THE EFFECT OF SURFACE COATINGS AND BONDED OVERLAYS ON MOISTURE MIGRATION

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DISCLAIMER

I. ABSTRACT

Tests were made on concrete specimens that had been coated with four different waterproofing materials to determine how far the coatings penetrated into the concrete. Also, coated surfaces and overlaid specimens were ponded over with 5% salt water and tap water to determine the effectiveness of each to prevent the migration of moisture into the concrete specimens.

Freeze-thaw tests were made on asphaltic overlays to determine the effect of freeze-thaw cycling on the overlays and the portland cement concrete beneath the overlays. Shear tests were made to determine the shear strength of concrete overlays bonded to concrete test blocks.

It was found that the deepest penetration, 0.054 to 0.062 in., was made by a mixture of linseed oil and kerosene. No damage was found under the asphaltic overlay after 59 freeze-thaw cycles. Shear bond strengths ranged from 61 psi to 267 psi when the cube surfaces were treated with surface coatings and 367 psi to 597 psi when the surfaces with coatings were sandblasted before overlaying.

KEY WORDS: concrete, bond (overlay to concrete), moisture gages, moisture penetration, surface coatings (protection and penetration), overlays, freeze-thaw

II. SUMMARY

Coating penetrations, moisture migration, shear bond strengths, and freeze-thaw tests are the subjects of this report. Five series of tests were made to generate information on the enumerated subjects. These tests are:

1. Penetration tests to determine depth of penetration of selected protective coatings, and the indicator(s) that may be used to indicate depth of penetration.
2. Moisture migration tests to determine the effectiveness of selected protective coatings in resisting moisture migration.
3. Moisture migration tests to determine the effectiveness of selected overlay systems in resisting moisture migration.
4. Freeze-thaw tests to determine the effect of freeze-thaw cycling on concrete overlaid with asphaltic concrete.
5. Direct shear tests to determine the effects of selected protective coatings on shear bond strength.

All of these tests were made in the laboratory using commercially available materials.

The findings, given in the same order as the tests enumerated above, are:

1. A mixture of phenolpthalein and the coating material was selected. The range of penetration was 0.054-0.062 inch for the linseed oil-kerosene mixture; 0.041-0.045 inch for the raw tung oil-kerosene mixture; 0.027-0.031 inch for the epoxy, EpoXeal, coating; and 0.013-0.017 inch for the commercial product, Thompson's Water Seal.

2. The raw tung oil-kerosene mixture resisted the migration of the 5% salt water best, followed by the linseed oil-kerosene mixture and Thompson's Water Seal, in that order. Against tap water, the migration resistance of the raw tung oil was best, followed by Thompson's Water Seal and the linseed oil-kerosene, in that order.
3. All overlay systems with the exception of the portland cement concrete were effective in maintaining the relative humidity at or below about 80%. The migration time required for ponded 5% salt water to migrate through the portland cement concrete overlays was about 7 days when the surfaces of the overlays were uncoated and about 30 days when the overlay surfaces were coated with a linseed oil-kerosene mixture.
4. The special rubber-asbestos asphaltic concrete overlays withstood the full 59 cycles of the freeze-thaw tests. No deterioration of the concrete beneath the overlays was noted at any time during the tests.
5. The effect of surface coatings on shear bond strength was to reduce the strength when compared to uncoated specimens. Sandblasting of the coated surfaces helped to restore shear bond strength.

III. IMPLEMENTATION STATEMENT

This report covers three stages of research conducted under this project. Those stages are: (1) sealing of portland cement concrete by penetrating type sealants and overlay systems, (2) depth of penetration of the penetrating type sealants, and (3) bonding of overlay systems to portland cement concrete.

This research has shown that the linseed oil-kerosene mixture used by THD as a water resisting coating for concrete penetrates the concrete deeply enough that it will not be easily eroded away by traffic. A tung oil-kerosene mixture has been shown to be an effective water resisting coating but its penetration depth was less than the linseed oil-kerosene mixture. The penetration depths of the epoxy coating and Thompson's Water Seal were much less than the linseed oil-kerosene mixture. The annual application of the linseed oil-kerosene mixture currently in practice for new concrete decks should be sufficient to last through a winter season without additional treatment.

No portland cement concrete or resinous material overlay should be applied to a deck which has been treated with water resistant surface material unless the surface material is first removed. Sandblasting or scarifying are used satisfactorily to prepare the concrete surface by removing materials that might reduce the bond strength of this type overlay.

Overlays of 1/2 inch thickness of resinous materials, mineral aggregates bound together with epoxy or polyester resins, are effective in sealing concrete decks against water. The overlays must be free of cracks and pin holes if they are to be completely waterproof. The overlay system consisting of a seal coat, a tack coat, and a 1-1/2 inch thick rubberized asphaltic concrete proved to be impervious to water in moisture migration and freeze-thaw tests. The seal coat consisted of 120-150 penetration asphalt and synthetic intermediate grade lightweight aggregate, and the tack coat consisted of a rubberized asphalt emulsion. That overlay system shows great promise of being an efficient and relatively inexpensive sealing and surfacing material.

IV. REPORT OF RESEARCH

A. INTRODUCTION

Many of the problems associated with durability of concrete bridge decks begin with the entry of water into the concrete through cracks and pores. Soluble chlorides are sometimes carried by the water. Electrochemical corrosion of reinforcing steel is enhanced by concentration of chloride ions resulting from chloride entry with water. Deicing salts and sea water are two common sources of chlorides. The depth of penetration of water into concrete is of interest because salt solutions which reach reinforcing steel will probably cause corrosion. Internal tension in the concrete caused by the accumulation of corrosion products is sometimes so great that spalling occurs in the vicinity of the corrosion.

Scaling of concrete surface mortar is the result, too, of water penetration. Alternate freezing and thawing of the water in pores and cracks cause gradual surface deterioration by flaking away the mortar.

Concrete that is kept dry is almost certain to be free of corrosive and freeze-thaw damage sometimes found in concrete bridge decks. A part of the research carried out in this project is directed toward preventing water from entering concrete. This report covers a study to determine the depth that water penetrates concrete with and without protective coatings and with overlays. Tests were made, too, to determine how deep into the concrete the coating materials penetrated. The depth of penetration is of interest particularly where abrasion from traffic is to be expected.

An earlier report (1) described tests and results that were used in selecting the surface treatments for this study. The overlay systems selected for this study are some of those that have been or are being considered for use by the Texas Highway Department, THD.

Concrete specimens that had been coated with waterproofing materials were examined to determine how far the coating penetrated. In other tests, coated surfaces and overlaid specimens were ponded over with 5% salt water and with plain tap water to determine the effectiveness of each to resist the migration of moisture into the concrete specimen.

