92	95	96	99	99
I	E-17-HE	SH 128 & I 25 WB	1972	Super Seal 400	NO	3	97	95	96	100	100
I	F-15-CE	El Rancho-I 70	1972	Protecto Wrap	NO	2	99	100	99	100	100
I	F-15-CC	Soda Creek I 70	1972	Superseal 400	NO	3	99	99	99	100	100
I	F-15-CA	Hyland Hills - I 70	1973	Superseal 4000	YES	3	87	94	94	91	90
I	H-17-CG	Larkspur - I 70	1976	Gilsabind No. 5	YES	3	-	-	-	85	86
I	F-12-AN	Vail Pass I 70	1977	Deckseal No. 50	YES	3	-	-	-	-	100
II	K-18-EP	SH 96 11th St.	1973	Coal Tar/Fiberglass	NO	1	99	100	100	100	100
II	J-18-BI	SH 16 Crows Gulch	1974	Superseal 4000	YES	3	92	88	94	89	92
II	K-18-EU	SH 45 RR	1974	Protecto Wrap	YES	2	95	99	99	100	100
III	F-10-AB	Walcott W-I 70	1971	Royston #10	NO	2	97	90	96	99	67
III	J-4-AT	Delta W SH 348	1972	Coal Tar/Fiberglass	NO	1	99	91	100	100	100
III	H-3-X	Fruitvale - I 70	1973	HD Bituthene	YES	2	82	85	92	86	98
III	H-3-Z	Fruitvale - I 70	1973	HD Bituthene	YES	2	-	92	100	100	98
III	H-4-Z	Mesa N & S	1973	Superseal 4000	YES	3	87	-	99	99	92
IV	C-17-EZ	Windsor E	1971	Protecto Wrap	NO	2	82	96	100	96	100
IV	B-24-AQ	Sterling	1972	Superseal 4000	NO	3	99	98	99	100	98
IV	D-16-CG	Longmont E.	1972	Superseal 400	NO	3	88	92	96	89	90
IV	E-16-FB	Table Mesa Drive	1973	Superseal 4000	YES	3	57	45	60	36	-
V	O-3-C	Mesa Verde	1972	Protecto Wrap	NO	2	38	69	92	53	-
VI	F-16-DX	8th Ave. I 25	1973	Husky #4	YES	3	-	76	92	94	96
VI	E-16-FO	Sheridan SH 36	1973	Protecto Wrap	YES	2	25	25	40	39	57
VI	F-17-FZ	I 25 & I 225	1977	Gilsabind No. 5	YES	3	-	-	-	-	100
VI	F-17-IG	74th Ave. over Canal	1976	Sahuaro Crumb Rubber	NO	3	-	-	-	-	80

System* 1 Built-up
2 Prefabricated
3 Single Component

Poorly placed membranes test poorly initially and continue to test poorly. There is a tendency for some membranes to heal with time as indicated by increased resistance readings. It was thought that migration of the membrane material out of the wheelpaths might cause eventual failure, but this did not occur.

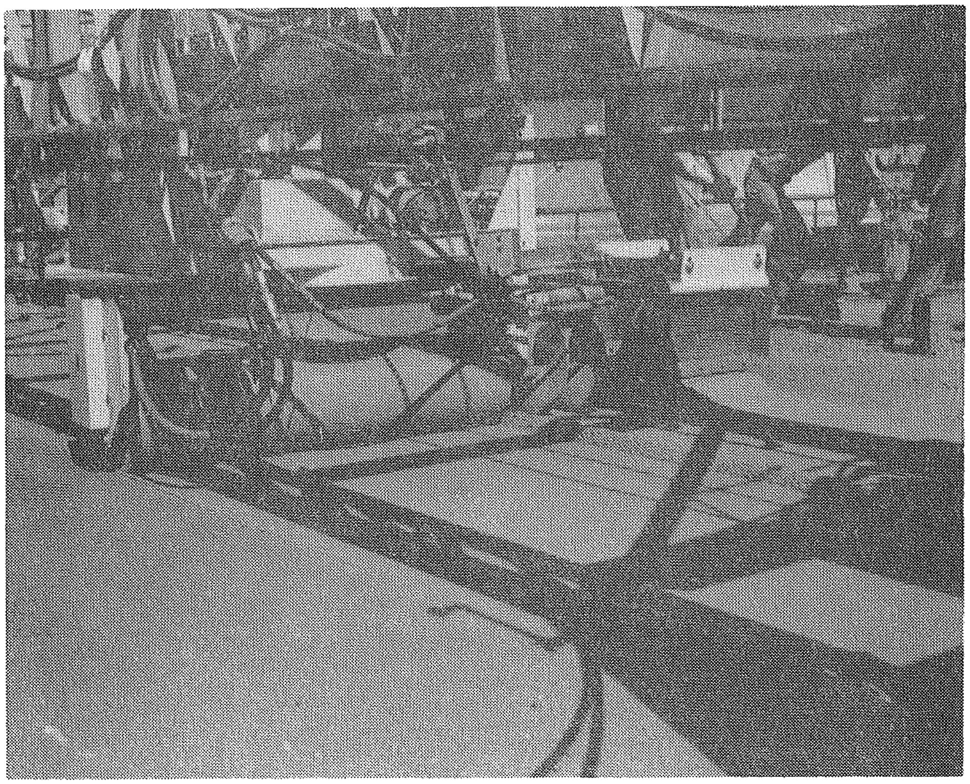
LATEX MODIFIED CONCRETE AS A BRIDGE DECK REPAIR AND PROTECTIVE SYSTEM

Latex modified concrete is reported to have higher strengths than standard concrete. It is also reported to have properties which do not permit the entry of chloride which is the active agent in steel corrosion. It was decided to use latex modified concrete as a surface course on several bridge decks in the Denver Metropolitan area on an experimental basis. The object is to determine if the latex polymer modified concrete will prevent further deterioration of these old bridge decks and become an acceptable substitute for the currently used impervious asphalt membrane and overlay system.

The modifying material is a latex admixture which is homgeneous, uniform, polymeric, nontoxic, film forming emulsion in water. The concrete mixture is composed of sand, coarse aggregate and cement in proportions of 2.5 to 2 to 1 respectively. The latex solids - cement ratio is 0.15 to 1 and the water cement ratio is between 0.35 and 0.40 to 1.

LATEX MODIFIED CONCRETE APPLICATION

Special self-contained, mobile, continuous mixing equipment is necessary to produce the complete latex modified cement concrete mixture. The latex modified concrete is placed on a previously prepared surface, leveled and finished with automatic leveling, vibrating, finishing machine. (See Photograph No. 2.) Texturing and curing operations should follow the finishing machine as soon as possible. Care should be taken in this operation since latex modified concrete has a tendency to dry rapidly in Colorado's semiarid climate if curing procedures are not conducted immediately after finishing.

