LOW COST BRIDGE DECK SURFACE TREATMENT

Research, Development,
and Technology

Turner-Fairbank Highway
Research Center
6300 Georgetown Pike
McLean, Virginia 22101

Report No.
FHWA/RD-84/001

Final Report
April 1984

U.S. Department
of Transportation

**Federal Highway
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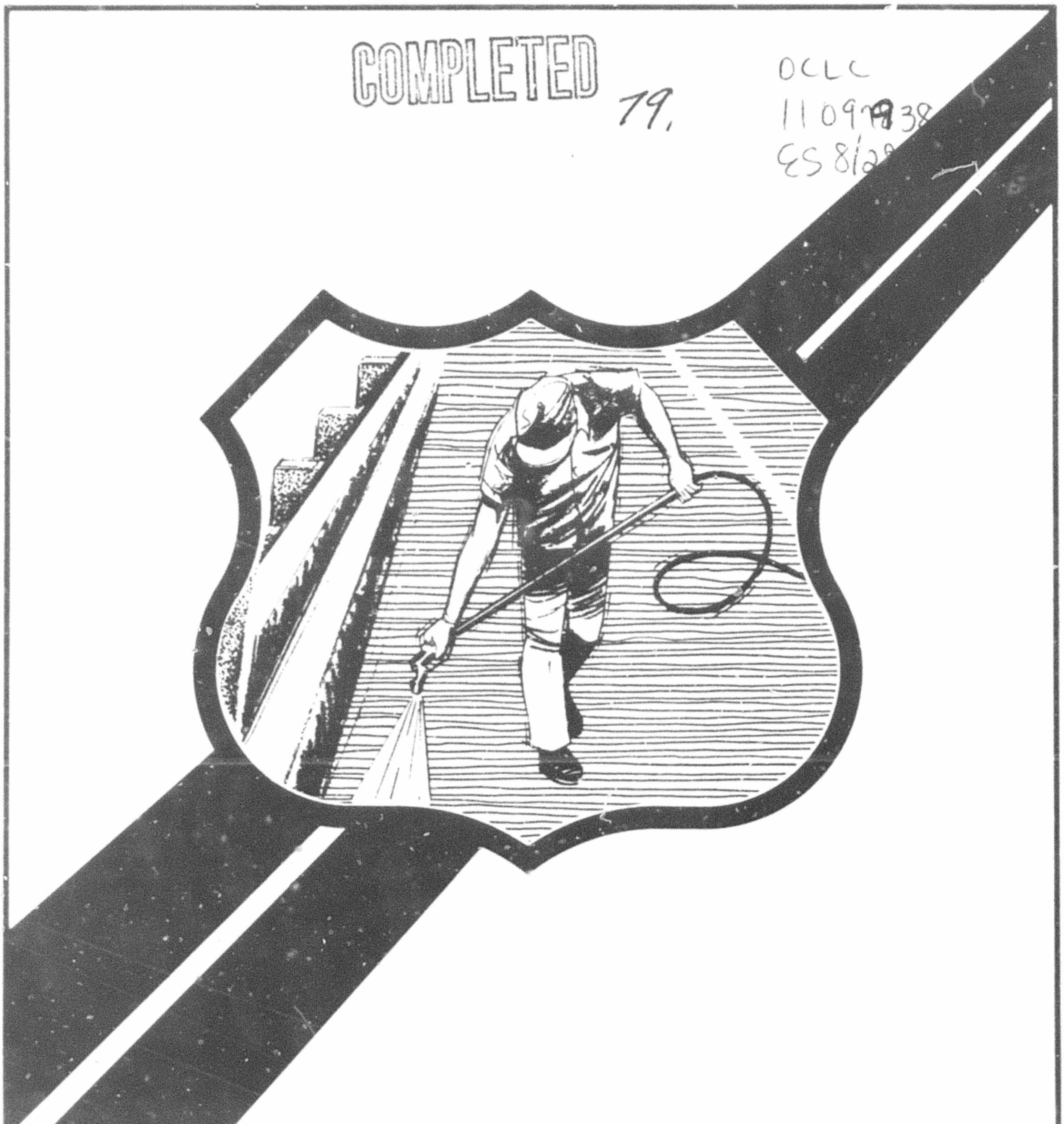

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FOREWORD

This report describes an investigation of alternative materials to a preformed membrane for sealing a bridge deck prior to placement of an asphaltic concrete overlay. The objective was to find materials with lower in place costs and more effective resistance to water penetration than the membrane systems.

A literature search and manufacturer inquires led to an initial list of 110 candidate materials. This list was pared to six materials which best met the study's requirements. These six were then evaluated in a series of laboratory tests including their effect on the following properties of non-airentrained concrete: water absorption; resistance to deicer scaling; and adhesion of asphaltic concrete. The materials were also evaluated for the effect of placing hot asphalt on them and their ability to seal a concrete surface after going through a period of outgassing.

The three best materials were then tested on portland cement concrete slabs in outdoor exposure. The slabs were overlaid with asphaltic concrete and then subjected to salt pondings. The sealers' effectiveness was measured by monitoring reinforcing steel corrosion and measuring the concretes' chloride content at the end of the test.

Richard E. Hay, Director
Office of Engineering
and Highway Operations
Research and Development

NOTICE

Technical Report Documentation Page

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16. Abstract

Low cost sealers and penetrants were investigated to evaluate materials which would reduce water penetration into concrete bridge decks to be overlaid with asphaltic concrete. A literature search and numerous letters to manufacturers resulted in 110 products for consideration. Follow-up letters and review of available laboratory and field data on the various materials reduced the list of candidates to 32 and subsequently to six materials. These six materials were subjected to a rigorous laboratory test program to define the ability of each material to: (a) Greatly reduce water absorption into concrete (b) Not adversely affect bond of asphaltic concrete to the treated portland cement concrete surface (c) Greatly increase the deicer scaling resistance of non-air entrained portland cement concrete. (d) Not be adversely affected by the placement of hot asphaltic concrete (e) Not lose effectivenesss as a result of concrete outgassing shortly after application. Three materials, Hydrozo 56, Pen Seal 50 and Radcon Formula #7 best met these criteria. These three materials were then evaluated in outdoor exposure tests. Large slabs were fabricated, cured, and treated with the sealers and then overlaid with asphaltic concrete and subjected to 5 months of outdoor exposure and salting. Companion slabs without sealers, both with and without asphalt overlays, were included as controls. Corrosion monitoring throughout the test period and chloride analysis after 158 days of exposure showed: (a) Salt penetrated deeper into the untreated slabs with asphalt overlays than into untreated slabs without asphalt (b) More top mat steel corrosion occurred on untreated slabs than on companion slabs treated with the sealers. Guidelines for the use of the three materials evaluated in laboratory and outdoor testing were prepared and are contained in this report.

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METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

LENGTH

Symbol	When You Know	Multiply by	To Find	Symbol
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km

AREA

Symbol	When You Know	Multiply by	To Find	Symbol
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha

MASS (weight)

Symbol	When You Know	Multiply by	To Find	Symbol
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t

VOLUME

Symbol	When You Know	Multiply by	To Find	Symbol
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3

TEMPERATURE (exact)

Symbol	When You Know	Multiply by	To Find	Symbol
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

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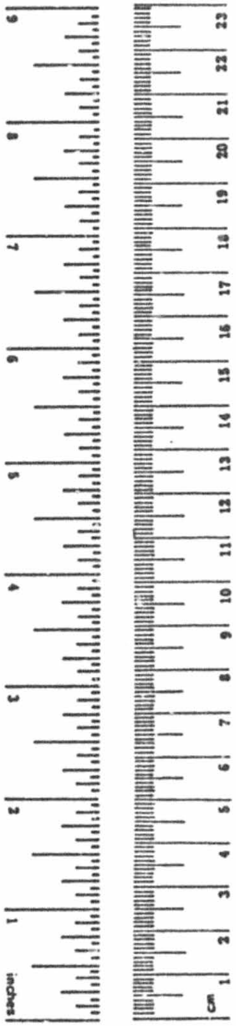
*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

LENGTH

Symbol	When You Know	Multiply by	To Find	Symbol
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi

AREA

Symbol	When You Know	Multiply by	To Find	Symbol
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	

MASS (weight)

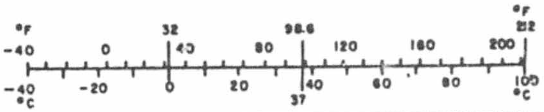
Symbol	When You Know	Multiply by	To Find	Symbol
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	

VOLUME

Symbol	When You Know	Multiply by	To Find	Symbol
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3

TEMPERATURE (exact)

Symbol	When You Know	Multiply by	To Find	Symbol
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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Chapter 1: Introduction

1.1 Background

The surfaces of bridge decks have had problems of maintenance and durability. The Interstate Highway System created a large number of bridges and changed the travel habits of the people. Almost all of the bridge decks in the United States are concrete slabs. Often these bridge slabs have been overlaid with asphaltic wearing surfaces in order to protect the top of the structural slab. However, the porous nature of this asphaltic surface allows water and deicing salts to penetrate to the top of the concrete slab where they stay for long periods of time. The combination of moisture and deicing salts together with freeze-thaw cycles attacks the concrete surface and deteriorates the slabs. Moisture and salt also penetrate the concrete and cause corrosion-induced deterioration which may eventually make the bridge deck structurally inadequate to carry the load.

To alleviate this situation the asphaltic wearing surface may be left out and slab thickness increased to act as an integral wearing surface. In addition, use of higher strength and dense concrete, larger cover for top reinforcement, epoxy coating of reinforcement, etc., have controlled the problems of corrosion of reinforcing steel and spalling of concrete. However, the decks are still subjected to traffic wear and freeze-thaw distress. This is particularly true if the air void system in the deck concrete is inadequate.

Traffic wear makes the deck smooth and slippery especially when it is wet, and may reduce the thickness of concrete over the reinforcing steel. The usual solution is to use an asphaltic overlay. Since the overlay tends to concentrate more moisture in and on the deck concrete, freeze-thaw distress may intensify or may start in new areas. To protect the deck concrete from this distress, a waterproofing membrane is placed between the deck and the overlay. However, the waterproofing membranes currently in use have high in-place costs and also not a perfect performance history. This has discouraged many States from using them. Therefore, a low cost treatment of the deck to achieve the same results, i.e., impermeable to water and good adhesion to the asphaltic wearing surface, is needed.

The development of effective surface-applied liquid sealers, coatings, or penetrants for use on bridge decks could provide added protection against the intrusion of salt-laden waters. This added protection would extend the life of bridge structures subjected to various environments. Such protective sealer materials could be used on new bridges as well as older bridges that are not already contaminated with chloride beyond tolerable limits.

The objective of this investigation was to identify and evaluate low cost surface treatments which prevent intrusion of water and deicing salts into the bridge deck while providing a good surface for adhesion of an asphalt overlay. The surface treatments investigated were tested in the laboratory and in outdoor exposure. Based on these evaluations, specifications for the application of the three most effective treatments were prepared.

This investigation included consideration of potential safety hazards associated with these materials, techniques of their application, and costs. Suitable guidelines for the use of these materials based on the manufacturers' technical information is provided in this report. Recommendations for laboratory testing procedures that could be used by chemical companies, highway agencies, and testing laboratories are also provided.

1.2 Research Approach and Methodology

Since this investigation was aimed at considering all available types of appropriate sealers, the research approach included a literature search of libraries, the Highway Research Board, the Asphalt Institute, American Association of State Highway and Transportation Officials offices, and chemical companies. Five laboratory investigations and outdoor tests were then run on the selected materials. Thus, the research consisted of the following tasks:

Task A. To conduct a literature search and to collect data on available sealants, penetrants, and membranes from various sources. To evaluate the available information to narrow down the list to the materials most suitable for the research objective and to contact the manufacturers of these materials to obtain any additional information on characteristics and test data. To evaluate all available data on these materials and to select six materials for laboratory testing after review and discussion with FHWA officials.

Task B. Test in the laboratory Portland Cement Concrete (PCC) specimens treated with the selected materials using the following tests:

Series I - Adhesion of asphaltic concrete to the treated PC concrete surface.

Series II - Resistance to water absorption.

Series III - Scaling resistance of treated plain PCC.

Series IV - Effect of placing hot (160°C) asphaltic concrete on treated PCC.

Series V - Effect of outgassing of concrete slabs at the time of material application.

Select three materials for the final outdoor testing based on the laboratory test results.

