Interim Report

REINFORCED CONCRETE BRIDGE DECK DETERIORATION: DIAGNOSIS, TREATMENT, AND REPAIR

PART II: TREATMENT

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<u>NOTE</u>: This is an interim report and results should not be construed as final. Several details of the research are limited in this report since its purpose is only to report current status.

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1. Introduction

This phase of the research is concerned with the treatment of bridge decks to prevent the initiation of surface deterioration or to attenuate deterioration that has already begun. It seeks a solution to the problem of determining what materials are effective as surface treatments in the prevention and/or spread of damage; the manner, extent, and schedule of application; and the relative merits of those found to be effective.

Recent reports have shown that the most widespread forms of bridge deck deterioration are surface scaling, surface spalling, and cracking.[(1,2)*] These are attributed to either low or zero entrained air or poor distribution of entrained air, subsidence of plastic concrete and drying shrinkage, and expansion of freezing water or of corroding steel. The entry of water and water-borne chemicals through pores and cracks provides a source for freeze-thaw expansion and for corrosion of reinforcing steel.

The above referenced reports indicate that insufficient cover of top reinforcement due to its misplacement in some instances has contributed to deterioration. The high mortar content of some of the reported concrete with its poor distribution of entrained air makes it particularly vulnerable to freeze-thaw scaling. Shrinkage

*Numbers in brackets refer to items in the Bibliography contained at the close of this report.

and stress cracks, both longitudinal and transverse, in negative moment regions provide routes of entry for water which makes it available for subsequent attack on concrete, steel, or both.

The problem of bridge deck deterioration cannot be blamed on any one cause, but deicing chemicals, along with water, accelerate the problem. It is hence reasoned that many problems of deterioration will be solved or at least attenuated by preventing moisture and harmful chemicals from entering the concrete. A surface treatment effective in preventing that entry is desired.

2. Objectives

1. To identify effective sealants.
2. To determine the effect of abrasion on the effectiveness of those sealants.
3. To determine the skid resistance of effective sealants.
4. To determine the effect of ultraviolet light on the effectiveness of those sealants.
5. To compare the relative advantages of effective sealants by considering:
    a. shut-down time of the bridge during application and curing,
    b. cost in place, and
    c. cost/effect time.

Though not a specific objective of this research, a material that would not materially change the color or alter other physical properties of the concrete was sought as a desirable material.

3. Materials

3.1 Concrete. The laboratory concrete mixes described in Appendix A were designed to meet the requirements of the Texas Highway Department for Class A (non air-entrained) and Class *A (air-entrained) concrete. In addition to laboratory concrete, cores were taken from several reinforced concrete bridge decks. The available data for the bridge cores are contained in Appendix B.

The laboratory concrete was mixed in batches ranging in size from 1 1/2 cubic feet to 6 cubic feet. The specimens were cast in a single layer and externally vibrated in oil-coated steel and wood forms, and the top surfaces were troweled and then given a light broom finish just prior to initial set. They were held in the forms for 24 hours, then removed from the forms and placed in a 100% relative humidity and 73°F moist room and allowed to cure 7 days. After curing, the specimens were air dried for a minimum of 21 days before being treated with various sealants.

3.2 Sealants. All of the sealants are described in Appendix C. The directions furnished by the manufacturers for preparation and application of the sealants were followed.

4. Description of Tests

4.1 Absorption Tests. Absorption tests similar to the wet-dry tests used in earlier research[3] were performed. Concrete blocks 3 in. x 3 in. x 4 in. long were treated on five sides and placed with the finished surface down in approximately 2 in. of both tap water and a 5% brine solution. The blocks were allowed to soak at ambient temperature for 24 hours then placed in a 140°F oven for 24 hours so that each 48-hour period constituted one cycle. It was noted that several cycles were required for the weight of the blocks to stabilize; hence for determining the average absorption, the first six cycles were disregarded, and average absorption was determined following the seventh cycle.

A second series of absorption tests was made in which half of the blocks were sandblasted on the finished surface prior to testing. The method of sandblasting is described in the section titled "Wear Tests."

4.2 Freeze-Thaw Tests. The freezing portion of the freeze-thaw cycles was performed by two household chest-type freezers. The freezers were maintained at 0°F ±5°F. For the thawing portion of this test, the blocks were removed from the freezers and allowed to set at room temperature (about 80°F) until they reached at least 40°F. In general, the freezing required 18 to 20 hours; and the thawing, 4 to 6 hours, hence a 24-hour cycle was used.

