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16. Abstract

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No bonded sand or discoloration was evident on the surface following the impregnation process. Cores revealed that polymer depth ranged from 1 in. (2.5 cm) to 1.9 in. (4.8 cm), with the greatest depth occurring in the area where the largest amount of monomer was used.

Costs of polymer impregnation based on bids received by the State Department of Highways and Public Transportation ranged from \$5/yd^2 (\$6.00/m^2) to \$15.00/yd^2 (\$18.00/m^2) for the largest bridge which had an area of 5396 yd^2 (4512 m^2).

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by

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Polymer-Impregnated Concrete for Highway Application

Research Project 3-9-71-114

conducted for

State Department of Highways and Public Transportation

in cooperation with the

U.S. Department of Transportation
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by the

CENTER FOR HIGHWAY RESEARCH
THE UNIVERSITY OF TEXAS AT AUSTIN

January 1976

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

PREFACE

This report represents a milestone in the research on polymer-impregnated concrete for improving durability of bridge decks. It describes the application of the procedures to an actual bridge and reports the results of bids on the first two bridges let in Texas.

The authors are indebted to the many people in the State Department of Highways and Public Transportation who have been very helpful with suggestions and encouragement during this research. Particular thanks are due John Nixon, Donald O'Connor, Maurice Ferrari, Andy Seely, and Clarence Rea for their valuable suggestions and encouragement. The help of Melvin Stephens of District 14 in providing access to the Center Point Road bridge is gratefully acknowledged. Tom Patty of D-9 was especially helpful in analyzing the cores from the bridge after impregnation. The interest of John Nichols of FHWA is also appreciated.

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ABSTRACT

The application of polymer-impregnated concrete to an actual bridge deck is described. A method of determining the need for cleaning the surface is presented which consists of performing monomer penetration tests on sandblasted and non-sandblasted cores.

The procedures used for the polymer impregnation of the Center Point Road bridge are described in detail. The deck was dried and cooled overnight. Monomer was applied at different rates on the test area and kept in place by means of a shallow sand cover. After the monomer was permitted to cool for several hours, the concrete was heated to polymerize the monomer.

No bonded sand or discoloration was evident on the surface following the impregnation process. Cores revealed that polymer depth ranged from 1 in. (2.5 cm) to 1.9 in. (4.8 cm), with the greatest depth occurring in the area where the largest amount of monomer was used.

Costs of polymer impregnation based on bids received by the State Department of Highways and Public Transportation ranged from $\$5/\text{yd}^2$ ($\$6.00/\text{m}^2$) to $\$15.00/\text{yd}^2$ ($\$18.00/\text{m}^2$) for the largest bridge which had an area of 5396 yd^2 (4512 m^2).

KEY WORDS: concrete, polymer impregnated concrete, polymer, bridge deck, water proofing, durability

SUMMARY

Polymer impregnation of concrete bridge decks has become possible for field applications. The process consists of drying the concrete, cooling it, applying monomer to the surface and allowing it to soak into the concrete, and heating the concrete to cure the monomer.

A test is described to determine if the concrete surface needs to be cleaned prior to impregnation. Cores are taken from the deck and subjected to a monomer penetration test to determine if sandblasted surfaces permit a faster rate of monomer intake than non-sandblasted surfaces.

The detailed procedures used for the impregnation of the Center Point Road bridge are presented. Using an insulated enclosure the concrete was dried for nearly six hours after the average surface temperature reached 260° F (127° C). The concrete was allowed to cool to 90° F (32° C). Monomer was applied to the concrete at rates ranging from 0.6 lb/ft^2 (28.7 N/m^2) to 1.1 lb/ft^2 (52.7 N/m^2). A thin sand cover was used to hold the monomer on the surface for the five-hour soaking time.

The monomer was polymerized by heat provided by steam injected into the enclosure. The maximum concrete surface temperature attained was 194° F (90° C). The entire curing operation required 2.5 hours.

The impregnated depth ranged from 1 in. (2.5 cm) to 1.9 in. (4.8 cm) with the greatest depth occurring in the area where the largest amount of monomer was used. Sand did not bond to the surface, nor was there any other change in the surface appearance.

Cost of polymer impregnation, based on bids received for two bridges, is in the range of \$10/yd^2 (\$12.00/m^2) to \$15/yd^2 (\$18.00/m^2).

IMPLEMENTATION STATEMENT

The results of this investigation indicate that practical procedures have been developed for the polymer impregnation of concrete bridge decks. Previous research has shown that the impregnated concrete surfaces are much more durable with respect to freeze-thaw deterioration and resistance to corrosion of reinforcing steel. The skid resistance is not impaired. Bids taken by the State Department of Highways and Public Transportation indicate that the process can be performed by contractors at reasonable costs.

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1.0 Introduction

1.1 Polymers in Concrete

The use of polymers in concrete is relatively new. The first research in the United States was begun less than ten years ago. It was found that when concrete was dried and soaked with a low-viscosity liquid called a monomer, which was subsequently cured or polymerized into a plastic or polymer, a composite material with properties greatly superior to ordinary concrete was produced. Compressive strengths of 20,000 psi (13790 N/cm^2), tensile strengths of 1600 psi (1103 N/cm^2), and moduli of elasticity of more than 6×10^6 psi (4.14×10^6 N/cm^2) were obtained. Excellent resistance to freeze-thaw deterioration, water absorption, and acid corrosion were noted (1-3).

1.2 Polymer Impregnation of Bridge Decks

It was theorized that polymer-impregnated concrete (PIC) would provide excellent durability when used in highway bridge decks. A research program was begun in 1970 for the State Department of Highways and Public Transportation (SDHPT) to develop procedures for impregnating highway bridge decks and to evaluate the results (4-8).

After considerable laboratory and field testing, the procedures are believed to be ready for implementation. The proposed techniques yield 0.5 in. (1.3 cm) or more of polymer impregnation and can be applied to large areas. Specifications for polymer impregnation prepared by the SDHPT are included in the Appendix.

The specifications for impregnation are summarized as follows:

1.2.1 Cleaning the Concrete Surface

The concrete surface should be clean of contaminants or foreign material. Sandblasting may be required to remove oil. Sweeping is adequate in the absence of contaminants such as oil or grease. A test procedure to determine the need for sandblasting is described in Chapter 3.

1.2.2 Drying

Drying is essential to remove moisture from the pores in the concrete to the depth required for polymer impregnation. The monomer cannot penetrate the pores with moisture present. The concrete surface temperature should be increased at a rate not greater than two degrees per minute and maintained between 225 and 260°F (107 to 127°C) for a minimum of five hours. Surface temperatures should be monitored to insure uniform distribution of heat. Insulated enclosures are necessary to minimize heat loss.

1.2.3 Cooling

After the drying is completed, the deck should be allowed to cool to a range of 50 to 90°F (10 to 32°C). If the concrete temperature is too high, the monomer will begin to polymerize too quickly and adequate penetration into the concrete will not occur. Care should be exercised to prevent moisture from re-entering the concrete during cooling.

1.2.4 Monomer Application and Soaking

The monomer, which is methyl methacrylate, has a lower viscosity than water. To achieve polymerization in a reasonable time and at a reasonable temperature, an appropriate initiator and cross-linking agent are added to the monomer and mixed thoroughly before application to the bridge deck. A minimum monomer application rate of 0.65 gal/sq yd (~0.60 lb / sq ft or 2.94 N/sq m) is specified. To achieve a polymer depth of 0.5 to 1.0 in. (1.27 to 2.54 cm), the monomer needs to soak into the concrete for 4 to 6 hours. It has been found that some medium, such as a 0.375 to 0.5 in (0.95 to 1.27 cm) sand cover, will hold the monomer in place during the soaking period, even on appreciable slopes. The monomer should be sprayed on the sand, covered with an evaporation barrier, and protected from direct sunlight during soaking.