Task C. Outdoor exposure evaluation of reinforced concrete slabs coated with the selected material.

Items monitored in outdoor testing included:

Series I - Ponding with chloride solution three times a week for five months, and definition of the effect of the ponding on reinforcement corrosion.

Series II - Definition of the amount of chloride ion penetration into each slab after completion of the ponding cycles using the AASHTO T260 analysis method.

Series III - Air void system characteristics using ASTM C457 on samples collected from the slabs.

Task D. Prepare specifications for application of the three most promising materials.

1.3 Candidate Material Selection

Based on the literature search a preliminary list of 110 potential materials was developed. An inquiry was sent to the manufacturers to explain the scope of our research and to request information on their materials related to the following properties or criteria:

a. Permeability (to water).
b. Adhesion to portland cement concrete.
c. Adhesion of asphaltic concrete to portland cement concrete treated with the candidate material.
d. Available results of tests on portland cement concrete with the materials using ASTM procedure C672, "Standard Test Method for Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals," or other freeze-thaw test methods.
e. Field data, if any, documenting successfully the use of material to mitigate freeze-thaw deterioration of non-air entrained concrete in very wet environments.
f. Material composition.
g. Cost per unit volume and approximate cost per square foot of deck surface coverage at the manufacturer's recommended rate of application.
h. Feasible methods and costs of application.
i. Effect of placing hot (160°C) asphaltic concrete on the cured sealant material.

j. Material toxicity.
k. Any special handling requirements.
l. Recommendation as to whether the material should be further evaluated in the testing program.

Out of the 110 inquiries, 32 responses were received. Many firms did not have all the information requested. Additional letters were sent and telephone inquiries made for clarification and to obtain more specific information. The remaining 78 firms were either no longer in existence or did not feel that their product was suitable for the purpose of this project.

The 32 materials were placed in one of the following categories, based on their behavior and interaction with concrete.

a. Penetrant.
b. Quasi penetrant.
c. Liquid membrane.
d. Preformed membrane.
e. Other (miscellaneous).

Eight materials were selected as being the best candidates for laboratory testing. These eight materials were:

11. FX-454.
12. Hydrozo 56.
13. Hydrocide Liquid Membrane (HLM 1000).
19. Nickelpoxy 1-30.
23. Pen Seal 50.
24. Radcon Formula #7.
25. Raylite B-36, B-12.
30. Tremco 150.

After elaborate discussion and detailed consultations with the contract manager, items 11 and 25 were eliminated from testing.

Before actually conducting the tests, the following information was obtained on the six selected materials:

a. Physical properties.
b. Manufacturer's data on applications.
c. Applications of materials (including surface preparation, limitation, precautions, etc.).

The results of this review are presented in tables 1 through 6.

Table 1. Technical Data for Hydrozo Clear 56

TECHNICAL DATA		MANUFACTURERS APPLICATION DATA	
Total solids	60% minimum	Weight	7.3±0.1 Lbs/gallon
Viscosity	2-5 cps.	No. of coats	1
Flash point	100°F.	Coverage	100 sq.ft/gallon
		Curing time	24 hours in air

APPLICATION OF MATERIAL	
Surface Preparation: Use a broom-with-vacuum. Clean up with a sweeping piece of equipment or use waterblast.	Limit of Application: When coating is first applied, the slickness of the surface may increase. It requires drying, check slickness before any traffic is allowed. These materials are not membrane materials.
Application: Painting of line strips should be done before application of seal coat. Surface air and material temperature should be 60°F. When applying materials in marginally low temperature; heavy brooming or warming of the material may be needed to help penetration into the surface. Test a small area before proceeding with the application of materials.	Clean-up: Clean equipment and tools with mineral spirits (paint thinner). Availability: Prompt shipment available from distributors or from plant. General Comments: Easily recoatable. Simple to apply.

Table 2. Technical Data for HLM 1000

PHYSICAL PROPERTIES	MANUFACTURERS APPLICATION DATA
Shore A Hardness (±5) : 40	No. of coats : 1
Tensile Strength psi (±25): 200	
Elongation Percent Avg : 650	Coverage : 5 gallons per 125 sq foot
100% Modulus psi (±10) : 100	
Service temperature range : -40°F to 180°F	Curing time : 36-48 hours

APPLICATION OF MATERIAL:

Surface Preparation: For best results, all concrete deck surface should be lightly steel trowelled to a fairly smooth finish. New concrete must be properly water cured; at least 14 days old and surface must be dry. Air voids or honeycombs should be opened up to allow HLM to fill the cavity. Application: Dump materials on the surface and spread immediately to ensure best workability. Best results are obtained by marking off 125 square foot area and evenly spreading contents of a 5-gallon unit with a rubber edged squeegee.	Limit of Application: Do not apply HLM 1000, (i) When temperature falls below 49°F. (ii) To the reinforcing steel. (iii) To damp surface. (iv) Not to be used as an exposed or wearing surface. Precaution: Harmful if swallowed. Clean-up: Tools and equipment shall be cleaned with Sonneborn Rubber 990. Availability: In 5-gallon pails or 55-gallon drum. General Comments: It is a cold applied, seamless, elastomeric membrane.

Table 3. Technical Data for Nicklepoxy #1-30

TECHNICAL DATA		MANUFACTURERS APPLICATION DATA	
Total solids	30% minimum	Weight	7.5 Lbs/gallon
Sp. Gravity	0.9 ± 0.12	No. of coats	2
Viscosity	10-20 cps	Coverage	200 sq.ft/gallon
Color	Clear	Curing time	24 hours
Shelf life	2 years		
Pot life	6 hours		

APPLICATION OF MATERIAL:

Surface Preparation:

Remove all debris, oil, grease, dirt and wax solutions from surface. New concrete should be cured before coating.

Mixing:

Two components may be mixed in 85/15 ratio by weight. Pour materials in a low speed power mixer (200-300 RPM) until one even color develops.

Application:

This penetrant sealer may be applied with rotary brush or sprayer. After surface preparation, allow concrete to dry. Presence of moisture will affect the penetration. Apply penetrant sealer evenly over area according to coverage requirements.

Limit of Application:

Two coats are required for proper application. Porosity of concrete will determine final coverage.

Precaution:

Can cause skin irritation and when used indoors, adequate ventilation should be provided.

Clean-up:

Use Methyl Ethyl Ketone, Xylene or other compatible solvents for cleaning

Storage:

Store in heated area.

Availability:

Available in 5-gallon or 55-gallon drums.

General Comments:

Having low viscosity, it penetrates and fills the capillaries and micropores.

Table 4. Technical Data for Pen Seal 50

TECHNICAL DATA		MANUFACTURERS APPLICATION DATA	
Total Solids:	50% minimum		
Viscosity :	20-30 cps	No. of coats:	2
Color :	Light amber	Curing time :	7 days
		Coverage :	
Shelf life :	2 years (store at max. 85°F)	1st coat :	100-150 sq.ft/gallon
		2nd coat :	250-300 sq.ft/gallon
Pot life :	2 hours		

APPLICATION OF MATERIAL:

Surface Preparation:

Prepare surface mechanically by sand blasting, hydroblasting or grinding.

Mixing:

Temperature of Pen Seal 50 for mixing must be above 50°F. Mix parts 1:1 by volume for three minutes.

Application:

Apply materials at surface temperature above 50°F, with squeegee, roller, or spraying equipment to clean and dry surface.

Precaution:

Use goggles, protective clothing and gloves.

Limit of Application:

Do not apply the materials when surface temperature falls below 50°F.

Clean-up:

Clean tools and equipment promptly after use with xylene or tolune.

Storage:

Store in a tightly sealed container in a dry place at normal room temperature (65°-85°F).

Availability:

Available throughout the year. Delivery in 1-2 weeks.

General Comments:

Penetrates into concrete and quickly cures to a hard durable epoxy.

Table 5. Technical Data for Radcon Formula #7

TECHNICAL DATA	MANUFACTURERS APPLICATION DATA
Total Solids : 31.4% min.	
Ash : 29.95%	
Viscosity : not given	No. of coats: 1
Color : colorless liquid	Coverage : 300 sq.ft./gallon
Boiling point, F: 212°	Curing time : 72 hours in water
APPLICATION OF MATERIAL:	
Surface Preparation: Remove all pooled or standing water and stains from concrete surface, prior to application. Thoroughly saturate surface with Radcon Formula #7, then allow to cure, fill, patch or resurface. Application: Radcon Formula #7 may be sprayed or flushed on horizontal surface or may be sprayed over the surface with a brush, squeegee, mop wool roller, etc. Coverage is approximately 300 sq. ft. per gallon. Make sure that all of surface is covered with solution.	Curing: Allow Radcon Formula #7 to cure for at least 3-6 hours. Flush surface with large amount of water every 24 hours for at least 72 hours. Precaution: Do not apply during rain or to wet surface or if temperature falls below 40°F. Do not apply to glass or glazed tiles, etc. Availability: Available in 5 gallon can or 55 gallon drums. General Comments: After treatment a barrier is set up below concrete surface.

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Table 6. Technical Data for Tremco 150

TECHNICAL DATA		MANUFACTURERS APPLICATION DATA	
Total solids	: 100%	Weight	: 13.2 Lbs/gallon
Viscosity	: 3000 to 9000 cps	No. of coats	: 1
Color	: Black		
Flash point	: -50°F to 180°F	Coverage	:
Shelf life	: 1 year or more	1st primer coat	: 250-400 sq.ft/gallon
Pot life	: 24 hours	2nd coat	: 1 Lb/sq.ft

APPLICATION OF MATERIAL:

Surface Preparation:

Concrete surface shall have a smooth, wood-float finish or better; and be free from dust, oil, etc.

Application:

Primer shall be evenly applied to all surfaces to be waterproofed at a rate of 250-400 square foot per gallon. After proper priming, TREMCO-150 shall be applied directly to the surface at a rate of 1 Lb/sq.ft.

Limit of Application:

This membrane is not designed for use as a finished traffic surface. TREMCO 150 must be heated in an oil-jacketed kettle with constant agitation.

Precaution:

Use with adequate ventilation. Avoid skin and eye contact. Harmful if swallowed.

Clean-up:

Tools and equipment shall be immediately cleaned up.

Availability:

Immediate availability from TREMCO warehouses. Twelve 50 Lb. cakes in a 50 gallon barrel.

General Comments:

Excellent for adhesion to PCC and asphaltic concrete. It is not used as a finished traffic surface.

The laboratory tests performed on the six candidate materials were:

1. Adhesion of asphaltic concrete to the treated portland cement concrete surface.
2. Resistance to water absorption.
3. Scaling resistance of treated portland cement concrete.
4. Effect of placing hot (160°C) asphaltic concrete on treated PCC.
5. Effect of outgassing of concrete slabs at the time of material application.

2.1 Materials and Specimens

The concrete used in tests was not air entrained and the water-cement ratio was 0.5. The mixture design provided a concrete compression strength of 4000 psi which is comparable to that of concrete used by State Highway Departments. The properties of the concrete were as follows:

	Quantity Per Yd^3
Cement	610 lbs.
Sand	1,248 lbs.
Coarse Aggregates	1,831 lbs.
Water	305 lbs.
Plastic Unit Weight	149.92 pcf
*Air Content	1.79 %
Water Cement Ratio	0.50
Slump	3.5 in.
28 day compressive strength	3,990 psi

*Computation of percentage of air in concrete is based on absolute volume method.

The job mix formula (J.M.F.) for the asphaltic concrete was a blend of aggregates as shown below:

SIEVE	#10	#7	Sand	J.M.F.
	% passing	% passing	% passing	% passing
3/4	100	100	100	100
3/8	100	98	100	99
4	96	29	98	80
8	74	3.4	86	60
16	50	1.7	78	45
30	32		58	30
50	21		16	14
100	15		2.5	8
200	10.7		.3	5.5

The binder was 5.7% A.C. 20. The aggregate consisted of crushed stone and sand.

The candidate sealer materials were applied to the portland cement concrete using the methods and procedures recommended by the manufacturers. Three different rates of application were used. One rate was the rate recommended by the manufacturer. The other rates used were 10 percent (15 percent for scaling and water saturation tests) above and below the recommended rates. The details of the rates of application, procedures, and other data for each of the six materials based on the manufacturer's recommendations are shown in tables 1 through 6. Slabs 12x12x3 in (300x300x75 mm) were used in tests for water absorption and scaling resistance. Slabs 5.5x5.5x3 in (137.5x137.5x75 mm) were used in tests for adhesion, the effect of placing hot asphalt on the concrete, and the effect of outgassing.