Table I lists the tests made in the study and gives the purpose of each test.

It was found that the overlay systems were in general effective in resisting moisture migration, that the waterproofing materials served to slow down moisture migration, and that the depths of penetration of the waterproofing materials differ. No correlation between depth of penetration and protection provided against freeze-thaw action was found to be evident in the laboratory study.

B. MATERIALS

The portland cement concrete slabs, 10 x 10 x 2 inches, and the 1½ inch thick overlays were made of natural sand and gravel taken from pits near Hearne, Texas. The maximum size of aggregate was 3/4 inch and 1/2 inch, respectively, for the slabs and overlays and the mixes are given in Table II.

The asphaltic concrete overlay mixes were as described by Epps and Gallaway (2). The mixtures, Table III, contained synthetic lightweight

TABLE I. A SUMMARY OF TESTS, OBJECTIVES, AND RESULTS

Test	Objectives	Results
Penetration	To determine indicator(s) that may be used to indicate depth of penetration and to determine the penetration of selected coatings.	A mixture of phenolpthalein crystals, isopropyl alcohol, and distilled water was selected. Penetration depths of the coatings ranged from a high of 0.054 to 0.013 inch.
Moisture Migration	To determine the effectiveness of waterproofing materials in retarding moisture migration.	Tung mix followed by LO* mix were most effective. Both more resistant to 5% salt water.
Moisture Migration	To determine the effectiveness of overlay systems in retarding moisture migration.	All overlay systems except the untreated concrete system were effective in resisting moisture migration.
Freeze-thaw	To determine the effect of freeze-thaw action on asphaltic concrete overlay systems.	No ill effects noted.
Shear	To determine the effect of waterproofing materials on bond stress.	All materials tested reduced the bond stress. Sandblasting helped to restore bond strength.

*Boiled linseed oil mixed with kerosene, 50%-50% basis.

TABLE II. CONCRETE MIXES

Weights in pounds per cubic yard of concrete

	CA lbs	FA lbs	Cement Type III	Water lbs	Air Content %	Slump in.
Slabs	1950	1295	516	300	-----	2-1/4
Overlays	1810	1130	660	306	6	2-3/4

TABLE III. MIXTURES USED FOR ASPHALTIC OVERLAYS

Mix Designation	Type D*	Type F*
Gradation:		
Passing 3/8 inch	100	100
Passing 3/8 inch, retained No. 4	10-30	0-10
Passing No. 4, retained No. 10	10-30	20-40
Total Retained No. 10	40-70	30-50
Passing No. 10, retained No. 40	10-30	10-30
Passing No. 40, retained No. 80	4-25	4-20
Passing No. 80, retained No. 200	7-25	2-15
Passing No. 200	3-8	2-8
Asphalt content, percent by dry weight of aggregate	8.5	10.5
Rubber, percent by weight of asphalt	3	3
Asbestos, percent of total mixture	3	3
Lightweight aggregate, expanded shale (rotary kiln process), percent by weight	40	40
Crushed limestone, Georgetown, percent by weight	40	40
Field sand, Lightsey, percent by weight	20	20

*Gradations closely resemble Texas Highway Department Class A Types D and F, respectively. The synthetic lightweight aggregate, Ranger, was produced at Ranger, Texas. The crushed limestone was taken from Georgetown, Texas. The latex rubber solids, pliopave L-170, was produced by Goodyear Tire and Rubber Company. The field sand, Lightsey, was obtained from near Bryan, Texas.

aggregates, crushed limestone, field sand, asphalt, rubber, and asbestos. The gradation of aggregates was obtained by blending 40% lightweight aggregate, 40% crushed limestone, and 20% field sand.

The asphalt, AC-5, contained 3% latex rubber solids by weight. The rubber was incorporated into the asphalt at the place of manufacture of the asphalt in order that a more nearly homogeneous asphalt rubber product could be obtained.

The chrysolite asbestos fibers used were graded as 7M as designated by the Quebec Standard Screen test.

The seal coat applied to the portland cement concrete consisted of 120-150 penetration asphalt cement applied at the rate of 0.3 gal/sq yd, and synthetic intermediate grade lightweight aggregate applied at the rate of 6 lbs/sq yd.

The tack coat, binder between the seal coat and asphaltic overlay, was applied at the rate of 0.083 gal/sq yd. An asphalt emulsion, EA-HVMS emulsified asphalt, high viscosity medium setting, was used together with 2% rubber solids by weight for the tack coat.

The epoxy overlay system consisted of a two component epoxy resin mixed with natural sand, 15% epoxy and 85% sand by weight.

The polyester overlay system consisted of a commercially available polyester resin and catalyst mixed with natural sand, 15% polyester resin, and 85% sand by weight.

C. SPECIMENS

General. Test specimens were 2-inch thick portland cement concrete slabs 10 inches square. The slabs were vibrated 18 seconds in wood forms on a vibrating table and were given a rough surface finish with a wood screed during vibration. After initial set, the slabs were covered with polyethylene sheet and cured for approximately 12 hours. They were then cured in a 73°F, 95% RH chamber until seven days old. After moist curing, the specimens were dried 21 days in a 73°F, 50% RH chamber.

Monfore (3) moisture wells were cast in series 2 and 3 that follow, at depths of 1/8, 2/8, and 3/8 inches from the finished surface, Figure 1.

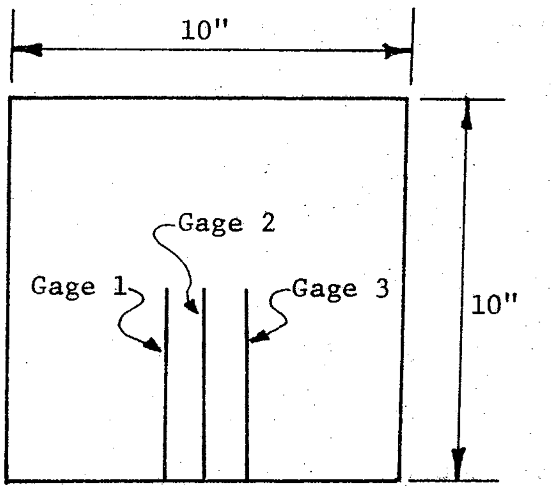
The methods and rates of application of coatings used in the following tests are described in an earlier report (1).

Series 1. Coatings 2-a, 7, 8-a, and 9, Table IV, were included in this series of tests for purposes of measuring the depth to which the coatings penetrate through the finished surface.