Test specimens for the freeze-thaw tests were 10-in. square blocks, 2 in. thick. These were treated on the finished surface only. After the blocks were treated, an 8-in. diameter galvanized steel ring 1 in. high was fixed to the surface with a silicone rubber compound.

A 5% brine solution made from rock salt was placed on the surface to a depth of 1/4 in. This solution was used to accelerate the tests and in an attempt to duplicate the effect of deicing salts used on bridge decks.

A rating scale similar to that used by the Battelle Institute[4] was used to measure scaling by a visual technique.

4.3 Wear Tests. Wear of the bridge deck was simulated by using a sandblasting apparatus, having a gun with a 1/4 in. bore and a vacuum pick-up for the sand. The sand used was a 20-30 Ottawa sand (ASTM C-190). The blocks were sandblasted for 30 seconds at an air hose pressure of 60 psi which delivered an average of 680 gms. of sand. The blocks were placed 11 1/4 in. from the nozzle of the gun in a specially constructed box illustrated in Figure I.

The broom-finished surface was sandblasted to expose and clean some of the top aggregate. The exposed area, about 3 in. in diameter, on a normal untreated block is shown in Figure II.

4.4 Ultraviolet Light Tests. Ultraviolet radiation can cause chemical activity in some materials, notably some asphalts,[5] but its effect on many sealants is not yet known.

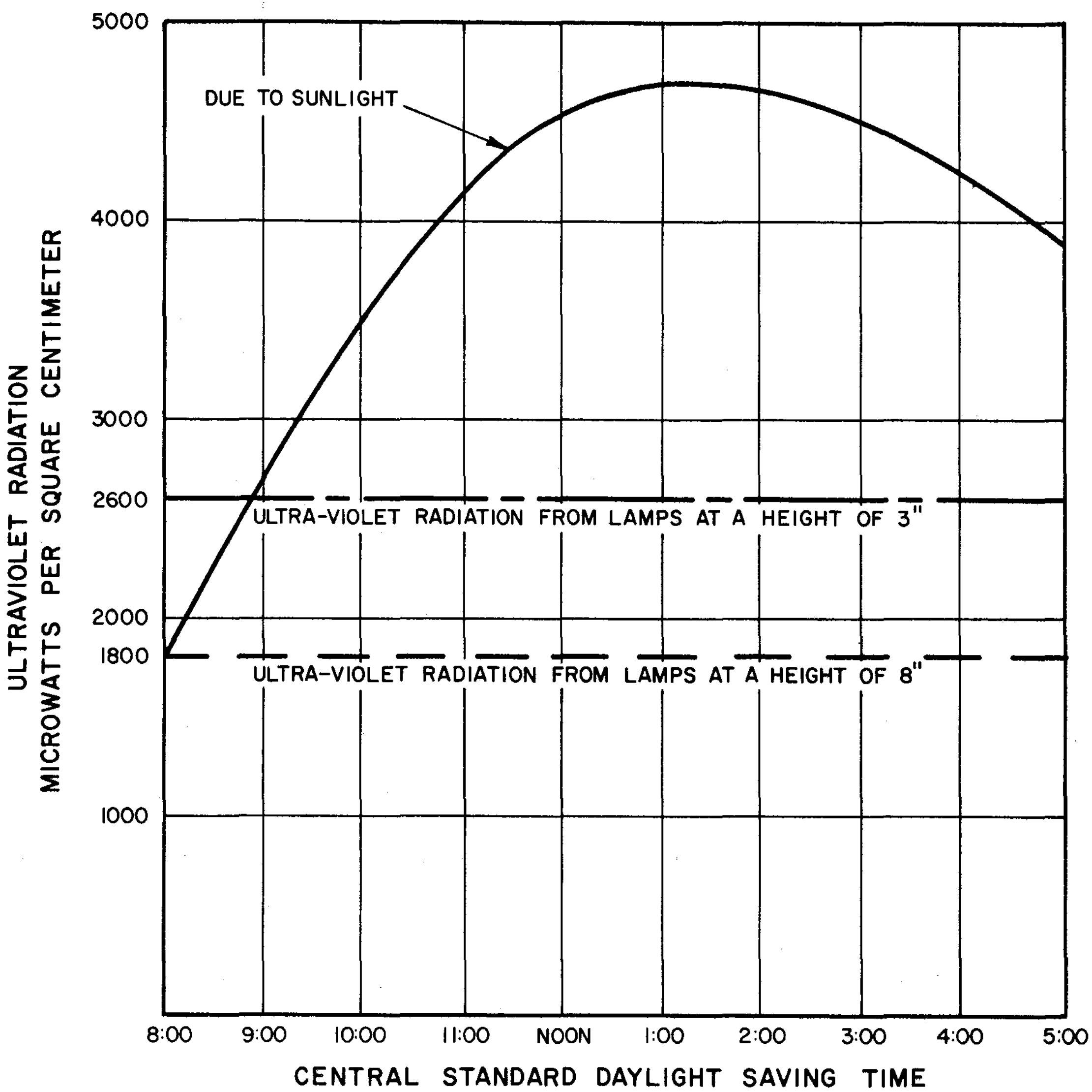
The treated surfaces of a number of specimens are currently under exposure to ultraviolet radiation in an effort to determine if sunlight reduces the effectiveness of selected sealants in freeze-thaw tests. Black ray ultraviolet lamps, maximum intensity at 360 Angstroms, set 3 in. above the treated surfaces are being used in these tests. These lamps at this height deliver