Specimens were cast in wooden forms. After the removal of the specimens from the forms the slabs were immersed for 7 days of water curing, then removed and weighed with an accuracy of 0.1 gram. Then they were allowed to air dry in a controlled climate room for 21 days at 73± 3 degrees F and 50± 5 percent R.H. on special racks which provided air circulation on all six sides of the slabs. The specimens were weighed to the nearest 0.1 gram after 21 days of air drying to determine weight loss from the saturated conditions. The slabs were coated with the selected materials following application and curing procedures recommended by the manufacturers. Concrete cylinders were cast at the time of placement of concrete and were used for checking the compressive strength. All cylinders show strengths in excess of the required 4000 psi (27.6 N/mm^2).

For all the tests, several slabs were tested without any treatment materials and acted as controls.

2.2 Procedures of Laboratory Tests

2.2.1 Adhesion of Asphaltic Concrete to the Treated PC Concrete Surface

The objective of the adhesion tests was to evaluate the adhesion of asphaltic concrete to portland cement concrete (PCC) treated with the selected materials. Seventy-two PCC slabs 5.5x5.5x3 in (137.5x137.5x75 mm) were cast and subdivided into three groups. Emulsion was placed on the specimen at a rate of 0.70 lbs/ft^2 to simulate field use of tack coat prior to placing an asphalt overlay. In each group four were controls and four specimens were covered with each of the five test materials. Since there was no standard for this test, it was performed using equipment designed in consultation with the contract manager. As shown in figure 1, a rigid wooden frame (2) was fixed to the table top. The concrete slab (3) was held tightly in the frame with the aid of steel clamps (13) and steel rods (4). A movable wooden frame (5) with all sides held by supporting screws (6) was designed to clamp on the asphalt overlay (7). A shear load was applied through this frame to the asphalt overlay by means of an adjustable steel plate (8) and movable steel cable (9). The load was applied by adding water to a container suspended from the steel cable. The weight was gradually increased by adding water to the container at a rate of 1 lb/sec and a minimum force in pounds at shear failure was determined for each material under test. A mechanical dial gauge was attached to find the beginning of movement of the block to indicate failure.

The results of the adhesion test are presented in table 7. Conditions of adhesion were made to represent actual field conditions. The asphalt plant manager also provided useful information regarding this.

Table 7. Laboratory Test Results for Shear Adhesion Between Material and Asphaltic Concrete/Material and PCC

Material		Portland Cement Concrete Surface with Complete Emulsion Covering			
No	Name	Specimen Slab No.	Load (lb)	Average Load (lb)	Shear Stress (psi)
12	Hydrozo 56	5B 6B	72.0 84.0	78.0	2.6
13	HLM 1000	17B 18B	30.0 28.0	29.0	0.96
19	Nicklepoxy 1-30	13B 14B	61.0 101.0	81.0	2.9
23	Pen Seal 50	9B 10B	87.0 96.0	91.5	3.0
24	Radcon Formula #7	1B 2B	85.0 77.0	81.0	2.7
-	Control Slabs	27B 28B	86.0 89.0	87.5	2.9

As seen in table 7 above, materials 12, 19, 23, and 24 demonstrated better adhesion than material 13. No particular explanation can be given for the different behavior of these products as no chemical composition can be obtained to investigate bond in detail. The results presented here, thus, should be taken as "mechanical" bonding only. The results of adhesion of asphaltic concrete to PCC slabs without and with spotty emulsion coverage were not significantly different from the data in table 7.

2.2.2 Resistance to Water Absorption

The objective of this test was to evaluate how effectively the six materials prevented water absorption of concrete soaked in lime water. Since there was no standard for this test, the procedure was defined through consultation with the contract manager.

Twenty PCC slabs 12x12x3 in (300x300x75 mm) were used for this test. Eighteen specimens (three for each material) were coated on all sides. The waterproofing materials were applied using procedures recommended by the manufacturers. Two uncoated specimens were subjected to the same tests as controls.

The specimens were weighed and submerged on end in a large holding tank filled with lime water. The test slabs were removed from the tank at regular time intervals, surface dried, and weighed. Immediately after each weighing the slabs were reimmersed in the water. This procedure was continued for 3 days until some specimens showed no weight gain.

Results of absorption tests are presented in table 8. As expected, there was considerable absorption of water in the beginning, but this slowed down as time passed. In general all specimens with coatings showed considerable less absorption than the control specimens throughout the test period.

As can be seen from figure 2, five out of six materials used were quite effective against absorbing water in concrete. One of the main criteria for selection of any material was to prevent such a penetration. Three materials had absorption of only 0.2 percent (when measured as gain in weight) compared to that of control specimens of 0.9 percent which was still increasing at the conclusion of the test.

2.2.3 Scaling Resistance of Treated Portland Cement Concrete

This test was carried out in accordance with the procedure of ASTM

C672-76 "Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals." Methods and rates of application of the different materials are shown in tables 1 through 6.

The deicing chemical consisted of a solution of calcium chloride having a concentration such that each 100 ml contained 4 g of anhydrous calcium chloride. The solution was ponded 1/4-inch deep in dikes on the specimens over an area of 90 square inches.

Twenty-one specimens, 12x12x3 in (300x300x75 mm), were cast. The composition of the concrete was the same as that used for the previous tests. Three of the specimens did not receive any treatment and were used as control slabs.

The specimens were subjected to freezing and thawing cycles consisting of 18 hours in a freezing environment followed by 8 hours at normal room temperature in laboratory air. The cycles were repeated daily. After the completion of every 5 cycles the specimens were flushed, the solution replaced, and the cycles continued. The specimens were visually observed for any scaling during the test. The following scale was used to judge the condition:

Rating	Conditions of Surface
0	No scaling.
1	Very slight scaling (1/8 in. depth, max., no coarse aggregate visible).
2	Slight to moderate scaling.
3	Moderate scaling (some coarse aggregate visible).
4	Moderate to severe scaling.
5	Severe scaling (coarse aggregate visible over entire surface).

The results of a rating after the completion of the indicated number of cycles are listed in table 9.

The review of the test results indicated the following:

1. All materials at the rate of application recommended by the manufacturers show vast improvements in scaling resistance when compared to control slabs after 90 days. At this time the control specimens had the rating of 5, indicating severe scaling. If one considers the effectiveness of these materials against scaling at the threshold of 35 days (when there was severe scaling for control specimens), all the coated specimens showed a significant resistance. This resistance, however, deteriorated at various rates from material to material.

2. HLM 1000 and Tremco 150 afforded the least protection against scaling resistance with a rating of 3 (moderate scaling) at 90 days.

3. The three materials most effective are Radcon #7, Hydrozo 56, and Nicklepoxy 1-30, which reached a rating between 1 and 2 at 90 days; indicating that they be considered for further work.

4. Three rates of application of these materials did not seem to affect the scaling resistance between the minimum and maximum dosages. Thus, one may conclude that a coverage as much as 15 percent below the one recommended by the manufacturer may also be acceptable. However, lesser application rates are not recommended because actual coverage may vary somewhat from place to place on the slab.

2.2.4 Effect of Placing Hot (160°C) Asphaltic Concrete on Treated PCC

It was determined that the maximum temperature of a hot asphalt concrete mixture when applied is about 160°C but drops drastically within approximately 40 minutes after application. To obtain qualitative data about the effect of placing hot asphaltic concrete on the sealant material, 45 PCC slabs 5.5x5.5x3 in (137.5x137.5x75 mm) were cast. Composition of the hot asphaltic concrete was the same as that used in 2.2.1. Since there was no standard test, results of these tests are presented in the form that can be utilized for further studies but not necessarily for comparison with other research. The aim was to determine the (detrimental) effect, if any, of using hot asphalt after the specimens were treated by these materials.

As before (in other tests) three rates were used to apply these materials. The result varied between "no effect" to some surfaces becoming viscous with the appearance of bubbles.

Different rates of application had no effect on the effect of placing hot asphalt on the specimens. The three conditions, putting emulsion on the treated surface at various rates, also did not affect the behavior of various slabs with the exception of one material as noted below.

Materials 12 and 24--Hydrozo 56 and Radcon Formula #7--were not affected (surface of treated concrete was in the same condition as it was before application of asphaltic concrete). Material 19--Nicklepoxy 1-30--became more viscous with some bubbles on the surface, and Material 13--HLM 1000--showed some liquid and bubbles on the surface.

Slab #68C with the Material 23--Pen Seal 50--had small bubbles in some places on the surface after removal of the asphaltic concrete overlay. This slab had emulsion on the entire PCC surface. Two other slabs with Material 23 and little or no emulsion did not show any effect at all.

2.2.5 Effect of Outgassing of Concrete Slabs at the Time of Material Application

Bridge deck concrete normally contains from 10 to 20 percent capillary, pore, and other void space by volume, much of which is filled with air. As the deck concrete temperature changes, this air either expands (temperature increase) or contracts (temperature decrease). The air expansion brought on by temperature increases causes some air to be expelled from the surface of the deck creating the phenomenon known as outgassing. This has caused problems in the application of membranes since the escaping air causes blisters and holes in the membrane.

To evaluate outgassing effects on PCC slabs treated with the selected materials 20 specimens 5.5x5.5x3 in (137.5x137.5x75 mm) were fabricated. The composition of the concrete was the same as for the other series of laboratory tests. For each material four slabs were used: two slabs with the recommended rate of application, one slab with 10 percent more and one with 10 percent less than recommended rate. All specimens were coated and then immediately were put in an oven at 170°C and kept there for 10 hours. Before being placed in the oven, all slabs were weighed on the scale with the accuracy 0.01 pound. After removal from the oven the specimens were immersed in water for 10 hours and then weighed again.

The effect of outgassing was studied using specimens similar to the earlier test. Again, this test was conducted merely to satisfy the practical problem as it exists in the field, although no standard test was available. The results of this test were tabulated and are presented in table 10.

Three Materials--Hydrozo 56, Radcon Formula #7, and Pen Seal 50--gained 0.8, 0.9 and 0.9 percent of weight respectively after removal from the oven and the 10 hour immersion. None of these materials showed any visible deterioration due to heating of specimens in the oven and after their removal.

Materials Nos. 19 and 13--Nicklepoxy 1-30 and HLM-1000--had gained more water, 1.3 and 1.1 percent respectively. Material 13, after 10 hours of being heated in the oven had very fine (small) bubbles all over the surface of the slab. The results of the test have shown the following:

1. The percentage of water absorption varied directly with the rate of application.

2. At manufacturer's recommended rate of application, Material Nos. 12, 23, and 24 showed the lowest absorption percentage for water.

Summary of the experimental data for laboratory tests is given in table 11. Based on the results for all five series of tests, the following three materials were selected for outdoor tests:

12. Hydrozo 56.
23. Pen Seal 50.
24. Radcon Formula #7.

Material #30--Tremco 150--was not tested because it showed poor resistance to water absorption.