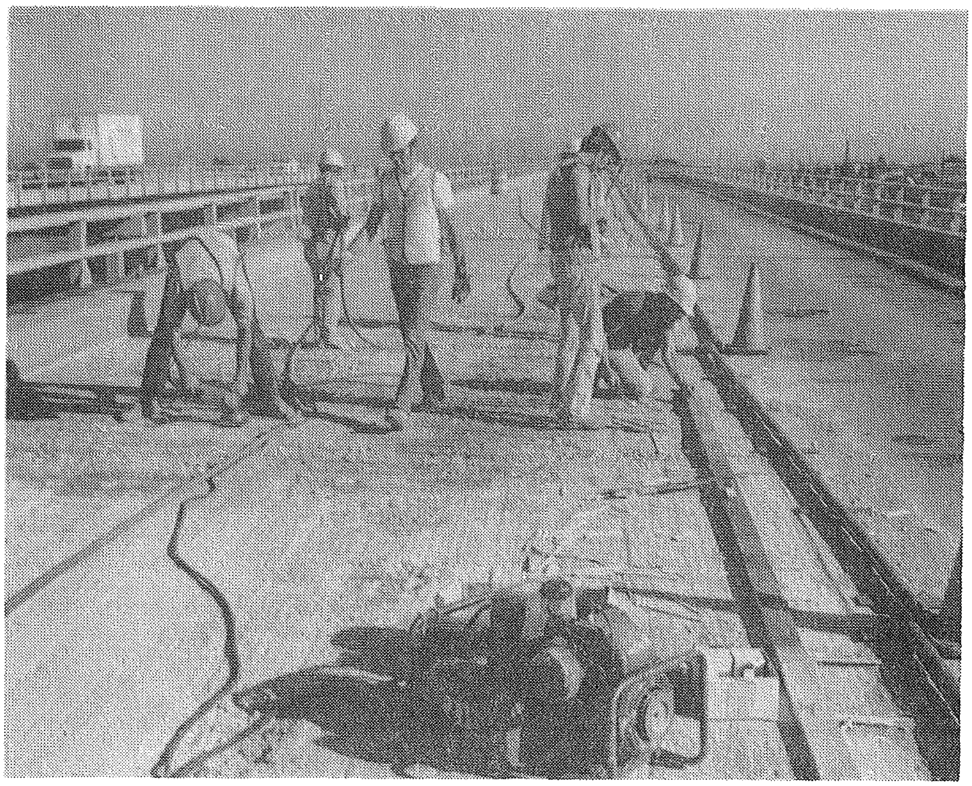


Photograph No. 2

Automatic Finishing Machine
and Latex Modified Concrete

PAST EXPERIENCES

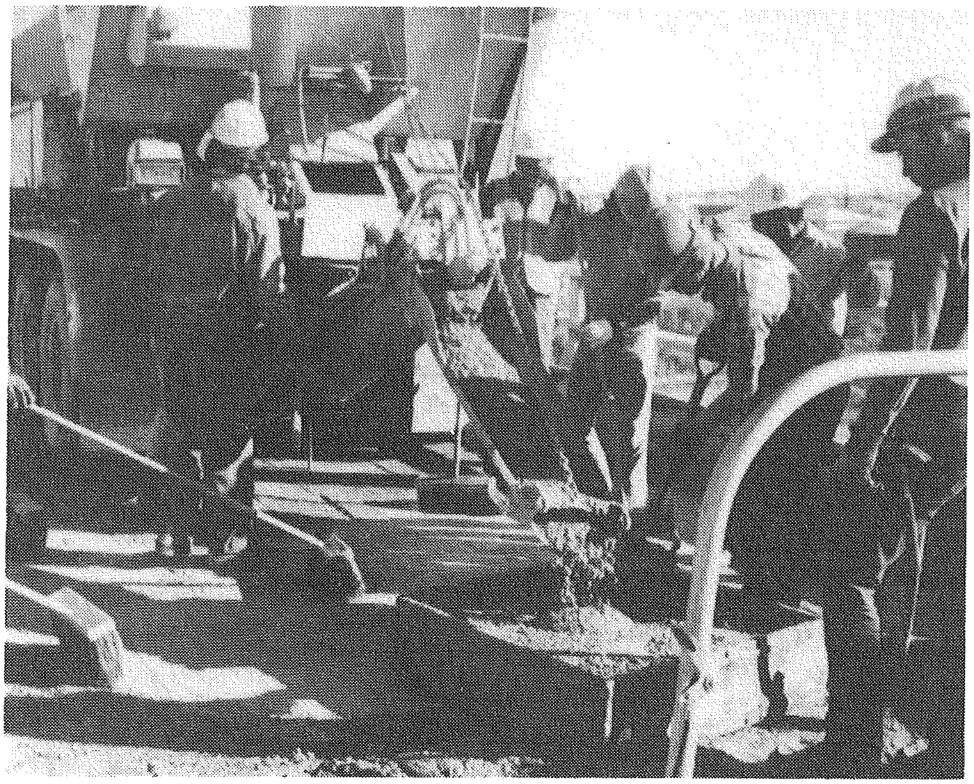
Colorado's first experience with the latex modified concrete system was in 1973. A badly deteriorated deck, I 225 northbound over Sand Creek was prepared to receive this system.



Photograph No. 3
Structure No. E-17-JT - I 225 Northbound Over Sand Creek
Removing Delaminated Concrete

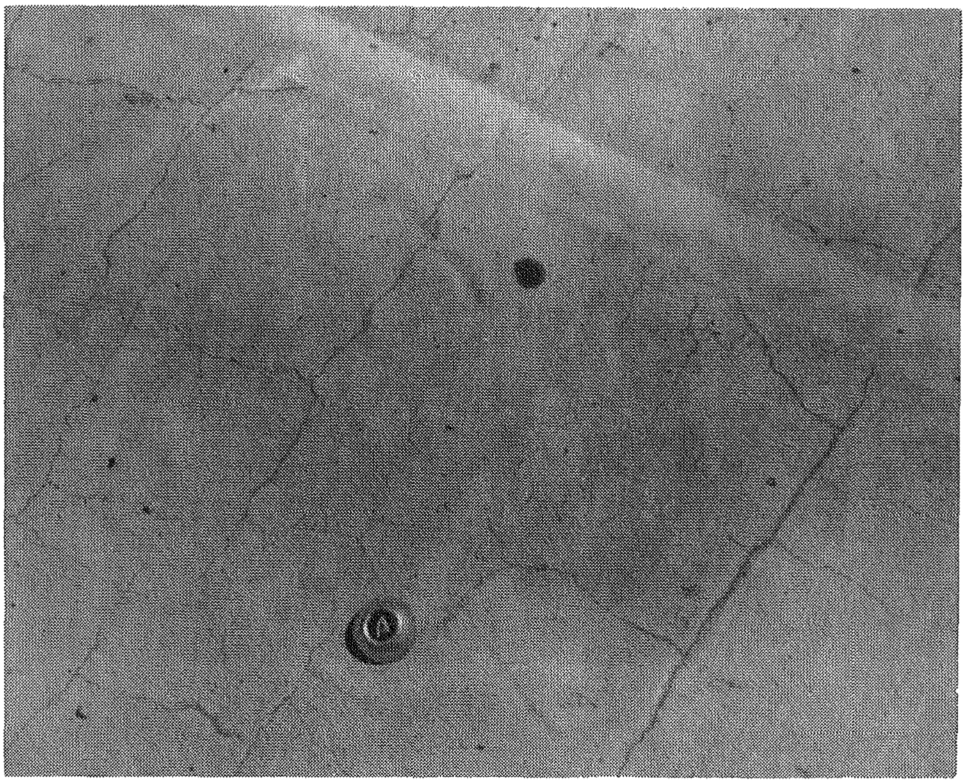
Preparation included grinding about 2 cm (.78 in) of concrete from the entire deck followed by jackhammering to remove delaminated concrete and sandblasting to remove rust from the steel.