FIGURE I.

SANDBLASTING APPARATUS FOR WEAR TEST

FIGURE II.

SANDBLASTED AND UNSANDBLASTED TEST SPECIMENS



ULTRA-VIOLET RADIATION DUE TO SUNLIGHT FOR AN AVERAGE SUMMER DAY SHOWN AS HOURS OF THE DAY VERSUS ULTRA-VIOLET RADIATION

FIGURE III

an energy of 2600 microwatts per square centimeter. This value is compared with the ultraviolet energy of sunlight in Figure III. It should be noted that the energy is equivalent to that produced by average summer sunlight at 9:00 a.m.

5. Results

The results of the absorption tests are shown in Table I. It is interesting to note that in general those sealants which rated well in the absorption tests also rated well in the freeze-thaw tests (Table II).

The results of the freeze-thaw tests are shown in Table II. The series of Tests A through G referred to in Table II are described in Appendix D.

Though each series of tests was not identical (refer to Appendix D), a few of the sealants were consistently more effective than others. From the results of these tests, the following sealants appear to be the most effective in preventing surface damage to non air-entrained concrete.

1. Boiled linseed oil either in raw or cut-back form.
2. Tung oil either in raw or cut-back form.
3. Sand-filled cold tar emulsion with a sealing primer.

However, at this point one should not exclude sand-filled asphaltic cements. This material was used only in a single series of tests and appeared to perform well. This performance, though, is still open to question because of the difficulty of visually recording deterioration of the surface of the concrete when it is covered by this sealant.

TABLE I

Absorption Tests Results

Rank	Sealant, Percent Absorption* of Brine Solution	Sealant, Percent Absorption of Brine Solution After Wear	Sealant, Percent Absorption of Tap Water	Sealant, Percent Absorption of Tap Water After Wear	Sum of All Tests
1	C(.133)**	C(.197)	I(.221)	I(.216)	C(.229)
2	I(.237)	B(.352)	C(.251)	C(.335)	I(.261)
3	B(.257)	I(.369)	G(.581)	G(.558)	N(.429)
4	J(.364)	K(.383)	N(.600)	J(.594)	B(.482)
5	E(.407)	J(.463)	J(.632)	N(.636)	G(.511)
6	G(.415)	G(.489)	B(.642)	B(.678)	J(.513)
7	K(.444)	F(.492)	E(.690)	E(.777)	E(.596)
8	H(.456)	D(.495)	H(.732)	H(.818)	H(.639)
9	D(.499)	E(.509)	F(.990)	K(.896)	F(.726)
10	F(.510)	H(.548)	D(1.116)	F(.910)	K(.740)
11	N(.653)	N(.625)	K(1.238)	D(.920)	D(.758)

$$\text{*Percent absorption} = \frac{\text{sum of the moisture gained and lost}}{\text{2X number of cycles x average weight of specimen}}$$

**Letters A, B, C. etc., refer to sealants described in Appendix C.

TABLE II

Freeze-thaw Tests Results

The numbers recorded in the columns below represent the number of cycles to failure. Freeze-thaw exposure of aggregates over 50% of the treated surface constituted failure. Columns A, D, and G represent the average of three specimens. Wear tests were made only on those specimens indicated in columns C and F.