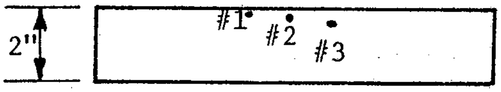
Series 2. Coatings 0, 2-a, 7, and 8 were included in this test series to determine the effectiveness of each coating in resisting moisture migration into the concrete.

Series 3. This series of tests was made to determine the degree to which overlays of epoxy mortar, polyester mortar, asphaltic concrete, and portland cement concrete resist moisture migration into the concrete base beneath them.

Series 4. This series of tests was made to determine the effect of coatings 0, 2-a, 7, and 8-a on the bond strength between old and new portland cement concrete.



Plan



Elevation

Gages 1, 2, and 3 are located 1/8, 2/8, and 3/8", respectively, below the top surface.

Figure 1. Location of Gages for Measuring Relative Humidity.

TABLE IV. DESCRIPTIONS OF COATINGS

Coating Number	Description
0	No coating
2-a	Two coats of 50-50 linseed oil and kerosene
7	Two coats of Thompson's Water Seal
8-a	Two coats of 50-50 tung oil and kerosene
9	One coat of EpoXeal with a touch-up coat

Series 5. In this series of tests, blocks overlaid with asphaltic overlays were alternately frozen and thawed to determine the effectiveness of the asphaltic overlays in protecting the underlying portland cement concrete base.

D. TESTS

Series 1. In laboratory tests, several materials were investigated as possible depth indicators. Those materials include oil base dyes, sulfuric acid, printer's ink, and phenolpthalein.

Both sawed and broken surfaces were observed using a variable power microscope. Depth measurements to 0.001 inch were recorded for each of the above depth indicators except the printer's ink.

1. Oil base dyes. Three colors (red, orange, and blue) were used. One gram of the dye was added to 100 ml of coatings 2-a and 8-a prior to applications. After the coatings had dried, eight to ten measurements of penetration depth were made over the 10 inch long broken and sawed surfaces.
2. Sulfuric acid. A 50% solution of sulfuric acid* was used as an indicator of depth of penetration with coating 2-a. It was applied evenly over the sawed and broken faces at room temperature and the specimens were then baked in a 270° oven for 2-1/2 hours. After removal from the oven, the specimens were allowed to cool before observations were made.

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*This method was suggested by Mr. William Kubie, Principal Chemist, Oilseed Crops Laboratory, U. S. Department of Agriculture.

3. Printer's ink. A mixture of 20% printer's ink was made with coatings 2-a, 7, and 8-a, and the mixture was applied to the top of the blocks. After drying, transverse surfaces, both broken and sawed, were made from each block. These surfaces were then observed under ultraviolet light to determine the penetration of the flourescent ink. A 35 mm SLR camera with a special filter was used to photograph the surfaces under the ultraviolet light.

4. Phenolpthalein. Phenolpthalein has the property of reacting with alkaline substances to indicate a pink color. Thus, in intimate contact with alkaline concrete particles, a pink color is seen. If the particles are coated to prevent intimate contact with alkali, no such color is indicated.

   An indicator was prepared by mixing 5 grams of phenolpthalein crystals, 500 ml of isopropyl alcohol, and 500 ml of distilled water. This solution was mixed with coatings 2-a and 8-a to produce a mixture of 20% indicator and 80% coating. Since the indicator would not mix with coatings 7 and 9, a mixture of indicator was made with coating 2-a. The resulting mixture was applied evenly on the sawed and broken surfaces of the blocks coated with coatings 7, 9, and 2-a. A mixture of coating 8-a and indicator was applied evenly to the sawed and broken surfaces of the blocks receiving coating 8-a.

Series 2. Specimens containing moisture wells as described earlier in this report were used in this test series. A relative humidity probe that was inserted into the moisture wells was used to determine relative humidity at depths of 1/8, 2/8, and 3/8 inch below the top surface.

The specimens in this test series were coated with coatings 0, 2-a, 7, and 8-a. After the coatings had dried, 8 inch diameter rings were bonded to the tops of the blocks. One set was ponded with a 1/2 inch depth of tap water and an identical set with 5% salt water*. Relative humidity versus time was recorded until each moisture well had reached 100% relative humidity.

Series 3. In this series of tests, overlays were bonded to the surfaces of the blocks to determine their effectiveness in resisting the passing of tap water and 5% salt water into the concrete base. The overlays included:

1. Epoxy mortar overlay, 1/2 inch thick, made up of 15% GuardKote 250 epoxy with 85% natural sand was used for this overlay. The epoxy and sand were mixed in a 5 gal can using a beater type blender attached to an electric drill. After mixing for five minutes, the mortar was poured onto the block surfaces and smoothed. When the mortar had lost its tackiness to the touch, it was rolled to provide compaction. After one day, the 8 inch diameter rings were bonded to the overlay and relative humidity data were recorded until the overlays were 60 days old.
2. A 1/2 inch thick polyester resin mortar made of 15% commercial polyester resin with 85% natural sand was used for this overlay. The procedure for preparing these overlays was the same as for the epoxy except that a wood maul was used for compaction. A wood screed was then used for strike off.

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*The salt solution contained 5% sodium chloride and 95% tap water by weight.

3. Asphaltic concrete, 1½ inch thick, was used for this overlay. A seal coat of 120-150 penetration asphalt cement and intermediate grade lightweight aggregate (Ranger) was applied to the blocks. After three days, a tack coat of EA-HVMS, emulsified asphalt, high viscosity medium setting, with 2% latex rubber solids was applied to the seal coat. Time was allowed for the EA-HVMS to break, i.e., to permit water to evaporate, then the hot mix was applied on top of the tack coat. The hot mix overlay was compacted by pressure from a hydraulic ram with a force of 14,400 lbs for one minute over the 10-inch square area.

4. A 1½ inch thick portland cement concrete overlay was bonded to the block surfaces with a portland cement grout. The overlays were cured in a 73°F, 100% RH chamber for seven days after which the overlaid blocks were placed in a 73°F, 50% RH chamber. After seven days in this chamber it became apparent that the drying would not be complete in time to complete the tests. The specimens were then removed to a 140°F, 25% RH chamber where they remained 25 days until relative humidity in the specimens reached 65 to 70%.

The containing rings were then bonded to the overlay surface after the 25-day drying period. Tap water and 5% salt water were ponded within the rings and relative humidity data were recorded. When the relative humidity in the moisture wells reached approximately 95%, the rings were removed and the overlaid blocks returned to the 140°F, 25% RH chamber for 14 days. Coating 2-a was then applied to the overlays and the test was repeated.

Series 4. This series of tests was made to determine the effect of coatings 0, 2-a, 7, and 8-a on the bond strength between old and new portland cement concrete.