Liquid latex was mixed with the concrete in special trucks on the job, placed and finished to a minimum thickness of 3.8 cm (1.5 in). A mechanical finishing machine leveled, vibrated and finished the latex modified concrete. (See Photograph No. 4).



Photograph No. 4
Structure No. E-17-JT - I 225 Northbound Over Sand Creek
Pouring Latex Modified Concrete

This material cracked quite extensively in a random pattern within a few days. There did appear to be more cracks in a transverse alignment corresponding to the reinforcing steel. A high water cement ratio is probably responsible for some of the cracking. Less water in the mix would have reduced the shrinkage cracks and would have produced a stronger material. Proper curing measures were not carried out soon enough after placement and finishing of the concrete. Nearly a hundred shrinkage cracks were removed by cutting around each crack with a diamond saw and then chipping out the concrete within that area. These areas were then patched with new latex modified concrete. The repair and patching was completed within four days. During the next two years the surface continued to crack to the extent shown in Photograph No. 5, taken in 1976.



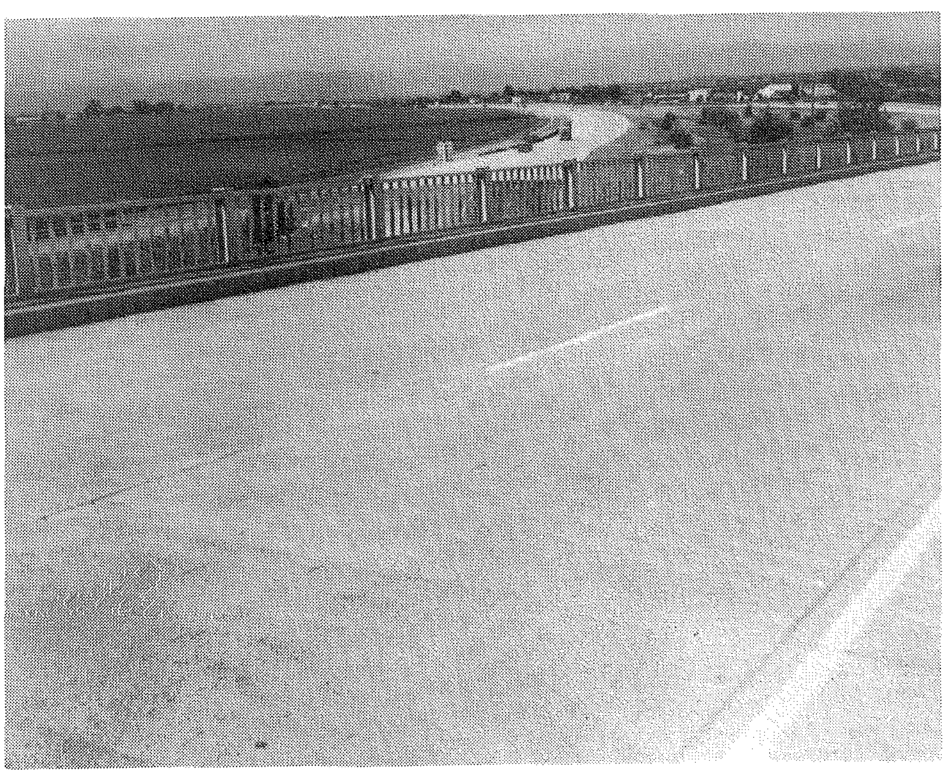
Photograph No. 5
Structure No. E-17-JT - I 225 Northbound Over Sand Creek
Fall 1976 - Extensive Cracking

In September of 1977 a rolling delamination detector was used on the Sand Creek Bridge. Analysis of the data from this test indicates that 19% of the surface is delaminated. The thickness and strength of the modified concrete may be resisting pop-outs to date, but this deck may require another repair project in the next few years.

RECENT USE OF LATEX MODIFIED CONCRETE

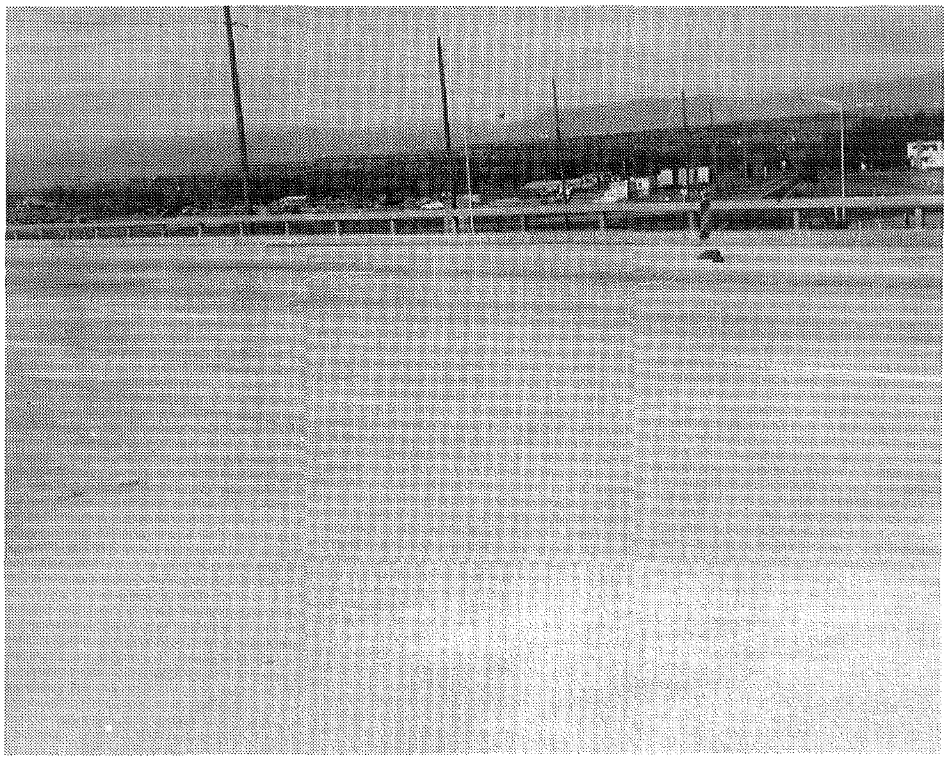
During the last few years more bridge decks in the Denver Metropolitan Area have developed an urgent need of major repair and resurfacing. Since 1973 other states and agencies have reported success with latex modified concrete. It was decided in 1976 to use latex modified concrete on several structures on an experimental basis. Design and construction procedures were to be used which would eliminate or minimize the problems which were encountered on the Sand Creek Structure.

Three bridge decks received latex modified concrete repair systems in 1976. Also one new structure (E-17-KT), I 76 over 96th Avenue, employed latex modified concrete as the top 3.8 cm (1.5 inches) surface wearing and protective course. These four decks looked and tested rather good in the fall of 1976.



