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Masood Rasoulian, Carl Burnett, Richard Desselles

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Baton Rouge, Louisiana 70808

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16. Abstract

In this project the effectiveness of silane-based chemicals as concrete sealants was evaluated for selected bridges throughout the state of Louisiana for a five-year period. The field evaluation was initiated after satisfactory results in the laboratory. In conjunction with this study, Louisiana State University conducted an additional investigation on detection of silane reaction using infrared spectroscopy.

The results obtained from the field study indicated that the silane-based chemicals provide some hydrophobic characteristics. The effects are not long-lasting and absorption decreased to 30% improvement over the untreated surface after four years. No changes in the chloride content or the corrosion activities were observed in treated or untreated bridges. The results of infrared spectroscopy indicated a depth of silane penetration of between 0 and 0.1" in the treated bridges.

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Concrete bridge deck, corrosion, moisture penetration, silane sealers

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EVALUATION OF EXPERIMENTAL INSTALLATION OF SILANE TREATMENT ON BRIDGES

FINAL REPORT

BY

MASOOD RASOULIAN, P.E.
CONCRETE RESEARCH ADMINISTRATOR

CARL BURNETT
RESEARCH ENGINEER

AND

RICHARD DESSELLES
CONCRETE RESEARCH TECHNOLOGIST

CONDUCTED BY
LOUISIANA TRANSPORTATION RESEARCH CENTER
LOUISIANA DEPARTMENT OF TRANSPORTATION AND DEVELOPMENT

IN COOPERATION WITH

U.S. DEPARTMENT OF TRANSPORTATION
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APRIL 1988

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ABSTRACT

In this project the effectiveness of silane-based chemicals as concrete sealants was evaluated for selected bridges throughout the state of Louisiana for a five-year period. The field evaluation was initiated after satisfactory results in the laboratory. In conjunction with this study, Louisiana State University conducted an additional investigation on detection of silane reaction using infrared spectroscopy.

The results obtained from the field absorption study indicated that the silane-based chemicals provide some hydrophobic characteristics. The effects are not long-lasting and absorption decreased to 30% improvement over the untreated surface after four years. No changes in the chloride content or the corrosion activities were observed in treated or untreated bridges. The results of infrared spectroscopy indicated a depth of silane penetration of between 0 and 0.1" in the treated bridges.

METRIC CONVERSION FACTORS*

To Convert from	To	Multiply by
	Length	
foot	meter (m)	0.3048
inch	millimeter (mm)	25.4
yard	meter (m)	0.9144
mile (statute)	kilometer (km)	1.609
	Area	
square foot	square meter (m^2)	0.0929
square inch	square centimeter (cm^2)	6.451
square yard	square meter (m^2)	0.8361
	Volume (Capacity)	
cubic foot	cubic meter (m^3)	0.02832
gallon (U.S. liquid)**	cubic meter (m^3)	0.003785
gallon (Can. liquid)**	cubic meter (m^3)	0.004546
ounce (U.S. liquid)	cubic centimeter (cm^3)	29.57
	Mass	
ounce-mass (avdp)	gram (g)	28.35
pound-mass (avdp)	kilogram (kg)	0.4536
ton (metric)	kilogram (kg)	1000
ton (short, 2000 lbs)	kilogram (kg)	907.2
	Mass per Volume	
pound-mass/cubic foot	kilogram/cubic meter (kg/m^3)	16.02
pound-mass/cubic yard	kilogram/cubic meter (kg/m^3)	0.5933
pound-mass/gallon (U.S.)**	kilogram/cubic meter (kg/m^3)	119.8
pound-mass/gallon (Can.)**	kilogram/cubic meter (kg/m^3)	99.78
	Temperature	
deg Celsius (C)	kelvin (K)	$t_k=(t_C+273.15)$
deg Fahrenheit (F)	kelvin (K)	$t_k=(t_F+459.67)/1.8$
deg Fahrenheit (F)	deg Celsius (C)	$t_C=(t_F-32)/1.8$

*The reference source for information on SI units and more exact conversion factors is "Metric Practice Guide" ASTM E 380.

**One U.S. gallon equals 0.8327 Canadian gallon.

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INTRODUCTION

Water and chloride intrusion into concrete bridge decks and other reinforced members accelerates corrosion of the embedded reinforcing steel. This ultimately results in large-scale delamination and spalling, necessitating costly repairs. This type of failure is mainly caused by the intrusion of the chloride ions into the concrete from deicing salts used in the winter or from the salt water environment of coastal areas. The corrosion of the reinforcing steel can be greatly abated if the intrusion of chloride into the concrete is substantially reduced by various methods.

The product selected for this project is claimed by the manufacturer to be a waterproofing, penetrating concrete sealer which reduces moisture absorption by concrete while allowing water vapor to escape from it. It is commercially known as Chemtrete. The composition is 40% alkylalkoxy silane and 60% ethyl alcohol. The material is applied to the surface by spraying or painting after the surface has been fully cleaned. It reacts with the silica in the concrete, creating a water-repellent surface. This product was evaluated in the laboratory and was found to decrease the absorption of moisture. This study was initiated to evaluate silane-treated bridges under field conditions. Five installations were made in the state for this purpose. Three of these bridges were located in the northern part of the state and the other two were located in the coastal areas of south Louisiana. This report covers the application procedures and evaluation of the field data obtained during the course of this study.

PURPOSE AND SCOPE

The purpose of this study was to investigate the effectiveness of silane as a concrete sealer through laboratory evaluation and field installation. Bridge decks from various locations that were exposed to deicing salts or a coastal environment were selected for treatment (three in north Louisiana and two in south Louisiana).

The product selected for this purpose was a silane-based chemical commercially known as Chemtrete.

The evaluation methods included in this study were:

a. Skid testing on the deck to insure that the skid resistance of the bridge deck is not adversely affected by the sealant and in the laboratory prior to application (British Portable Skid Tester).

b. Moisture absorption tests from cores taken from bridge decks and laboratory samples.

c. Chloride content analysis on bridge deck.

d. Half-cell corrosion resistance measurements.

The bridge decks, curb, railing, girders, caps and accessible portions of the piling for each selected section from each bridge were treated for this evaluation.

METHODOLOGY

Each bridge was evaluated prior to the application of the chemical to establish the baseline data for comparison to the performance of silane. The tests that were run on each bridge included (See Appendix A for specifications):

1) British Portable Skid Tester:
   This test is designed to determine the coefficient of pavement friction. This was done to insure that proper friction existed on the bridge decks after the application of silane chemicals.

2) Absorption Test:
   After being oven-dried, cores taken from the treated bridge decks were sealed with paraffin on all surfaces except the top (the riding surface). These cores were then submerged in water and weighed at several intervals to determine the 24-hour, 48-hour and 28-day absorption rates. Absorption is the primary indicator of the amount of intrusion of water and chloride into the concrete.

3) Chloride Content:
   Pulverized concrete samples were taken from each treated and reference section at depths of 1/16 in. to 1/2 in. and 1/2 in. to 1 in. Each sample was analyzed for determination of chloride content present at that layer.

4) Half-Cell Test:
   This test was used to determine the extent of the corrosion activity of the reinforced steel embedded in concrete by measuring the electrical half-cell potentials. The absorption test, chloride content analysis and half-cell test were repeated 2 and 4 years after installation to compare results to the baseline data to determine the effectiveness of silane chemical.

FIELD INSTALLATION

For the field installations, individual spans on each bridge were chosen for treatment. Chemtrete was applied to the bridge deck, curb, gutter, railing, and areas underneath the bridge such as caps, girders, and portions of the accessible concrete piling. For bridge decks, Chemtrete was applied at the rate of 125 square feet per gallon of chemical. All other areas were treated at the rate of one gallon to 175 square feet as recommended by the manufacturer. The rate of application was the same for all the bridges. The application procedures for each bridge were as follows:

1) Corey Overpass
   This bridge is located on U.S. Route 165, the Columbia-Monroe Highway, over the Missouri-Pacific railroad in Caldwell Parish. This two-lane bridge is heavily traveled and has been in service since 1936. A 24' x 40' area of this bridge (one span length) was treated with Chemtrete in October 1981. The concrete was cleaned by water-blasting prior to application of the chemicals. As recommended by the manufacturer, a spray bar mounted on the back of the truck was used to spray the deck, as depicted in Figures 1 and 2. The rails, caps and underside of the bridge were treated using a spray gun, as shown in Figure 3. The pump pressure for this application was approximately 25 to 30 psi.

2) Missouri Pacific Overpass
   This bridge, located on LA 526, the Shreveport Industrial Park Loop in Caddo Parish, is one of the new bridges (constructed in 1981) selected for this evaluation. The treated area for the sealant application was 24' x 82', covering the two northbound lanes. The area was cleaned by sandblasting prior to application of the overlay. Approximately 18 gallons of chemical were used for this test section. Figure 4 shows the application of the

sealant by a spray gun. The application rate was measured to check against specifications, as shown in Figure 5. Figure 6 depicts the treated area after application of the material and prior to drying.