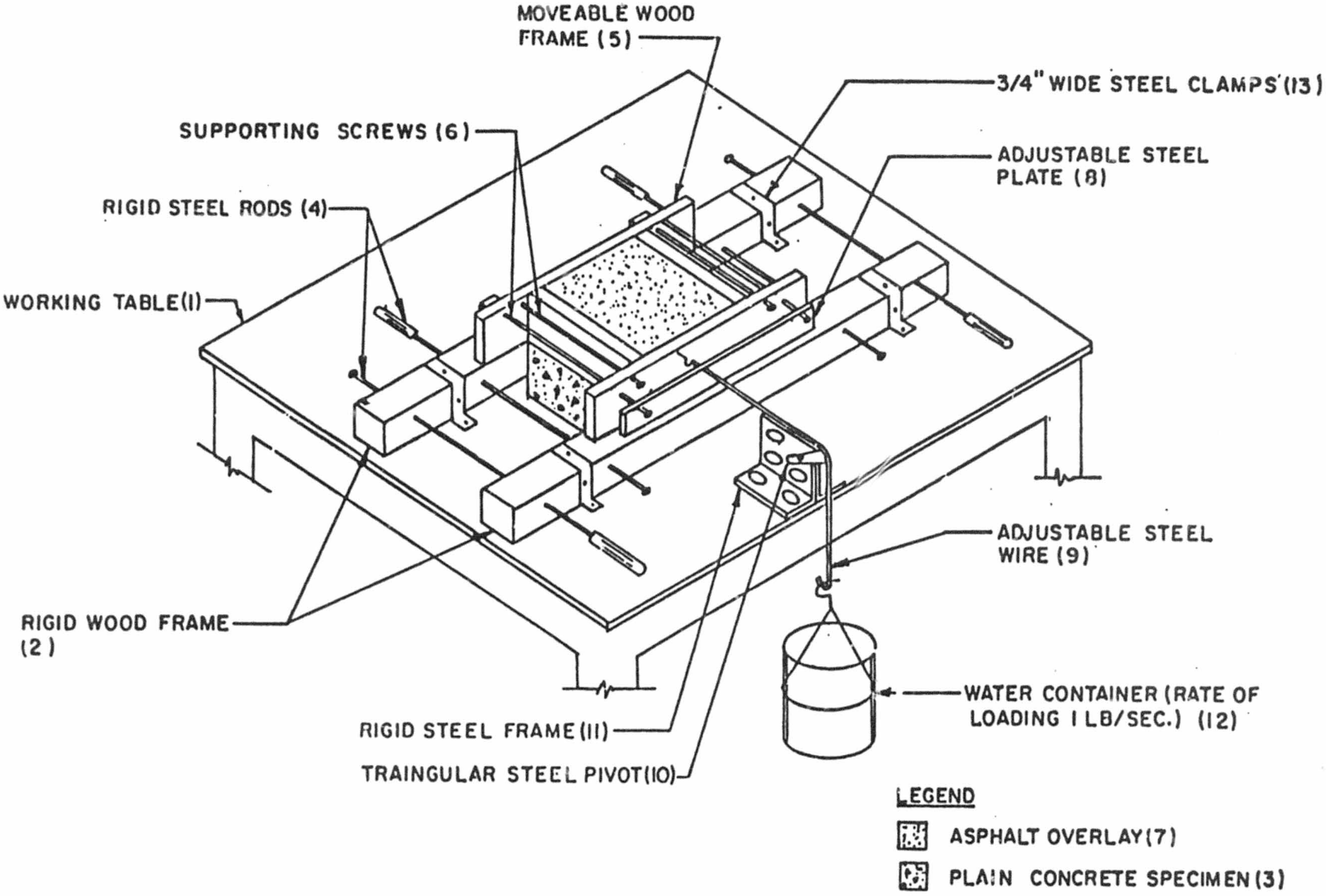
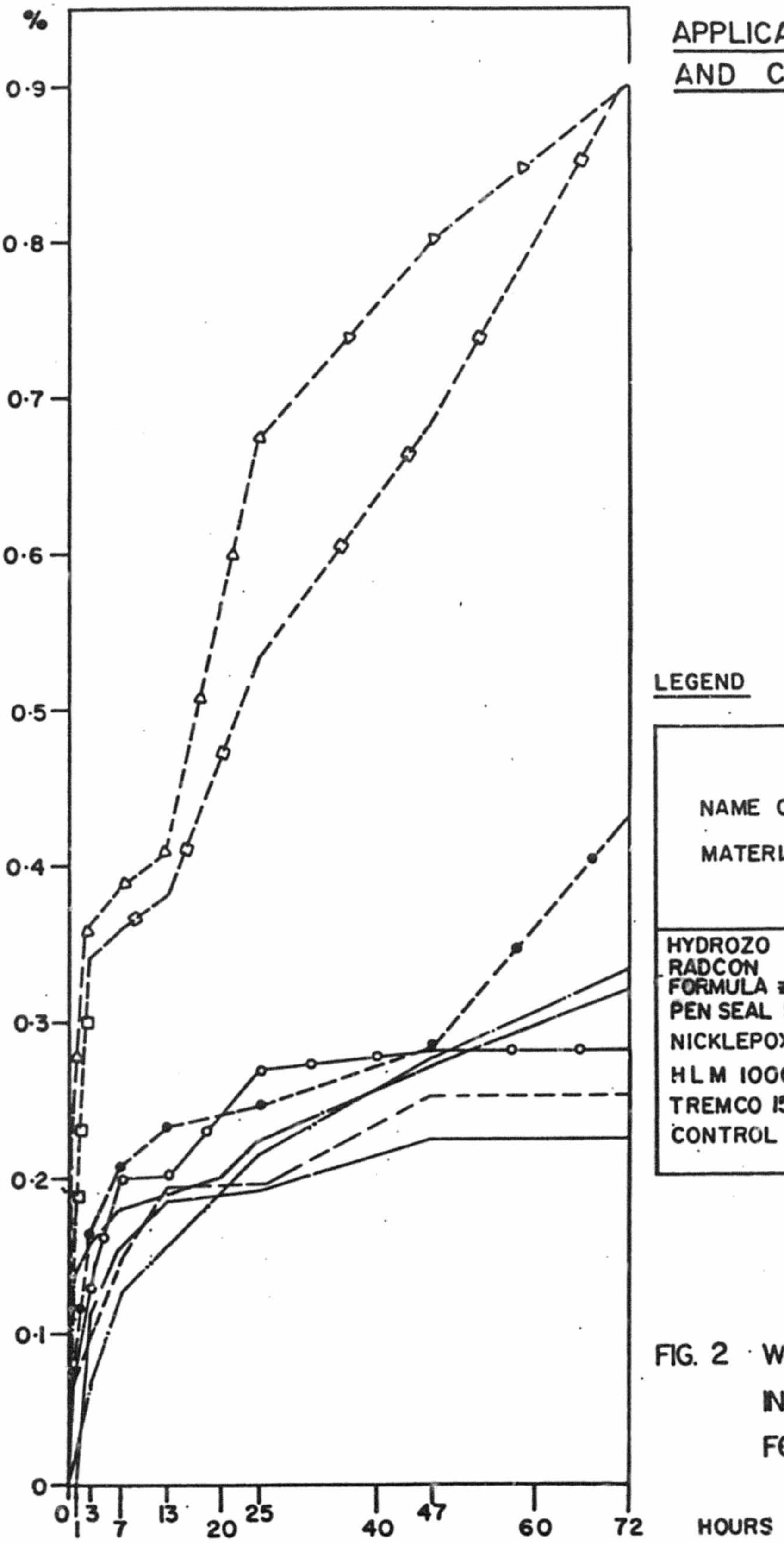


FIG. 1 LABORATORY TEST FOR SHEAR ADHESION

Table 8. Percentage Weight Change During 72 Hours Soaking Period
(Concrete Treated with Penetrant or Coating)

No.	Material	Recommended Rate of Application (gal/ft^2)	Slab. No.	SOAKING PERIOD PERCENT WEIGHT CHANGE AFTER HOURS						
				HOURS 1	3	7	13	25	47	72
12	HYDROZO 56	0.01	12	0.07	0.136	0.2	0.2	0.26	0.28	0.28
13	HLM 1000	0.040	20	0.138	0.154	0.18	0.2	0.22	0.27	0.32
19	NICKLEPOXY 1-30	0.0050	15	0.025	0.065	0.125	0.152	0.214	0.276	0.33
23	PEN SEAL 50	0.014	17	0.008	0.115	0.15	0.178	0.192	0.224	0.22
24	RADCON FORMULA #7	0.0033	8	0.07	0.095	0.148	0.195	0.195	0.251	0.25
30	TREMCO 150	0.08	22	0.112	0.164	0.208	0.232	0.248	0.28	0.42
	CONTROL SLAB	-	5 6	0.17 0.23	0.34 0.36	0.36 0.39	0.38 0.41	0.538 0.676	0.680 0.8	0.90 0.90



APPLICATION MATERIALS AND CONTROL SLABS

LEGEND

NAME OF MATERIAL	AS MARKED	RECOMMENDED RATE OF APPLICATION (gal./ft^2)
HYDROZO 56	——o——	0·010
RADCON FORMULA #7	— — — —	0·003
PEN SEAL 50	————	0·0140
NICKLEPOXY I-30	——··——	0·005
HLM 1000	——·——	0·040
TREMCO 150	— — ● — —	0·080
CONTROL SLAB	— — △ — — —□— —□—	——

FIG. 2 WEIGHT GAIN DURING STORAGE IN LIME WATER CONTINUOUSLY FOR 72 HOURS

Table 9. Results of Scaling Resistance at PCC Treated with Selected Materials

Specimen Number	Coating Material	Recommended Rate of Application (g/ft^2)	Number of Cycles																		
			5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95
30	Hydrozo 56	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1
42	HLM 1000	0.04	0	0	0	0	0	0	1	1	1	1	1	2	2	2	2	3	3	3	3
39	Niklepoxy 1-30	0.005	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1
36	Pen Seal 50	0.014	0	0	0	0	0	0	0	0	0	0	1	1	1	1	2	2	2	2	2
33	Radcon Formula #7	0.0033	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45	Tremco 150	1.0 lb/ft^2	0	0	0	0	0	0	0	0	1	1	1	1	1	2	2	2	2	2	2
48	Controls		2	3	3	3	4	4	5	5	5	5	5	5	5	5	5	5	5	5	5
49	Controls		2	2	2	3	3	4	5	5	5	5	5	5	5	5	5	5	5	5	5
50	Controls		2	3	3	4	4	5	5	5	5	5	5	5	5	5	5	5	5	5	5

Table 10. Results of Test to Study the Effect of Outgassing

MATERIAL NO.	SPECIMEN SLAB NO.	APPLICATION RATE (Gal/ft^2)	SPECIMEN CONCRETE SLABS: 5.5x5.5x3 in			
			WEIGHT BEFORE PLACING IN OVEN (lbs)	WEIGHT AFTER REMOVAL FROM OVEN AND 10 HOURS SOAKING IN WATER (lbs)	PERCENT BY WEIGHT GAIN	AVERAGE % BY WEIGHT GAIN
12	5C	0.01	8.6	8.67	0.8	0.8
	6C	0.01	8.21	8.28	0.8	
13	17C	0.04	9.45	9.55	1.1	1.1
	18C	0.04	10.2	10.31	1.1	
19	13C	0.005	9.8	9.92	1.2	1.3
	14C	0.005	9.21	9.34	1.4	
23	9C	0.014	7.67	7.74	0.9	0.9
	10C	0.014	8.20	8.27	0.9	
24	1C	0.0033	8.4	8.47	0.8	0.9
	2C	0.0033	7.5	7.57	0.9	

Table 11. Experimental Data Collected from Results of Laboratory Tests done on Different Materials

MATERIAL	Recommended rate of application, gal/ft^2	Percentage of water gain, (Test 2.2.1) %	Shear Stress, (Test 2.2.2) psi	Rating of Scaling Resistance at the end of 95 cycles (Test 2.2.3)	Effect of Placing hot (160°C) Asphalt on Treated PCC Slabs (Test 2.2.4)	Percentage of water gain, (Test 2.2.5) %
Hydrozo 56	0.01	0.28	2.6	1	No effects have been observed	0.8
HLM 1000	0.04	0.32	1.0	3	Same effect as for Nicklepoxy, but material became liquid	1.1
Nicklepoxy 1-30	0.005	0.33	2.7	1	Has been affected by 160°C hot asphalt & material was more viscous	1.3
Pen Seal 50	0.014	0.22	3.0	2	Some bubbles were observed on the slab #68C (emulsion all over the surface), but not as much as observed on HLM and Nicklepoxy	0.9
Radcon Formula #7	0.0033	0.25	2.7	0	No effects have been observed	0.9
Tremco 150	0.08	0.42	Not tested	2	Not tested	Not tested
Control Slabs	-	0.90	2.9	5	Not tested	Not tested

The objective of Task C was to test, under outdoor conditions, the three treatment materials: Hydrozo 56, Pen Seal 50 and Radcon Formula #7, which performed the best during laboratory tests. The outdoor tests involved the preparation of large concrete slabs, application of the sealers and placement of asphalt overlays. The slabs were then exposed on posts at the Federal Highway Administration outdoor test site in McLean, Virginia. Testing included:

1. Ponding with chloride solution three times a week for 5 months, and defining the effect of the ponding on reinforcement corrosion.

2. Defining the amount of chloride ion penetration into each slab after completion of the ponding cycles using the AASHTO T260 analysis method.

This Chapter describes the procedures, equipment, and materials used for these tests and the results obtained.

3.1 Materials and Specimens

Ready mix concrete was utilized to fabricate the test slabs. All concrete had a water cement ratio of about 0.5 by weight and target slumps were 3.5 inches in all instances. Three different mixes, each with a different target air content (0 to 3 percent, 3 to 5 percent and 5 to 8 percent) were used. Table 12 provides mix design and compressive strength information for the 3 concretes.