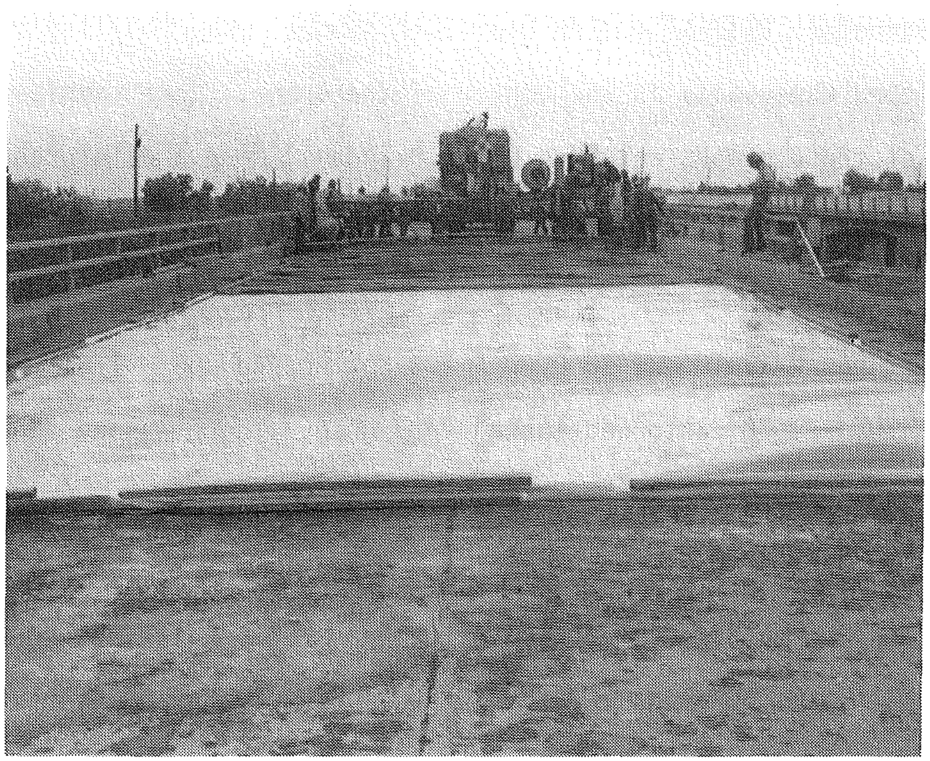
Photograph No. 6
Structure No. E-17-DQ - Westbound Over SH 85
Fall 1976 - Shortly After Treatment

Quality control, testing and inspection were maintained at a very high level. The placement, finishing, and curing of the latex modified materials was done with great care to achieve a high quality protective system.



Photograph No. 7
Structure No. E-17-KT - I 76 Over 96th

August 1976 - New construction Class D Concrete was used as structural concrete and 3.8 cm (1.5 in) of latex modified concrete was used a a surface course.



Photograph No. 8
Structure No. E-17-1B - I 76 Westbound Over I 270
Wet burlap and plastic sheeting are placed immediately after the concrete is finished

These four bridges and the Sand Creek bridge were inspected and tested in the fall of 1976. The tests included the half cell electrical potential, depth to the top layer of reinforcing steel, chloride content and visual inspection. Visual inspection of these decks in the fall of 1976 indicated that they all looked to be in satisfactory condition. A visual inspection of the four structures was made during the spring of 1977 as part of the continuing evaluation program. On the I 76 structure westbound over SH 85 there were numerous hairline cracks on the surface of the entire deck. The construction joint down the centerline did not appear to be watertight.

On Structure E-17-KT - I 76 Over 96th Avenue, many hairline cracks had developed especially in the center of the spans. Core samples proved that 75% of these cracks were 7.5 cm (3.0 inches) deep and intercepted the steel. Therefore, the latex modified surface course was not 100% watertight or chloride-proof.

Structures E-17-IU - I 70 Over I 225 Northbound and E-17-IT - I 225 Southbound Over I 70 Eastbound looked very good. There was no apparent damage of any kind.

Tables 3 and 4 show the results of the 1976 and 1977 tests. The data collected during the first fall following construction is intended to be used as a base line to compare all future years in which the same tests will be conducted. This data is taken after the repair but before any sand and salt operation starts. Any change in test results in following years can be readily determined. After only one winter of salt applications the spring 1977 data seems to indicate higher chloride content and a higher percentage of active corrosion in these latex concrete structures.

The chloride content and electric half cell tests indicate that some corrosion of reinforcing steel is already taking place. If these trends continue we can expect to see more cracking the next few years. However, the higher strength of latex modified concrete may retard or prevent pop-outs for considerably longer than could be expected of regular Class D concrete.

During the construction season of 1977, six more bridges received the latex modified concrete repair and protective system on an experimental basis. These structures are I 70 over 32nd and 20th Avenues, and I 76 over I 270. All six were in very bad condition as can be seen in Photographs No. 9, 10 and 11. These bridge decks were cleaned of all delaminated concrete

Table 3

Latex Modified Concrete Repair System

Copper Sulfate Half Cell Electrical Measurement

Construction Date	Location	Active Corrosion 0.35 Volts or more 1973+	Fall 1976*	Spring 1977	Fall 1977*
1976	E-17-KT I 76 over 96th New 1976		0	1%	
1957	E-17-DQ I 76 over SH 85 Resurfaced 1976		69%	100%	
1965	E-17-JT I 225 over Sand Creek Resurfaced 1973	72%	18%	38%	
1965	E-17-IT (Top Deck) I 225 over I 70 Resurfaced 1976		12%	100%	
1965	E-17-IU (Second Deck) I 70 over I 225 Resurfaced 1976		48%	63%	
1968	E-16-HF I 70 WB over 32nd Resurfaced 1977	52%			15%
1968	E-16-HE I 70 EB over 32nd Resurfaced 1977				3%
1968	F-16-HK I 70 WB over 20th Resurfaced 1977	15%			64%
1968	F-16-HJ I 70 EB over 20th Resurfaced 1977				45%
1967	E-17-IA I 76 WB over I 270 Resurfaced 1977				2%
1967	E-17-IB I 76 EB over I 270 Resurfaced 1977				1%

+Tests before placement of the system.
*Tests after placement of the system but before winter salt applications.

Table 4

Latex Modified Concrete Repair System

Location and Date System was Applied	Cm (in.) Avg. Steel Depth	Kilograms of Cl^- per Cu. Metre (Pounds of Cl^- per Cu. Yd.) 1973+	Fall 1976*	Spring 1977	Fall 1977*	Average Daily Heavy Trucks
E-17-KT I 76 over 96th New 1976			0.25 (0.42)	0.46 (0.78)		690
E-17-DQ I 76 over SH 85 Resurfaced 1976			1.32 (2.22)	3.09 (5.21)		340
E-17-JT I 225 over Sand Creek Resurfaced 1973		3.74 (6.3)	2.09 (3.53)	5.55 (9.36)		395
E-17-IT (Top Deck) I 225 over I 70 Resurfaced 1976			0.97 (1.63)	2.02 (3.40)		395
E-17-IU (Second Deck) I 70 over I 225 Resurfaced 1976			0.98 (1.65)	0.81 (1.36)		505
E-16-HF I 70 WB over 32nd Resurfaced 1977	5.3 (2.08")	3.62 (6.1)			1.03 (1.74)	300
E-16-HE I 70 EB over 32nd Resurfaced 1977	4.1 (1.6")				0.94 (1.59)	300
F-16-HK I 70 WB over 20th Resurfaced 1977	4.6 (1.83")	3.92 (6.6)			0.48 (0.81)	300
F-16-HJ I 70 EB over 20th Resurfaced 1977	4.4 (1.75")				0.97 (1.63)	300
E-17-IA I 76 WB over I 270 Resurfaced 1977	5.4 (2.13")				0.63 (1.07)	520
E-17-IB I 76 EB over I 270 Resurfaced 1977	5.3 (2.1")				0.28 (0.47)	520

NOTE: 1.2 Kg of Cl^-/Cu. M. is considered sufficient to cause steel corrosion.