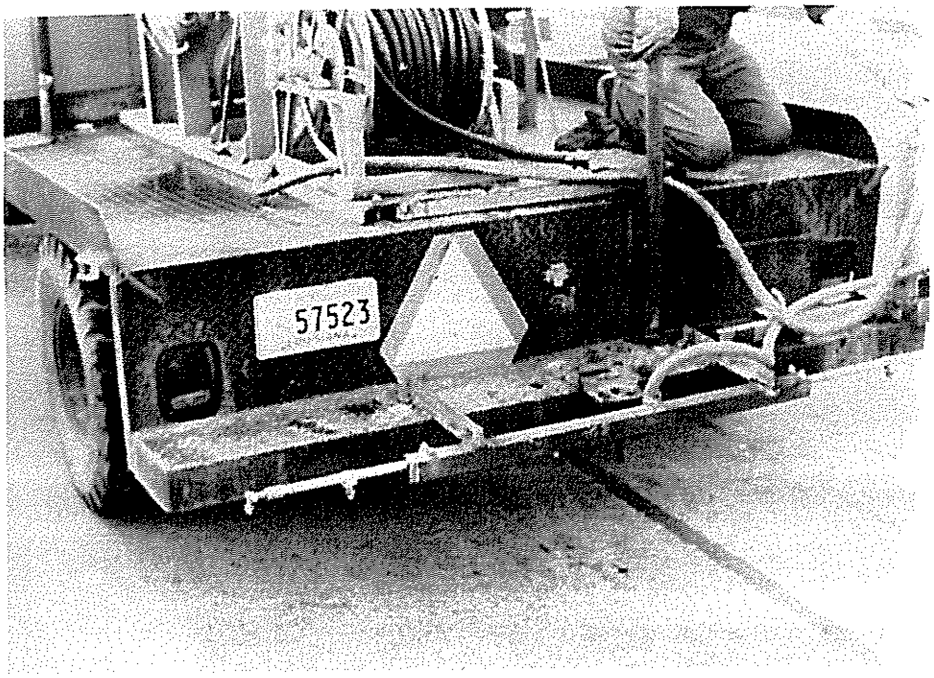

FIGURE 1

Spray Bar for Application of Sealant, Corey Overpass

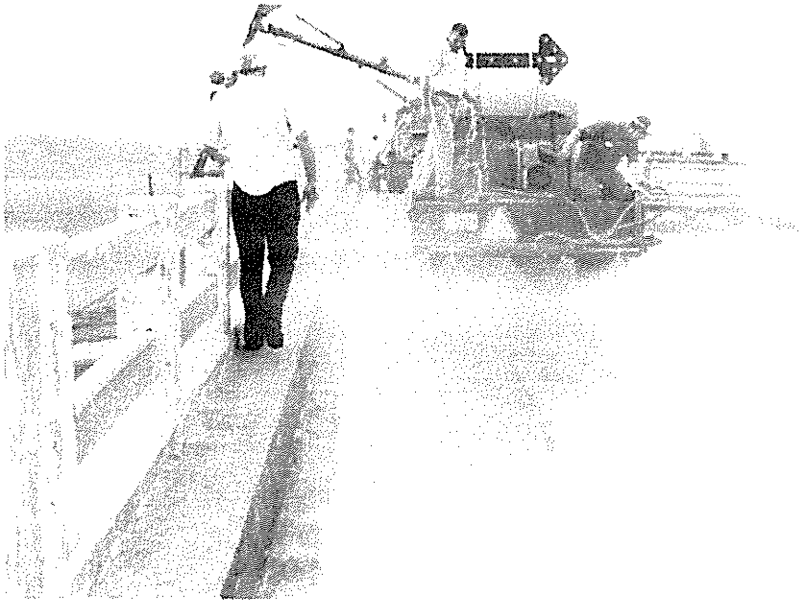

FIGURE 2

Chemtrete Application, Corey Overpass

FIGURE 3

Treatment of the cap, Corey Overpass

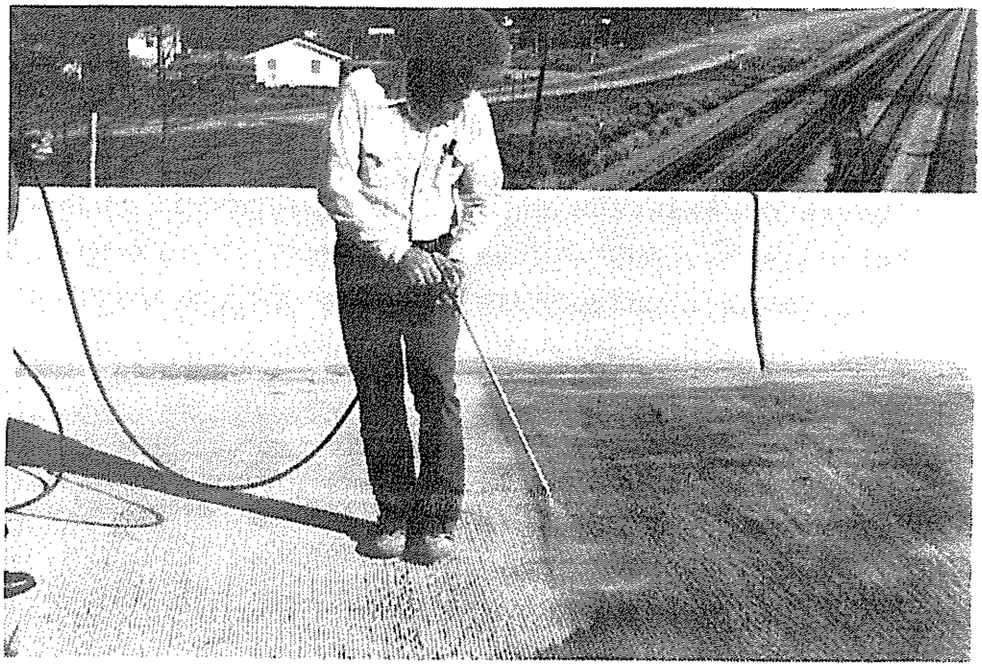

FIGURE 4

Sealant material being applied to Mo-Pac Bridge in Shreveport, LA

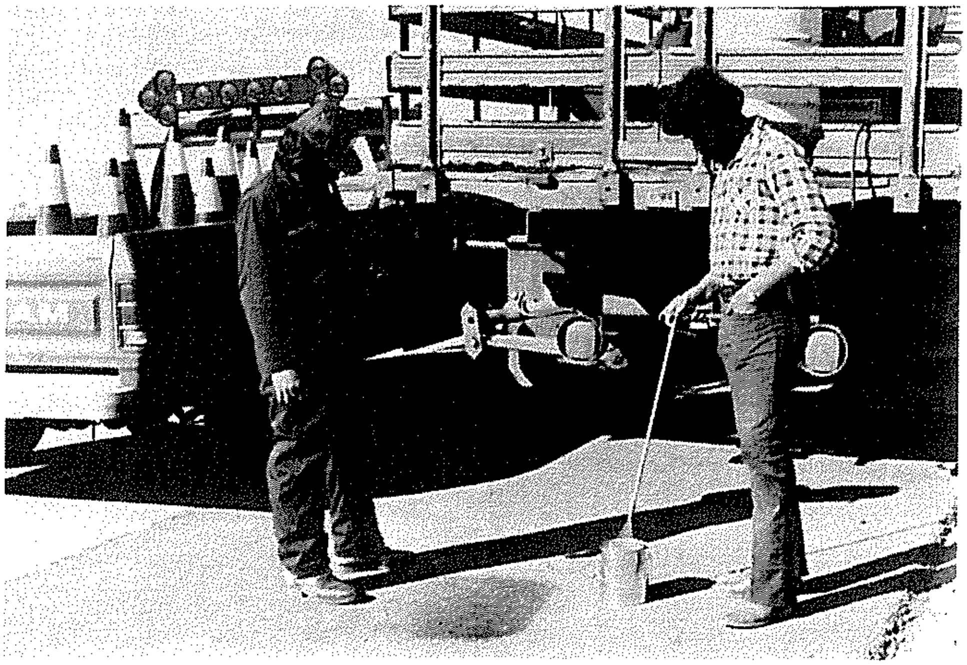

FIGURE 5

Checking the output of the spray gun

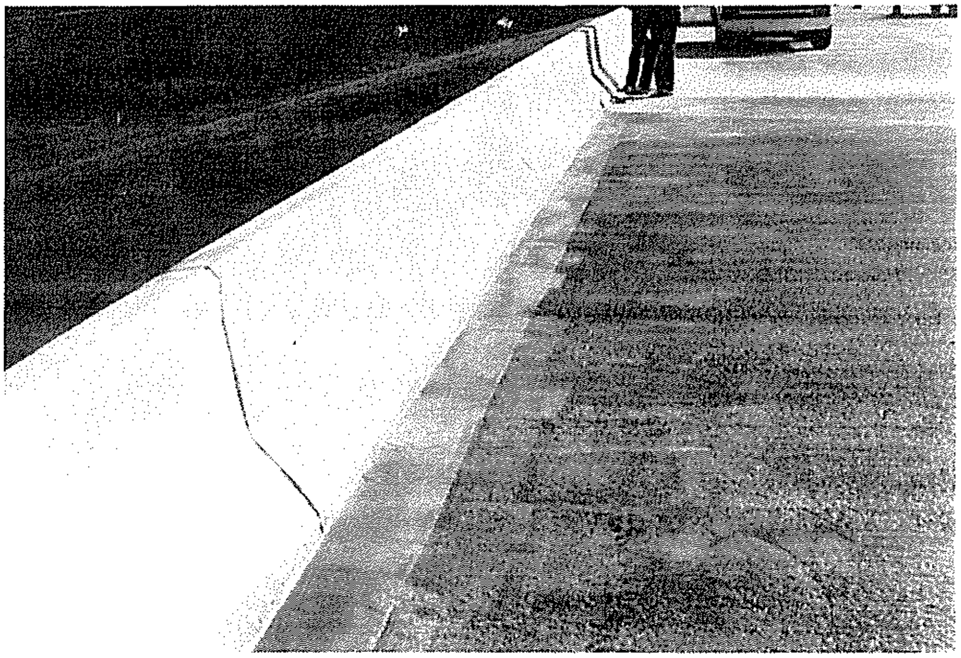

FIGURE 6

Treated area before drying

3) I-10 Bridge over Lake Pontchartrain

This bridge is located in the southern part of the state between Saint Tammany and Orleans parishes. On the eastbound lanes, Chemtrete was applied to a 40' x 65' area of the bridge deck, as shown in Figure 7. The chemical was also applied to the underside portions of the bridge deck, as shown in Figure 8. It took approximately 75 gallons of material to treat this test section. The area was sandblasted prior to application in December of 1981. The I-10 bridge has been in service since 1961.

FIGURE 7

Chemtrete application, I-10 Bridge over Lake Pontchartrain

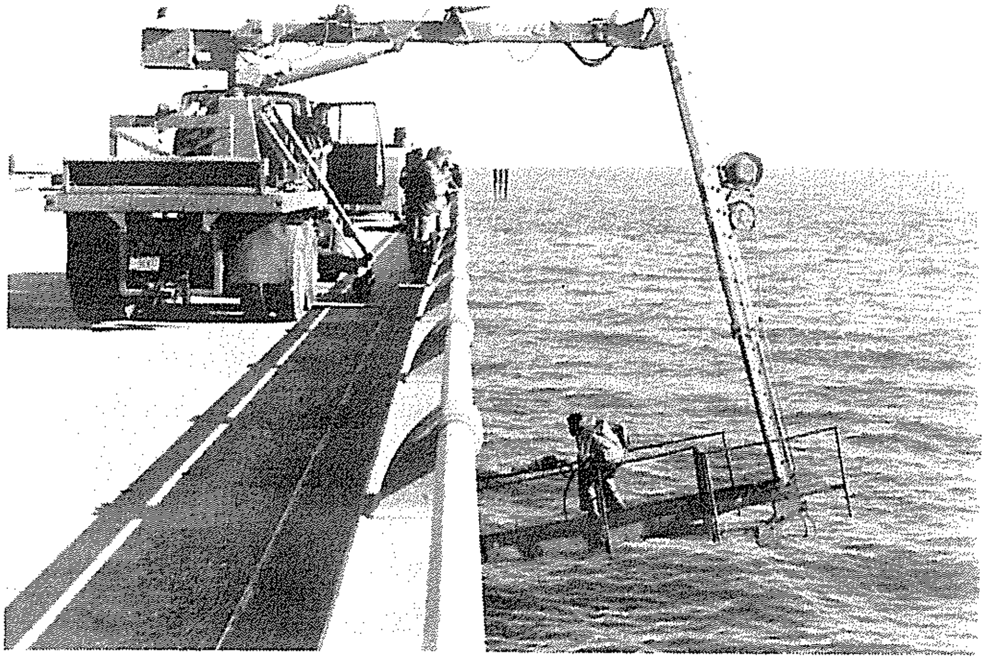

FIGURE 8

Chemtrete application, I-10 Bridge over Lake Pontchartrain

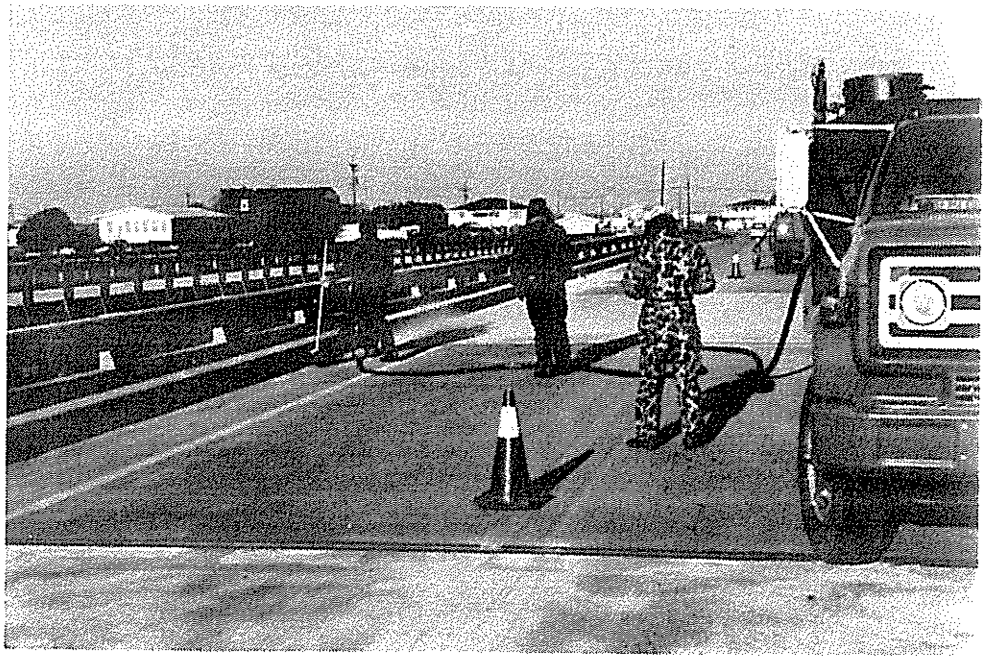

FIGURE 9

Sandblasting operation, Caminada Bay Bridge

4) Caminada Bay Bridge

This bridge, one of the older bridges selected for this study, was built in 1959. This bridge is located in Jefferson Parish and connects the towns of Golden Meadow and Grand Isle. Span No. 93 of this two-lane bridge was treated with Chemtrete in December of 1981. Sandblasting was used to clean the test area, as shown in Figure 9. The chemical was also applied to the underside areas, pile caps and the above-water portions of the pilings in the selected span. Figure 10 shows the treatment of the bridge railing. The snooper truck was utilized to treat the underside, as shown in Figure 11. The size of the test section was the area of one span (28' x 40').

FIGURE 10

Treatment of the bridge parapet

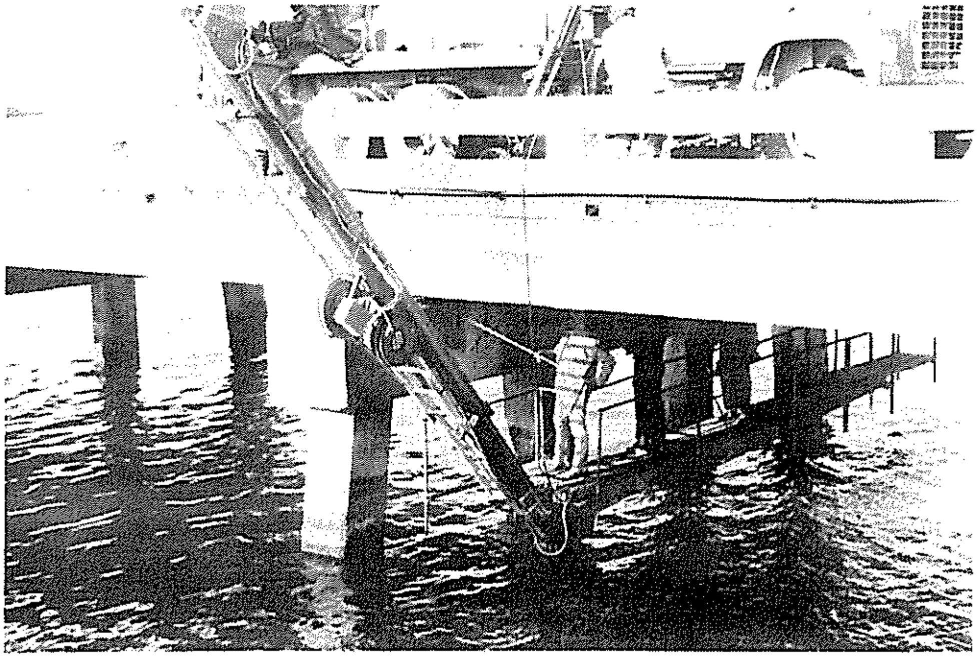

FIGURE 11

Pile cap application, Caminada Bay Bridge

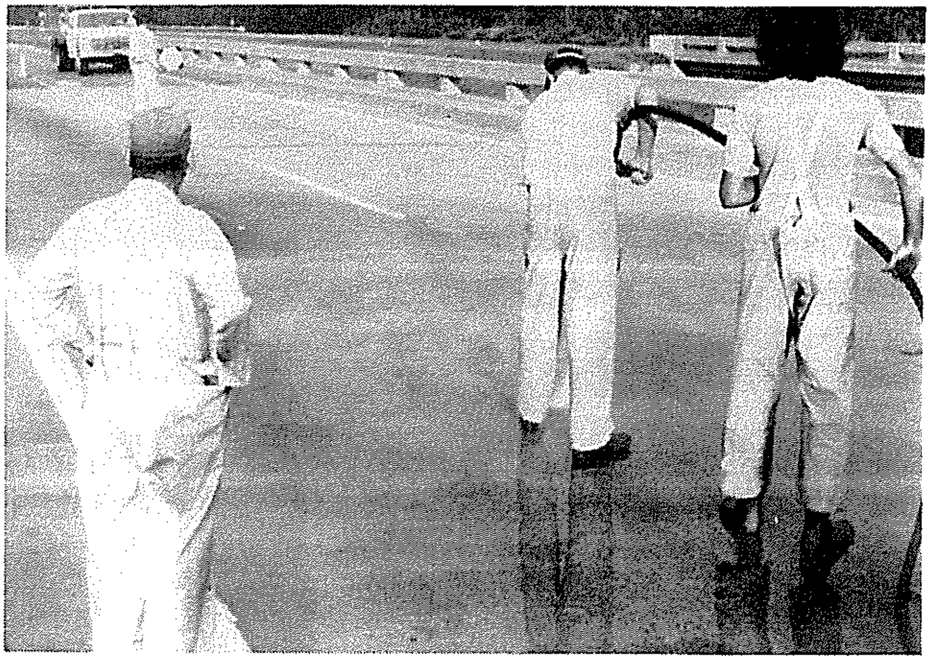

FIGURE 12

Water-blasting operation, Bayou Lafourche, Bridge I-20

5) Bayou Lafourche Bridge

This bridge, built in 1966, is located in Richland Parish in the northern part of Louisiana on I-20. The surface of the test area was cleaned by high-pressure water blast, as shown in Figure 12. Approximately 80 gallons of Chemtrete material were used on a 28' x 60' deck area and on girders, cap, piles and the underside of the deck, as seen in Figure 13. A spray bar mounted at the back of a truck was utilized to spray the chemical, as depicted in Figure 14. The deck was treated in October of 1981.