Table 12. Properties of the concrete.
(Quantities per yd^3)

Materials	Unit	Mix Design		
		1	2	3
Gravel	lb	1840	1840	1820
Sand	lb	1209	1036	1135
Cement	lb	630	660	550
Water	lb	315	337	264
Air Content	%	2.2	3.5	8.1
Water Cement Ratio	-	0.50	0.51	0.48
Plastic Unit Wt.	Pcf	147.9	143.4	139.6
Average 28 Day Compressive Strength	psi	4218	3952	4301

The characteristics of the air void systems measured on each hardened concrete is summarized below and shown in detail in Appendix II:

Mix Number	Percent Air	Average Chord Length, inches	Specific Surface in^2/in^3	Spacing Factor inches
1	3.0	0.0183	219	0.0283
2	3.1	0.0057	706	0.0091
3	5.4	0.0070	574	0.0082

Asphaltic concrete for the overlays was obtained from a commerical batch plant. Mix composition was the same as that described in Chapter 2 for the laboratory specimens.

Twenty-four 3 ft by 3 ft by 4 inch (900 x 900 x 100 mm) slabs were fabricated. As shown in figure 3, each slab contained two reinforcing mats, composed of welded wire fabric (4/4 W.W.F.). The mesh was positioned in the wooden forms such that 1.0 inch of concrete cover would be obtained on both the top and bottom surfaces. Thermocouples were positioned in the concrete to allow temperature monitoring.

After concrete placement, curing was accomplished using wet burlap and polyethylene which remained in place for 3 days. The forms were then removed, the slab sides coated with epoxy, and then exposed outdoors for 21 days. The sealers were then applied to the appropriate slabs at the recommended rates defined earlier and after 6 days the asphalt overlays were placed on all but selected control slabs. The slabs were then positioned on racks above ground for testing. Wiring to facilitate the corrosion measurements involved the insertions of a resistor and switch between the two reinforcing mesh mats. The test matrix is given below in table 13.

Table 13. Outdoor Test Slabs Details.

Group	Overlay	Application Material	Number of Test Slabs		
			Mix 1	Mix 2	Mix 3
I	With Asphalt Overlay	Hydrozo 56	2	2	0
		Radcon Formula #7	2	2	0
		Pen Seal 50	2	2	0
II	With Asphalt overlay	Without Application Material	2	2	2
III	Without Asphalt Overlay	Without Application Material	2	2	2

3.2 Salting

The slabs were salted Monday, Wednesday, and Friday of each week during the 5-month test program using a 3 percent sodium chloride solution. Caulking compound dams around the edges of the top surface of each slab and several coats of epoxy on the sides of the asphalt overlay were used to prevent leakage of the ponding solution. In all instances sufficient solution was added to cover the asphalt surface to a depth of about one-sixteenth of an inch.

3.3 Evaluation Procedures

Because of the timing of slab fabrication and testing and the short duration of the test program, it was not possible to await freeze-thaw deterioration of the portland cement concrete as the means of evaluating the effectiveness of the sealers.

To provide a valid, but more rapid assessment the slabs were subjected to deicer applications as noted in 3.2, corrosion monitoring was performed, and chloride samples were taken after salt water ponding for about 5 months. Since salt must penetrate concrete via water, it was believed that if the pore-filling sealers being studied prevented significant chloride buildup and embedded steel corrosion, they would also prevent water absorption, thus minimizing freeze-thaw deterioration. If for example, placement of the asphalt overlay negated a material's ability to reduce salt penetration, it was believed that the material's ability to reduce moisture penetration and deicer scaling would be similarly adversely affected. Two layers of reinforcement in each slab allowed the monitoring of the presence or absence of a macrocorrosion cell functioning between the top steel (macroanode) and the bottom steel (macrocathode), and changes in the resistivity of the concrete located between the two steel mats.

To facilitate the corrosion measurements, contact between the steel mats within each slab was avoided and the mats were wired together externally. By placing a resistor and switch in series between the mats, the desired corrosion characteristics could be monitored as follows:

1. The switch coupling the two steel mats remained closed during the testing except when specific data were being obtained. As a result, the voltage drop across the resistor is indicative of the corrosion current ($I = V/R$), if any, flowing between the mats. Previous research by the Federal Highway Administration has shown that when a critical amount of chloride penetrated to the top steel, while the bottom steel remained in chloride free concrete, the corrosion current as so measured would increase from zero to a significant value.

2. The polarized driving voltage of the above referenced corrosion cell, if any, can be approximated by uncoupling the circuit and measuring the "instant off" voltage difference between the two steel mats. Such measurements were made in this study.

3. The resistivity of the concrete between the two steel mats was assessed by measuring the AC resistance after uncoupling the switch. It was believed that changes in the AC resistance with time would be indicative of changes in moisture content of the concrete.

4. Both concrete resistivity (mat to mat AC resistance) and corrosion current are affected by temperature. Since this was an outdoor study, all data could not be obtained at constant temperature. Therefore, in all instances when the above data were obtained concrete temperature was also recorded using the thermocouples placed in each slab. The measured data was then adjusted to a single temperature base (70°F) using formulas previously defined and reported by the Federal Highway Administration. Thus, the current at 70°F is designated i_{70}.

3.4 Findings

The concrete resistance data indicate that, in general, the mat to mat resistance increased slightly with time for all slabs. However, no great differences were seen for sealed versus untreated slabs. Such a result is not surprising since the testing period was only of short duration, the concrete being monitored was in the center of each slab, and others have shown that concrete several inches below the surface dries very slowly. Thus, unfortunately, the concrete resistance data were not very helpful in defining effectiveness of the sealers.

The corrosion current and driving voltage data are slightly more helpful. Using the leadwire connection mode used in this study, a negative ΔV, the polarized driving voltage of the corrosion macrocell, should develop and be maintained when sufficient chloride penetrated to the top steel level and corrosion of the top steel began (but the bottom steel level remained chloride free). Similarly, a negative corrosion current i_{70}, develops and is maintained. Consistently positive ΔV's and i_{70}'s indicate bottom steel corrosion and the top steel functioning as a macrocathode. This latter condition must be avoided if the test technique is to evaluate salt penetration into the top slab surface.

A total of 55 sets of data were obtained on each slab during the 158 day test period. Because of the large data volume and the fact that much of the data showed no corrosion (i.e. are zero), all data are not listed herein. Rather, table 14 presents typical temperature adjusted data for a corroding slab and a discussion of the results for each slab is given below by variable:

1. Controls (untreated) no asphalt overlay,
   2.2% air - slabs 1 and 13
   3.5% air - slabs 11 and 21
   8.1% air - slabs 9 and 23

Table 14. Typical Temperature Adjusted Data for a Corroding Slab

SLAB No. 23

Variable: Control, No Asphalt Overlay; 8.1% Air

DATE	DAYS OF SALT-ING	ΔV (mv)	i_{70} (μA)	R (ohms)
1-22-83	-	-	0	4.1
1-27-83	-	-	0	3.7
1-28-83	6	-	0	3.2
2-04-83	13	-	-879	4.4
2-07-83	16	-	-751	4.3
2-09-83	18	-	-839	4.3
2-16-83	25	-	-868	3.9
2-25-83	34	-	-1047	3.9
2-28-83	37	-	-213	4.2
3-02-83	39	-	-568	3.5
3-04-83	41	-	-101	3.9
3-11-83	48	-	-168	4.4
3-19-83	56	-2	-131	4.4
3-21-83	58	-3	-166	4.5
3-23-83	60	-3	- 66	4.1
3-25-82	62	-4	-142	4.9
3-28-83	65	-4	-199	4.4
3-30-83	67	-4	-192	5.3
4-01-83	69	-3	-398	4.2
4-04-83	72	-4	- 96	4.6
4-07-83	75	-4	-203	4.7
4-09-83	77	-4	-198	4.6
4-11-83	79	-3	-185	5.3
4-13-83	81	-4	-201	5.3
4-16-83	84	-3	-	6.1
4-18-83	86	-4	-191	4.8
4-20-83	88	-3	-145	4.9
4-22-83	90	-3	-112	4.7
4-25-83	93	-4	-205	4.9
4-27-83	95	-3	-191	4.2
4-29-83	97	-3	-184	5.1
5-02-83	100	-3	-121	5.2
5-05-83	103	-5	-246	5.1
5-06-83	104	-6	-232	5.2
5-09-83	107	-5	-243	5.1
5-11-83	109	-5	-283	4.2
5-13-83	111	-5	-270	4.8
5-18-83	116	-7	-383	4.7
5-20-83	118	-13	-377	4.9
5-23-83	121	-11	-476	5.8
5-25-83	123	-7	-384	5.0
5-27-83	-	-	-	-
6-01-83	130	-7	-296	5.7
6-03-83	132	-8	-265	5.4
6-07-83	136	-6	-391	5.6
6-08-93	137	-7	-341	5.5
6-10-83	139	-11	-240	6.1
6-13-83	142	-8	-294	6.5
6-15-83	144	-20	-310	4.0
6-17-83	146	-17	-243	6.3
6-20-83	149	-6	-432	6.3
6-22-83	151	-9	-604	4.8
6-24-83	153	-6	-391	6.3
6-27-83	156	-11	-342	6.5
6-29-83	158	-13	-407	6.5

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Definite top mat corrosion of the steel on slabs 1 and 23 started early in the test program (13 days of salting) and continued to the end of the program. Slab 13 also showed signs of macrocell corrosion between 48 and 81 days of salting and slab 11 showed low level corrosion during much of the measurement period. Slabs 21 and 9 showed no signs of mat to mat corrosion thru 158 days of salting.

2. Controls (untreated), with asphalt overlay:

   2.2% air - slabs 5 and 16
   3.5% air - slabs 20 and 24
   8.1% air - slabs 10 and 22

   Definite top mat steel corrosion occured on slab 5 throughout the test program. Definite top mat steel corrosion was present on slab 24 from the 100th day of salting through completion of the test program. No significant mat to mat macrocell corrosion is indicated on slabs 16, 10, 20, and 22 through 158 days of test.

3. Hydrozo 56 treated, with asphalt overlay:

   2.2% air - slabs 4 and 11
   3.5% air - slab 7, no data for slab 17

   No significant top mat rebar corrosion was noted on any of the slabs. The positive i_{70} and ΔV values for slab 4 indicated bottom mat corrosion probably due to salt solution which ran down the sides of the slab and was absorbed by the concrete on the bottom of the slab. When such occurs, the test technique is negated since the bottom steel is no longer a primary macrocathode. Such bottom mat corrosion, of course does not indicate failure of the sealer.

4. Pen Seal 50 treated, with asphalt overlay:

   2.2% air - slabs 2 and 15
   3.5% air - slabs 8 and 19

   No significant top mat steel corrosion was indicated on any of the slabs.

5. Radcon Formula #7 treated, with asphalt overlay:

   2.2% air - slabs 3 and 14
   3.5% air - slabs 6 and 18

   Slab 3 showed no significant top mat corrosion through 100 saltings but bottom mat corrosion after 103 saltings prevents evaluation using this test technique after that time. Slabs 14 and 18 showed no significant mat to mat corrosion throughout the test. The data for slab 6 are conflicting with the driving voltage data indicating significant corrosion after about 77 saltings, but the corrosion currents are very low or zero.

In summary, only 4 slabs showed definite macrocell corrosion of the top mat steel. All four of these were unsealed control slabs (2 with asphalt overlays and 2 without).

Chloride samples were obtained at three locations along a diagonal on each slab after completion of the 158 saltings. At each location, the asphaltic concrete was removed and powdered concrete samples were obtained at 2 depths (0 to 1 inch and 1 to 2 inches) and analyzed for total chloride in accordance with AASHTO T260. The total chloride in the concrete before salting (i.e. baseline) was defined by obtaining and analyzing powdered samples from cylinders made during slab fabrication.

The chloride data are summarized as absorbed chloride (total chloride after 158 days of salting minus baseline chloride) by slab and variable in table 15 and figure 4.

The chloride content data indicate that:

1. For the untreated slabs, salt penetrated deeper into the portland cement concrete when an asphalt overlay was present than when the overlay was omitted. These data point out the need for the sealer materials being studied herein.

2. Pen Seal 50 was quite effective in reducing salt penetration into asphalt overlaid slabs. All four slabs treated with the material exhibited reduced penetration, averaging only 15 percent of the control at the 0 to 1 inch depth and only 18 percent at the 1 to 2 inch depth.