1.2.5 Polymerization

To polymerize or cure the monomer, heat is applied. There are several appropriate heat sources such as steam, ponded hot water, heating blankets, and warm air. Due to the flammable nature of the monomer, open flame heat sources should not be used. A curing time of about two hours at a surface temperature of 140 to 175°F (60 to 79°C) is required. After polymerization the sand is removed from the deck.

1.3 Advantages of Polymer-Impregnated Bridge Decks

It has been found that polymer-impregnated concrete bridge decks have significantly more durability (4-7). The increased durability is primarily the result of much lower water absorption because of the polymer-filled pores.

Freeze-thaw resistance of PIC has been found to be significantly improved. The protection against chloride intrusion, even for concrete submerged in sea water, has been found to be excellent. This results in much better protection against corrosion of the reinforcing steel in PIC as compared to ordinary concrete.

1.4 Demonstration of Polymer-Impregnation Procedures

This report describes the polymer impregnation of a portion of the Center Point Road Bridge over IH 35 near Austin. Since the demonstration also served the purpose of research, the SDHPT specifications were not followed in every detail. A detailed description of each phase of the process is presented. A summary of bids received on the polymer impregnation of two SDHPT bridges is given.

2.0 MATERIALS USED FOR IMPREGNATION

2.1 Definition and Description

There are several components of the monomer system that are used for impregnation. Definitions and descriptions of the various components and processes required for impregnation are presented in this section.

2.1.1 Polymer

A polymer is defined as a giant molecule made up of thousands of smaller molecules in a regular pattern. Examples of polymers are plastics, fibers, rubber, and adhesives. Some of the polymers found in nature are cellulose, wool, cotten, hair, skin, and muscle. Synthetically-produced polymers include nylon, polyester, polyurethane, polyethylene, and poly(vinyl chloride). Another synthetic polymer is poly(methyl methacrylate), or PMMA, which is similar to the polymer most commonly used in the impregnation of concrete. Two common trade names of PMMA are LUCITE and PLEXIGLAS.

2.1.2 Monomer

A monomer is a small molecule from which polymer molecules can be made. Monomers, including methyl methacrylate (MMA) from which poly(methyl methacrylate) is made, have "double bonds," which permit them to become polymers by the process of polymerization.

2.1.3 Polymerization

Polymerization is the chain reaction process by which a monomer is converted to a polymer. Once a chain of polymer is started, monomer molecules are added very rapidly until the process is completed for that chain. New chains are continually formed until all of the monomer is reacted.

2.1.4 Initiator

The initiator, sometimes loosely called a catalyst, is an agent which initiates polymer chains. The initiator used in this study is 2, 2'-Azobis(isobutyronitrile), or AIBN, which decomposes into free radicals which actually start the chain growth. The rate of the reaction is very dependent upon temperature. At 75°F (24°C) the half-life of AIBN is 6 months; at 100°F (38°C), 3 weeks; and at 160°F (71°C), 3 hours. In this study the AIBN was DuPont's Vazo 64; however, equivalent products are sold by other companies.

2.1.5 Cross-Linking Agent

The cross-linking agent is a monomer with more than one double bond which, when added to a monomer formulation, results in harder, more chemically and thermally resistant polymer. A cross-linked, more rigid molecular structure is produced. The cross-linking agent used in this study was trimethylolpropane trimethacrylate (TMPTMA). It was used because it increases the rate of polymerization of MMA (reduces the cure time).

2.1.6 Inhibitor

The inhibitor is a free radical scavenger which is added to monomers to prevent unwanted, and possibly dangerous, polymerization from occurring during shipping and storage because of spurious free radicals that may be generated. Manufacturers are required to provide a minimum amount of inhibitor in MMA which is shipped by commercial carriers. The specifications of the SDHPT require between 9 and 12 ppm of the inhibitor methyl ester of hydroquinine (MEHQ). TMPTMA must also be inhibited. Less than the required amount of inhibitor may result in polymerization during storage or soaking. More than the required amount may interfere with polymerization. Generally the contractor would not have to add inhibitor to either the MMA or TMPTMA since it would have been added by the manufacturer.

2.2 Monomer Formulation

The monomer formulation used in this study consisted of 100 parts by weight of MMA; 5 parts by weight of TMPTMA; and 0.5 parts by weight of AIBN. Successful impregnation requires that polymerization not occur until the monomer mixture has properly penetrated into the concrete. Once the desired monomer penetration has been reached, polymerization should proceed promptly by the addition of heat. The polymerization rate increases dramatically as the temperature increases.

2.3 Test for Monomer Formulation

After the monomer mixture has been applied to the concrete, the formulation cannot be changed. Therefore it is extremely important that the correct combination of monomer, initiator, and cross-linking agent be used.

A test has been developed that can quickly determine if the correct formulation has been made. The test involves measuring the time required for a specified amount of monomer mixture to polymerize when a test tube containing the monomer is placed in boiling water. Different combinations of MMA, AIBN, and TMPTMA will require different times for polymerization.

The test procedure is as follows:

1. A given amount of monomer mixture is placed in a test tube which is placed in boiling water.
2. Time is measured from the instant the test tube is placed in the water until the monomer has polymerized. For the purpose of the test, polymerization is assumed to be completed when the bubbles, which start rising as the monomer is heated, are "frozen" in the polymer.

Tests have been performed for different proportions of MMA, AIBN, and TMPTMA at two different temperatures for different volumes of monomer mixture. The results are shown in Table 2.1. The time required for polymerization is very dependent on the amount of AIBN and TMPTMA and, to a lesser

Table 2.1 Time for Polymerization,

Min : Sec[a]

Temperature		Volume, ml	AIBN, % (wt)					
Air	Solution[b]		0.25			0.50		
			TMPTMA, % (wt)			TMPTMA, % (wt)		
			0	2.5	5.0	0	2.5	5
73°F (22.8°C)	67°F (19.4°C)	3	10:30	3:45	3:00	6:45	3:00	1:50
		6	10:45	3:50	2:45	6:15	3:00	2:10
		9	10:10	3:55	2:45	6:20	3:00	2:25
95°F (35°C)	82°F (27.8°C)	3	8:45	2:05	2:50	4:10	3:05	2:25
		6	8:20	4:00	3:20	5:45	3:15	2:40
		9	8:30	4:45	3:30	6:45	3:25	2:25

[a] Tests conducted at elevation of approximately 600 ft (180 m) above sea level using 15mm x 125 mm test tube.

[b] Initial temperature of monomer solution prior to immersion in boiling water.

extent, the air temperature and volume of monomer used in the test. For the mix proportions required by the SDHPT specifications the time is approximately two minutes and 25 seconds for 9 ml in the range of temperatures tested.

It should be noted that the time will be a function of the barometric pressure, and therefore the elevation above sea level will affect the time. It is recommended that for each job the time for polymerization for the correct monomer formulation be established by means of several test repetitions. To minimize variations in the results, tests should always be conducted at the same air temperature.

2.4 Safety

2.4.1 Storage

Individual materials should be stored in accordance with manufacturer's recommendations. The initiator, e.g. AIBN, should not be stored in the sun, in air-tight containers, nor in unrefrigerated areas. When AIBN decomposes it forms nitrogen gas and a toxic liquid. The dust of AIBN in air is very explosive so it should be kept in closed containers (not air-tight). AIBN should not be stored in the same space as the MMA or TMPTMA. All three materials should be stored in a cool ventilated area out of direct sunlight. The AIBN should be refrigerated to prevent decomposition. Open flames or other fire hazards should not be permitted in the storage areas.