+Tests before placement of the system.
*Tests after placement of the system but before winter salt applications.

and latex modified concrete was applied in a similar manner as described earlier. The materials and workmanship were inspected and tested to assure that the best quality projects were attained.

Initial base test data and inspection was conducted on these six structures in the fall of 1977. These test data are also on Tables 3 and 4.

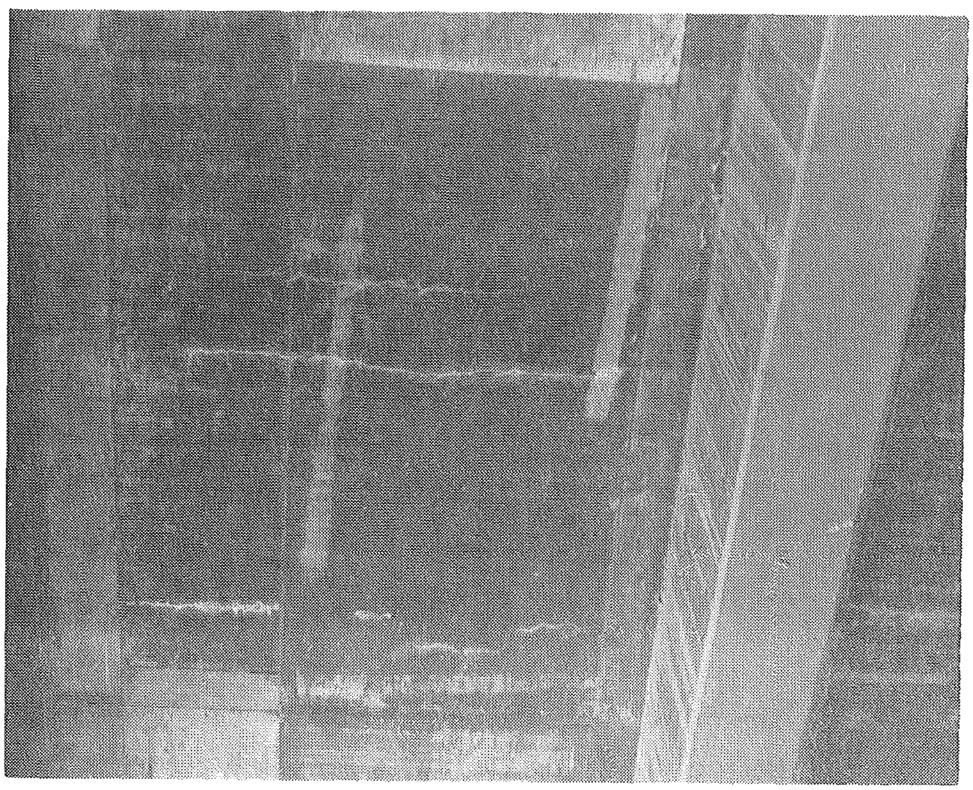
OBSERVATIONS

Visual observation of the underside of the four decks at I 70 at 32nd and 20th Avenues have some cracks in the original deck and residual salt efflorescence from previous salt applications. The surfaces all looked very good after construction.

Photograph No. 9
Structure No. E-17-1B - I 76 Eastbound Over I 270

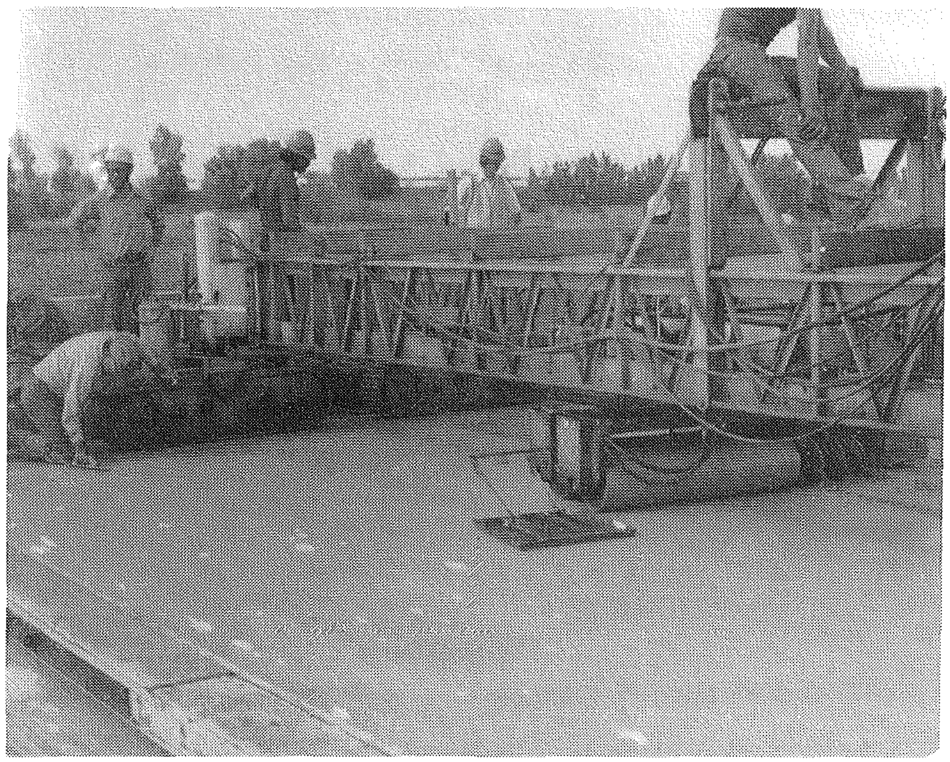
Before receiving the latex modified concrete repair and protective system this structure was badly delaminated and patched.

Photograph No. 10
Structure No. E-16-HF - I 70 Westbound Over 32nd Avenue
Before corrective and protective treatment.



Photograph No. 11
Structure No. E-16-HF - I 70 Westbound Over 32nd Avenue
Underside showing some cracks and residual salt from previous deicing operations.