Series 5. In this series of tests, asphaltic overlays were bonded to the surfaces of the 10-inch square blocks as described in Series 3. Eight-inch diameter rings were bonded to the surfaces of the overlays and 5% salt water, ponded within the rings. The blocks were then alternately frozen and thawed. Once each week the blocks were removed to the laboratory where the old 5% salt water was discharged. The surfaces were flushed with tap water and brushed to remove any loose particles. They were then visually inspected for any signs of deterioration. If no signs of deterioration were found, the blocks were recharged with 5% salt water and the cycling was begun again. Cycling continued until 59 freeze-thaw cycles were completed.

V. TEST RESULTS

Results of tests are given in this section in the form of tables, charts, and discussion.

Series 1. Several methods were investigated in measuring the depth of penetration of various coatings. The oil base dyes mixed well with coatings 2-a and 8-a but could not be made to mix with the other coatings used in these tests. On the broken and sawed surfaces, orange remained the brightest of the three colors; it showed a fairly well-defined depth of penetration. The blue and red dyes were practically washed out during the sawing, making the penetration depth indistinct. Even on the broken faces, the penetration depth of the latter two dyes was not well defined.

The 50% solution of sulfuric acid applied evenly to broken faces of blocks that had received coating 2-a produced carbon, black in color, when it reacted with the oil. The color gradually faded with depth into the block, making the limit of penetration hard to identify under close inspection. When viewed from a distance of two to three feet, however, the depth seemed to be fairly well defined as shown by Figure 2.

When faces of blocks coated with mixtures of printer's ink and coatings 2-a and 8-a were viewed under ultraviolet light, fluorescence of the ink was evident. The depth was not well defined, however, making measurements difficult and subject to question as to accuracy. Attempts were made to record the fluorescence by photographic means using a special filter. The photographs were of low quality and did not clearly define penetration limits.

Figure 2. Penetration of Coating 2-a as Indicated by the 50% Solution of Sulfuric Acid.

A chemical reaction that produces a distinctive pink color takes place when phenolpthalein and clean portland cement concrete come in contact. When the phenolpthalein solution alone was placed on the concrete surface, the reaction was very fast. However, when the mixture of phenolpthalein with a coating was placed on the concrete surface, the reaction was much slower. The sensitive solution caused no color change in that portion of the concrete penetrated by coatings and it proved to be a good indicator of penetration depth. Since the phenolpthalein could not be made to mix with coatings 7 and 9, the mixture of phenolpthalein and coatings 2-a was used to determine the penetration depths of those coatings.

Table V summarizes the penetration data recorded for coatings 2-a, 7, 8-a, and 9. Each of the coatings was applied to two blocks. Each block was then cut twice at random positions to give four faces from which penetration data were recorded. The average depth of penetration in inches was 0.058 for coating 2-a, 0.015 for coating 7, 0.043 for coating 8-a, and 0.029 for coating 9. A statistical analysis of the data from coatings 7, 8-a, and 9 showed that there was no significant difference between blocks with a given treatment, a slight difference between faces within blocks, and a significant difference between coatings. When a 95% confidence limit (95% of the time the penetration depth measured will be within the limits given) is

TABLE V. INDICATED PENETRATION OF VARIOUS SURFACE COATINGS IN CONCRETE

Coating Number	Coating Description	Range of Indicated Penetration for 95% Confidence (in.)
2-a	2 coats 50-50 linseed oil-kerosene	0.054 - 0.062
7	2 coats Thompson's Water Seal	0.013 - 0.017
8-a	2 coats 50-50 tung oil-kerosene	0.041 - 0.045
9	1 coat EpoXeal with a touch-up coat	0.027 - 0.031

Each range of values represents 160 readings.

applied to the data, a range over which the data may vary is found. That range (Table V) in inches was 0.058±0.004 for coating 2-a, 0.015±0.002 for coating 7, 0.043±0.002 for coating 8-a, and 0.029±0.002 for coating 9.

Stewart and Shaffer (4) found no apparent correlation between depth of penetration of the sealer and the final rating of the concrete. Data presented here along with data from an earlier report (1) support that finding. In the Stewart and Shaffer test, penetration of linseed oil and mineral spirits was found to be less than 0.01 inch. Penetration for linseed oil and kerosene reported here was found to be about 0.05 inch. No reason can be given for the difference in penetrations except that different materials for concrete and for depth indicators may influence the results.

<u>Series 2</u>. Moisture migration into portland cement concrete occurs quickly when no protective coating is provided. The moisture migration to the depth of a moisture well was evident when free moisture appeared in that well. Tap water and salt water both can penetrate to a depth of 3/8 inch within three hours, the penetration by 5% salt water being somewhat faster than the tap water (Figure 3). Figure 3 represents one set of data and is intended to show a trend. The trend was the same for other data but the magnitudes were different. When a protective coating was provided, the time required to penetrate 3/8 inch can be extended to several days. Coating 7 provided approximately the same resistance to both tap and salt water whereas coatings 2-a and 8-a were less resistant to tap water than they were to salt water. Of the three coatings tested, coating 8-a was the most resistant to both tap water and 5% salt water. Table VI lists the times of penetration of 100% relative