2.4.2 Mixing and Handling

Methyl methacrylate is only moderately toxic, but it does have a flash point below 100°F (38°C) (10). It is classified as a Class I flammable liquid by the National Fire Protection Association. The concentration in air should be kept below 100 ppm to avoid irritation to the skin of personnel, and in no case should workers be exposed to concentrations in excess of 400 ppm. MMA has a very pungent smell, and as little as a few parts per million can be easily detected. In open areas, such as bridge decks, it is highly unlikely that excessive concentrations will be encountered. Concentrations in excess of 800 ppm may be explosive.

Vapor monitoring devices are available for conditions which require that monomer concentrations be known.* The unit can be placed several hundred feet away from the area to be monitored, and a "cold" sensor can be run to the monomer area.

Grounding cables should be used on all containers when pouring. Metal stirring rods should not be used in metal containers. The AIBN and TMPTMA should be mixed into the MMA just prior to application. The monomer solution should be stirred with wooden paddles or bubbled with an air hose until the components are thoroughly mixed.

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*Environmental Measurement Systems, Seattle, Washington.

Waste material should be disposed of by incineration or polymerization under controlled conditions or incorporated into a land fill in accordance with federal, state, and local regulations.

Workmen should wear protective goggles and gloves while handling the materials. Saturated clothing should be removed and the affected skin area washed with soap and water.

3.0 Description of Center Point Road Bridge

3.1 Background

Center Point Road Bridge was constructed in 1957, with the last slab placed in December of that year. It was opened to traffic in early 1958. The bridge crosses over IH 35 approximately 3 miles (4.8 km) south of the city of San Marcos in Hays County, Texas.

The Center Point Road bridge is a six span, simply supported structure (Fig. 3.1). Each span consists of six prestressed concrete girders with a 6.25-in. (15.9-cm) cast-in-place slab. The spans are 40, 50, 65, 65, 50, and 40 ft (12.2, 15.2, 19.8, 19.8, 15.2, and 12.2 m) in length and the roadway is 24 ft (7.3 m) wide.

All polymer impregnation was carried out on the 40-ft (12.2-m) span on the west end of the bridge. In this section of the bridge the deck has an average longitudinal slope of 4.17% and a transverse slope of 0.83% on each side of the centerline of the roadway.

3.2 Concrete Mix

The concrete was a 5 sk/cu yd (2734 N/cu m) Class A transit mix with partially crushed limestone gravel aggre-

Fig. 3.1 Center Point Road Bridge

gate. The water-cement ratio for the mix was 6.5 gal/sk. The mix had an average slump of 3.5 in. (8.9 cm). No admixtures were used in the mix. The slab was belt finished.

3.3 Traffic History

The bridge is subjected to very light traffic in the range of 50 to 100 vehicles per day. The heaviest vehicles it receives on a regular basis are farm trucks.

3.4 Condition of Bridge Surface

The surface of the bridge appeared clean and sound. Linseed oil or other types of sealer had never been applied to the surface. The deck had received two deicing salt treatments, in 1959 and 1960.

Several shrinkage cracks were in evidence across the area that was selected for impregnation. Two or three months prior to the impregnation, maintenance personnel from the SDHPT, District 14, inspected the bridge and determined that water had been leaking through the cracks.

A test has been developed to evaluate the condition of the concrete surface for monomer penetration. The test, which is described in the following section, was used on the Center Point Road bridge.

3.5 Evaluation of Bridge Surface for Monomer Penetration

3.5.1 Need for Method of Evaluation

There are several variables that affect the monomer penetration into concrete. Generally the lower the monomer viscosity the greater the rate of penetration. But even for MMA, which has a low viscosity, the penetration rate has been found to be influenced to some extent by the water-cement ratio. The higher the water-cement ratio, the more porous the concrete and the greater the monomer absorption rate.

But the greatest effect on monomer penetration is the condition of the surface. The presence of road film or sealers, such as linseed oil, can seriously restrict or even prevent monomer penetration into the concrete. Generally new bridges pose no problem unless curing compound was used or linseed oil or other sealer has been applied.

To assist in the evaluation of bridge deck surfaces, a test has been developed and applied to 7 bridges in the Austin area. The method is primarily designed for bridges which have been in service to determine if the surface requires cleaning prior to impregnation.

3.5.2 Test Procedure

The test procedure is described in detail in Reference 9. A summary of the test follows.

1. Cores, at least 2 in. (5.08 cm) in diameter, are taken from each bridge in pairs. A pair of cores should be taken from each area that has a different surface appearance.
2. The wearing surface of one of each pair of cores is sandblasted to remove oil or other road film.
3. The cores are dried at a minimum temperature of 240°F (116°C) until a constant weight is reached. The sides of the cores are coated with epoxy and cured in the oven. Final weights of the cores are obtained.
4. The cores are placed with the wearing surface down on a cloth or paper towel wick below the surface of the monomer.
5. The monomer weight gain is measured by removing the core, drying the monomer from the surface, and weighing the core.
6. The monomer weight gain is plotted as a function of the square root of time. Results for the sandblasted and non-sandblasted core are plotted on the same graph for sake of comparison.
7. If the sandblasted core shows a significantly greater weight gain for the same time, the implication is that the penetration is impaired by the road film. Sandblasting has been shown to be a satisfactory method for cleaning concrete even if linseed oil has been recently applied (6).

3.5.3 Test Results

Seven bridges in District 14 were evaluated by the test procedure. Two cores, 2 in. (5.08 cm) in diameter, were taken from each bridge. A typical plot of monomer weight gain versus the square root of time, shown in Fig. 3.2, indicates a linear relationship.

There was no indication that sandblasting improved the monomer penetration rate in the cores for any of the 7 bridges tested. No apparent relationship could be found between rate of monomer weight gain and water-cement ratio, slump, or cement factor. This may have been the result of the small core size in combination with the one-in. diameter large aggregate used in most of the bridges. Monomer cannot penetrate most of the aggregate used locally, and the presence of a relatively large piece of aggregate near the surface of the core could result in lower monomer penetration compared to a core in which no large aggregate was located near the surface. For this reason, it is recommended that a minimum core diameter of three times the diameter of the largest aggregate be used for monomer penetration rate tests.

The results of the penetration tests on cores from the Center Point Road bridge are shown in Fig. 3.2. It may be observed that no apparent difference existed in monomer penetration for the sandblasted and non-sandblasted cores. It was concluded that the deck need not be sandblasted prior to polymer impregnation.