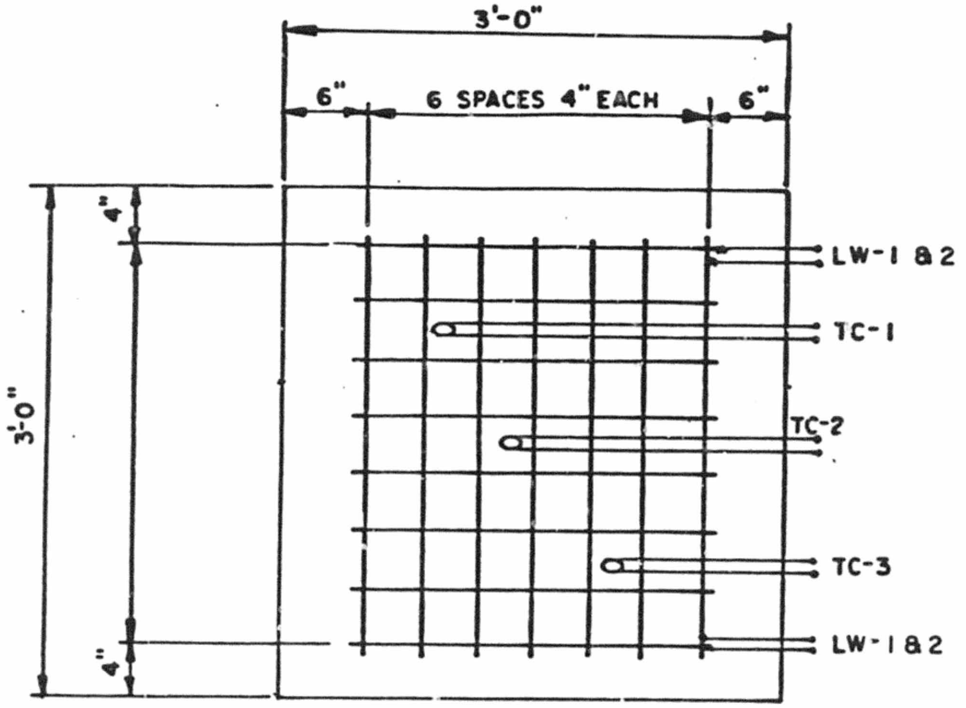
3. Hydrozo 56 was also quite effective in reducing chloride absorption, averaging only 29 percent of the control at the 0 to 1 inch depth and 22 percent of the control at the 1 to 2 inch depth. In fact on 3 of the 4 slabs treated with Hydrozo 56, performance was equal or better in effectiveness than that exhibited by the Pen Seal 50 treated concrete. (On the 4th slab, 2 of the 3 samples at the 0 to 1 inch depth showed higher salt penetration, thus raising the average.)

4. The Radcon Formula #7 data are inconclusive. Two of the slabs indicated good effectiveness in reducing salt penetration and the other two slabs indicated even more salt penetration than the untreated controls. These contradictions do not allow any conclusions to be drawn as to the effectiveness of this material.

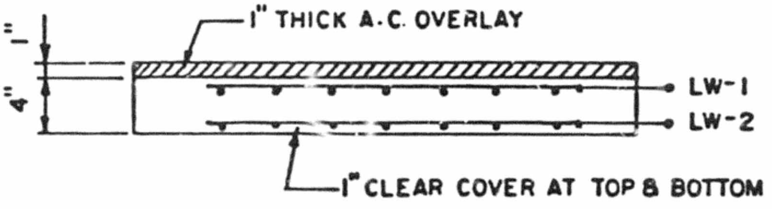
Table 15. Summary of Chloride Analyses

Material	Slab Number	Asphalt Overlay	Average Absorbed Chloride, lbs Cl^-/yd^3 0 to 1 inch depth	1 to 2 inch depth
Uncoated	1	No	8.34	0.11
	13	No	8.34	0.12
	11	No	5.25	0.24
	21	No	4.55	0.14
	9	No	4.88	0.26
	23	No	7.91	0.12
Uncoated	Average	No	6.55	0.17
Uncoated	5	Yes	4.67	0.41
	16	"	3.62	0.54
	20	"	4.70	0.33
	10	"	8.62	2.25
	22	"	4.76	0.60
	24	"	3.65	0.48
Uncoated	Average	Yes	5.00	0.77
Hydrozo 56	4	Yes	3.60	0.27
	12	"	0.17	0.02
	7	"	1.42	0.22
	17	"	0.53	0.16
Hydrozo 56	Average	Yes	1.43	0.17
Pen Seal 50	2	Yes	0.60	0.07
	15	"	0.19	0.10
	8	"	1.47	0.13
	9	"	0.66	0.26
Pen Seal 50	Average	Yes	0.73	0.14
Radcon Formula #7	3	"	2.23	0.07
	14	"	1.72	0.02
	6	"	12.6	0.63
	18	"	14.85	1.87
Radcon Formula #7	Average	Yes	7.85	0.65

Notes: All chloride analyses in accordance with AASHTO T-260. Absorbed chloride in total chloride minus baseline (that originally in the concreting materials). Baseline chloride was 0.30 lbs Cl^-/yd^3 Lbs Cl^-/yd^3 was calculated assuming a concrete unit weight of 145 lbs/ft^3.



PLAN

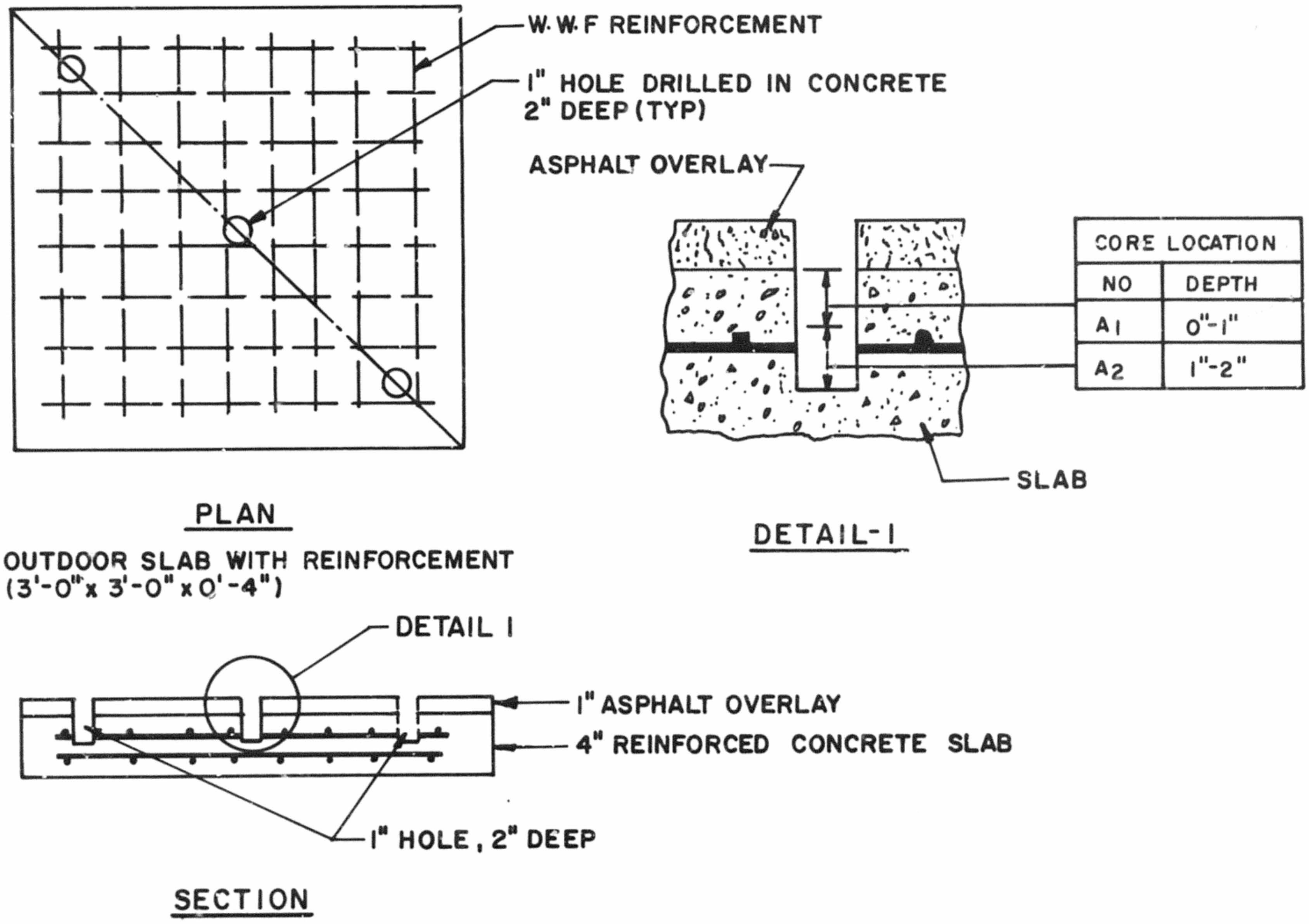


SECTION

LEGEND

AS MARKED	PARTICULARS
TC-1	COPPER CONSTANTAN THERMOCOUPLE WIRE TT-T-24
TC-2	DO
TC-3	DO
LW-1	LEAD WIRE @ TOP
LW-2	DO @ BOTTOM

FIG. 3 OUTDOOR EXPOSURE SLAB WITH REINFORCEMENT AND THERMOCOUPLES DETAILS



PLAN

OUTDOOR SLAB WITH REINFORCEMENT
(3'-0" x 3'-0" x 0'-4")

DETAIL-1

SECTION

FIG. 4 CHLORIDE DATA COLLECTION IN OUTDOOR SLABS

Chapter 4: Summary and Conclusions

Low cost sealers were investigated to determine materials which would reduce water and salt penetration into concrete bridge decks to be overlaid with asphaltic concrete. Such materials are needed because the asphalt overlay often acts as a "sponge," trapping water and salt on the portland cement concrete deck surface. As a result, freeze-thaw deterioration can be induced in poor or marginally air entrained concrete which in the past (as a "bare" deck) did not exhibit such distress because the concrete never was critically saturated when frozen.

A literature search and numerous letters to manufacturers resulted in 110 products for consideration. Follow-up letters and review of available laboratory and field data on the various materials reduced the list of candidates to 32 and subsequently to six materials. These six materials were subjected to a rigorous laboratory test program to define the ability of each material to:

a. Greatly reduce water absorption into concrete.
b. Not adversely affect bond of asphaltic concrete to the sealed portland cement concrete surface.
c. Greatly increase the deicer scaling resistance of non-air entrained portland cement concrete.
d. Not be adversely affected by the placement of hot asphaltic concrete.
e. Not lose effectiveness as a result of concrete outgassing shortly after application.

Three materials, Hydrozo 56, Pen Seal 50, and Radcon Formula #7 best met these criteria. Typically, 72 hours of water absorption for the treated concrete was reduced to about 1/4 compared to untreated concrete; and, moreover, treated concrete absorbed less water after 72 hours immersion than the untreated (controls) absorbed in 3 hours; little freeze-thaw scaling of slabs treated with these materials occurred through 95 daily cycles, while untreated slabs showed severe scaling after 35 cycles. Bond of asphaltic concrete was not greatly affected by the pressure of these materials. The application of hot asphaltic concrete and portland cement concrete outgassing did not appear to adversely affect the performance of these materials.

These three materials were then evaluated in outdoor exposure tests. Large slabs were fabricated, cured, treated with the sealers and then overlaid with asphaltic concrete and subjected to 5 months of outdoor exposure and salting. Companion slabs without sealers, both with and without asphalt overlays, were included as controls. Corrosion monitoring throughout the test period and chloride analysis after 158 days of exposure showed:

a. Salt penetrated deeper into the untreated slabs with asphalt overlays than into untreated slabs without asphalt.

b. More top mat steel corrosion occurred on untreated slabs than on companion slabs treated with the sealers.

c. The Pen Seal 50 and Hydrozo 56 sealers were both quite effective, typically reducing salt penetration by 4 or more times when compared to untreated controls with asphaltic concrete overlays. Conflicting results on the Radcon Formula #7 slabs made definite conclusions for this material impossible.

Guidelines for the use of the three materials evaluated in outdoor testing were prepared and are contained in Appendix I.