Series* / Sealants**	A (1)	C (1)		B (2)	D (2)	F (3)		E (4)	G (4)
		Sand Blasted				Sand Blasted			
B	15	28	36	15					
C	27					9	34		
D	23	18	15	22					
E	37	54	49	80				39	36
F	27	27	28	4		34	38		
G	27	51	41	69				30	32
H	26								
I	42	49	41	80				30	34
J	20	54	54						
K	9	13	6					21	33
N		27	40						
O		8	27	9					
P					42				
Q					17				
R					26				
S					48				32
T		54	50						
U		54	41						

* For a complete description of each series of tests, see Appendix D.
** Letters A, B, C, etc., refer to sealants described in Appendix C.
(1) Laboratory Concrete Blocks .
(2) Heated Concrete Blocks .
(3) Special Concrete .
(4) Bridge Deck Cores .

The findings of these tests lend support to the findings of earlier research.[3,4,6] Tung oil, a material not included in much of the early work, was also shown to be an effective sealant.

The bridge deck cores used in the freeze-thaw series of tests failed internally, crumbled apart, after a number of cycles. This failure occurred before any surface deterioration had taken place. As shown in Columns E and G of Table II, the number of cycles to failure is essentially the same for all treatments. Further tests are necessary to determine if the surface treatment of old non-scaled, sound concrete bridge decks is of value against surface deterioration due to freeze-thaw action.

Only those sealants which were shown to be most effective in the tests conducted to date will be used in further research in this study. Tests currently underway are designed to determine the effects of ultraviolet radiation on the effectiveness of the sealants. The skid resistance characteristics of each sealant and the cost-effectiveness of each sealant will also be studied for the most effective sealants.

Scholer and Best[6] have shown that linseed oil is effective in retarding scaling even if applied after some surface deterioration has occurred. This characteristic will also be examined for the effective sealants considered in this phase of our study.

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APPENDIX A

Laboratory Concrete

Design Factors for Non Air-Entrained Concrete

Type I Portland Cement - 5 sacks per cubic yard

Water/Cement Ratio = 0.60

Slump = 3 in.

Coarse Aggregate No. 3 - 1.0 in. max. size

Fine Aggregate No. 1 - Fineness Modulus 2.90

Fine Aggregate represented 44% of the absolute total volume of aggregate.

Design Factors for Air-Entrained Concrete

Same as above except designed for 5% air using an air-entraining agent.

Results of 13 Batches of Non Air-Entrained Concrete

Avg. 28-day compressive strength - 4,160 psi

Avg. unit weight - 148.2 pcf

Avg. percent entrapped air - 1.8 percent

APPENDIX B

Six 4 in. diameter cores were taken from the following bridges:

Bridge over the Trinity River on State Highway No. 7 in Houston County, District 11, Structure No. 19, constructed in 1957.

Bridge over the Attoyac Real on FM 138 in Shelby County, District 11, Structure No. 12, constructed in 1961.

Bridge over the Sabine River on U.S. 271 in Smith County, District 10, constructed in 1956.

All of these structures exhibited little or no surface deterioration and had not been treated, sealed, or overlaid with any material.

APPENDIX C

Sealants

Code Letter	Description
B	A penetrating oil and resin which advertises to penetrate the concrete surface and then polymerizes to seal the surface. Trade name -- WATCO, Penetrating Sealer, manufactured by WATCO-Dennis Corporation.
C	A two component epoxy membrane used as a membrane curing compound. Trade name -- Colma Membrane Compound, manufactured by Sika Chemical Corporation.
D	A penetrating sealer based on acrylic resins. Trade name -- Horntraz, manufactured by W. R. Grace & Company.
E	A mixture of 50% by weight tung oil and 50% mineral spirits. Trade name -- Tung Oil Anti-Spalling Compound, manufactured by Pan American Tung Research and Development League.
F	A penetrating sealer composed of several compounds which are polynerized and carried in an aromatic solvent. Trade name -- Thompson's Water Seal, manufactured by E. A. Thompson Co., Inc.
G	A mixture of 50% boiled linseed oil and 50% kerosene.
H	A mixture of 50% boiled linseed oil emulsion and 50% water.
I	Boiled linseed oil applied at 212°F to a block at 140°F.