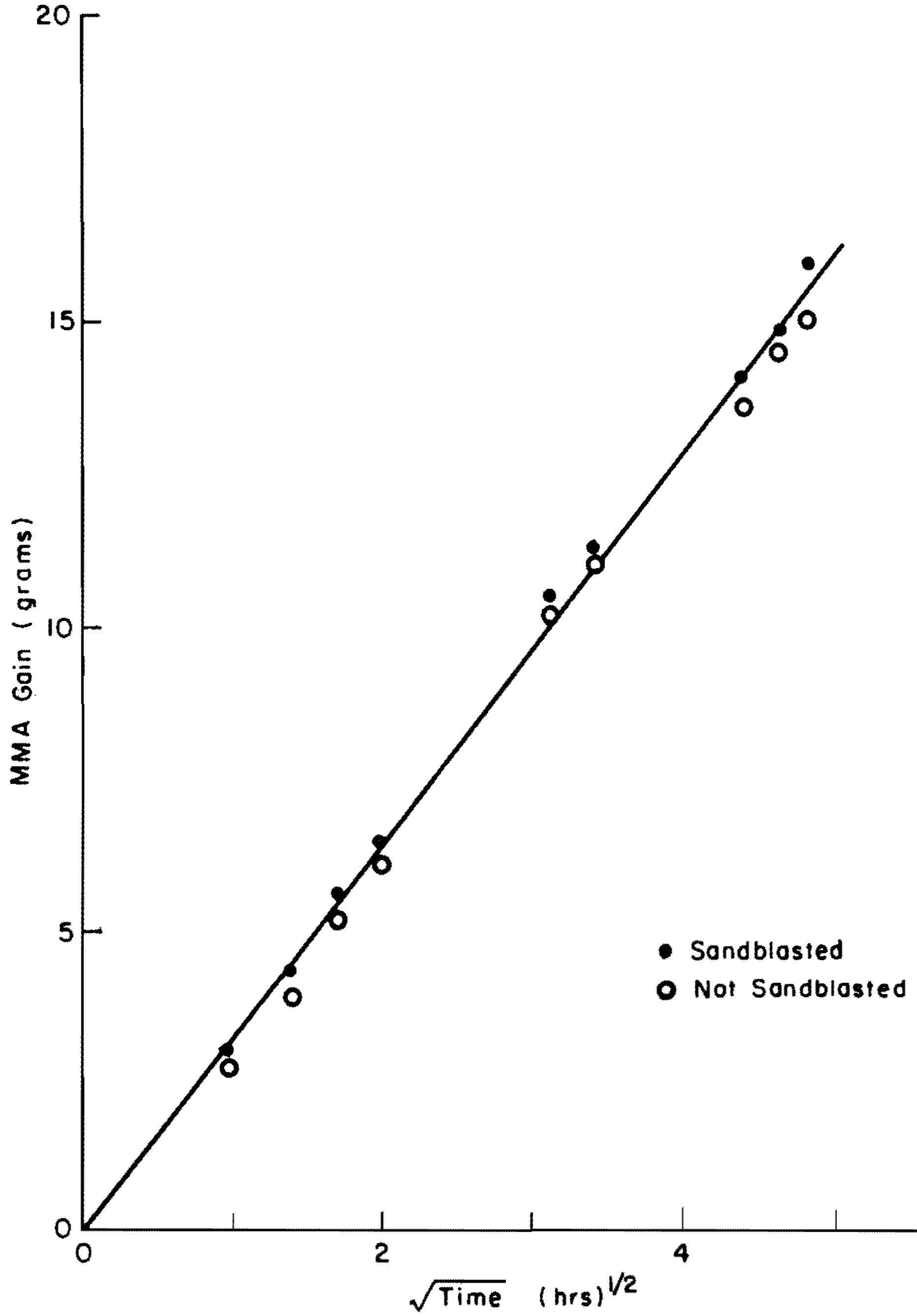


Figure 3.2 Monomer Weight Gain as a Function of the Square Root of Time for Center Point Road Bridge

4.0 Impregnation Procedure for Center Point Road Bridge

4.1 Schedule of Operations

The impregnation demonstration began on Thursday, September 25, 1975, when equipment was moved to the site. Drying actually began on Friday morning, September 26. The concrete was cooled overnight and the monomer was applied and cured Saturday, September 27. Final clean-up was performed Monday, September 29. Cores were removed Friday, October 3. A detailed schedule of the operations is given in Table 4.1. A description of some of the most important equipment is given in the Appendix.

4.2 Test Site Preparation and Equipment Setup

All work performed on the bridge was carried out at the west end, on a section 40-ft long and 24-ft wide (12.2 m by 7.3 m). The actual test area was located symmetrically about the centerline of the roadway and was 12-ft wide and 24-ft long (3.65 m by 7.3 m).

The test area was located in the center of the roadway to minimize stresses resulting from an unsymmetrical drying pattern. Fig. 4.1 shows the location of the test area.

Table 4.1

Schedule of Operations

Thursday, September 25, 1975

1300	Equipment moved to bridge
1500	Test area swept clean
	3/8-in. sand cover placed over test area
	Thermocouples attached to deck
	Drying enclosure erected
	Burners assembled

Friday, September 26, 1975

0830	Burner at west end of enclosure fired up
1015	Burner at east end fired up
1745	Burners shut off
	Top of enclosure removed, cooling begins
1930	Enclosure covered for the night

Saturday, September 27, 1975

0700	Began preparing test area for soaking; Monomer mixed
0800	Began applying monomer to deck
0845	Monomer application completed; (Applied 0.6 lb/ft^2 to south side of test area and 0.8 lb/ft^2 to north side)
1130	Applied additional 0.3 lb/ft^2 to east third of test area
1200	Began setting up equipment for curing
1325	Began application of steam for curing
1555	Stopped curing