There may be other materials available which would perform well in this use. And still others may be developed in the future. We recommend that users and manufacturers evaluate products in the future, <u>using the procedures defined in this report</u> and require the materials meet the following criteria:

1. Water Absorption Test: The average water absorption of treated concrete after 72 hours of immersion shall be less than that absorbed by companion untreated controls in 3 hours.

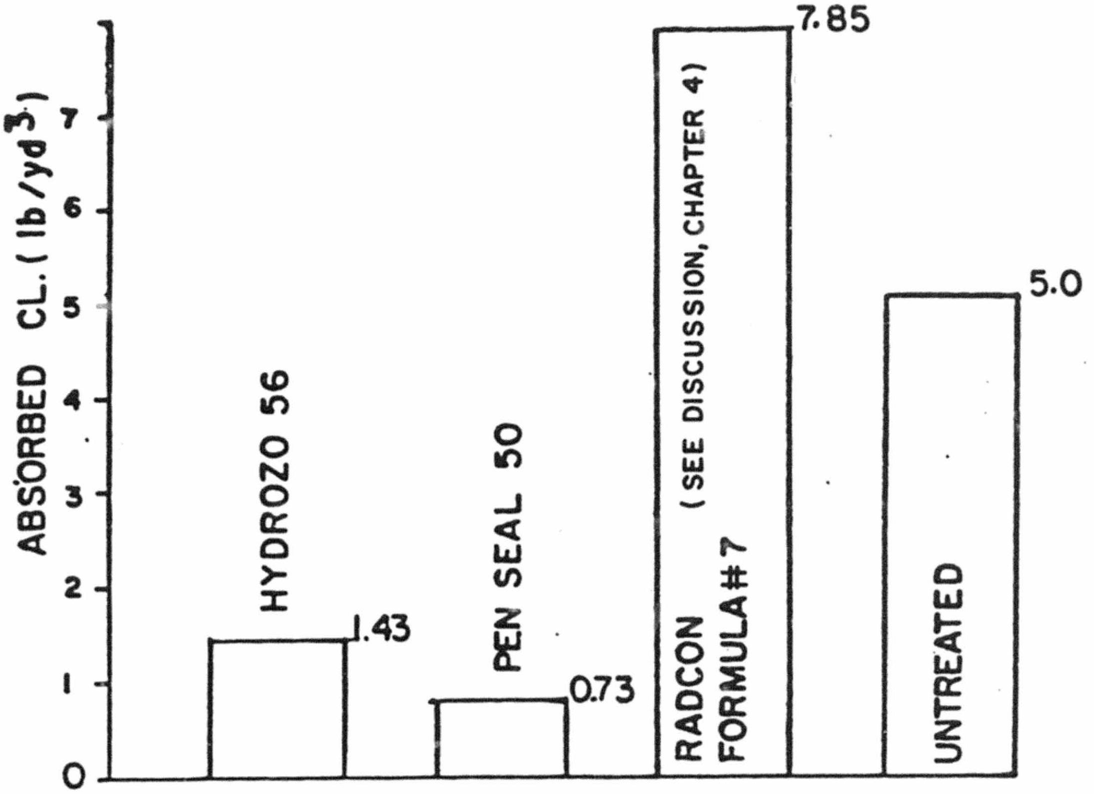
2. Scaling Resistance: The median scaling rating for treated non-air entrained concrete shall not exceed 2 through 95 ASTM C672 deicer scaling cycles. Control (untreated) slabs of the same concrete shall also be tested and show a scaling rating of 5 in 50 or less cycles for the test to be considered valid.

3. Asphaltic Concrete Adhesion: Average shear bond adhesion of asphaltic concrete to portland cement concrete treated with the sealer shall not be less than 90 percent of the average exhibited by untreated controls. An asphalt emulsion tack coat shall be applied to the deck at the rate of 0.7 lbs/ft^2.

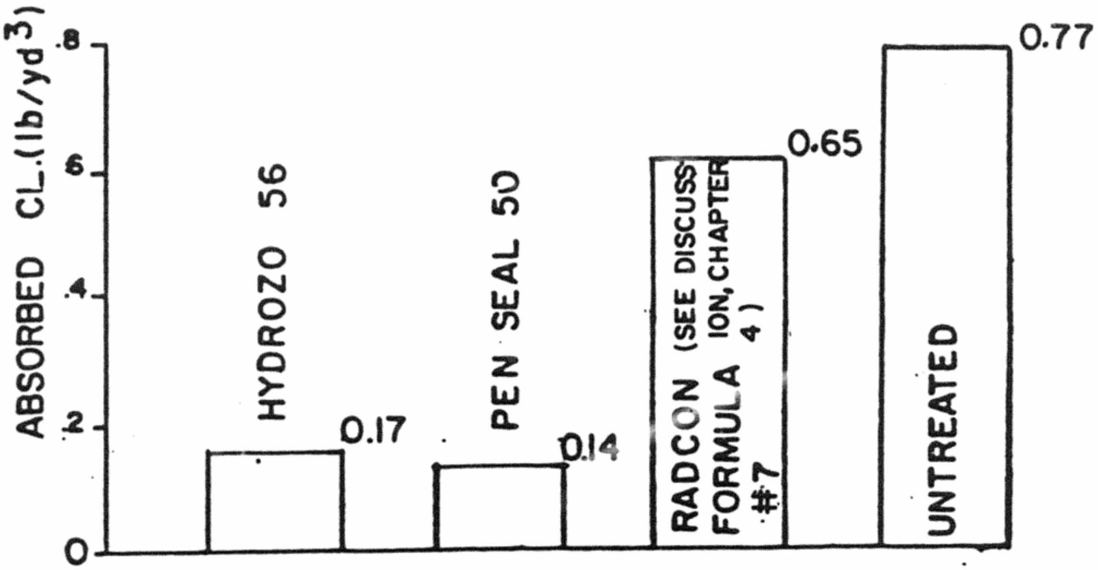
4. Chloride Penetration: Chloride penetration into large portland cement concrete slabs which are treated, then overlaid with asphaltic concrete and subjected to 20 weekly ponding cycles under outdoor exposure, shall not exceed 30 percent of that exhibited by controls at both the 0 to 1, and 1 to 2 inch depths.

Obviously, only materials which met criteria 1 thru 3 would be subject to the large slab outdoor exposure test. It is believed, however, that criterion 4 is needed to help insure the sealer will be effective under "field" applications of asphaltic concrete.

This work supplements a more extensive study of sealing materials conducted by Wiss, Janney, Elstner and Associates (WJE) for the National Cooperative Highway Research Program and described in reference 2. The present study was to determine the products which would produce protection against freeze-thaw damage. The WJE study was to find products which would prevent or reduce the entry of chlorides which produce corrosion induced deterioration. The products selected for one type of protection are not necessarily effective in producing protection against the other distress mechanism.



FOR 0 TO 1" DEPTH



FOR 1" TO 2" DEPTH

FIG. 5 BAR CHART SHOWING CHLORIDE PENETRATION INTO SLABS WITH ASPHALT OVERLAYS

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APPENDIX I

Material # 12: Hydrozo 56

1.0 Material

Hydrozo 56 is a liquid penetrant containing solids up to 60 percent maximum. It is a unique composition of resin-fortified, oil-based material with appropriate additives and thinners.

2.0 Surface Preparation

A new or old concrete surface shall be cleaned thoroughly and adequately before application of the material to allow effective penetration. To achieve this, a complete waterblast of the surface shall be done or the entire surface shall be cleaned up with a broom-with-vacuum setup equipped with a sweeping mechanism.

Utmost care shall be taken to clean up the major oil accumulations. Old aspahlt and surface laitance shall be removed with scrapers followed by sand blasting or chemical cleaning. Use air or vacuum to remove final dust and loose debris. All patchwork in the concrete surface including crack control, caulking, expansion joint sealing, etc., shall be done over the prepared concrete surface, prior to the application of the material. Before application, painting of line stripes shall be done over the surface (if not to be overlayed).

3.0 Application

A small area shall be tested prior to application. The material then shall be applied with a flooding action, at an approximate rate of 100 ft^2/gallon by using a push broom. The flooding of the material over the entire surface will help the material penetrate deeply into concrete. This shall be further achieved by using soft bristled brooms over the flooded surface.

On lightweight concrete or on more porous concrete surfaces, the material shall be applied at a rate of 75-85 ft^2/gallon. A low pressure airless spray shall be used during this application procedure and the surface shall be broomed by means of push brooms or mechanical brooms to assist penetration of the material.

Working temperatures of the air, material, and concrete surface shall be between 40°F to 100°F during application. When the working temperature falls below 40°F, special precautions such as heavy brooming or warming of materials etc., shall be done, so as to help the material penetrate into the concrete.

For concrete decks which are over occupied areas or for other locations which require a fully flexible membrane, this material shall not be used.

The material is recoatable, simple to apply, and does not increase or decrease the skid resistance of concrete if applied according to instructions. All excess material shall be squeegeed off the concrete surface after 5 minutes or excessive slickness may result. The slickness of surface may temporarily increase immediately after material application. However, it will return to normal when the coating becomes dry. Check the surface before any traffic is allowed to assure that the coating has completely dried and full traction has returned.

All equipment including tools shall be cleaned with mineral spirits or Hydrozo cleaning thinner, immediately following application of the material.

4.0 Curing

Allow 12 hours minimum under normal drying conditions for the material to cure. A small amount of light traffic may be allowed after curing is completed.

5.0 Asphalt Overlay

Before applying an asphalt overlay on the coated concrete surface, the entire surface shall be completely dried and air cured for a minimum of 12 hours. After rain, allow 24 hours of air drying before overlaying.

6.0 Toxicity

The material is non-toxic and the fumes are harmless to inhalation in the concentrations normally occurring during application.

Material #23: Pen Seal 50

1.0 Material

Pen Seal 50 is a clear, light amber-colored, penetrating liquid containing 50% solids. It is available in the market as a two component solvent, composed of epoxy resins and organic amines.

2.0 Surface Preparation

Old concrete should be structurally sound. Weak sections, dirt, laitance, curing compounds, and other foreign matter shall be removed before application of the material. The concrete surface shall be treated with a 10 percent solution of hydrochloric acid or shall be prepared by sand blasting/water blasting, in a range of 3000 to 5000 psi pressure or grinding to the satisfaction of the engineer in charge.

New concrete shall be allowed to attain its maximum initial shrinkage condition thereby allowing excess water to evaporate before application.

Utmost care shall be taken to clean up the major oil accumulations. For best results the surface shall be free from petroleum, dirt, oil, or any loose material. Rust or stains may be removed if desired.

3.0 Application

Thorough and complete mixing is of vital importance for uniform curing. To achieve this, two parts of materials A and B shall be mixed at a volume ratio of 1:1 for 3 minutes using a jiffy mixer or equal powered electric drill at a low speed (400-600 RPM); the material may also be mixed by vigorous and thorough action with a paint stirrer. At the time of mixing, the working temperature must be above 50°F.

The material shall be applied on a completely dry concrete surface by means of squeegee, roller, or spraying equipment or use of conventional airless spraying with a nozzle tip orifice of approximately 0.026 in. in diameter. The surface temperature must be above 50°F.

One coat at an application rate of 100-150 ft^2/gallon shall be adequate if the material is being used as a penetrating sealer, but if it is being used as a protective coating, and the concrete is porous, two coats shall be required for best results with application rate of 100-150 ft^2/gallon for the first coat and 250-300 ft^2/gallon for the second coat.

The surface shall be dry at the time of application and shall be completely covered with the material.

All excess material shall be squeegeed off the finished surface soon after the application work is completed to assure that no excess solids remain to cause excessive slickness.

Tools and other equipment used shall be cleaned promptly with xylene, toluene, or methyl ethyl ketone (MEK) solvent.

Material (once exposed to air) shall be used within 2 hours, but it will remain in good condition up to 2 years if stored in airtight cans at an average temperature of 80°F.

4.0 Curing

Sufficient time should be allowed for the solvent to evaporate before application of any asphalt overlay. A minimum of 6 hours at temperatures of 70°F and above and a range of 18-24 hours for temperatures between 40-70°F are necessary. The surface appearance will be glossy when the sealer is cured. Broadcast silica sand at 1 to 1-1/2 pounds/square yard is recommended to enhance the mechanical adhesion of the asphalt. The application of sand should be done immediately after application of Pen Seal 50, i.e., before it is becomes dry.