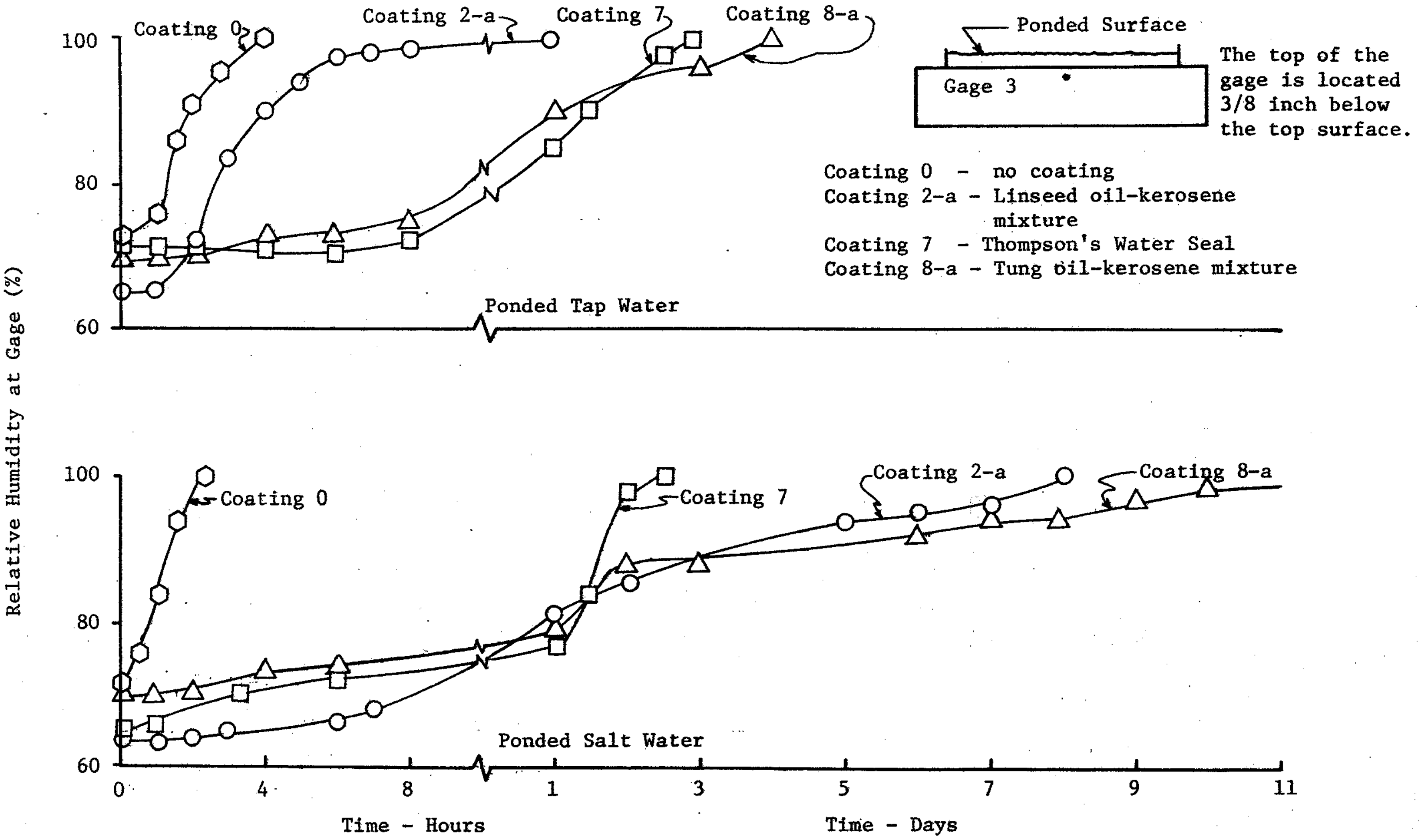


Figure 3. Penetration Time; Ponded Tap and Salt Water on Coatings 0, 2-a, 7 and 8-a.

humidity to depths of 1/8, 2/8, and 3/8 inch when various coatings are used.

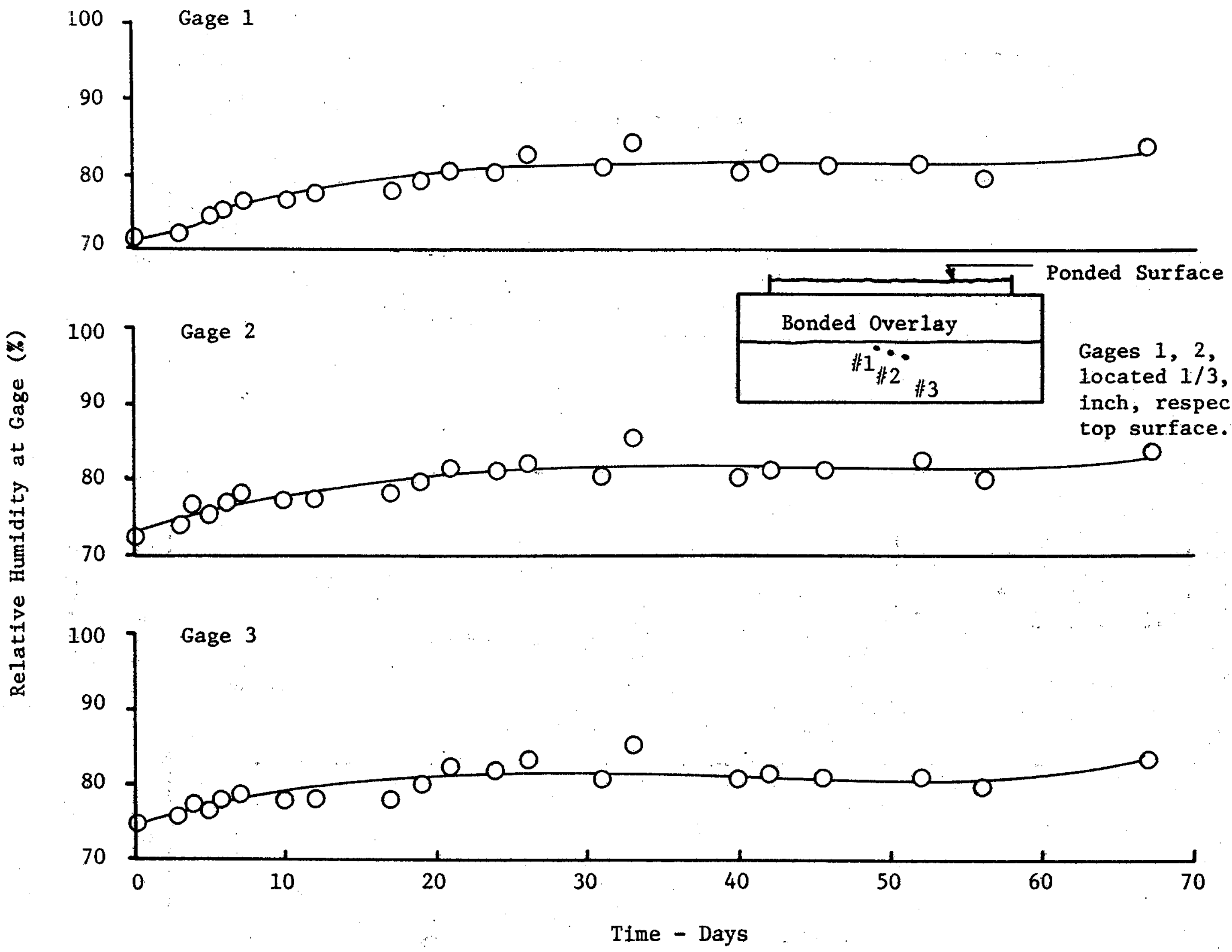
Series 3. Results from this series of tests indicate that thin bonded overlays can be effective in resisting moisture migration into the concrete beneath the overlay. Generally, the ponded water remained on the overlays approximately 60 days. It is not likely that water would stand on most bridges for more than two or three weeks. The 60-day time period then may be taken as a safe upper limit in time for surfaces to be covered with water, tap or salt.