Monday, September 29, 1975

Afternoon	
	Completed removal of equipment from bridge

Friday, October 3, 1975

Morning	
	Cores taken

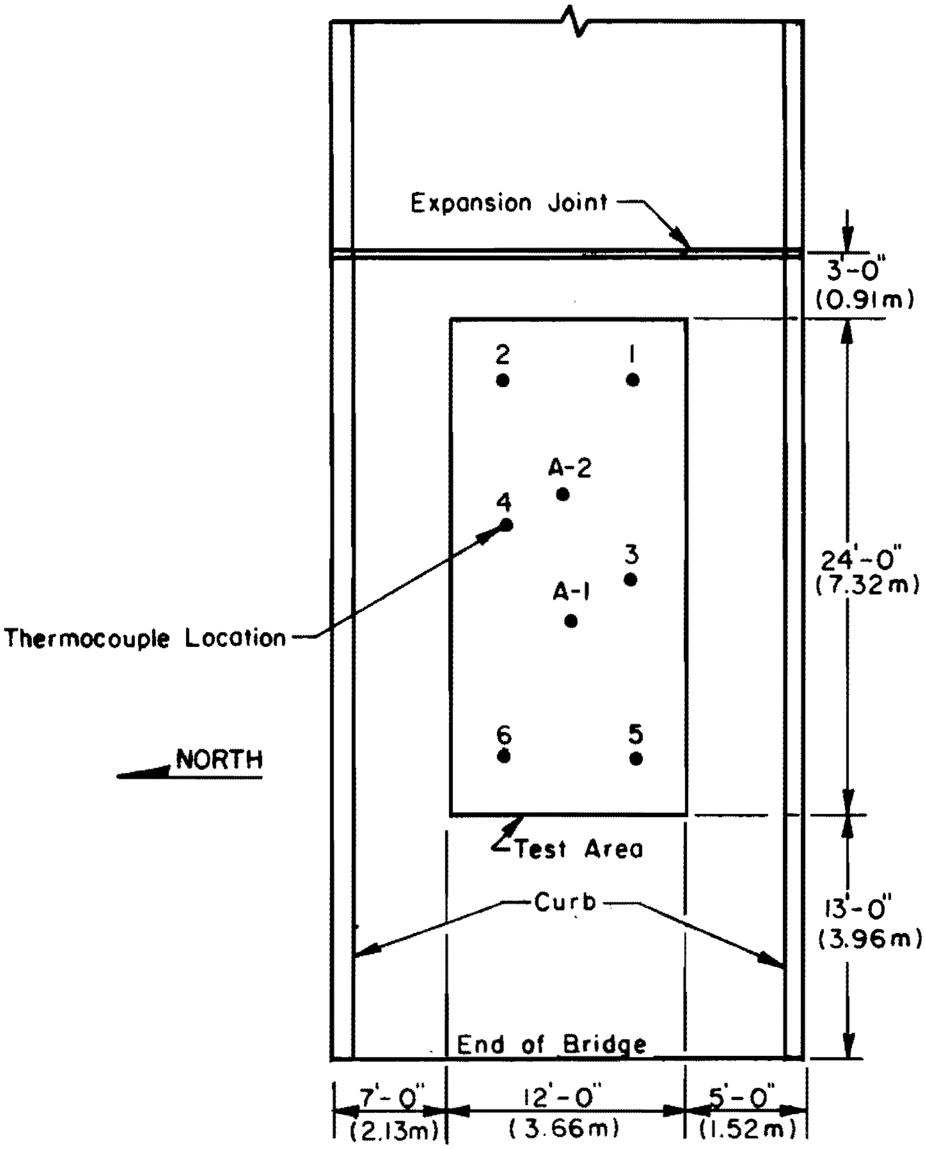


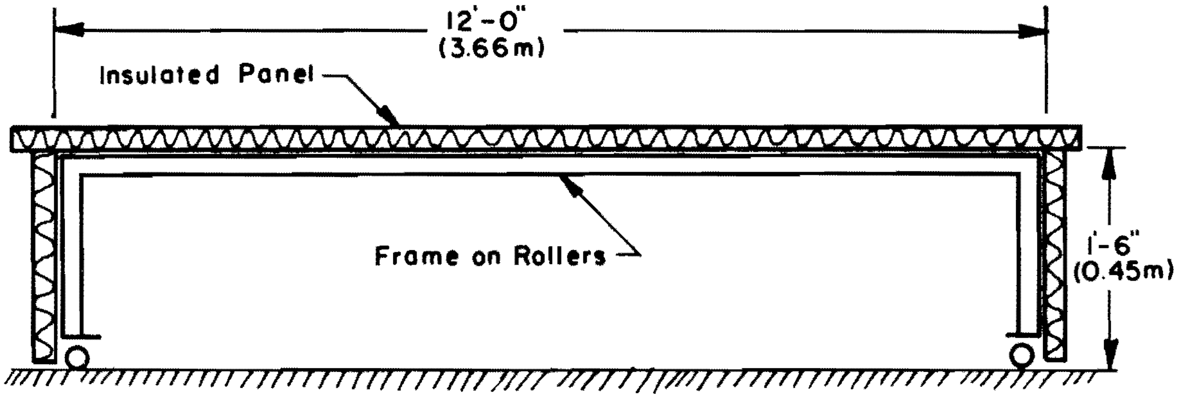
Figure 4.1 Plan of Test Area

The deck was swept with a broom in order to remove dirt and other debris. Next a 0.375-in. (0.95 cm) sand cover was placed over the test area. Placing the undried sand prior to drying the concrete slab permitted the sand to be dried thoroughly prior to monomer application. The sand cover also assisted in distributing the heat more uniformly.

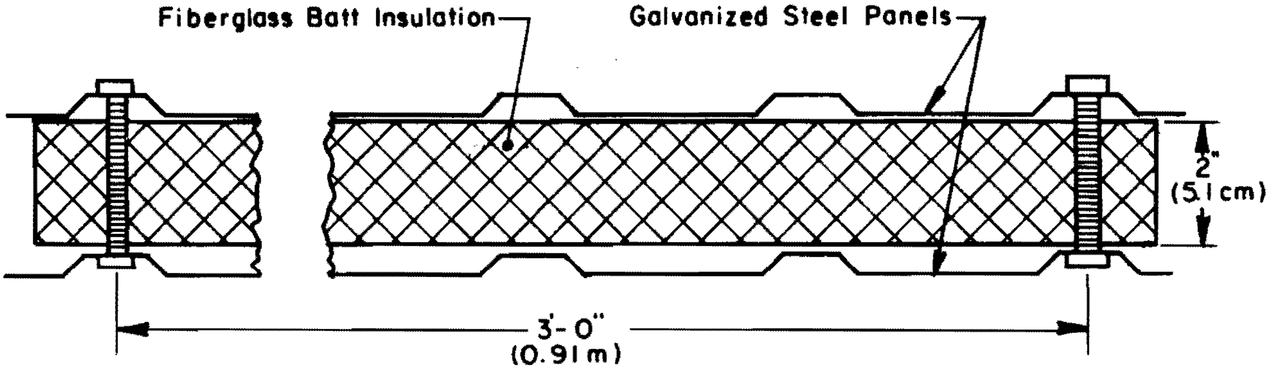
The drying enclosure was then assembled and placed on the test area. The drying enclosure consists of two 12-ft by 12-ft by 1.5-ft (3.65 m by 3.65 m by 0.46 m) sections. The sections are constructed of a light steel framework covered with panels made of sheet metal and fiberglass insulation (Fig. 4.2). The enclosure is constructed so that it can be easily assembled and disassembled by bolting. The top of the enclosure consists of removable panels made of galvanized metal sheets and fiberglass batt insulation (Fig. 4.2).

Eight thermocouples were used to monitor temperatures. Six were attached to the concrete to monitor the surface temperatures. The other two extended up 3 in. (7.5 cm) from the surface and were used to monitor the air temperature within the enclosure. Figure 4.1 indicates thermocouple locations. The sand was then given a final screeding (Fig. 4.3).

The burners and gas lines were assembled and set in place (Fig. 4.4). A piece of sheet metal approximately 2 ft by 4 ft (0.6 m by 1.2 m) was placed on top of the sand



a. Transverse Section



b. Section Through Insulated Roof Panel

Figure 4.2 Cross Section of Enclosure

Fig. 4.3 Screeding Sand to Thickness of 0.375 in.

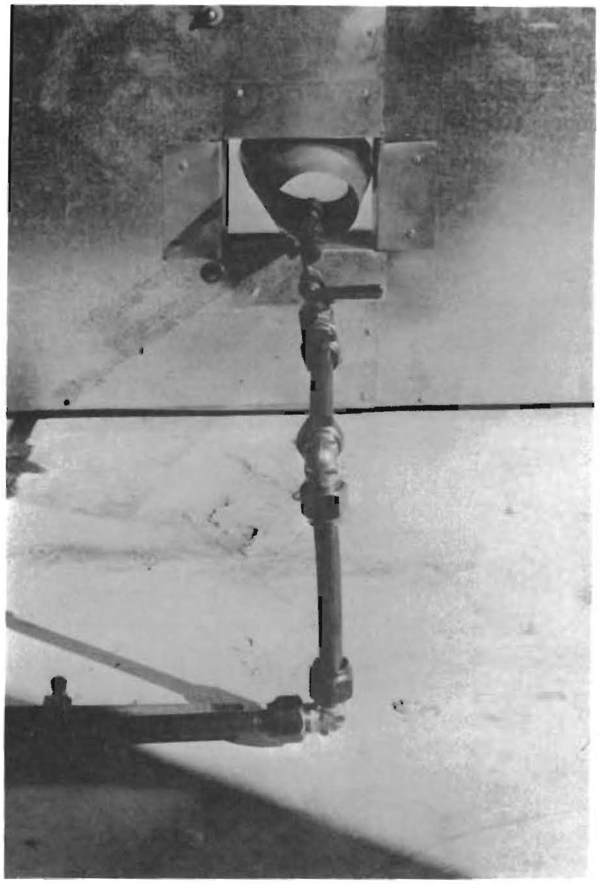


Fig. 4.4 Burner Placed in Enclosure

directly under the burners. This was done to prevent the flame from the burners from directly contacting the sand cover and developing a localized hot spot.

Three hours were required for a four-man crew to complete all of the work. The assembling and placement of the drying enclosure took approximately 45 minutes.

4.3 Drying the Slab

The deck was dried using open flame burners to heat the air within the enclosure. The drying equipment consisted of two 500,000 BTU/hr propane fired burners, one located at each end of the drying enclosure. The gas supply was a 300-gal (1136 *l*) portable tank located off the bridge. The concrete surface temperature at 0830 hours, when the first burner was ignited, was 73°F (23°C).