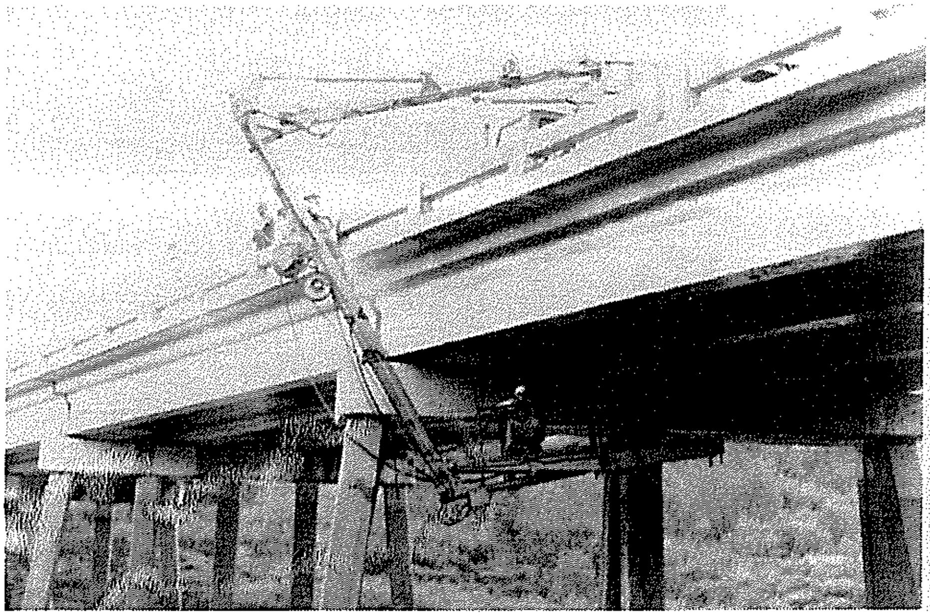

FIGURE 13

Chemtrete application of the pile cap

FIGURE 14

Treatment of the bridge deck I-20, Bayou Lafourche Bridge

LABORATORY EVALUATION

Prior to the field application, concrete samples treated with Chemtrete were tested in the laboratory, using the following acceptance criteria to determine Chemtrete silane's effectiveness.

1. Freeze and thaw durability, ASTM C-666, procedure B. Durability factor of treated specimen shall be greater or equal to comparable air-entrained concrete.

2. 90-day chloride ponding test (FHWA procedures). Two treated concrete blocks were subjected continuously to a 3 percent solution of NaCl for a period of 90 days. The samples were taken by rotary drill at depths of 1/16" to 1/2" and 1/2" to 1" (six samples per block). The pulverized concrete was chemically analyzed for chloride accumulation.

3. Absorption Test ASTM 642
   48 hours - Maximum of .5 percent absorption by weight
   28 days - Maximum of 1.0 percent absorption by weight

4. Skid Test (British Portable Skid Tester)
   Not less than reference section (untreated)

DISCUSSION OF RESULTS

Laboratory Results

Freeze and Thaw durability test

The durability of the treated concrete was improved, as shown in the following table:

TABLE 1

LAB DURABILITY RESULTS

Specimen	Avg. Durability Factor	Avg. No. of Cycle
Ref. (untreated	9.2	46
Treated	26.4	132

The coated blocks achieved a 187 percent increase in the durability factor because of treatment with Chemtrete. Three treated samples and three reference samples were used in this test.

90-Day Chloride Permeability Test

The results of this test on the treated samples are shown below:

TABLE 2

90-DAY CHLORIDE RESULTS

Sample Depth (Inches)	95% Chloride Level lbs/y^3 (Conc.)	Max. Acceptance Level lbs/y^3
1/16 to 1/2	12.22	7.25
1/2 to 1	7.00	1.80

The 1/16- to 1/2-inch depth was 68% percent higher in chloride content than allowed and the 1/2- to 1-inch depth, the chloride accumulation was approximately 4 times higher. Concrete made with standard Louisiana materials with no additive, at the 1/2-inch depth, has an accumulation of about 17 lbs of chloride, and at the 1-inch depth, an accumulation of 8 lbs of chloride per cubic yard of concrete.

Absorption Test

Table 3 lists the absorption data that was obtained on the laboratory-made concrete samples, which were fully treated with the chemical after being oven-dried. These samples were fully submerged in water for the duration of the test.

TABLE 3
LABORATORY ABSORPTION TEST

Submergence Period	% Absorption (treated)	% Absorption (Ref.)
24 hours	0.17	3.56
7 days	0.39	3.90
28 days	0.66	4.00
4 months	1.10	4.35

The 7-day blocks absorbed 22 percent less water than the maximum that was specified for the acceptance criteria. The 28-day blocks absorbed 34 percent less than the maximum specified value. In comparison to the reference (untreated) concrete, Chemtrete seemed to do an effective job in sealing the concrete, as measured in the laboratory using laboratory-made samples and procedures.

Skid Results

Because of the rapid drying of the material and its penetrating nature, Chemtrete did not affect the skid properties of the concrete surfaces.

The specimens that were treated with Chemtrete provided results satisfactory enough to warrant a field evaluation of the performance of silane-based chemicals as concrete sealers.

FIELD EVALUATION

Absorption Test

Perhaps one of the most important aspects of the effectiveness of concrete sealers is their ability to resist the penetration of moisture, which will subsequently reduce the ingress of chloride ions, thus delaying or stopping the embedded rebar corrosion. Therefore, emphasis was placed on this test to determine the effectiveness of the sealer in the reduction of moisture penetration. For each evaluation period two cores were taken from the bridge deck (approximately from the area near the right wheel path and the middle of the lane) for both the control and the test sections. The areas treated underneath the selected bridges could not be cored since proper equipment were not available. For the purpose of this test, the samples were heavily coated in paraffin wax except for the top (the riding surface), then fully submerged in water. The percent absorption rate for each group of samples were determined after 1 day, 2 days and 28 days of submergence. The specifications that were used allowed a maximum absorption rate of 1 percent after 28 days of submergence (See Appendix A for specifications).

The following is a brief discussion for each selected bridge deck.

Corey Overpass

The results of the absorption test are listed in Table 4. The bar chart shown in Figure 15 also depicts the 1-day, 2-day and 28-day absorption rates from one month to four years after treatment for the Corey Overpass. The 1 percent absorption limit after 28 days was not met by the samples that were taken more than one year after the treatment. Furthermore, the cores from the untreated section showed only about a 0.22 percent higher rate of water absorption (1.70 percent for treated and 1.92 percent for the reference) when the treatment age was more than one year. Obviously, any protection that was there during the first year of application had dissipated after the third year.

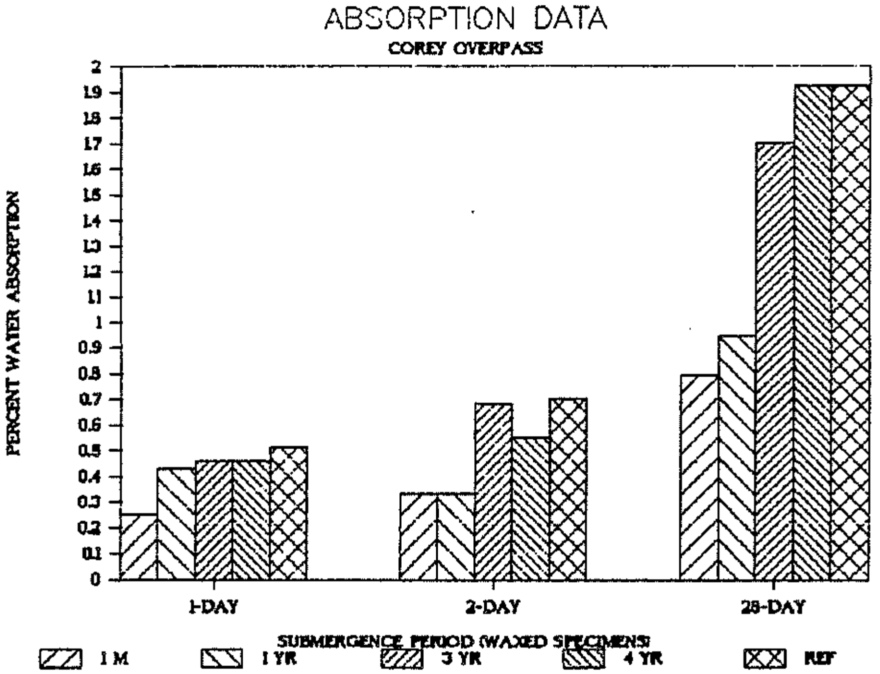

FIGURE 15

Absorption Data
Corey Overpass

TABLE 4

ABSORPTION DATA, COREY OVERPASS, % WATER ABSORBED

DATE	EVENT	1-DAY	2-DAY	28-DAY
DEC. 81	ONE MONTH AFTER TR.	0.25	0.33	0.79
DEC. 82	ONE YEAR AFTER	0.43	0.33	0.95
MAY 84	THREE YEARS AFTER	0.46	0.68	1.70
AUG. 85	FOUR YEARS AFTER	0.46	0.55	1.92
AUG. 85	UNTREATED SECTION	0.51	0.70	1.92

Bayou Lafourche Bridge

The absorption results are indicated in Table 5 and in Figure 16. The cores were waxed as already described, and the absorption rates were determined after 1, 2 and 28 days of submergence in water. The effectiveness of the chemical seemed to have been dissipated after one year. The cores taken at the other ages showed approximately the same absorption rate as obtained by the untreated samples.

Missouri-Pacific Overpass

This bridge was approximately 3 months old when it was treated. Initially, there was a concern about the material's effectiveness on bridges more than 20 years old. It was believed that the pores in the concrete of older bridges may have been filled so much by the contaminants that even with a thorough cleaning they would not allow full penetration of the chemicals. The absorption results obtained on this bridge did not fall within the expected range. As presented in Table 6 and Figure 17, the absorption rate was higher than the 1 percent at all ages and the untreated section did show the same and even lower absorption rates at 28 days than some of the treated sections.

Caminada Bay Bridge

The cores taken at the bridge from the treated section showed an acceptable absorption rate after two years of treatment (less than 1 percent after 28-day submergence). This absorption rate was not maintained on the samples that were taken 4 years after the treatment. However, as depicted in Figure 18 and Table 7, the treated section showed half as much absorption as the untreated section, which indicates the chemicals are still effective. An absorption rate of 1 percent after 28 days of submergence is difficult to achieve in the samples that are more than one year old (or two years in the case of this bridge).