Thin bonded overlays generally were effective in resisting moisture migration into the concrete beneath them. The blocks covered with epoxy mortar overlays showed no appreciable change in relative humidity when subjected to ponded tap water but there was an 8 to 10% increase when subjected to ponded 5% salt water, Figure 4. The relative humidity in blocks covered with polyester mortar overlays changed from an initial 70% to 90% at 30 days and then gradually decreased to 85% at 60 days. The reason for this gradual decrease in relative humidity is not known.

The blocks covered with the 1½ inch thick portland cement concrete overlays, Figure 5, reacted practically the same when subjected to ponded tap and 5% salt water. The relative humidity had reached 90 to 95% after 7 days and remained almost constant at that level for an additional 20 days. The blocks were dried and coated with coating 2-a. Results after the coating was applied are shown in Figure 6. Both Figure 5 and Figure 6 show that gage 3 required approximately 10 days to reach 90% relative humidity. A period of time in which no data were recorded is shown in Figure 5 and the rate of change in relative humidity is assumed as shown. However, it is possible that the relative humidity could have reached the 90% level prior

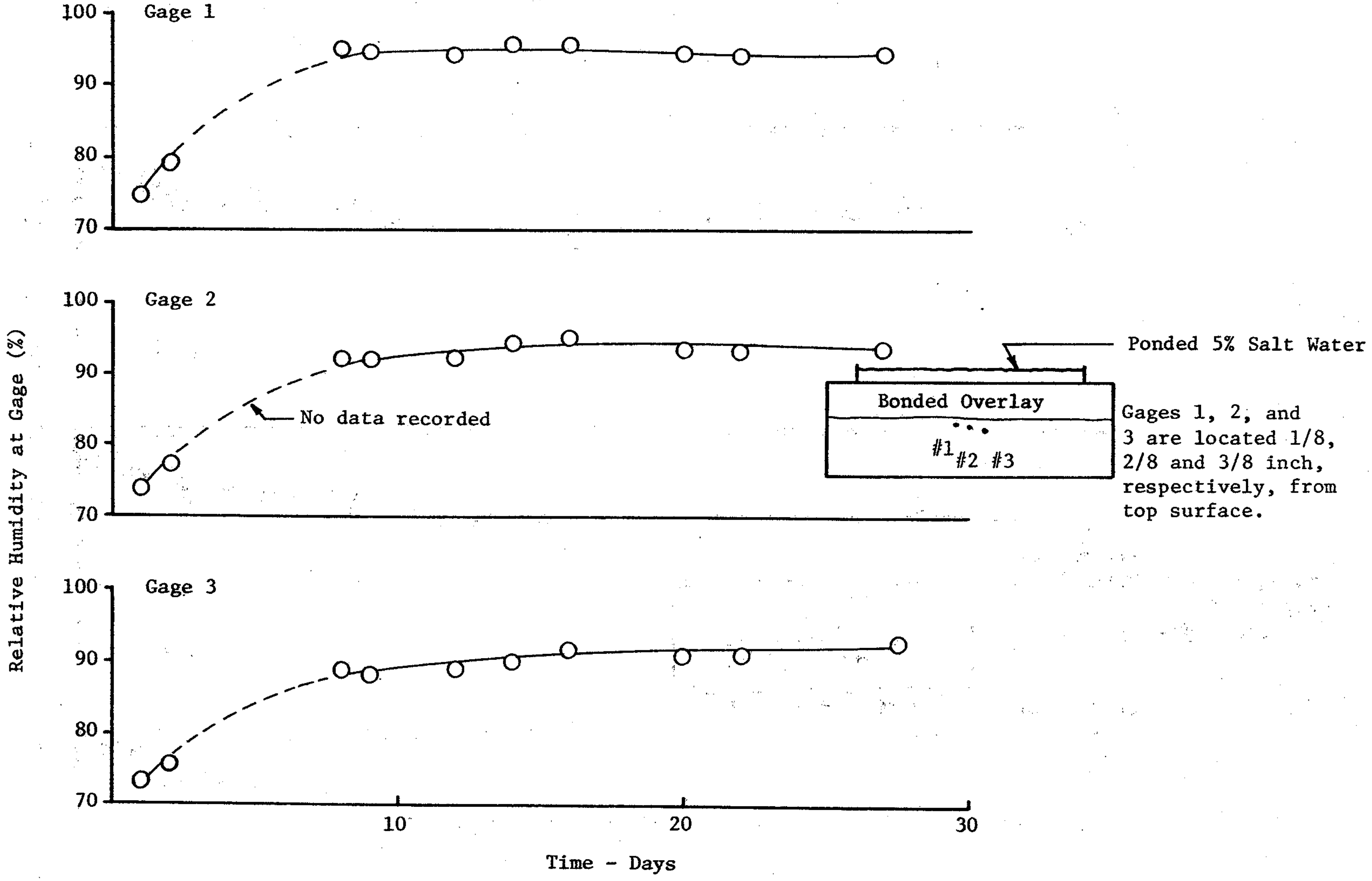
TABLE VI. MOISTURE PENETRATION TIME

Coating Number	Penetration Time for Relative Humidity to Reach 100%			Type of Ponded Water
	1/8 in. Depth	2/8 in. Depth	3/8 in. Depth	
0	60 min.	110 min.	175 min.	Tap
0	20 min.	60 min.	150 min.	Salt
2-a	1/2 hr.	7 hrs.	1 day	Tap
2-a	1-1/2 hr.	1-1/2 days	8 days	Salt
7	21 hrs.	27 hrs.	2-3/4 days	Tap
7	24 hrs.	27 hrs.	2-1/2 days	Salt
8-a	2 hrs.	1 day	5 days	Tap
8-a	8 days	13 days	13 days	Salt



Gages 1, 2, and 3 are located 1/3, 2/8, and 3/8 inch, respectively, below top surface.

Figure 4. Penetration Time; Ponded Salt Water on Epoxy Mortar Overlay.



Gages 1, 2, and 3 are located 1/8, 2/8 and 3/8 inch, respectively, from top surface.

Figure 5. Penetration Time; Ponded Salt Water on 1-1/2 Inch Thick Concrete Overlay.