The drying operation was comprised of two stages. The first stage consisted of increasing the concrete surface temperature gradually to 240 to 260°F (116 to 127°C). The second step was the actual drying operation in which the slab was allowed to dry for a minimum of five hours at a temperature of 260 to 300°F (127 to 149°C).

Initially only the burner at the west end of the enclosure was fired. This was to insure a gradual temperature increase to minimize thermal gradients and stresses in the slab. An upper limit of 2°F (1.1°C) per minute is currently contained in the SDHPT specifications, although more experience with larger-scale drying may lead to a relaxation of this limit. The burner at the east end was fired at 1015 hours when it became apparent that the heating rate was leveling off.

During the drying operation the surface temperatures were not uniform, and, as a result, some "hot" and "cold" spots developed. In order to achieve a more uniform temperature profile, the perimeter of the enclosure was sealed at the base with sand, and panels on the top of the enclosure were opened slightly to ventilate the high temperature areas (Fig. 4.5).

The entire drying operation took 9.25 hours, with a temperature build-up time of about 3.5 hours and a drying time of 5.75 hours. Approximately 45 gal (170 l) of propane were required for drying.

Table 4.2 gives the time-temperature log for the drying operation. Fig. 4.6 graphically indicates the air and slab surface temperatures versus drying time. It can be observed that a temperature differential of approximately 60°F (33°C) existed between the high and low thermocouple readings from the slab, with a maximum temperature of 336°F (187°C) at the end of the drying cycle. The average temperature increased to 300°F (167°C) when the burners were turned off.

Fig. 4.5 Venting of Enclosure During Drying

Table 4.2
Drying Operation
Time-Temperature Log

Time	Temperature (°F)									
	Slab Surface							Air		
Sept. 26, 1975	1	2	3	4	5	6	Average	Air-1	Air-2	Avg.
0830	71	71	73	74	74	74	73	71	67	69
0845	100	83	83	89	86	83	87	244	243	243
0900	122	106	117	112	107	99	110	317	343	330
0915	128	117	140	125	115	102	121	370	371	370
0930	142	133	155	145	129	114	136	457	428	442
0945	152	145	162	160	144	129	152	466	405	430
1000	154	149	170	170	150	133	154	---	401	401
1015	156	153	180	179	159	143	162	---	411	411
	Burner at East End Turned On									
1030	194	213	197	220	181	166	195	578	543	560
1045	212	280	217	249	212	205	229	612	544	578
1100	222	310	237	272	231	221	248	630	578	604
1115	231	314	263	281	244	233	261	601	552	576
1130	228	315	273	279	247	233	262	522	454	488
1145	233	318	280	288	243	233	266	555	460	507
1200	233	303	273	282	237	233	260	516	411	463
1215	244	297	271	280	239	232	260	525	344	434
1230	246	302	266	285	234	230	260	554	436	497
1300	246	306	258	291	233	233	261	540	406	473
1330	249	298	255	282	235	233	259	506	356	431
1400	262	304	268	294	243	239	268	518	389	453
1430	256	299	257	286	238	236	262	502	432	467
1500	254	292	258	281	236	236	260	454	370	412
1530	276	295	276	286	259	250	274	474	396	435
1600	290	312	287	291	267	254	284	477	399	438
1630	298	316	304	295	274	260	291	483	413	448
1700	294	321	305	295	276	259	292	470	318	394
1730	300	341	312	312	278	264	301	509	406	457
1745	292	336	313	303	276	261	297	---	---	---
	Burners Turned Off									

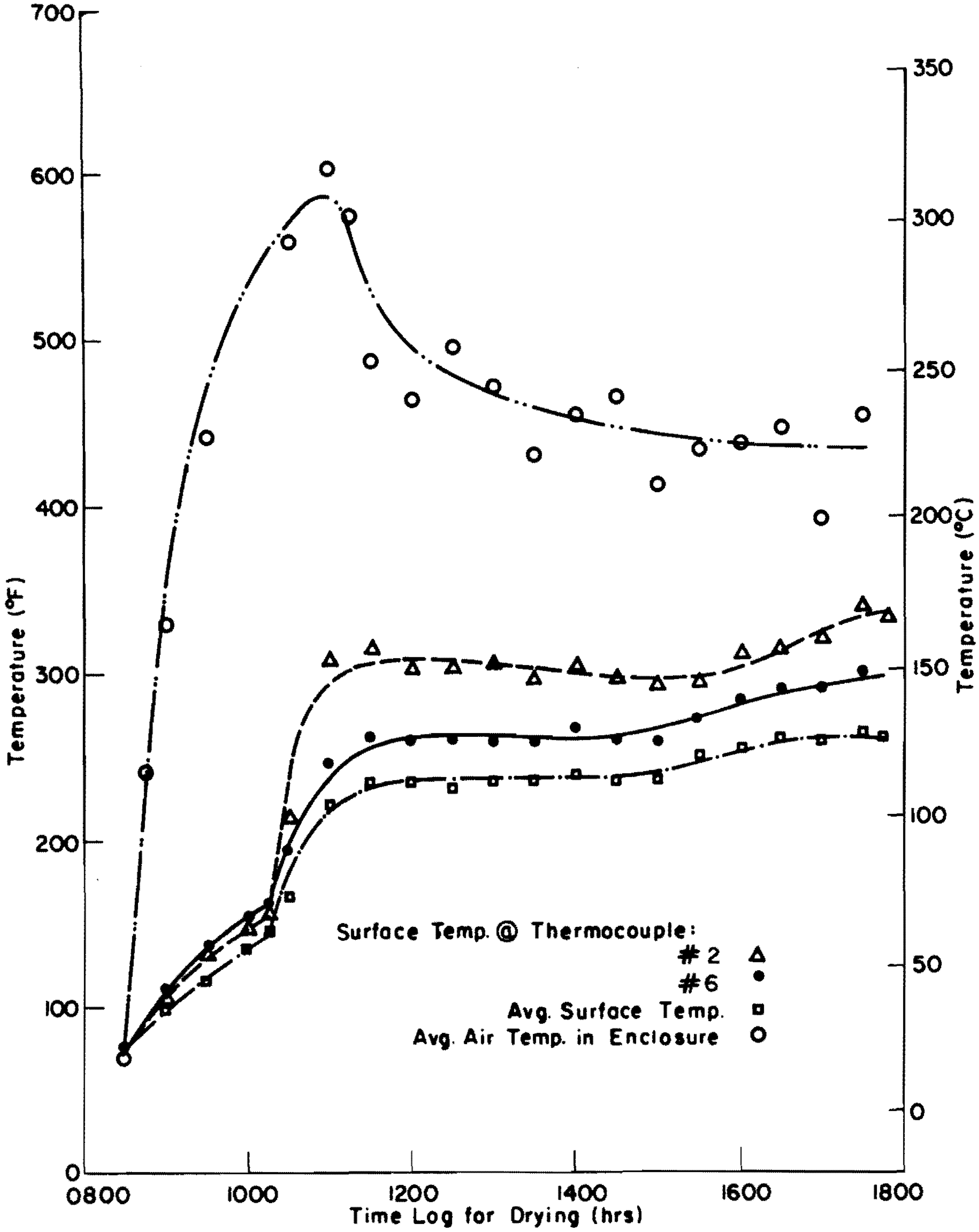


Figure 4.6 Drying Temperature vs. Time

4.4 Cooling

Upon completion of the drying operation the top of the drying enclosure was removed at 1800 hours and the slab was allowed to cool. The sand cover was not removed during the cooling period.