J A cold tar pitch emulsion placed in a sand slurry applied on top of a cold tar solution primer. Trade name -- Jennite J-16, manufactured by Maintaince Inc.

K Untreated

N A tri chlorosilanated tallow in mineral spirits.

O A mixture of sodium silicate and solvent. Trade name -- Tropikure Silicate During Agent, manufactured by Hooker Chemical Corporation.

P A cold tar, Texas designation RT-11. After application a 12-20 grit sand was rolled into the tar.

Q A cut back cold tar, Texas designation RTCB-6. After application a 12-20 grit sand was rolled into the mixture.

R A rubberized asphaltic material, Texas designation RC3D. After application a 12-20 grit sand was rolled into the mixture.

S An asphalt cement, Texas designation AC-5. After application, a 12-20 grit sand was rolled into the compound.

T Raw Tung Oil applied at 212°F to a concrete block at 140°F.

U A mixture of 50% boiled linseed oil and 50% mineral spirits.

APPENDIX D

Freeze-Thaw Tests

Series A

Three (10" x 10" x 2") specimens were treated with each sealant as listed in Table 1.

TABLE 1

Sealant	Method of Application	Rate of Application (gals/sq. yd.)	Comments
B	Brushed on	.086	placed in 140°F oven for 24 hrs. after treating.
C	Brushed on	.051	
D	Brushed on	3 thin coats	
E	Sprayed on	.025 1st coat .015 2nd coat	
F	Sprayed on	.051 1st coat .051 2nd coat	
G	Sprayed on	.025 1st coat .015 2nd coat	
H	Brushed on	.041	
I	Brushed on	heavy coat	blocks were placed in 140°F oven for 24 hrs. prior to treating
J	Brushed on	thin primer coat 2-heavy emulsion coats	no sand slurry used
K			Untreated

Series B

One (10" x 10" x 2") specimen was treated with each sealant as listed in Table 2. All specimens were held in a 140° F oven for 24 hrs. prior to treatment.

TABLE 2

Sealant	Method of Application	Rate of Application gals/sq. yd.
B	Sprayed	0.085
D	Sprayed	0.137
E	Sprayed	0.068
F	Sprayed	0.120
G	Sprayed	0.120
I	Brushed on	0.068
O	Sprayed	0.085

Series C

In this series two specimens (10" x 10" x 2") were treated with each sealant as shown in Table 3. The sealants were applied until the surface had apparently absorbed all the sealant it could. After the sealants were applied one block of each set was subjected to wear as described in section 4.3.

TABLE 3

Sealant	Method of Application	Rate of Application (gals/sq. yd.)	Comments
B	Sprayed	0.051	
D	Sprayed	0.068 0.068 2 coats	
E	Sprayed	0.075 0.085 2 coats	
F	Sprayed	0.085 0.085 2 coats	
G	Sprayed	0.068 0.085 2 coats	
I	Brushed	thin coat	140°F block
O	Sprayed	0.085	
N	Sprayed	0.075 0.128 2 coats	
T	Brushed	thin coat	140°F block
U	Sprayed	0.089 0.085 2 coats	
V	Brushed	1 primer coat 2 sand slurry coats	
K			Untreated

Series D

Three specimens (10" x 10" x 2") were treated with sealants P, Q, R, and S. All of the blocks were held in a 140°F oven for 24 hrs. prior to treatment. Each of the sealants were heated to a workable viscosity and then buttered on to the blocks with a metal spatula. Then a 12-20 grit sand was rolled into the surface.

Series E

These four specimens were 4" diameter cores taken from a bridge being razed near Thorndale, Texas. The bridge was about 20 years old and had been overlayed with 2 in. of asphaltic concrete. Sealants E, G, I, and K were brushed on in two heavy coats.

Series F

In this series sealant "C" was sprayed on fresh concrete as a curing compound to produce two test specimens one of which was later subjected to wear as described in section 4.3. Two other test specimens were prepared using sealant "F" as an admixture and then spraying the fresh concrete with sealant "F" as a curing compound. Here again one of the blocks was subjected to wear as described in section 4.3.

Series G

Six sets of three specimens, one specimen from each of the bridges described in Appendix B, were treated with sealants E, G, I, S, T, and K similar to series C and D.