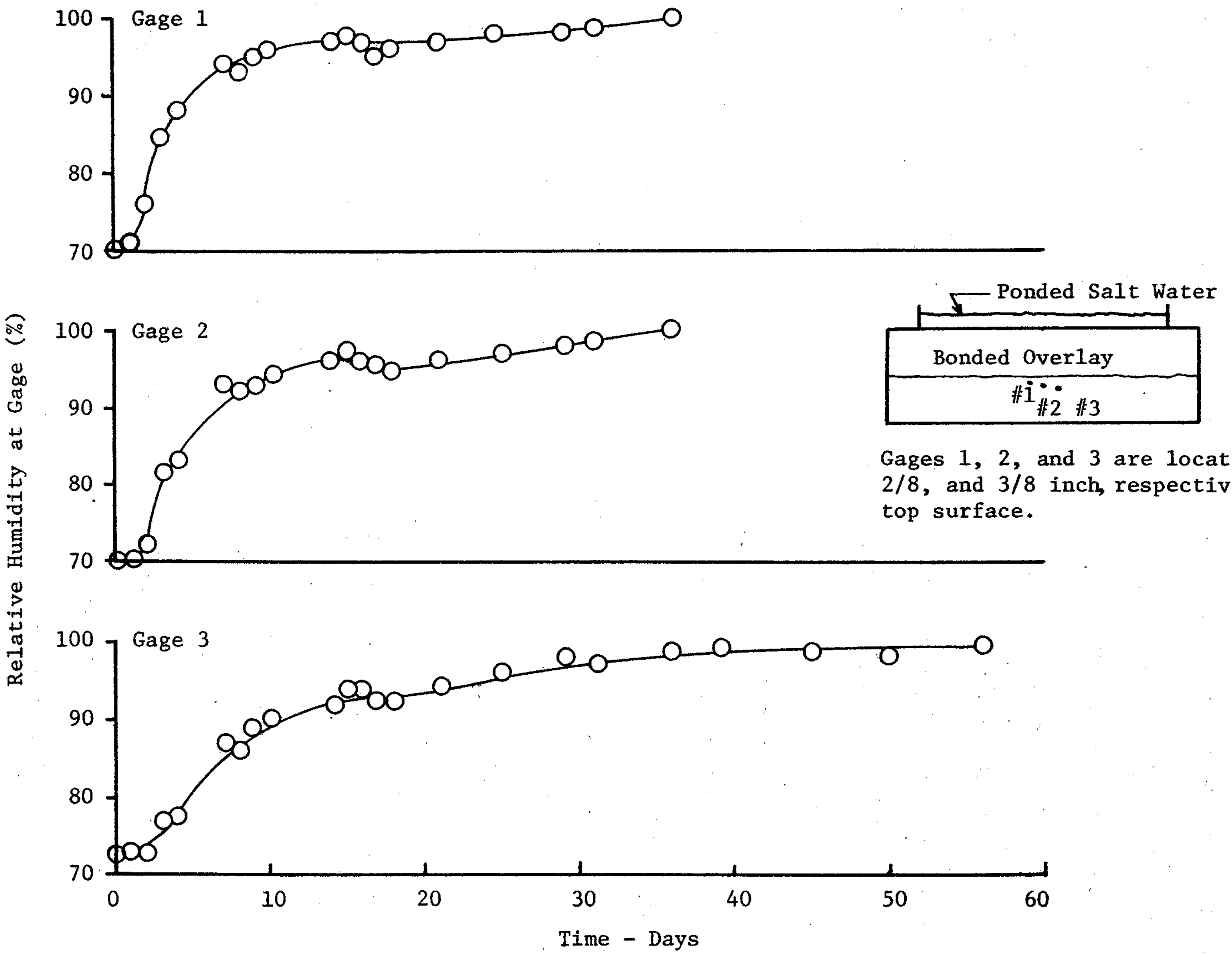
to the 10 days indicated.

The $1\frac{1}{2}$ inch thick asphaltic overlays were tested in the same manner as the other overlays. No change in relative humidity was recorded in any of the blocks of either type of asphaltic overlay. Figure 7 is a typical example of those data.

Series 4. Shear Tests. Surface penetration is a very important part in a portland cement concrete overlay operation. Sinno and Furr (5) showed that motor oil on the overlaid surface greatly reduces the bond capacity between new and old concrete when little or no surface preparation is made.

Overlays were sheared from cubes that had received coatings 0, 2-a, 7, and 9-a with no surface preparation and from cubes that had recieved coatings 2-a and 7 followed by sandblasting as the surface preparation, Table VII. A force parallel to the interface between overlay and base specimens was applied to the overlay and gradually increased until the specimen failed. The force per unit area of bonded surface, bond stress, was found for each specimen. When no surface preparation was made, the bond stress was 578 psi for uncoated cubes, 61 psi for coating 2-a, 88 psi for coating 7, and 267 psi for coating 8-a. When the surface was prepared by sandblasting, the bond stress for coating 2-a cubes was 367 and 597 psi for coating 7.

Coating 8-a was not included in these tests on sandblasted surfaces. The shear bond strength of overlay over this coating without sandblast treatment was 267 psi, Table VII. It has been established by Gillette (6) that 200 psi is an acceptable bond strength value for pavement overlay. Theoretical calculations (7) have shown that the bond between a 2-inch



Gages 1, 2, and 3 are located 1/8, 2/8, and 3/8 inch, respectively, from top surface.

Figure 6. Penetration Time; Ponded Salt Water, on a 1-1/2 inch Concrete Overlay Coated with Coating 2-a.