The top of the enclosure was left open until early evening when the humidity began to increase. The top panels were put back on the enclosure at 1930 hours and covered with polyethylene to minimize absorption from the air. This was done to prevent moisture from getting back into the slab.

It was found that the polyethylene film trapped too much of the warm air within the enclosure, so at 2200 hours the polyethylene at both ends of the enclosure was pulled back. Also the end panels were propped open to allow air to flow through the enclosure to increase the cooling rate. The west end of the enclosure was raised a couple of inches to allow air to flow directly over the sand cover. The enclosure was ventilated this way for the rest of the night.

Table 4.3 gives the time-temperature log during cooling. Fig. 4.7 shows the time versus temperature relationship at the warmest and coolest locations, as well as the average for the test area. Temperatures were monitored until 0700 in the morning and then the thermocouples were removed prior to soaking. The portion of the average temperature curve between 0700 and 1325 hrs was extrapolated from the first readings for the curing operation. The estimated slab temperature when soaking began was 90°F (32°C).

Table 4.3
Cooling Operation
Time-Temperature Log

Time	Slab Surface Temperature (°F)						
Sept. 26, 1975	1	2	3	4	5	6	Average
1800	219	254	295	255	241	226	248
1830	184	194	256	216	195	192	206
1900	162	171	218	193	180	181	184
1930	156	163	195	178	171	168	171
2015	157	167	178	172	163	163	166
2200	145	153	157	157	150	150	152
2300	133	140	150	146	133	136	139
2330	133	133	141	141	126	133	134
Sept. 27, 1975							
0400	109	111	117	115	109	111	112
0630	99	100	105	103	97	100	100
0700	99	98	102	98	93	95	97

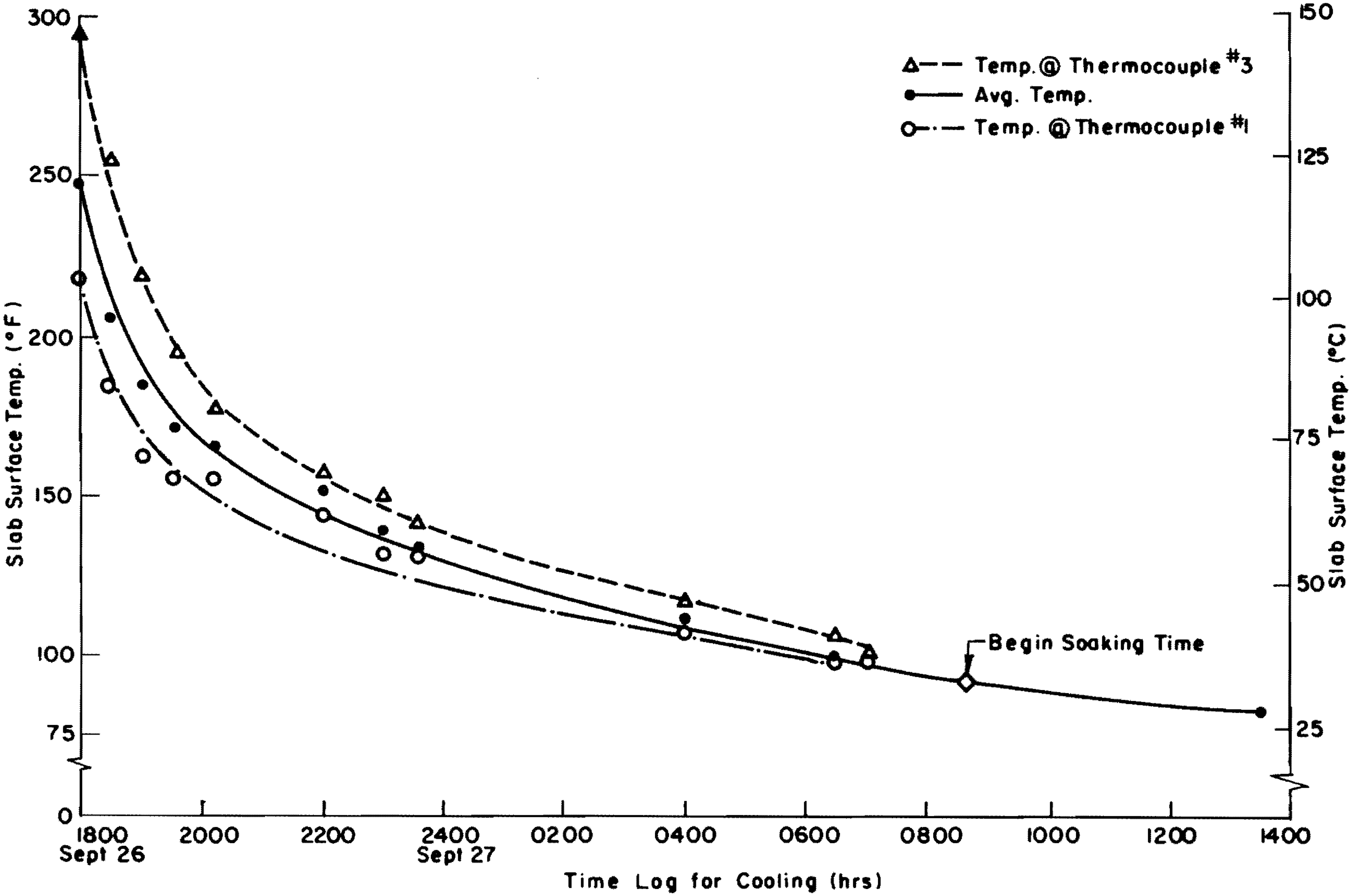


Fig. 4.7 Cooling Temperature vs. Time

The time required for cooling could probably be reduced significantly by using exhaust fans to remove the warm air or by blowing cool air over the surface.

4.5 Monomer Application

4.5.1 Preparation of Area for Monomer Application

After the slab had been allowed to cool overnight the drying enclosure was removed from the test area. The thermocouples were removed from the slab surface and the sand was screeded smooth. The test area was then divided up into six equal sections of approximately 46 sq ft (4.3 sq m) to assist in applying the monomer uniformly.

4.5.2 Monomer Mixing and Application

The monomer system consisted of methyl methacrylate (MMA) mixed with 5% cross-linking agent, trimethylpropane trimethacrylate (TMPTMA), and 0.5% initiator, AIBN.

The monomer was mixed in seven equal batches of approximately 4 gal (15.1 l) each. The first six batches were each applied to one of the six premarked areas. This gave each of these areas a monomer application of 0.6 lb/sq ft (28.7 N/sq m). The seventh batch was then applied to the three areas along the north side of the test area. This additional monomer brought the monomer loading on these three areas up to 0.8 lb/sq ft (38.3 N/sq m). Fig. 4.8 indicates the monomer application rates by area.

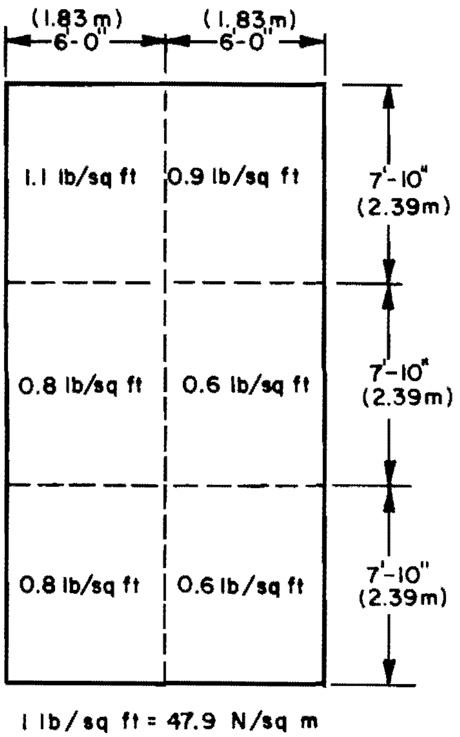


Figure 4.8 Monomer Application Rates on Test Area

The monomer was mixed by placing 15,000 cc (3.96 gal) of MMA in a 5-gal (18.9-l) can and adding 70.5 grams (0.155 lb) of AIBN to the MMA. The MMA was then stirred with a wooden paddle until the AIBN was dissolved. Then 750 cc (0.198 gal) of TMPTMA was added, and the mixture was again stirred. The batch of monomer was then transferred to the application can. Mixing of each batch took place just before being applied to the slab.