5.0 Toxicity

The material contains an aromatic solvent and it may, therefore, cause skin irritation or other allergic problems. Use goggles, protective clothing, and gloves while working with the materials.

Material #24: Radcon Formula #7

1.0 Material

Radcon Formula #7 is a clear colorless penetrating liquid containing a maximum of 32 percent solids. It is an aqueous solution of sodium silicate containing specific activators to achieve penetration and chemical bonding to the cementitious portion of concrete.

2.0 Surface Preparation

Old concrete surfaces to be sealed shall be clean and dry. The cleaning shall be performed using Radcon Formula #4 or by brooming or by other approved means.

New concrete shall be cured for at least 28 days prior to application. The surface shall be cleaned and dried as described above.

All new concrete deck surfaces shall be lightly troweled to a fairly smooth finish for best results, and shall also be free from petroleum, dirt, oils, and any loose material. Rust or stains may be removed if desired.

All joints, cracks, and openings around protrusions shall be sealed by pre-stripping or caulking, and shall be repaired to the satisfaction of the Engineer. Radcon Formula #7 shall be used as a bonding agent between the existing concrete surface and any patching material.

3.0 Application

On horizontal concrete surfaces, the material shall be spread over the surface with a brush, squeegee, mop, wool roller, etc. It is important that all areas are completely covered with the material at an application rate of 250 ft^2/gallon.

On vertical concrete surfaces, the material shall be sprayed on with low pressure (20-30 psi) for deep, rapid penetration. The coverage shall be at a rate of 200 ft^2/gallon.

The material shall not be applied during rain or to a wet surface or if the temperature falls below 40°F (4°C).

Do not apply the material on glass, tiles, etc. When spray equipment is used, if spraying is to be interrupted for more than 5 minutes, the spray orifice shall be placed in water.

All excess material shall be squeegeed off the surface immediately after application is completed. Equipments and tools used in application procedures shall be cleaned with water.

4.0 Curing:

The concrete surfaces treated with the material shall be allowed to dry for 3-6 hours. Then the surface shall be flushed with a large amount of water, every 24 hours, for at least 72 hours.

The entire wet surface shall be covered with plastic sheetings and allowed 72 hours for curing.

After the curing period, the surface shall be inspected for disappearance of a shiny appearance; if shiny surface still appears, the surface should be rewatered.

After curing is complete, the surface is ready for traffic.

5.0 Asphalt Overlay

The surface treated with Radcon Formula #7 shall be overlayed with asphaltic concrete only after the 72 hour water flushing period and complete drying of the surface. Prior to application of an overlay, the concrete surface treated with the material shall be well watered, which will provide microscopic etching of the surface. The etching is very important for mechanical bond of the overlay with the surface.

6.0 Toxicity

The material is non-toxic, non-caustic, and non-flammable. It is also bio-degradable.

APPENDIX II

Table 16. Results from sample collected from slab no. 13 (Mix 1) for air void system characteristics using ASTM C457

Line number	No of voids	Traversed paste + coarse aggregate (inches)	Traversed air (inches)
1	4	2.84	0.04
2	2	2.85	0.02
3	4	2.81	0.10
4	1	2.85	0.02
5	3	2.83	0.05
6	7	2.77	0.09
7	6	2.72	0.15
8	6	2.76	0.11
9	4	2.81	0.05
10	5	2.79	0.07
11	7	2.78	0.07
12	7	2.72	0.12
13	6	2.70	0.14
14	5	2.76	0.07
15	3	2.82	0.02
16	7	2.74	0.09
17	5	2.70	0.11
18	3	2.74	0.06
19	4	2.69	0.12
20	3	2.75	0.04
21	5	2.60	0.21
22	5	2.71	0.09
23	4	2.75	0.05
24	5	2.69	0.10
25	6	2.63	0.14
26	3	2.74	0.05
27	6	2.85	0.07
28	3	2.88	0.04
29	3	2.87	0.06
30	5	2.89	0.05
31	3	2.88	0.03
32	2	2.83	0.10
33	7	2.75	0.19
Total	149	88.75	2.72

Table 17. Results from sample collected from slab no. 6
(Mix 2) for air void system
characteristics using ASTM C457

Line number	No of voids	Traversed paste + coarse aggregate (inches)	Traversed air (inches)
1	12	2.90	0.09
2	11	2.83	0.08
3	12	2.84	0.08
4	19	2.79	0.09
5	23	2.77	0.13
6	4	2.87	0.03
7	11	2.86	0.05
8	13	2.82	0.08
9	18	2.78	0.11
10	17	2.82	0.09
11	12	2.82	0.10
12	18	2.78	0.12
13	14	2.81	0.07
14	9	2.80	0.08
15	15	2.80	0.07
16	11	2.78	0.13
17	16	2.85	0.08
18	7	2.91	0.02
19	13	2.86	0.06
20	22	2.82	0.09
21	22	2.79	0.13
22	12	2.87	0.07
23	12	2.82	0.09
24	10	2.82	0.06
25	21	2.46	0.09
26	14	2.50	0.07
27	12	2.47	0.08
28	20	2.44	0.12
29	15	2.51	0.07
30	20	2.45	0.11
31	23	2.42	0.16
32	33	2.43	0.16
Total	491	87.49	2.78

Table 18. Results from sample collected from slab no. 23 (Mix 3) for air void system characteristics using ASTM C457

Line number	No of voids	Traversed paste + coarse aggregate (inches)	Traversed air (inches)
1	30	2.54	0.21
2	26	2.54	0.21
3	27	2.55	0.20
4	26	2.60	0.16
5	27	2.59	0.16
6	42	2.49	0.27
7	21	2.62	0.15
8	24	2.58	0.18
9	25	2.55	0.22
10	29	2.57	0.19
11	21	2.65	0.15
12	31	2.57	0.21
13	19	2.66	0.13
14	17	2.64	0.15
15	11	2.70	0.09
16	15	2.59	0.19
17	11	2.75	0.05
18	16	2.70	0.10
19	16	2.73	0.09
20	15	2.69	0.11
21	13	2.73	0.08
22	11	2.77	0.06
23	25	2.68	0.14
24	29	2.67	0.15
25	27	2.59	0.23
26	32	2.57	0.25
27	12	2.74	0.10
28	13	2.74	0.10
29	16	2.75	0.10
30	17	2.75	0.11
31	23	2.69	0.12
32	20	2.66	0.13
Total	687	84.65	4.79

Table 19. Computation of air void system parameters in Mix 1.

(Slab No. 13)

$$\text{Percentage Air} = \frac{\text{traversed air}}{\text{total traverse}} \times 100 = \frac{2.72}{91.47} \times 100 = 3.0\%$$

$$\text{Average Chord Length, } \ell = \frac{\text{traversed air}}{\text{No. Voids}} = \frac{2.72}{149} = 0.0183 \text{ in.}$$

$$\text{Specific Surface, } \alpha = \frac{4}{\ell} = \frac{4}{0.0183} = 219.1$$

Calculated paste content based on mix design = 28.3%

$$\therefore \frac{P}{A} = 9.4$$

$$\text{Spacing Factor, } \bar{L} = \frac{3}{\alpha} \left[1.4 \left(\frac{P}{A} + 1\right)^{1/3} - 1\right]$$

$$\bar{L} = \frac{3}{219.1} \left[1.4 \left(9.4 + 1\right)^{1/3} - 1\right] = 0.0281 \text{ in.}$$

Table 20. Computation of air void system parameters in Mix 2.

(Slab No. 6)

$$\text{Percentage Air} = \frac{\text{traversed air}}{\text{total traverse}} \times 100 = \frac{2.78}{90.27} \times 100 = 3.1\%$$

$$\text{Average Chord Length, } \ell = \frac{\text{traversed air}}{\text{No. Voids}} = \frac{2.78}{491} = 0.006 \text{ in.}$$

$$\text{Specific Surface, } \alpha = \frac{4}{\ell} = \frac{4}{0.006} = 706.5$$

Calculated paste content based on mix design = 32.1%

$$\therefore \frac{P}{A} = 10.3$$

$$\text{Spacing Factor, } \bar{L} = \frac{3}{\alpha} \left[1.4 \left(\frac{P}{A} + 1\right)^{1/3} - 1\right]$$

$$\bar{L} = \frac{3}{706.5} \left[1.4 \, (10.3 + 1)^{1/3} - 1\right] = 0.009 \text{ in.}$$

Table 21. Computation of air void system parameters in Mix 3.

(Slab No. 23)

$$\text{Percentage Air} = \frac{\text{traversed air}}{\text{total traverse}} \times 100 = \frac{4.79}{89.44} \times 100 = 5.4\%$$

$$\text{Average Chord Length, } \ell = \frac{\text{traversed air}}{\text{No. Voids}} = \frac{4.79}{687} = 0.007 \text{ in.}$$

$$\text{Specific Surface, } \alpha = \frac{4}{\ell} = \frac{4}{0.007} = 573.7$$

Calculated paste content based on mix design = 28%

$$\therefore \frac{P}{A} = 5.2$$

$$\text{Spacing Factor, } \bar{L} = \frac{3}{\alpha} \left[1.4 \left(\frac{P}{A} + 1\right)^{1/3} - 1\right]$$

$$\bar{L} = \frac{3}{573.7} \left[1.4 \left(5.2 + 1\right)^{1/3} - 1\right] = 0.008 \text{ in.}$$

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FEDERALLY COORDINATED PROGRAM (FCP) OF HIGHWAY RESEARCH AND DEVELOPMENT

The Offices of Research and Development (R&D) of the Federal Highway Administration (FHWA) are responsible for a broad program of staff and contract research and development and a Federal-aid program, conducted by or through the State highway transportation agencies, that includes the Highway Planning and Research (HP&R) program and the National Cooperative Highway Research Program (NCHRP) managed by the Transportation Research Board. The FCP is a carefully selected group of projects that uses research and development resources to obtain timely solutions to urgent national highway engineering problems.*

The diagonal double stripe on the cover of this report represents a highway and is color-coded to identify the FCP category that the report falls under. A red stripe is used for category 1, dark blue for category 2, light blue for category 3, brown for category 4, gray for category 5, green for categories 6 and 7, and an orange stripe identifies category 0.

FCP Category Descriptions

1. Improved Highway Design and Operation for Safety

Safety R&D addresses problems associated with the responsibilities of the FHWA under the Highway Safety Act and includes investigation of appropriate design standards, roadside hardware, signing, and physical and scientific data for the formulation of improved safety regulations.

2. Reduction of Traffic Congestion, and Improved Operational Efficiency

Traffic R&D is concerned with increasing the operational efficiency of existing highways by advancing technology, by improving designs for existing as well as new facilities, and by balancing the demand-capacity relationship through traffic management techniques such as bus and carpool preferential treatment, motorist information, and rerouting of traffic.

3. Environmental Considerations in Highway Design, Location, Construction, and Operation

Environmental R&D is directed toward identifying and evaluating highway elements that affect the quality of the human environment. The goals are reduction of adverse highway and traffic impacts, and protection and enhancement of the environment.

4. Improved Materials Utilization and Durability

Materials R&D is concerned with expanding the knowledge and technology of materials properties, using available natural materials, improving structural foundation materials, recycling highway materials, converting industrial wastes into useful highway products, developing extender or substitute materials for those in short supply, and developing more rapid and reliable testing procedures. The goals are lower highway construction costs and extended maintenance-free operation.

5. Improved Design to Reduce Costs, Extend Life Expectancy, and Insure Structural Safety

Structural R&D is concerned with furthering the latest technological advances in structural and hydraulic designs, fabrication processes, and construction techniques to provide safe, efficient highways at reasonable costs.

6. Improved Technology for Highway Construction

This category is concerned with the research, development, and implementation of highway construction technology to increase productivity, reduce energy consumption, conserve dwindling resources, and reduce costs while improving the quality and methods of construction.

7. Improved Technology for Highway Maintenance

This category addresses problems in preserving the Nation's highways and includes activities in physical maintenance, traffic services, management, and equipment. The goal is to maximize operational efficiency and safety to the traveling public while conserving resources.

0. Other New Studies

This category, not included in the seven-volume official statement of the FCP, is concerned with HP&R and NCHRP studies not specifically related to FCP projects. These studies involve R&D support of other FHWA program office research.

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* The complete seven-volume official statement of the FCP is available from the National Technical Information Service, Springfield, Va. 22161. Single copies of the introductory volume are available without charge from Program Analysis (HRD-3), Offices of Research and Development, Federal Highway Administration, Washington, D.C. 20590.