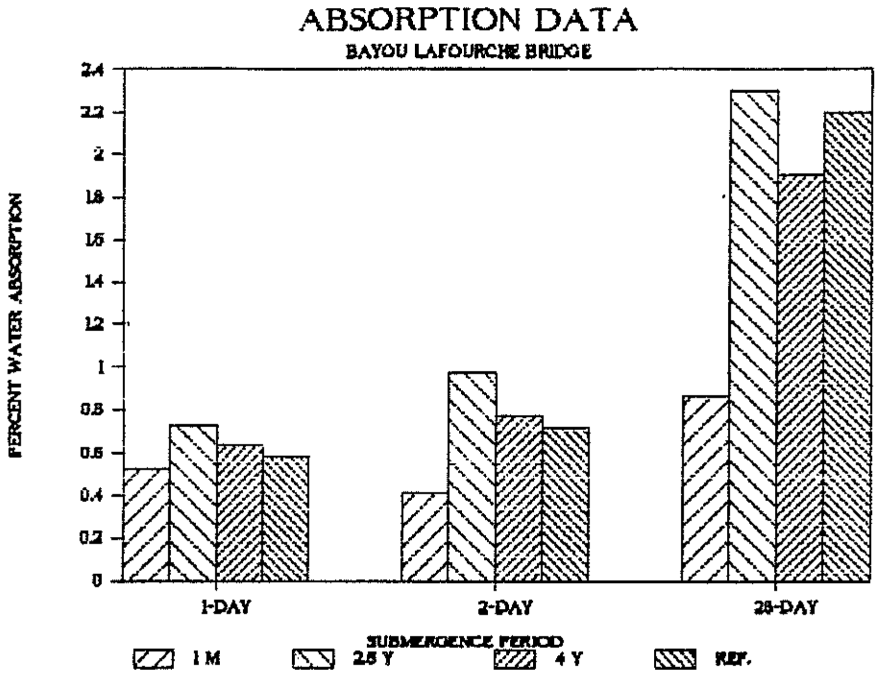

FIGURE 16

Absorption Data
Bayou Lafourche Bridge

TABLE 5

ABSORPTION DATA, BAYOU LAFOURCHE, % WATER ABSORBED

DATE	EVENT	1-DAY	2-DAY	28-DAY
DEC. 81	ONE MONTH AFTER APPLI.	0.52	0.41	0.86
MAY 84	2.5 YEARS AFTER	0.73	0.97	2.30
AUG. 85	4 YEARS AFTER	0.63	0.77	1.90
AUG. 85	UNTREATED SECTION	0.58	0.72	2.20

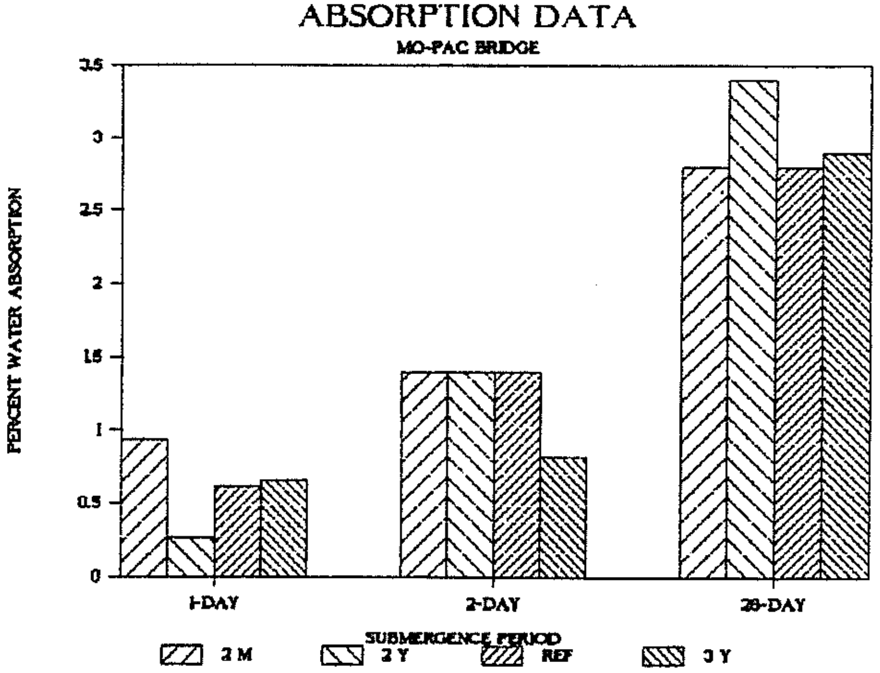

FIGURE 17

Absorption Data
Mo-Pac Bridge

TABLE 6

ABSORPTION DATA, MISSOURI PACIFIC BRIDGE, % WATER ABSORBED

DATE	EVENT	1-DAY	2-DAY	28-DAY
MAR. 82	TWO MONTHS AFTER APPLI.	0.94	1.4	2.8
MAY 84	TWO YEARS AFTER	0.27	1.4	3.4
MAY 84	REFERENCE	0.62	1.4	2.8
AUG. 85	THREE YEARS AFTER	0.66	0.82	2.9

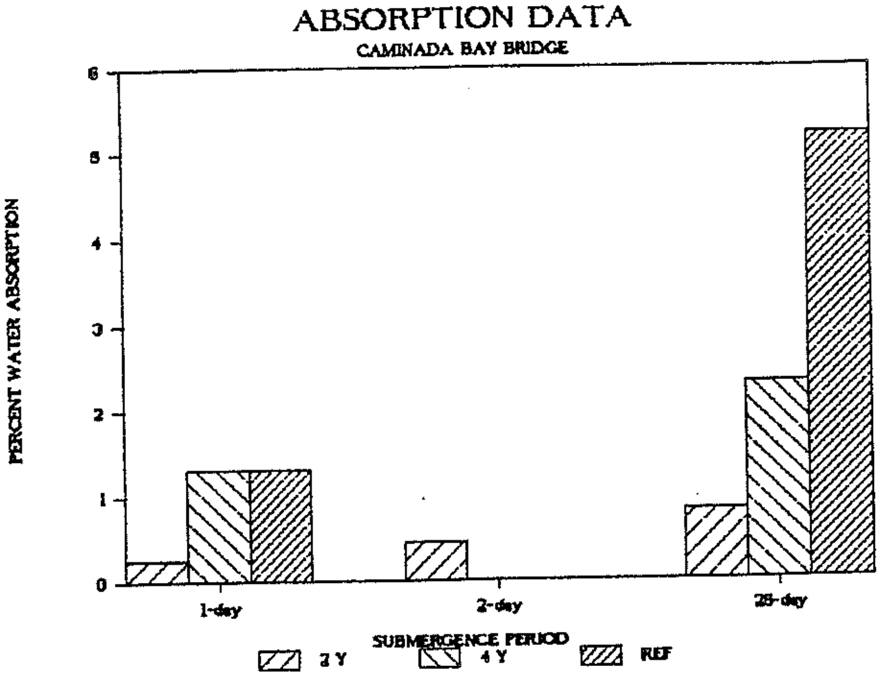

FIGURE 18

Absorption Data
Caminada Bay Bridge

TABLE 7

ABSORPTION DATA, CAMINADA BAY BRIDGE, % WATER ABSORBED

DATE	EVENT	1-DAY	2-DAY	28-DAY
MAY 1984	TWO YEARS	0.24	0.44	0.82
SEP 1985	FOUR YEARS	1.3		2.3
SEP 1985	UNTREATED	1.3		5.2

I-10 Bridge over Lake Pontchartrain

As experienced on the other bridges, the effectiveness of the chemical seems to decrease with age. Referring to Figure 19, the reason for higher absorption rates by the samples that were taken one month after treatment cannot be explained. Since all of the samples were heavily coated with wax, the chances of moisture penetrating through them was remote. Excluding the results obtained on the samples that were taken after one month of treatment, this bridge showed the longest effectiveness of the treated samples, which was close to the 1 percent limit on the 4 year-old samples. However, the absorption result obtained on the untreated sample showed an absorption rate of only 1.5 percent, compared to the 4 or 5 percent expected value from an untreated sample. Table 8 shows the actual results of the absorption rate.

Overall absorption results showed a general decrease in effectiveness of the material with time. In order to quantify this decrease, the absorption rates of cores taken from the test bridges were averaged and the percent reduction from the average absorption rate of the reference sections was determined. The results are shown in Figure 20. The absorption rate was decreased by 46 percent one month after the application of the sealant, as compared to the absorption rate of the untreated sample. After four years the reduction was 35 percent. The test data used for this calculation was determined by the testing of the waxed cores described in the methodology. The same analysis of the laboratory results showed a reduction of over 80 percent (after 28 days) in absorption rate of treated material when compared to the reference sample. Although the similar types of concrete were specified in all the bridges tested, variation in cement brand, aggregate source, and placement of concrete during the construction do affect the absorption rate, as previously described in the discussion of the individual bridges. In evaluation of such chemicals, it is difficult to accurately measure the absorption rate of the concrete in a treated bridge deck by testing the waxed samples, since the concrete cores are not uniform. Other nondestructive in situ methods of determination of absorption rates should be investigated.

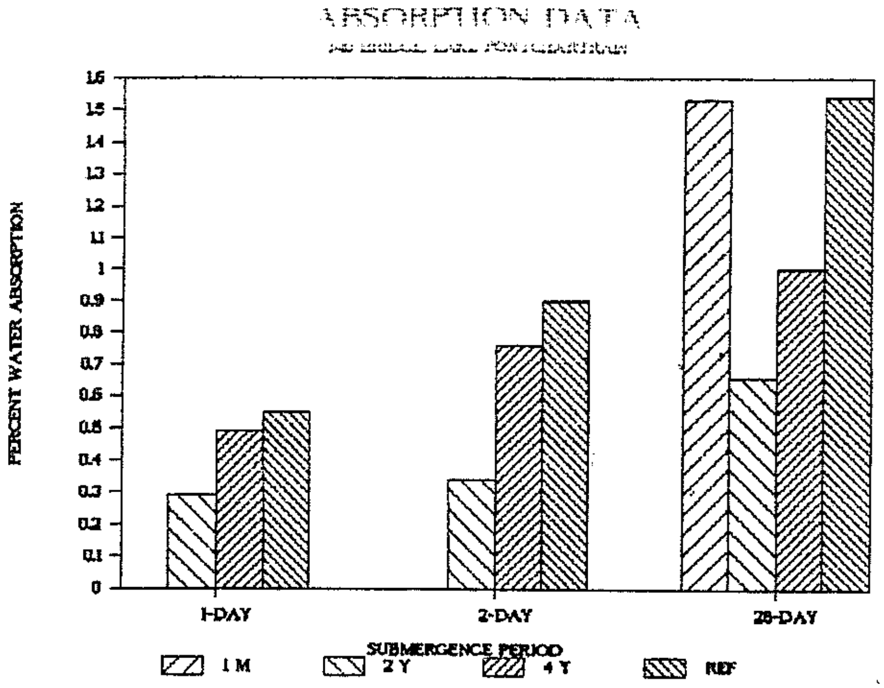

FIGURE 19

Absorption Data
I-10 Bridge, Lake Pontchartrain

TABLE 8

ABSORPTION DATA, I-10 BRIDGE, LAKE PONTCHARTRAIN % WATER ABSORBED

DATE	EVENT	1-DAY	2-DAY	28-DAY
DEC. 81	ONE MONTH AFTER TREATMENT			1.53
MAY 84	TWO YEARS AFTER TREATMENT	0.29	0.34	0.66
AUG. 85	FOUR YEARS AFTER	0.49	0.76	1.00
AUG. 85	UNTREATED SECTION	0.55	0.9	1.54

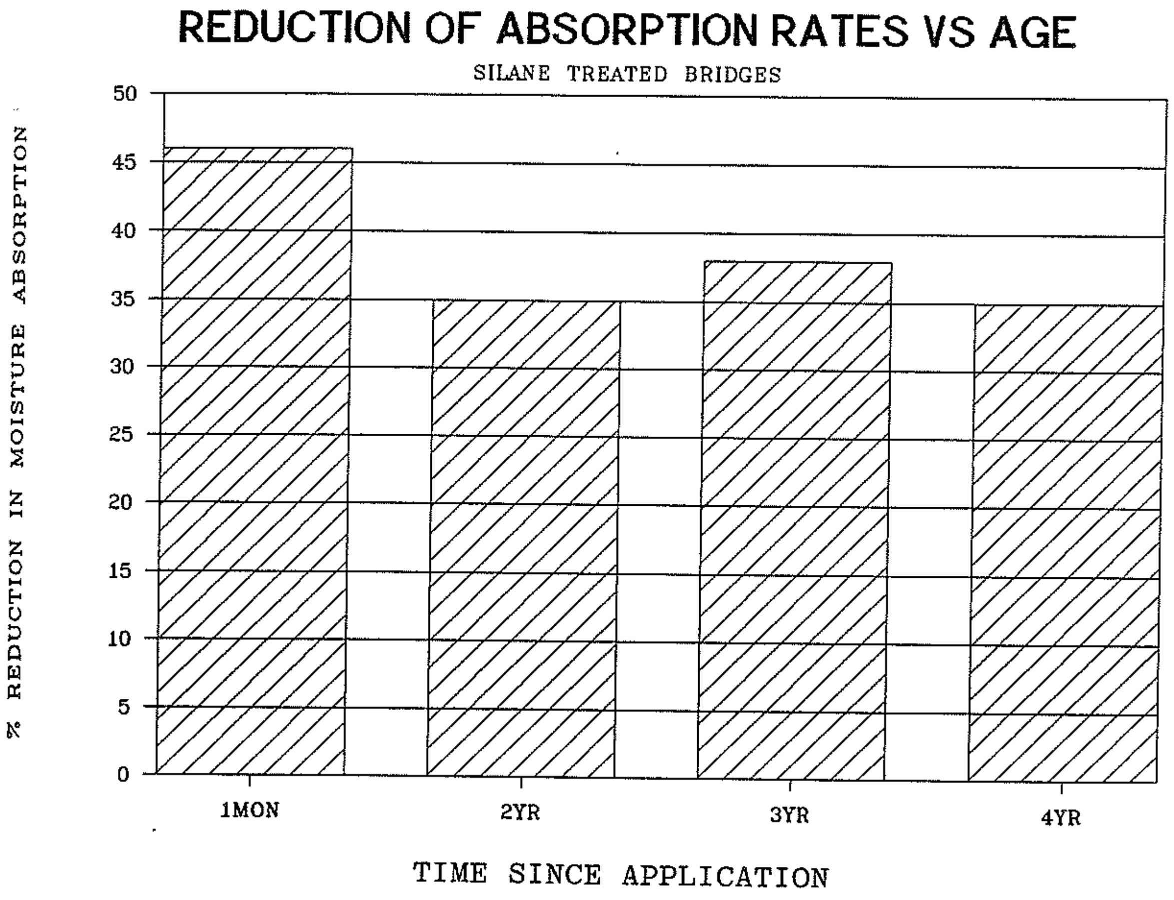

FIGURE 20

Reduction of Absorption Rates VS. Age
Silane-Treated Bridge Decks

CHLORIDE ACCUMULATION

Chloride content of the bridge decks was measured by analyzing pulverized concrete taken from the bridge decks by rotary drill. Basically, the same problem that exists in the determination of the absorption rate of concrete by testing cores seems to be present in chloride determination. Because of the nonuniformity of concrete, a consistent pattern of decrease in the chloride accumulation was not observed in the treated bridges. Furthermore, chloride content taken from the bridge deck varies with time and the location of the sample. Although efforts have been made to take the chloride samples from approximately the same location, great variations have been observed in the data. In order to accurately evaluate the performance of the silane material, the chloride content of the selected bridges initially was determined for the treated section and also the control section. Subsequent readings were compared with the initial reading and variation from one year to the next was determined. The chloride data for all bridges tested is shown in Table 9.