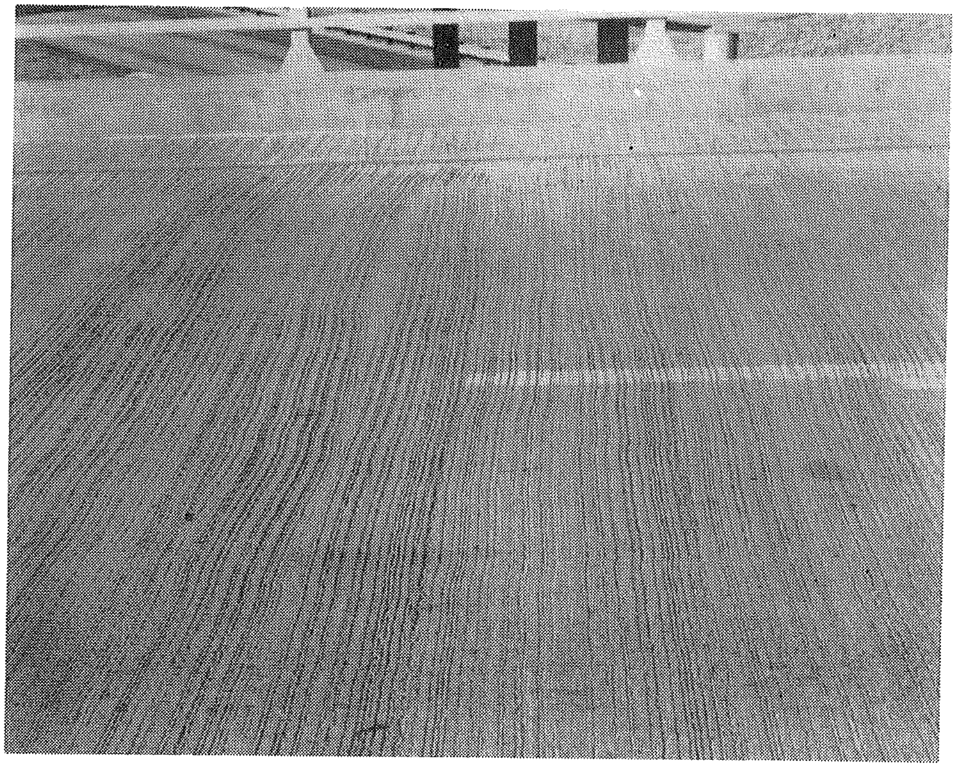
One small problem encountered in the repaired decks was that small spots of latex rich water surfaced after the finishing process. The water was sprayed on before the latex modified concrete was dumped to obtain a good bond with the old concrete. These spots are thought to have been caused by excess free water standing in low areas of the cleaned and jackhammered deck.



Photograph No. 12
Structure No. E-17-1B - I 76 Eastbound Over I 270

Finishing Machine.
White spots are water and latex.

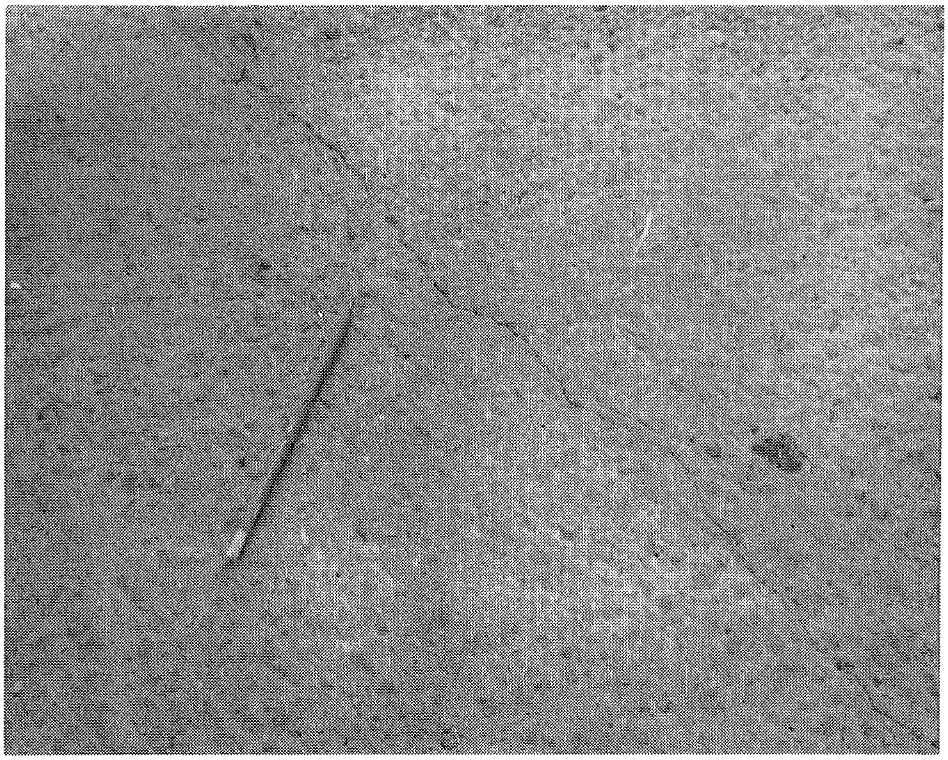
Some free water collected in the low spots. Vibrating and finishing caused the water to come to the surface carrying some latex with it. The opinion of project personnel was that not enough latex was lost to worry about. The white spots were worn off by traffic after a few weeks. (See Photograph No. 12.)



Photograph No. 13
Structure No. E-17-1B - I 76 Eastbound Over I 270

Completed latex modified concrete surface - Photograph taken just after construction
A steel tined broom was used to create this texture.

Photographs No. 13 through 15 show the completed surface of some of the latex modified concrete protective system.



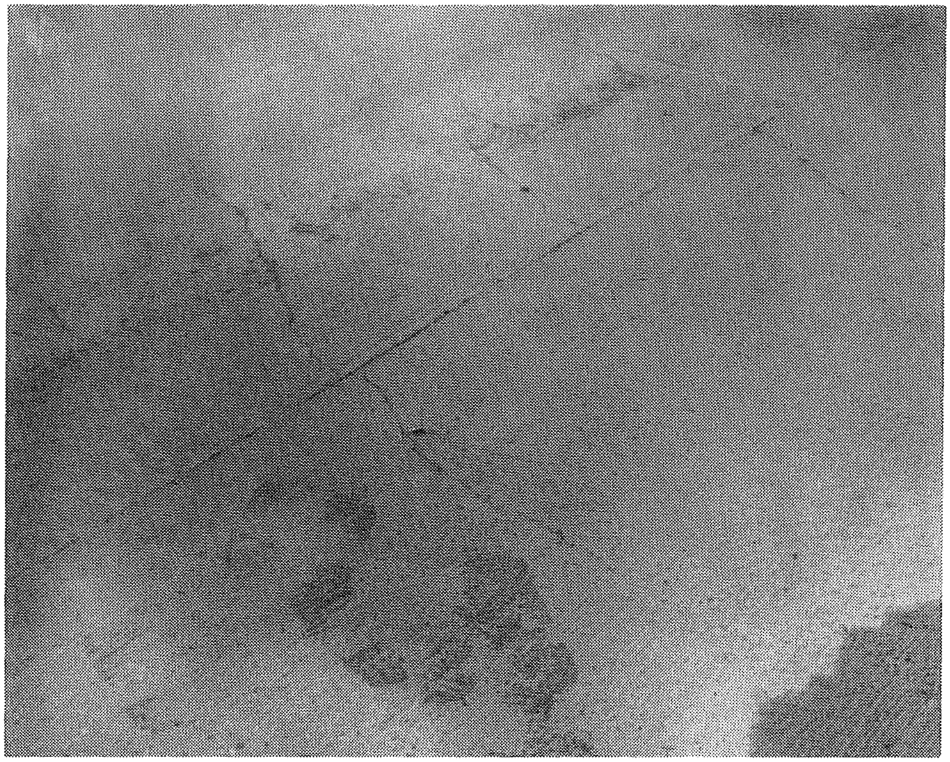
Photograph No. 14
Structure No. F-16-HK - I 70 Westbound Over 20th Avenue

Resurfaced in 1977 - Photograph taken four months after resurfacing.