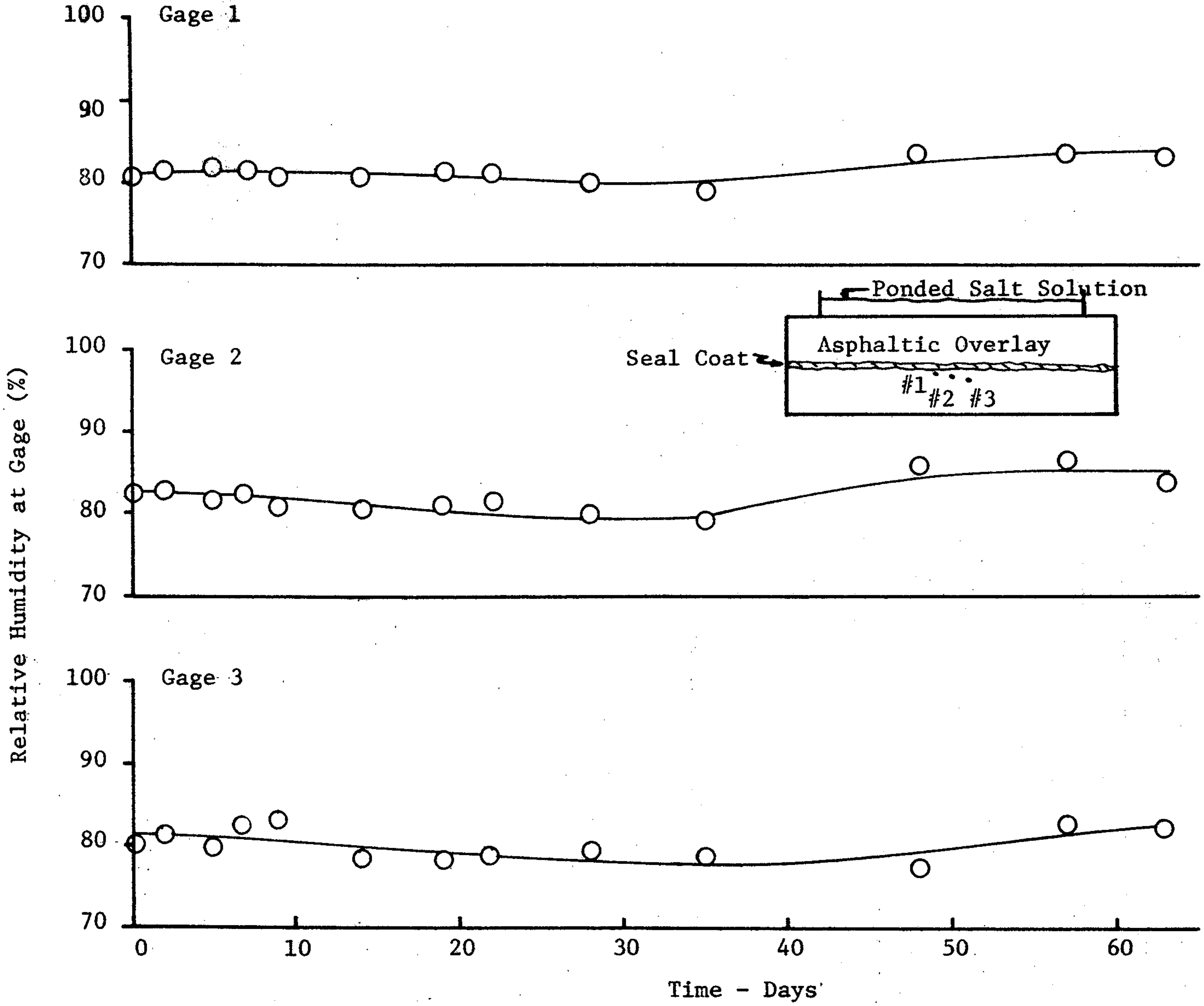


Figure 7. Penetration Time; Ponded Salt Water on Asphaltic Concrete Overlay.

TABLE VII. SHEAR BOND STRENGTH

Coating Number	Surface Preparation	Bond Stress* (psi shear)
0	None	578
2-a	None	61
7	None	88
8-a	None	267
2-a	sandblast **	367
7	sandblast **	597

*Average of three specimens
**Sandblasted after coating had been applied and cured

overlay and 7-inch thick bridge slab when flexed under an AASHO H-20 wheel is approximately 64 psi. Since the 267 psi strength is greater than either of these values, further tests were not made. Had the test been made, it seems reasonable to assume that the bond stress would not have been lowered but increased.

The sandblasting seemed to have removed all of coating 7 but not all of coating 2-a. This is supported by data from series 1 in which the depths of penetration were measured. The sandblasting removed approximately 1/32 inch of the surface which would have removed all of the concrete penetrated by coating 7, but only about 60% of that of coating 2-a.

Series 5. Freeze-Thaw. Tests reported in an earlier report (1) have shown that deterioration can develop under a seal coat when alternately frozen and thawed.

In tests of this series, freeze-thaw cycling of the asphaltic overlays continued for 59 cycles. After 25 and 38 of those cycles, one of each type overlay was removed in order to examine the concrete surface which showed no signs of deterioration. The penetration of the 5% salt water into the overlay was measured with a ruler to be ¼ to ½ inch. No apparent distress was in evidence when the blocks were removed from the test.

The material of the earlier tests (1) consisted of a sand filled asphalt seal coat. The material used in the tests reported here was not the same as those in the earlier tests, and the application was not the same. It is seen from test data that behavior of the latest system was superior to that of the earlier tests.

VI. CONCLUSIONS

The following conclusions are made on the basis of tests performed in this investigation. An explanatory note follows each conclusion.

1. Surface coatings of 50%-50% mixture of linseed oil and kerosene penetrated almost 1/16 inch into the portland cement concrete used in these tests.

   The two-coat application of 50%-50% boiled linseed oil and kerosene penetrated to a depth of 0.05 to 0.06 inches; the 50%-50% mixture of tung oil and kerosene applied in two applications penetrated approximately 0.04 inches; EpoXeal, an epoxy penetrant, to 0.03 inches; and Thompson's Water Seal to approximately 0.015 inches.

2. Surface treatment of concrete with a mixture of kerosene and either boiled linseed oil or tung oil (50%-50% basis) delays the penetration of both tap water and 5% salt water into concrete.

   Relative humidity measurements taken at 3/8 inch from the horizontal surface of the portland cement concrete showed that tap water penetrated 3/8 inch of uncoated concrete within 3 hours whereas from 1 to 5 days were required for tap water penetration of the linseed oil and tung oil treated surfaces. Penetration of 5% salt water to 3/8 inch delayed up to 13 days.

3. Thin uncracked resinous and rubberized asphaltic overlays provide effective barriers to entry of moisture into concrete, and a portland cement concrete overlay retards the entry of moisture.

One-half inch thick overlays of epoxy mortar and polyester mortar concretes were effective in maintaining the relative humidity below about 85% to when ponded over with 5% salt water for the 60-day period of the test. The 1½ inch thick portland concrete overlay delayed the 5% water for a period of about 10 days. A rubberized asphaltic overlay filled with expanded shale, limestone, and field sand provided a near complete seal to the laboratory concrete.

4. Surface treatments designed as moisture barriers can measurably reduce the shear bond strength of an overlay applied to the freshly treated concrete surface.

   The shear bond strengths of a portland cement concrete overlay placed on a concrete surface treated with linseed oil-kerosene mixture, tung oil-kerosene mixture, and Thompson's Water Seal are reduced from about 578 psi for the untreated surface to 61 psi, 267 psi, and 88 psi, respectively, for the freshly treated surfaces. Sandblast conditioning of the linseed oil and Thompson's Water Seal treated surfaces restored them to 367 psi and 597 psi shear strength, respectively.

5. No freeze-thaw deterioration developed over 59 freeze-thaw cycles on concrete surfaces overlaid with the rubberized asphalt used in the tests.

VII. REFERENCES

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