It was believed that the most reasonable way of determining the effectiveness of the sealant was to compare the accumulation rates of the treated and untreated sections. The data showed the chloride content of a bridge deck at the depths tested is not accumulative and varies. This conclusion was reached from the decrease in the accumulation rate on some of the bridges. Also, because of the mild winters in Louisiana, there is very limited salt application on bridges; therefore, there is very little increase in the chloride content in bridges, as shown in the data. There is also a variation in the chloride content from year to year in the same general area, which indicates that the chloride content is not accumulative in bridge decks and that it may increase or dissipate (especially when there is a lack of salt application). The data obtained does not show a consistent pattern for the reduction of chloride penetration in concrete bridge decks. Any such evaluation is difficult because of the variation of chloride content in concrete. Varying amounts of chloride content at different times does not allow a clear interpretation of the data in determination of the effectiveness of the sealer.

TABLE 9
CHLORIDE DATA, LBS/CUBIC YD OF CONCRETE
(95TH PERCENTILE)

			SAMPLE DEPTH			ACC.RATE/YEAR	
DATE	SECTION	TEST DATE	1/2"	1"	YEARS	1/2"	1"
COREY OVERPASS							
OCT-81	CHEMTRETE	OCT-81		3.67	0.0		
OCT-81	REFERENCE	OCT-81		3.43	0.0		
OCT-81	CHEMTRETE	DEC-82	2.76	2.26	1.2		-1.19
OCT-81	REFERENCE	DEC-82	1.83	2	1.2		-1.21
OCT-81	CHEMTRETE	MAY-84	3.38	4.45	2.6	0.24	0.30
OCT-81	REFERENCE	MAY-84	3.68	2.83	2.6	0.72	0.32
OCT-81	CHEMTRETE	OCT-85	3.39	3.34	4.0	0.38	-0.08
OCT-81	REFERENCE	OCT-85	7.17	6.69	4.0	1.89	0.81
I-10, LAKE PONTCHARTRAIN BRIDGE							
DEC-81	CHEMTRETE	OCT-81	2.28	2.28	-0.1		
DEC-81	REFERENCE	OCT-81	0.1	0.1	-0.1		
DEC-81	CHEMTRETE	APR-84	2.22	1.75	2.4	-0.03	0.22
DEC-81	REFERENCE	APR-84	0.76	0	2.4	0.28	-0.04
MISSOURI PACIFIC OVERPASS							
JAN-82	REFERENCE	JAN-82	0.1	0.1	0.0		
JAN-82	CHEMTRETE	JAN-82	0.1	0.1	0.0		
JAN-82	REFERENCE	MAY-84	1.6	0	2.3	0.65	-0.04
JAN-82	CHEMTRETE	MAY-84	1.88	0.99	2.3	0.77	0.38
JAN-82	REFERENCE	MAR-85	3.57	3.78	3.1	1.11	1.17
JAN-82	CHEMTRETE	MAR-85	3.02	2.93	3.1	0.93	0.90
BAYOU LAFOURCHE BRIDGE, I-20							
OCT-81	REFERENCE	MAY-84	4.71	2.06	2.6		
OCT-81	CHEMTRETE	MAY-84	3.44	1.16	2.6		
OCT-81	REFERENCE	OCT-85	3.88	3.32	4.0	-0.58	0.89
OCT-81	CHEMTRETE	OCT-85	1.99	0.85	4.0	-1.02	-0.22
CAMINADA BAY BRIDGE							
DEC-81	REFERENCE	OCT-81	6.2	6.7	-0.2		
DEC-81	CHEMTRETE	OCT-81	7.1	5.3	-0.2		

TABLE 9 (CONT'D)

CHLORIDE DATA, LBS/CUBIC YD OF CONCRETE

(95TH PERCENTILE)

			SAMPLE DEPTH			ACC.RATE/YEAR	
DATE	SECTION	TEST DATE	1/2"	1"	YEARS	1/2"	1"
DEC-81	REFERENCE	APR-84	3.95	3.94	2.4	-0.95	-1.16
DEC-81	CHEMTRETE	APR-84	5.24	7.22	2.4	-0.78	0.81
DEC-81	REFERENCE	AUG-85	2.8	3.41	3.7	-0.91	-0.88
DEC-81	CHEMTRETE	AUG-85	3.69	3.62	3.7	-0.92	-0.45

Discussion of Corrosion Measurements of Selected Bridges

The corrosion activities of the treated and untreated bridge decks were measured according to ASTM C876, "Half Cell Potentials of Reinforcing Steel in Concrete."

As was indicated in the discussion of chloride data, because of the lack of salt applications, the bridges tested did not show any indication of corrosion activity as measured by this test. Half cell measurements were taken over a grid pattern of 5' x 5' over the entire span of the test area. The average readings of all of the bridges tested were below 0.35 VCSE, which is considered to be the active corrosion level by ASTM C876. This was true for the bridges that were located in the coastal environment. Corey Overpass, located in north Louisiana, showed a very limited area (less than 4 percent of the readings) with measurements of greater than 0.35 VCSE; however, the average reading was well below the corrosion threshold. The half cell measurements are indicated in Table 10 for each of the bridges and each date tested. It is also evident that the sealant and the reference (untreated) section did not show significant differences in corrosion activities.

It is believed that the relatively short testing period (4 years) is not sufficient to demonstrate the difference between sealant-protected bridge decks and untreated decks. Also, it is evident from the corrosion data that the bridge decks evaluated in this study do not suffer from corrosion activities caused by salt or environmental conditions, and it seems that the concrete cover over the rebars provides adequate protection against corrosion. However, this conclusion is limited to the concrete bridge decks. Other submerged structural members in coastal environments may experience higher corrosion activities which were not evaluated in this project.

TABLE 10
HALF CELL DATA
(VOLTS)

BRIDGE	DATE	SITE	HIGHEST	LOWEST	AVERATE
CAMINADA	10/06/81	REF	0.22	0.02	0.07
CAMINADA	10/06/81	SEALANT	0.15	0.01	0.07
CAMINADA	08/21/85	REF	0.02	0.14	0.06
CAMINADA	08/21/85	SEALANT	0.03	0.16	0.06
LAFOURCHE	09/17/81	SEALANT	0.18	0	0.09
LAFOURCHE	05/01/84	REF	0.25	0.01	0.1
LAFOURCHE	05/01/84	SEALANT	0.13	0	0.05
LAFOURCHE	10/02/85	REF	0.16	0	0.06
LAFOURCHE	10/02/85	SEALANT	0.16	0	0.06
MO-PAC	01/27/82	REF	0.3	0.01	0.04
MO-PAC	01/27/82	SEALANT	0.09	0.01	0.05
MO-PAC	05/15/84	SEALANT	0.28	0.01	0.11
MO-PAC	05/15/84	REF	0.3	0	0.01
MO-PAC	10/03/85	SEALANT	0.15	0	0.05
MO-PAC	10/03/85	REF	0.17	0	0.06
PONTCH	10/27/81	SEALANT	0.2	0	0.11
PONTCH	10/27/81	REF	0.13	0	0.08
PONTCH	04/11/84	SEALANT	0.19	0	0.11
PONTCH	04/11/84	REF	0.16	0	0.07
COREY	11/30/82	SEALANT	0.46	0	0.12 (4% of readings >.35
COREY	11/30/82	REF	0.27	0	0.08
COREY	05/02/84	REF	0.32	0.03	0.15
COREY	10/01/85	SEALANT	0.29	0	0.09
COREY	10/01/85	REF	0.41	0	0.09 (3% of readings >.35

Results from the Infrared Spectroscopy

The depth of penetration of silane material could not easily be detected by visual examination of the wetted specimens. In order to have a better understanding of the silane reaction with concrete, a separate study was initiated with Louisiana State University to observe the silane reaction by slicing a 0.5" x 0.5" x 2" cube of concrete taken from a treated core into several 0.05" thick pieces, which were ground after removal of large aggregates and mixed with potassium bromide to be tested by an infrared spectrometer. The samples represented the deck surface of the bridge and also layers from material extending past the point where any visible penetration was observed. A separate report is available on this study (summary is included in Appendix B).

In this additional study, siloxanes (produced by a reaction between the cement matrix and silane) were detected in the infrared spectra of treated samples, indicating that the silane penetrated the concrete. The measured depth of visible penetration was compared to the depth of penetration determined by infrared analysis. The depth of penetration was determined by counting the number of layers which had infrared absorption bands caused by the chemical reactions between silane and the concrete. Comparison of IR spectra and visual observations of the cores indicated that the depth of the hydrophobic layer was less than the depth of the silane penetration. The actual measured depth range was from 0 to 0.1 inch.

It was concluded that the silane penetrated the concrete and bonded the silanoal to the substrate, but bonding did not occur for the entire depth of penetration. The water-repelling layer may be thinner than expected because of the application techniques or because of an undesirable reaction caused by the chemical composition of the cement. The visual examination suggests that the reactions did not produce a hydrophobic layer beyond the thin (.1") layer near the surface.

CONCLUSIONS AND RECOMMENDATIONS

The following are the conclusions derived from these studies:

1. The effectiveness of silane-based material in waterproofing concrete decks was not demonstrated to be as great as was shown in laboratory tests. There is also evidence that the effect of the silane chemical decreases with age in the treated bridge decks.

2. There were no significant differences between the corrosion activities of the treated and untreated bridge decks; however, no active corrosion was evident in the bridges tested. Long-term testing is necessary to evaluate the corrosion activities of treated or untreated bridges.

3. The amount of chloride as measured from pulverized concrete taken from the bridge decks did not reveal any advantage or disadvantage in using the silane chemical. No consistent pattern could be found in the chloride measurements.

4. Absorption tests conducted on the waxed core samples seem to be the most feasible method for evaluating the water-repelling properties of any sealant in the field.

5. The infrared spectroscopy of the treated core indicated that silane penetration had occurred. However, the reaction did not produce a hydrophobic layer beyond a thin (0.1") layer very near the top.

6. Because of relatively mild winters and limited salt applications, bridge decks tested generally showed low corrosion activities and may not warrant the use of sealants.

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APPENDIX A

LOUISIANA DEPARTMENT OF TRANSPORTATION AND DEVELOPMENT
TEST PROCEDURES
FOR
LABORATORY TESTING OF
WATER REPELLANT SEALANT MATERIALS
FOR
CONCRETE SURFACES

DESCRIPTION

These specifications cover the laboratory testing procedures and acceptance criteria for evaluation of water repellant sealant materials for use on concrete surfaces.

TESTING PROGRAM

The testing program will consist of chemical tests on the concrete sealant material and laboratory testing on the hardened concrete (surface) treated with this material. Material in sufficient quantity (approximately one gallon) will be supplied for this testing.

<u>Chemical Tests</u>

1. Infrared Spectrophotometric Analysis - This test shall be performed in accordance with DOTD Designation: TR 610.
2. Chloride content - The chloride content analysis shall be performed in accordance with DOTD Designation: TR 502.
3. Solid Content - The solid content of the sealant shall be performed in accordance with DOTD Designation: TR 224.
4. Specific gravity.
5. pH.

Physical Requirements

The laboratory specimens to be treated with the sealant for the tests shall be made of a concrete mix meeting the following requirements:

Cement - The cement used in any series of tests shall be a Type 1 portland cement conforming to ASTM Designation: C 150.

Fine Aggregate - Concrete sand as per Standard Specifications 1003.02.

Coarse Aggregate - Class A gravel conforming to Standard Specifications 1003.03 and of the following mix proportions:

Passing	Retained	% by Weight
1-1/2"	3/4"	25
3/4"	1/2"	45
1/2"	No. 8	30

Concrete Mixing

The concrete shall be machine mixed in accordance with DOTD Designation: TR 224. The concrete required for making the specimens for testing shall have a cement content of 6.5 ± 0.05 sacks per cubic yard of concrete and a fine to coarse aggregate ratio of 40/60 by volume. All the specimens shall be made and cured according to ASTM Designation: C 192 for 28 days moist curing, then 7 days in the 50% rh room before the application of the sealant (unless otherwise specified).

Air Content - Air content for the air-entrained concrete shall be 5.0 ± 0.2%.

Water/cement ratio - The water/cement ratio shall not exceed 0.50.

Concrete sealants - The water repellant sealant material shall not significantly stain, discolor or darken the concrete.

Tests on Plastic Concrete

(a) Slump - "Method of Test for Slump of Portland Cement Concrete" (DOTD Designation: TR 207.)

(b) Air Content - "Method of Test for Air Content of Freshly Mixed Concrete by the Pressure Method" (ASTM Designation: C 231).

Application Rate

The abraded* specimens (either by sandblasting) or hand-held rotary abrasion machine), after curing time as specified in concrete mixing section above, shall be fully coated with the sealant, either by brushing on or by submergence in the liquid according to the manufacturer's recommendations; the recommended application rate shall be in the ranger of the manufacturer's recommendations.