Cracks recently appeared in this and several other latex modified concrete decks.

Photograph No. 15
Structure No. E-17-IT (Top Deck - I 225 Over I 70)

Resurfaced in 1976 - Some new cracks have recently appeared in the latex modified surface.

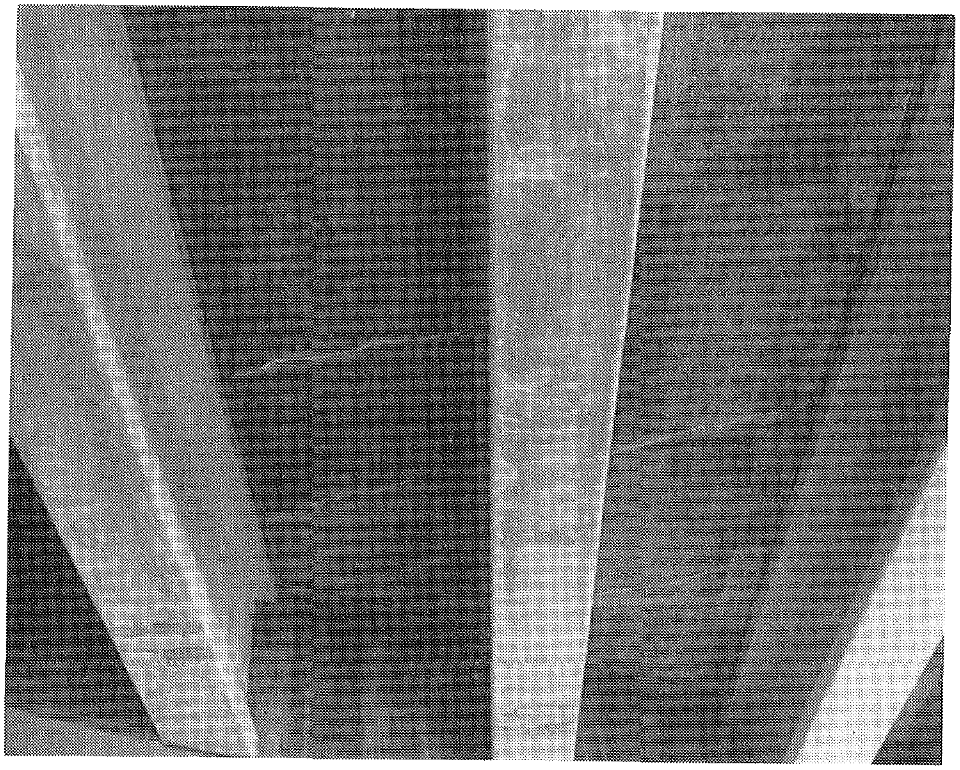


Photograph No. 16
Structure No. E-17-KT - I 76 Over 96th Avenue

New in 1976 - Surface cracks present in the spring of 1977 have increased in number, length and width

Photograph taken in November 1977

This is the new structure built in 1976. There are a considerable number of cracks in this deck. (See Photograph Nos. 16 and 17.) These cracks are continuous and vertical from top to bottom through the top latex modified concrete and the bottom Class D concrete.



Photograph No. 17
Structure No. D-17-KT - I 76 Over 96th Avenue
Salt efflorescence near cracks on the underside of the deck of this new structure

One major conclusion of a recent study and report RATE OF DETERIORATION OF CONCRETE BRIDGE DECKS IN COLORADO is that the average daily truck traffic is a contributing factor in the deterioration of bridge decks. In this study definite correlations were established between heavy truck traffic, cracking and acceleration of delamination and pop-outs. The average daily heavy truck traffic reported on Table 4 appears sufficient to be considered a factor in the rate of deterioration of these bridge decks.

LIQUID CURING COMPOUND

An additional experimental feature was incorporated into the Project I 270-6(9) which was latex modified concrete on the structures at I 76 over I 270. The experimental feature was a newly developed liquid membrane used as a sprayable formulation of a curing compound for latex modified concrete. The liquid curing compound was sprayed on the fresh finished and textured concrete on Structure E-17-1B.

Photograph No. 18
Structure No. E-17-1B - I 76 Eastbound Over I 270

Spraying liquid curing compound in place of burlap and plastic sheets.

Note: The bright white spots are not curing compound - they are water and latex.

This liquid must be applied with an airless spray gun. Burlap and plastic were on the job site in case of a breakdown of this sensitive spray equipment. The curing compound was used over the entire deck. State and contractor personnel were pleased with this operation because it could be applied to wet concrete very soon after the finishing machine. The use of this compound saves labor and preserves the surface texture much better than burlap.

The results were very good and the only surface cracking occured at a place where there was a delay in mixing and delivery of the concrete mix. These cracks are not the fault of the curing compound as this liquid curing compound is considered to be a definite advantage over wet burlap curing procedures.

LATEX MODIFIED CONCRETE CONCLUSIONS

Latex modified concrete, 3.8 cm (1.5 inches) thick placed on a clean prepared deck is intended to protect the lower part of the deck from corrosion by preventing chloride penetration to the reinforcing steel. Cracks or any other flaws in the latex modified concrete surfacing which allows entry of salt defeat the purpose of the design.

Recent inspections of structures which have latex modified concrete surface courses indicate that they are all cracked to some extent. It is possible that heavy truck traffic and bridge design features cause excessive deflection of these bridge decks, contributing greatly to the cracking. As a thin surface course becomes more dry and brittle, cracks are reflected from the old underlying concrete.

At the points where chlorides come into contact with steel, corrosion is likely in progress. Corrosion will very probably progress laterally along the steel to cause delamination.

The thickness and strength of the concrete (either Class D or Latex Modified) will determine if and when pop-outs will occur. Considerable time may be required to determine the value of this design.

FUTURE NEEDS

The follow-up program to monitor the continued effectiveness of water-proofing membranes should continue especially those using recently developed materials. Cement samples for chloride analysis will be taken from under some of these membrane covered decks to determine the reliability of the respective tests. Monitoring and testing all of the latex modified concrete bridge decks will continue until definite conclusions are reached.

An attempt will be made to measure the deflection of some of these bridge decks as heavy truck traffic crosses them. Bridge design engineers will be consulted to determine if measured deflections are within tolerable limits as compared to design prediction deflections.

Due to the inconclusive performance of the latex modified concrete repair systems at this time, it is recommended that additional use of this sytem be limited to special cases. If used, care should be exercised in the construction and performance evaluation. A final recommendation will be made after more observations and conclusions can be drawn from the eleven bridge decks now in service.