*Note: The entire surface of the specimen subjected to the sealant shall be abraded not more than 1/16" deep.

[If this amount of liquid is difficult to apply in the laboratory and to figure the application rate, then the specimen shall be fully coated by the sealant and the application rate calculated as follows: Weight of the specimen after application minus (-) the weight of the specimen before application of the sealant used to treat the specimen. The applied rate can be calculated by dividing the applied sealant weight by its density to determine the volume of the applied sealant, convert this volume to gallons and divide this volume (gallons) into the total applied area (sq. ft.) of the specimen to determine the application rate. The application rate of 100-150 sq. ft. per gallon shall be used as a guide.]

Time of Application

The time of application of the sealant to the concrete surface shall be after 28 days of moist curing and seven days in the 50% rh room.

Tests on Treated Concrete

The following tests shall be performed on the treated specimens with a minimum period of 24 hours being allowed for the surface of the treated specimens to dry:

(1) Absorption test
(2) Freezing and thawing test
(3) Scaling test
(4) Skid resistance test (British Portable)
(5) 90-day chloride permeability test
(6) Compressive strength test (no acceptance criteria)

Absorption test - 48 hour and 28 day absorption rates shall be determined according to ASTM Designation: C 642. A minimum of three (3) specimens are required for both reference and treated concrete. The specimens shall be treated and then let dry for 24 hours in the laboratory air before immersion in water.

Freezing and thawing test - (Air-entrained concrete only) The freezing and thawing test shall be performed in accordance with ASTM Designation: C 666, Procedure B. A minimum of three (3) coated specimens are required for this test, along with three (3) specimens for the reference. The specimens shall be cured as stated previously in the Concrete Mixing section before application of the sealant and should dry for 24 hours in the laboratory air before the start of the test.

Scaling resistance test - Three (3) treated blocks and three (3) reference blocks shall be subjected to the scaling tests according to "The Method of Test for Scaling Resistance of Concrete Surface Exposed to Deicing Chemicals" (ASTM Designation: C 672). This test is required on air-entrained concrete.

Skid resistance test - Skid resistance tests shall be performed on treated and untreated concrete surfaces by the British Portable Skid Resistance Tester. This test is required if the sealant is to be used on roadway or bridge deck riding surfaces. The surface of the freshly poured concrete specimen made for this test shall have a finish similar to a broom finish.

90-day chloride permeability tests - The 90 day chloride permeability test shall be performed as follows:

(a) Four (4) 3" x 9" x 15" plain concrete slabs shall be made from concrete of the required mix design.

(b) Slabs shall be cured with wet burlap for 24 hours after the molding, 13 days in the moist room and 21 days in the laboratory air (73.4 ± 3° F., 50 ± 4% rh).

(c) After the curing period, the top surface of the three specimens shall be slightly abraded (not more than 1/16"). A full coverage of the top surface shall be obtained by brushing the sealant on the specimen. The process shall be repeated for the three specimens. After the application, the blocks shall remain in the laboratory air for 24 hours to dry.

(d) 1-inch high x 1-inch wide dams shall be placed around the three treated specimens. All four slabs shall then be placed in a 73.4 ± 3° F., 50 ± 4% rh room for 90 days. Three of the slabs shall be subjected to continuous ponding with a 1/2 inch deep, 3 percent sodium chloride solution during the 90-day period. Glass plates shall be placed over the three ponded specimens to retard evaporation of the solution and additional solution shall be added when necessary to maintain the 1/2 inch depth.

(e) After the 90-day ponding, the solution shall be removed from the slabs, and after drying, the surface shall be wire brushed until all salt crystal buildup is completely removed.

(f) Samples for chloride analysis shall then be taken from all the four slabs, in accordance with the rotary hammer procedure as described in report FHWA-RD-74-5 or by dry coring (1-1/2" minimum diameter cores) and dry sawing.

Three samples shall be obtained from each slab at each of the following depths:

1/16" to 1/2"
1/2" to 1"

(g) The baseline chloride content for the concrete shall be determined as the average chloride content of the sample obtained from the 1/16" to 1/2" and the 1/2" to 1" depths within the slab that was not ponded with the 3 percent NaCl solution.

(h) The absorbed chloride content of each sample from the three ponded slabs shall be determined as the difference between the total chloride content of that sample and the baseline value calculated in item (g) above. If the result is less than zero, the result shall be reported as zero.

The reporting for this test shall include:

(1) Each total chloride value determined in item (f).
(2) The average and maximum baseline chloride value in item (g).
(3) Each calculated absorbed chloride value determined in item (h).
(4) The average and maximum absorbed chloride values calculated in item (h) for each depth.
(5) 95% level chloride content which can be calculated from the following formula:
95% chloride content = average + 1.645 (std. deviation)

A set of reference specimens shall be made according to the above procedures.

Compressive strength tests - Treated concrete specimens shall be tested in accordance with ASTM Designation: C 39.

ACCEPTANCE CRITERIA

Absorption rate: Maximum 0.5% by weight 48 hours
Maximum 1.0% by weight 28 days

Note: Required only if an increase in strength is expected in the treated concrete, or a loss in strength may be possible.

Freezing and thawing durability factor: The durability factor of the treated specimens shall be at least equal to the durability factor of the reference concrete (air entrained)

90-day chloride permeability: The 95% chloride level shall not be greater than 7.25 lbs. Cl/yd^3 of concrete for the 1/16" to 1/2" depth range and 1.8 lbs. Cl/yd^3 of concrete for the 1/2" to 1" depth range.

Scaling resistance: A maximum rating of 2 after 50 cycles.

Skid resistance characteristics: A skid number of above 55 on the British Portable Skid Tester and at least 90% of the reference concrete with the reference concrete having a skid number of at least 60 or more shall be obtained on concrete surfaces treated with the sealant.

FIELD EVALUATION

If satisfactory laboratory test results are obtained, then a field evaluation will be required. The water repellant sealant material should be installed and evaluated for a period of one year for endurance or durability characteristics against traffic and weather, along with skid resistance characteristics, sealant characteristics and any associated problems of installation and maintenance.

APPENDIX B

SUMMARY REPORT
Determination of Bridge Deck Concrete Reaction Depth When Treated by Silane Sealers

by

College of Engineering
Louisiana State University
Baton Rouge, LA 70803

INTRODUCTION

Commercial silane sealing compounds are considered to be an effective method for protecting of concrete and reinforcement bars from water damage and chloride ion attack. The silane is believed to chemically react with silicate phases in the cement matrix and aggregate phases to producing a water-repellant surface layer. Application can be by spraying at low pressure (15 psi) (3.068m^2/1) or by painting on concrete at a rate of approximately 125 sq. ft./gal. (103.5 kPa) (1,2) as recommended by the manufacturer. It is important that the concrete surface must be clean to allow complete penetration into pores and capillaries.

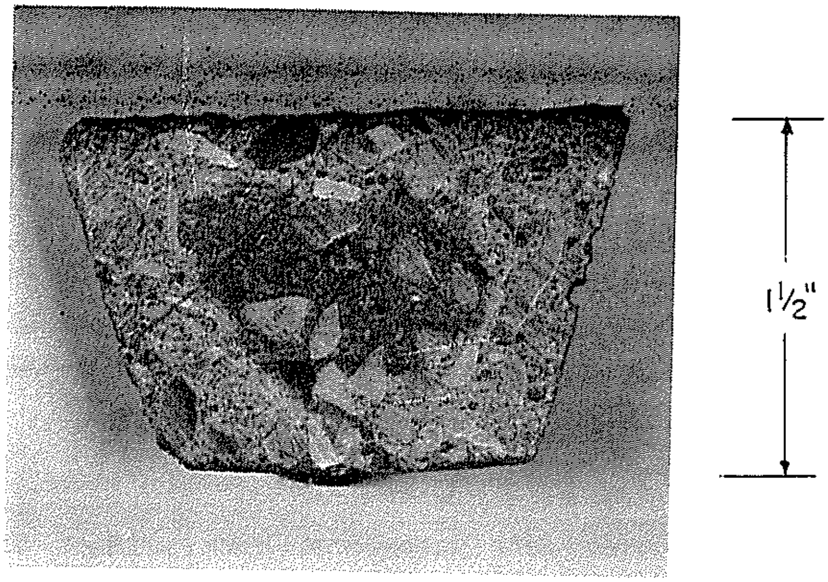

Fig. 1. Concrete core treated with silane. Light colored area is a water repelling layer

Proper application can produce a water-repelling layer of concrete up to 1/2" (1.27 cm) thick, as shown in Fig. 1.

In this study, concrete cores were examined by infrared spectroscopy (IR) to determine the extent of penetration. Many studies of silane-treated concrete have been reported (e.g. 3-5), but it is believed that there have been no other studies of penetration effectiveness using infrared analysis.

The cores were obtained from concrete bridge decks which had been treated with silane by the Louisiana Department of Transportation and Development. Visual examination of wetted cross-sections showed that a water-repelling layer of less than 1/2" (1.27 cm) resulted from the treatment. Infrared analysis indicated an extensive amount of silane had penetrated the concrete but a hydrophobic layer was not formed. A possible explanation is that the expected chemical reaction between the silane and the silicates contained in the hardened cement paste plus aggregate did not occur. Further work is currently in progress to quantify the amount of silane at each layer depth into the concrete and to identify the chemical cause for incomplete reaction between silane and silicate phases.

SAMPLE DESCRIPTION

Concrete cores were taken from five bridges in Louisiana. Bridge locations and core identification numbers are listed in Table 1. Core dimensions were 4" (10.2 cm) diameter by 3"-5" (7.6-12.7 cm) long as shown in Fig. 2.

TABLE 1. Concrete Core Samples

TREATMENT	LOCATION	IDENTIFICATION NUMBER
Chem-Trete	Missouri Pacific Overpass	1363-1
	Highway 526 Loop	1363-2
	Span #2	1363-3
	Shreveport, LA	1363-4
	Bayou Lafourche Bridge	1360-1
	I-20 Eastbound	1360-2
	Span #3	1360-3
	Monroe, LA	1360-4
	Lake Pontchartrain Bridge	1341-3
	I-10	
	Span #5	1341-4
	New Orleans, LA	
	Corey R.R. Overpass	1355-1
	Northbound	1355-2
	Span #2	1355-3
	Corey, LA	1355-4
	U.S. Highway 190	1427
	Span #8	
	Krotz Springs, LA	
Sil-Act	U.S. Highway 190	1428
	Span #6	
	Krotz Springs, LA	
Untreated	Lake Pontchartrain Bridge	1343-1
	Span #7	
	New Orleans, LA	
	Missouri Pacific Overpass	1362-2
	Highway 526 Loop	
	Span #1	
	Shreveport, LA	
	U.S. Highway 190	1423-1
	Span #7	
	Krotz Springs, LA	

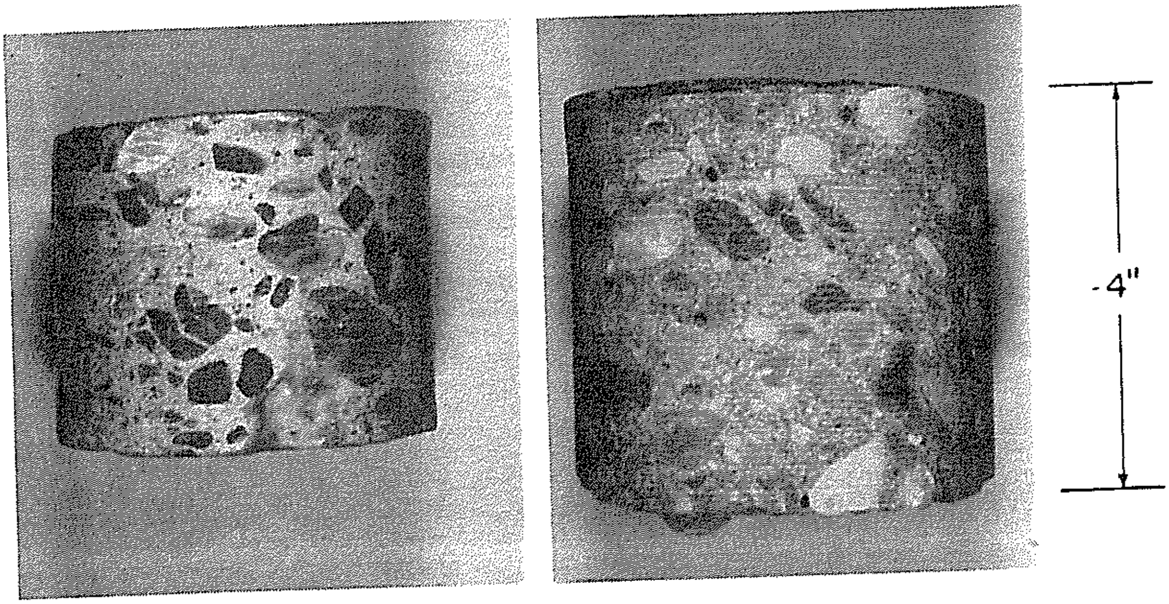

Figure 2. Concrete Core Samples

The bridges are located throughout the state thereby representing a variety of deck ages and environments. The distribution of bridges over the state is shown in Fig. 3. Silane had been applied from 4 to 6 years prior to this study. There was no attempt, however, in this initial study to correlate observations with these parameters.

The cores provided for the study were treated with either Sil-Act* or Chem-Trete silane (commercial) treatments. Sil-Act is a

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Note*: Sil-Act a product of Advanced Chemical Technologies Suite 1103, West 2601 Northwest Expressway, Oklahoma City, OK 73112, and Chem-Trete is manufactured by Dynamit Nobel AG, 10 Link Drive, Rockleigh, NJ 07647.

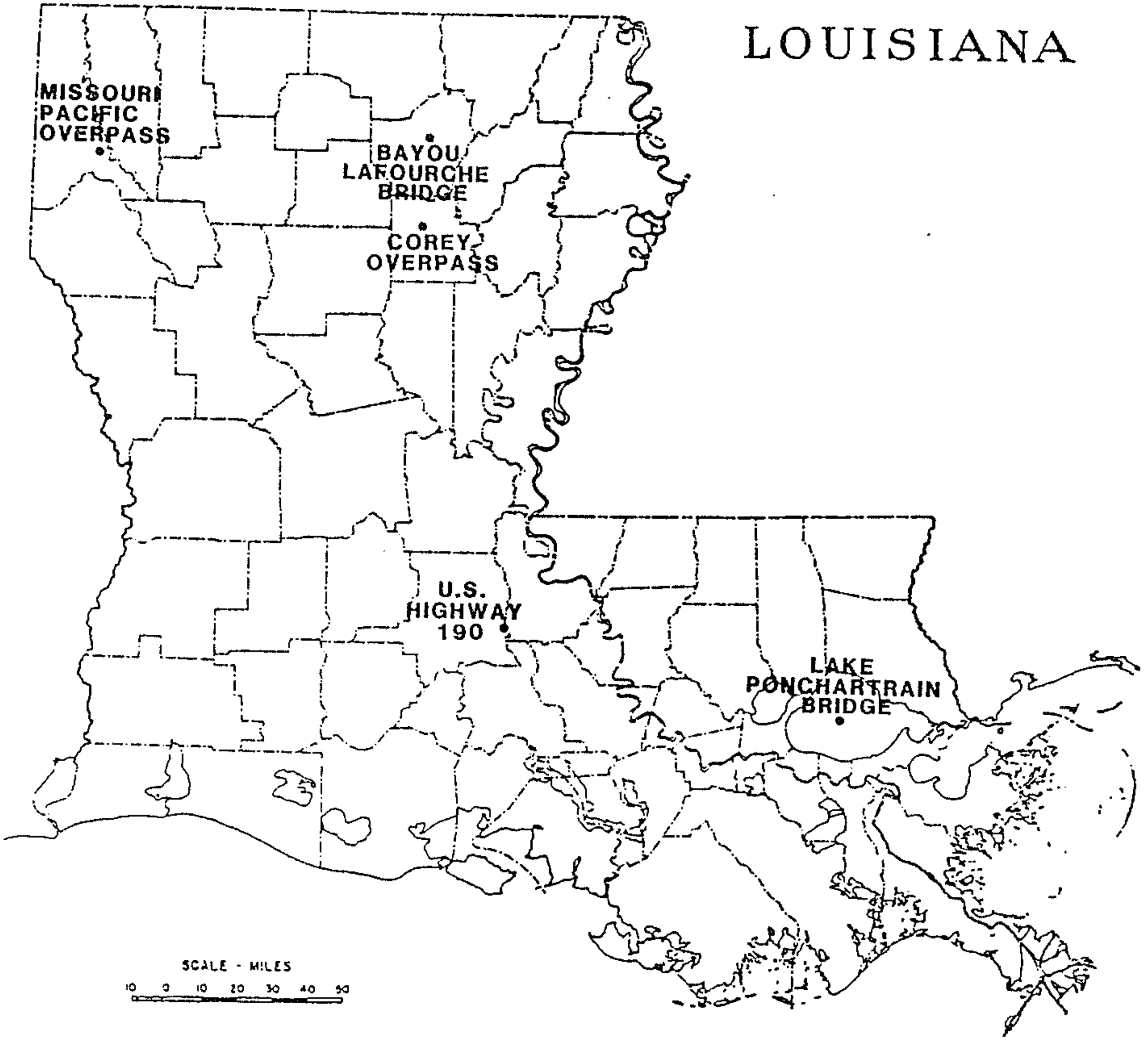


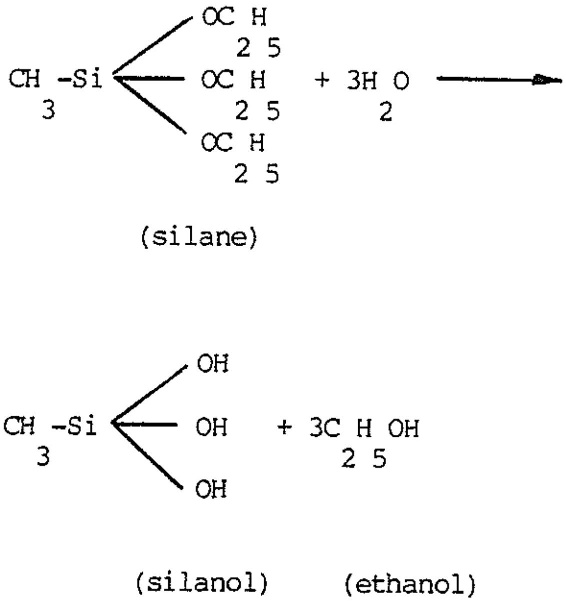
Figure 3. Bridge Locations

TABLE 2. Bridge Treatment Ages

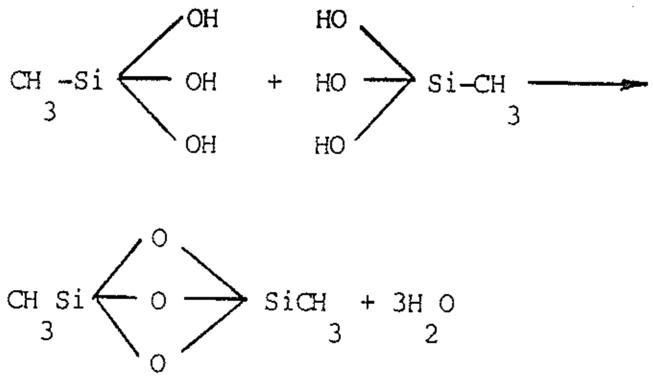
Bridge	Location	Date Treated
Missouri Pacific Overpass	Shreveport	Jan. 1982
Bayou Lafourche	Monroe	Nov. 1982
Lake Pontchartrain	New Orleans	Dec. 1981
Corey Overpass	Corey	Oct. 1981
U.S. Highway 190	Krotz Springs	June 1984

solution of 40% isobutultrimethoxy silane in 60% anhydrous isopropanol and Chem-Trete is a solution of 40% alkyl-alkoxy silane and 60% ethanol.

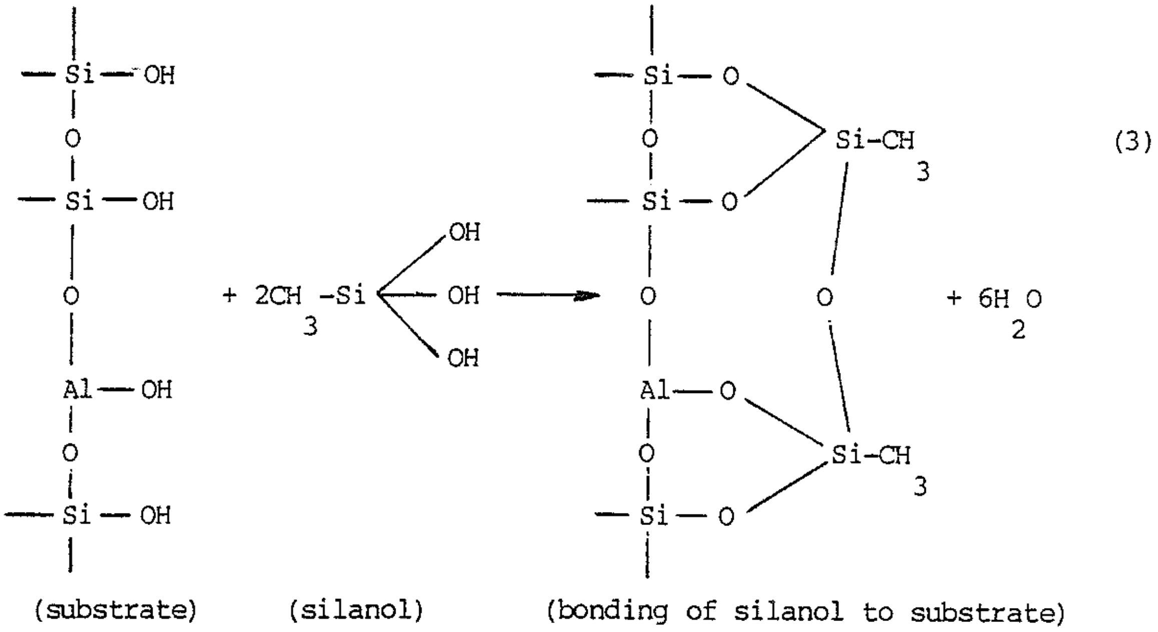
Both products form a hydrophobic layer by bonding a water-repelling hydrocarbon to the silicates in the concrete as explained by Wang(5). In the case of alkyl-alkoxy silane, the reaction occurs when alkoxy groups of silane hydrolyze in the presence of water as shown in Equation 1. The free acid groups (Si-O-H) in the resulting silanol react with each other or with the concrete substrate. If the free acid groups react with each other, an undesirable condensation reaction results, given in Equation 2. However, as shown in Equation 3, a reaction between the free acids and concrete produces siloxane groups (Si-O-Si) while leaving the $(Si-CH_3)$ groups unaffected. The $(Si-CH_3)$ groups impart a non-wettable hydrophobic sur-



(1)



(2)



face to the concrete substrate, making the substrate surface water repellant.

SAMPLE PREPARATION

A small representative concrete sample, approximately 1/2"x1/2"x2" (1.27x1.27x1.27 cm), was cut from the center of the top surface of the core. A diamond wafering saw with a 4" (10.2 cm) blade was then used to cut the sample into several 0.05" (0.13 cm) thick layers. The initial layer was taken from the deck surface of the core and subsequently layers from material extending past the point where visible penetration was observed. The concrete sample from each layer was placed in a vacuum dessicator and dried overnight at 60 ^{o}C. After drying, large aggregate pieces were removed and the remaining sample was crushed with a mortar and pestle and then passed through a No. 80 sieve.

Potassium bromide was used to create a finely dispersed concrete particle layer for IR analysis because it is not excited by infrared rays. Care must be taken when using potassium bromide pellets, however, since they are easily contaminated and readily absorb water as noted by Conley (6).

Measured quantities of concrete powder and potassium bromide were mixed in a vibrating mill mixer. The mixture was compressed in an evacuable pellet die as recommended by Conley (6) and the resulting translucent pellet was analyzed using infrared analysis. A ratio of 0.0001 oz (0.003 g) of concrete to 0.007 oz (0.20 g) of potassium bromide was experimentally determined to be a convenient ratio since it produced infrared patterns with strong silane peaks.

A Perkin Elmer Model 238 Infrared Spectrometer was used. Wave number was varied continuously from 4000 cm^{-1} to 200 cm^{-1}.

Infrared spectra for several samples are shown in Appendix I. Included are treated cores, untreated concrete, liquid silane treatment samples, and control samples containing controlled amounts of silane.

DATA ANALYSIS

The qualitative analysis of silane penetration was accomplished by comparing spectra from the treated concrete, a control sample, and the liquid silane. Examples of each are shown in Fig. 4. By observing characteristic absorption bands (peaks) occurring in the treated sample and not occuring in the control sample, it was possible to identify those peaks corresponding to vibrations of bonds associated with the silane molecule. As shown in Figure 4, there are certain bands which are visible in the concrete spectra and not visible in the silane spectra. They occur at 460 cm^{-1}, 780 cm^{-1} and 3520 cm^{-1} and are not useful for indicating the presence of silane.

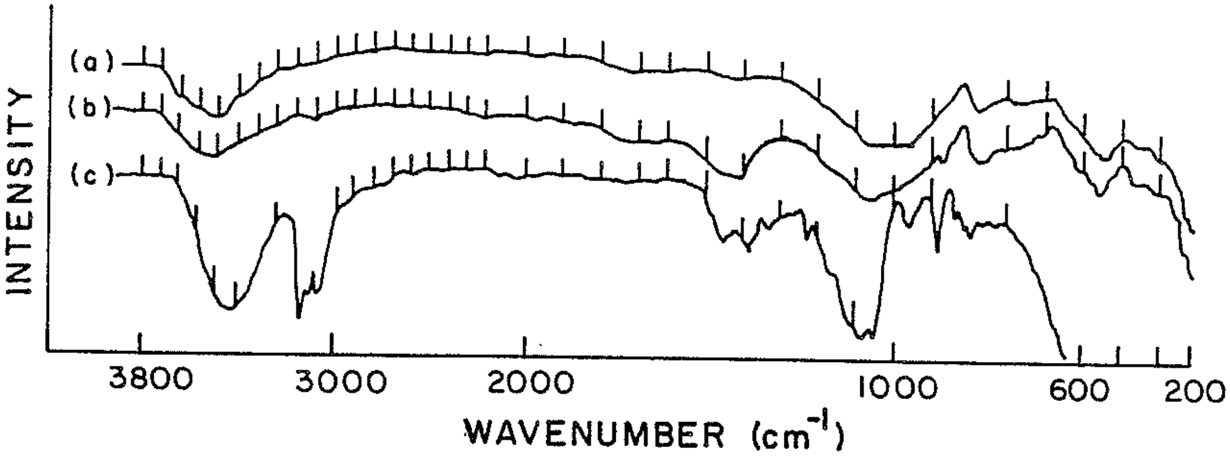


Fig. 4 IR Spectrum of (a) control sample, (b) treated sample, and (c) liquid silane sample

Analyses of IR spectra of treated cores reveal an absorption band between 1070 cm^{-1} and 1080 cm^{-1}. The siloxane band is visible at 1075 cm^{-1} in the IR spectra of cores 1355-1, 1363-2 and 1427, shown in Figs. 5, 6, 7. An IR band at approximately 1070 cm^{-1} is due to asymetric Si-O-Si stretching in siloxanes; siloxanes are a result of chemical reactions between silane and concrete (7). This band, therefore, can be used as an indicator of silane penetration into the core.