A P P E N D I X

EASTERN FEDERAL HIGHWAY PROJECTS OFFICE
REGION 15

Demonstration of a Steel Corrosion Detection Device

In Colorado

May 1971

U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
REGION FIFTEEN

FIELD OPERATIONS - CORROSION DETECTION PHASE

1. DEFINITION OF TERMS

a. Corrosion - Oxidation of reinforcing steel.
b. Standard Half cell - A copper plate immersed in a saturated copper sulfate solution.
c. Potential - Level of the electrical charge.
d. Normal Potential - Any metal in water or water solution has a tendency to throw atoms into solutions as ions. There is an actual solution tension and level of electric charge which will differ in degree with the position of the metal in the activity series.
e. Standard oxidation potentials for metals in a saturated solution of their own ions.

Metal	Reaction	E^{O} (Volts)
Zn	Zn+2 + 2e-	+ 0.763
Fe	Fe+2 + 2e-	+ 0.440
Cu	Cu+2 + 2e-	- 0.337

EXAMPLE: Fe - Cu = 0.440 - (-0.337) = 0.777 volts

f. Difference in potentials - The algebraic difference in potential of one metal from that of another.
g. Electromotive Series - Potentials of metals surrounded by a saturated solution of their own ions.

2. INTRODUCTION

In recent years premature concrete bridge deck deterioration has been reported with sufficient frequency to warrant modifications that will minimize such problems in the future.

Recent reports have identified concrete spalling as the most serious form of bridge deck deterioration, because of the severe effect it has on riding surfaces, the reduction in structural capacity and the difficulty in making a permanent repair. It has also become apparent over the past several years that the use of deicing chemicals has significantly accelerated the spalling process.

Research studies made by the State of California, Division of Highways, in cooperation with the Bureau of Public Roads, indicate most spalling of concrete bridge decks to be caused by corrosion of the reinforcing steel which can exert an internal pressure in excess of 4,000 pounds per square inch.

The purpose of steel corrosion detection tests is to:

a. Identify the cause of corrosion.
b. Provide a means for evaluation of repair methods.
c. Aid in evaluating preventive measures and design changes.

Proof of equipment performances will be shown by making electrical measurements on both old and new structures and by analyzing the concrete for salt content at various depths. In a few States the reinforcing steel will also be checked for visual evidence of corrosion.

3. TESTING INSTRUMENTS AND EQUIPMENT

The following equipment is being used by the Region 15 Corrosion Detection Team - other equivalent equipment would be adequate.

a. Hewlett-Packard D.C. null voltmeter.
b. Copper copper-sulfate half cell.
c. Two spools of No. 16 wire, one spool containing 100 feet of two-wire cable each connected to a jack on the spool for easy connection to the voltmeter and spring clips on the end for making connections to the reinforcing steel. The two wires are used to allow the changes in the field. (The two sizes of clips are necessary to allow easier connections to the reinforcing steel.) The other spool contains 300 feet of insulated No. 16 wire with a jack on the spool and a spring clip for attaching to the copper copper-sulfate half cell.
d. A hand drill, self-powered, with masonry bit.
e. Hand tools - hammer, chisel, files, etc.
f. An ohm-meter similar to Simpson No. 313 volt ohm-meter.
g. A 12-inch x 12-inch x 1/8-inch copper plate with clip for connecting the ohm-meter and means to connect a 36-inch handle - The entire bottom surface must be covered with sponges using wood dowel pins for connectors.

4. TESTING PROCEDURES

The following procedures should be followed when testing reinforced concrete bridge decks or continuously reinforced concrete pavements, for active corrosion of the reinforcing steel.

a. Measure and mark a 5-foot grid on the surface to be tested. (If conditions warrant, the grid may be increased or decreased.)

b. Locate a reinforcing bar or other connection to the reinforcing steel. A positive connection to the top of reinforcing steel is desired; however, if this is not feasible, the bridge railing expansion joints, light standards, drainage scuppers or other exposed steel may provide a positive connection to the reinforcing steel provided:

   (1) The connection must not be galvanized.
   (2) Checking the electrical level at various distances must show no constant decrease in electrical level.

c. Uncoil an ample length of wire to reach all areas to be tested, attach minus (-) jack of voltmeter to the reinforcing steel and plus (+) jack to the copper copper-sulfate half cell.
d. Check voltmeter battery for satisfactory charge.
e. Zero voltmeter on lowest scale.
f. Switch to WM-AM on the one (1) volt scale and make measurements of the electrical potential at each grid point. The half cell requires a wet sponge attached to the bottom contact to aid in making a good electrical contact with the concrete.

   Potential readings from 0 to 0.30 volt are normal for sound concrete with no active corrosion in the reinforcing steel. When potential readings of 0.35 volt or more are encountered, the reinforcing steel is actively corroding.

g. Record the readings on graph paper and plot the lines of equipotential.

The following procedure should be followed when applying resistance tests on bridge decks with membrane water-proofing system.

a. Measure and mark a 5-foot grid on the surface to be tested. (If conditions warrant, the grid may be increased or decreased.)
b. Wet the surface to be tested thoroughly and repeatedly allow the water time to permeate through the surface. The water should contain a wetting agent (95 mls of wetting agent to 5 gals water).
c. Locate a reinforcing bar or other connection to the reinforcing steel. A positive connection to the top mat of the reinforcing steel is desired; however, if this is not feasible, the bridge railing, expansion joints, light standards, drainage scuppers or other exposed steel may provide a positive connection to the reinforcing steel provided:

Checking the resistance level at various distances along an exposed portion of the concrete must show a constant resistance level, thus indicating a positive connection to the reinforcing steel.

d. Uncoil an ample length of wire to reach all areas to be tested, attach the minus (-) jack of the ohm-meter to the reinforcing steel and the plus (+) jack to the 12-inch x 12-inch x 1/8-inch copper plate. Wet spongs.
e. Check ohm-meter battery for satisfactory charge.
f. Zero ohm-meter.
g. Switch to highest range of ohm-meter and record reading - if no reading is attained, switch to next lower range until a reading is attained. Reverse connections to meter and average the readings to reduce the error induced by galvanic coupling of the copper plate and the reinforced steel.

 Resistance readings of bare concrete will vary from 1000 to 1300 ohms per sq. ft. Depending on the magnitude of the external galvanic voltages that exists, gross errors can occur in this low resistance range. For example, with the leads connected with one polarity the value can be in the order of 1000 ohms per sq. ft. By reversing the leads, the values can be in the order of 3000 or 4000 ohms per sq. ft.

 It is speculated (according to California Study) that an excellent waterproof coating for bridges would always have an electrical resistance greater than 500,000 ohms per sq. ft., while a poor or perforated coating would never have a resistance greater than 100,000 ohms per sq. ft.

 Note: For a more comprehensive study record readings of the corrosion detection device and the resistivity device.

h. Record the readings on graph paper and plot lines of equal resistance.

5. PROCESSING AND REPORTING DATA

Record the following data:

a. Location (route, nearest town and project number)
b. Type of construction
c. Year constructed
d. Number of spans
e. Major repairs
f. Span tested and date

Complete plotting equipotential or equiresistance lines, write a narrative including a statement on condition of the surface and your opinion as to whether active corrosion is present, or for resistance measurements a statement on apparent effectiveness of the membrane.