Another absorption band occurs at 794 cm^{-1} in some treated and may result from Si-C stretching in the Si-CH_3 group. However, this band also appears in the spectra of some untreated samples and was, therefore, not used as identification.

The spectrum from the first 0.05" (0.13 cm) layer of each core exhibits the most intense peak at 1070 cm^{-1}, then with each subsequent layer the intensity decreases; the decrease is due to a decrease in the amount of silane in the sample. The band eventually disappears completely for layers deep into the core.

The depth of silane penetration is determined by noting the depth at which the 1075 cm^{-1} peak disappears and by visually observing the depth of penetration of a wetted core. Core No. 1427 had a visual penetration of 0.05" (0.13 cm). However, the IR spectra for this core indicated that the intensity of the peak at 1075 cm^{-1} does significantly change until a depth of 0.15" (0.39 cm) is reached. Other depth comparisons are shown in Table 3.

Table 3. Silane Penetrations Determined by

Visual Inspection and by IR Analysis

Core No.	Depth of Penetration in Inches (cm) Visual	IR
1427	0.05 (0.13)	0.15 (0.38)
1355-1	0.05 (0.13)	0.20 (0.51)
1363-2	0.1 (0.26)	0.20 (0.51)

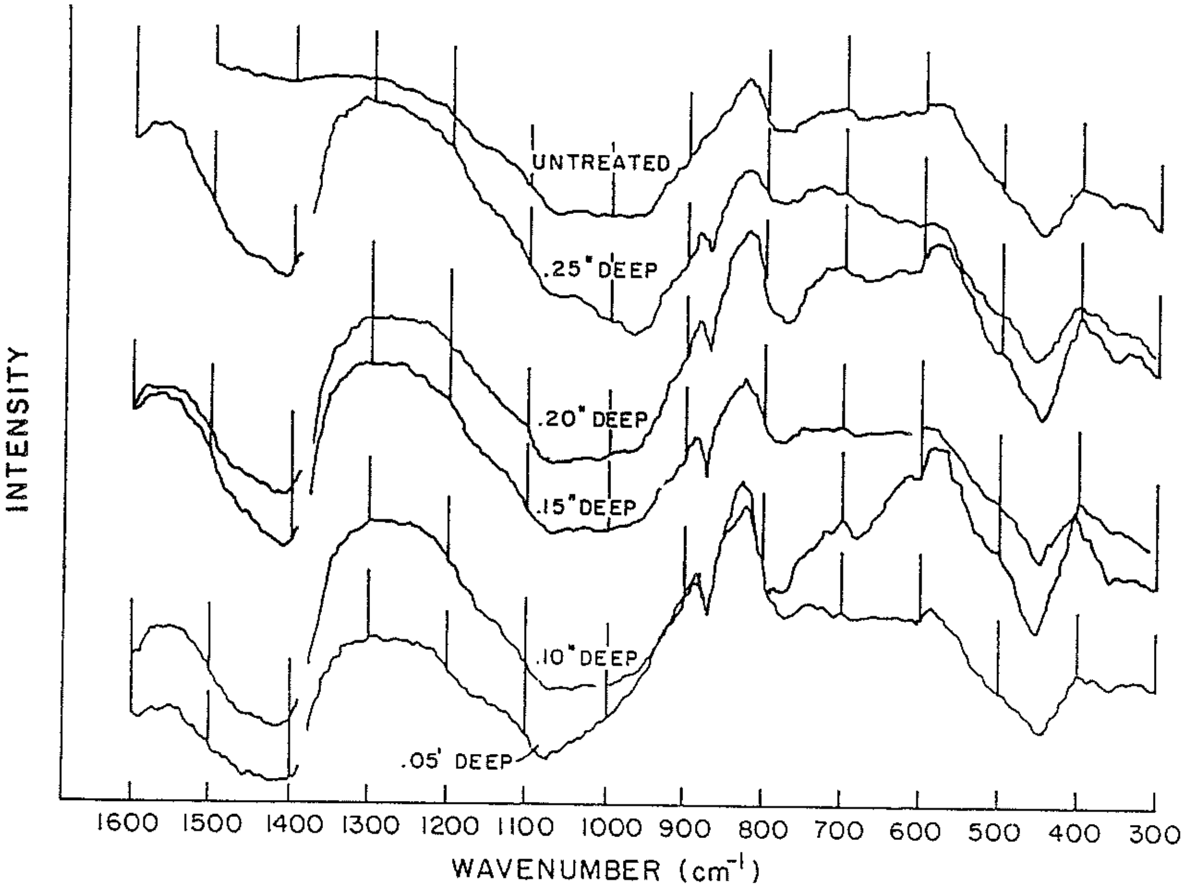


Figure 5. Infrared Spectrum for Sample 1355-1

Treatment: Chem-Trete

Visual Penetration: 0.05" (0.13 cm)

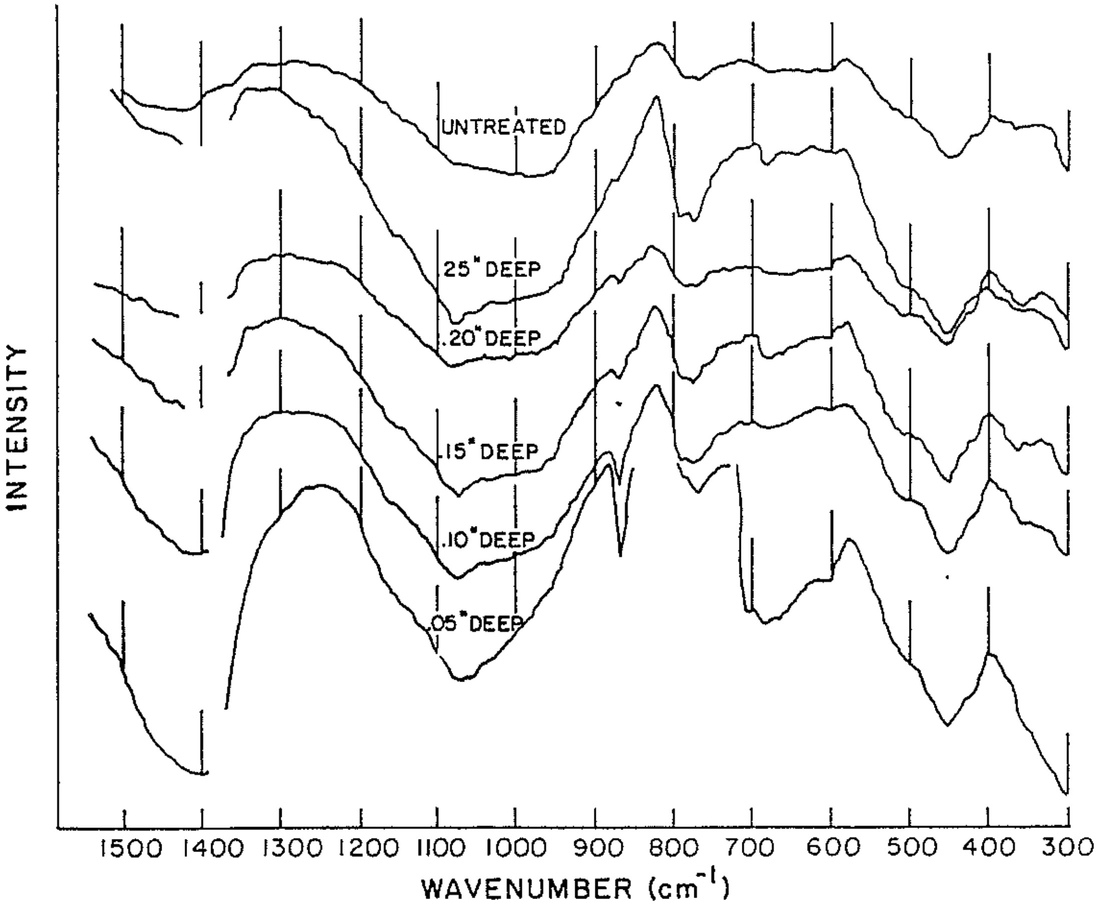


Figure 6. Infrared Spectrum for Sample 1363-2

Treatment: Chem-Trete

Visual Penetration: 0.05" (0.13 cm)

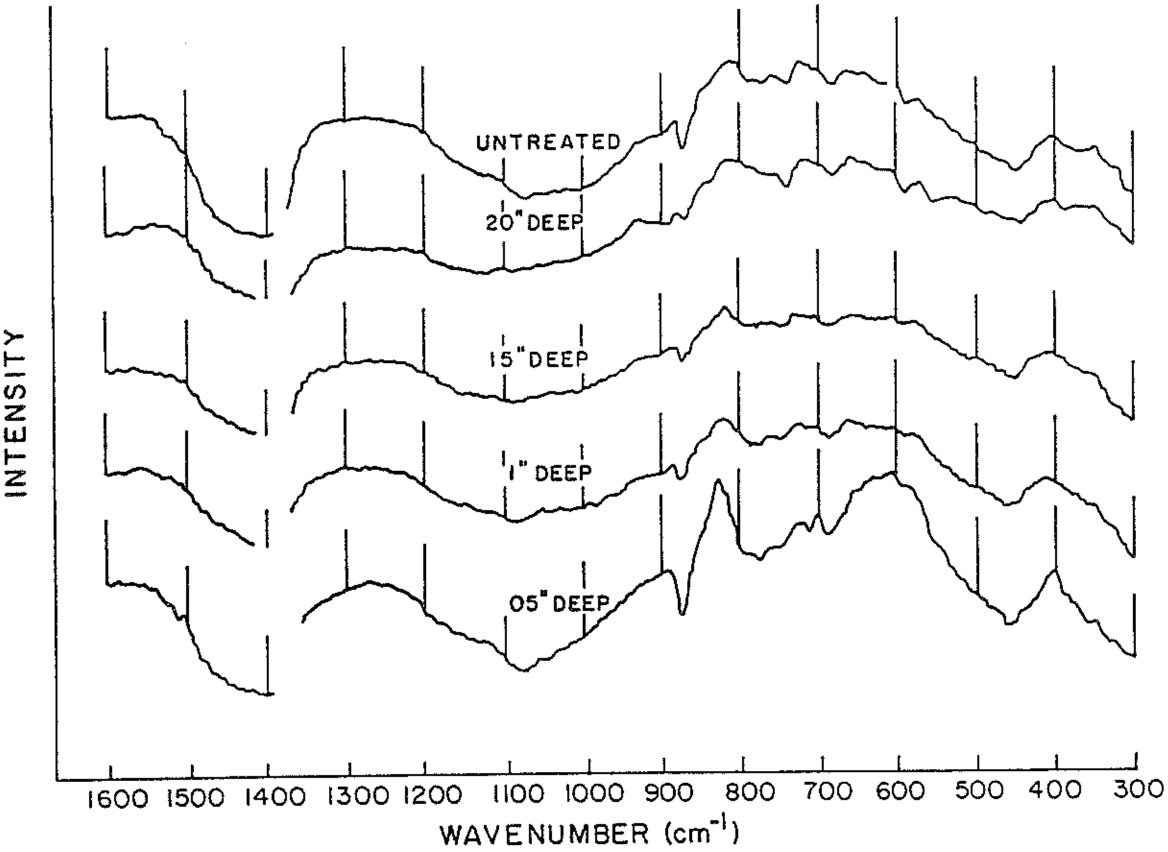


Figure 7. Infrared Spectrum for Sample 1427

Treatment: Chem-Trete

Visual Penetration: 0.05" (0.13 cm)

The IR results suggest that silane penetration has occurred and that some chemical reactions produced siloxanes. However, the visual examinations suggest that the reactions did not produce a hydrophobic layer beyond the thin layer very near the surface.

Since the amount of silane affects the intensity of the absorption band, quantitative analysis of silane content can be performed by measuring the intensity of absorption bands in treated samples containing known amounts of silane (7). An approximation of the maximum amount of silane (by weight) in treated concrete can be made assuming the amount of silane used in a typical treatment is 125 ft^2/gal. (3.068 m^2/l) applied to a depth of 1/2" (1.27 cm). The average weight percent silane in a 1/2" x 1' (1.27 cm x 30.5 cm) section is approximately 4.4%. Samples with increasing amounts of silane added to a known weight of concrete can be used to construct a calibration curve. These experiments are beginning in the author's laboratory.

CONCLUSIONS

Five samples treated with silane were examined. Each sample was cut into 0.05" thick sections starting at the concrete surface and extending past the point of visible penetration and then an infrared spectrum was then produced for each layer. The depth of penetration was determined by counting the number of layers which had infrared absorption bands caused by the chemical reactions between silane and concrete. Among the products of these reactions, siloxane was the main indicator for silane penetration. Comparison of IR spectra and visual observations of the cores indicates that the depth of the hydrophobic layer was less than the depth of silane penetration. When the desired reaction occurs, the hydrophobic layer is visible in the wetted cross-section of the core. The thickness of the hydrophobic layer should ideally be from 0.25-0.5" (0.64-1.27 cm), but the actual measured depths range from 0-0.1" (0-0.25 cm).

It is concluded that silane penetrated the concrete and bonded the silanol to the substrate, but bonding did not occur for the entire depth of penetration. The water-repelling layer appeared thinner than expected, perhaps because of application techniques or because of silanol molecular bonding to each other due to the chemical composition of the cement. Observation of the tested cores has shown that the visible depth of the dry layer is less than the depth at which silane peaks are identifiable in the IR spectra.

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