The monomer was applied beginning at 0800 hours using a specially constructed 5-gal (18.9 l) can equipped with a spray bar attached to the can by a plastic hose. The monomer was sprayed back and forth over the sand cover until the monomer was exhausted (Fig. 4.9). After the monomer was applied, the area was quickly covered with polyethylene film to minimize loss of monomer due to evaporation. When the last of the monomer had been applied to the test area (0845 hrs) and it had been completely covered with polyethylene, the top panels from the drying enclosure were placed over the film (Fig. 4.10). This was done to shade the test area from the direct sunlight and prevent a temperature increase which could result in premature polymerization.

It was noted after the monomer had been soaking for about 2.5 hrs that the sand was drying out faster than had been expected. It was decided that an additional batch of monomer would be applied to the eastern third of the test area. This increased the monomer loading on the northeast

Fig. 4.9 Application of Monomer

Fig. 4.10 Shading of Test Area During Monomer Soaking

corner to 1.1 lb/sq ft (52.7 N/sq m) and the monomer loading on the southeast corner to 0.9 lb/sq ft (43.1 N/sq m) (see Fig. 4.5).

The average total soaking time for the first monomer application was approximately 5 hours. The soaking time for the additional application was 2 hours.

4.6 Curing Operation

After the monomer was allowed to soak into the concrete, steam was used to polymerize it. Steam was injected into the enclosure to heat up the slab and thus cause the monomer to polymerize.

At 1200 hours preparations for the curing operation were begun. The sand cover and polyethylene film were left on the slab. The enclosure was moved back over the test area and new thermocouples were placed on the surface of the concrete through slits cut in the polyethylene. The wires were run across the top of the polyethylene and covered with sand to protect them from the heat. The steam distribution system was then assembled within the enclosure (Fig. 4.11).

Each steam manifold consisted of 1.5-in. (3.8-cm) ID pipe with 0.25-in. (0.6-cm) diameter holes drilled into opposite sides of the pipe at 11 in. (28 cm) o.c. to allow for distribution of the steam. The area and spacing of the holes were such that the combined area of the holes was

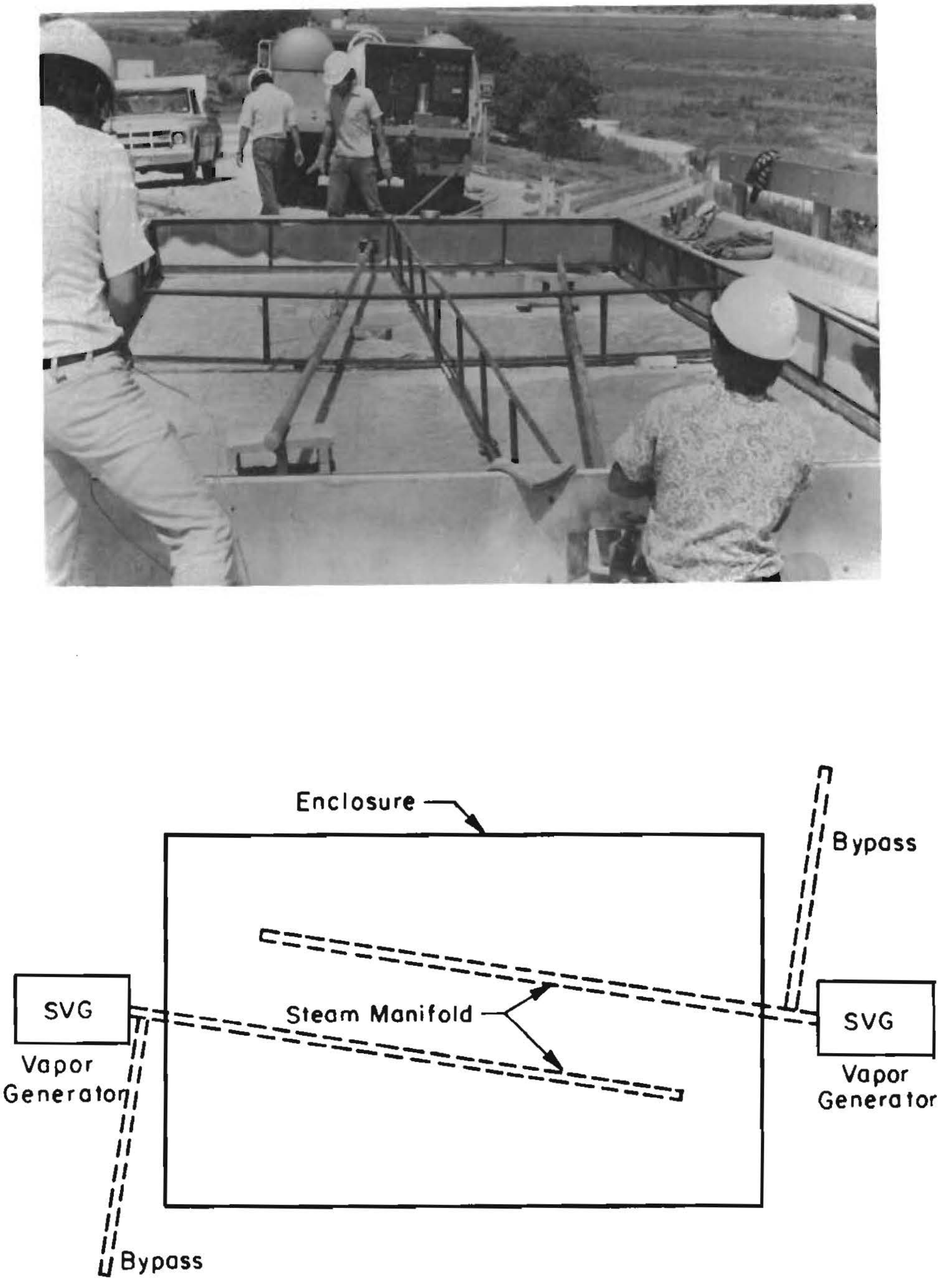


Figure 4.11 Placement of Steam Manifold

equal to the cross-sectional area of the pipe. Two separate manifolds were set up so that a vapor generator could be hooked up at each end of the enclosure in order to supply enough steam to insure polymerization. The piping system was suspended about 8 in. (20 cm) from the surface of the polyethylene film. Each steam line into the enclosure was equipped with a bypass line so that all steam could be diverted away from the enclosure while the steam flow and temperature were adjusted. This also prevented propane gas from accumulating inside the enclosure before combustion occurred in the vapor generator.

After the distribution system had been assembled, the top of the enclosure was put into place. To minimize heat loss, the bottom was sealed by placing sand around the bottom edges. The top of the enclosure was sealed by covering all of the edges between the top panels and the enclosure with tarps. The entire enclosure was then covered with a sheet of polyethylene film. After the enclosure had been sealed and the vapor generators were attached the curing operation was started (Fig. 4.12).

Only the vapor generator at the east end was used during the curing operation. Initially it was planned to use one to build up the surface temperature before turning the second one on. But it was found that one was adequate to supply sufficient heat to polymerize the monomer.

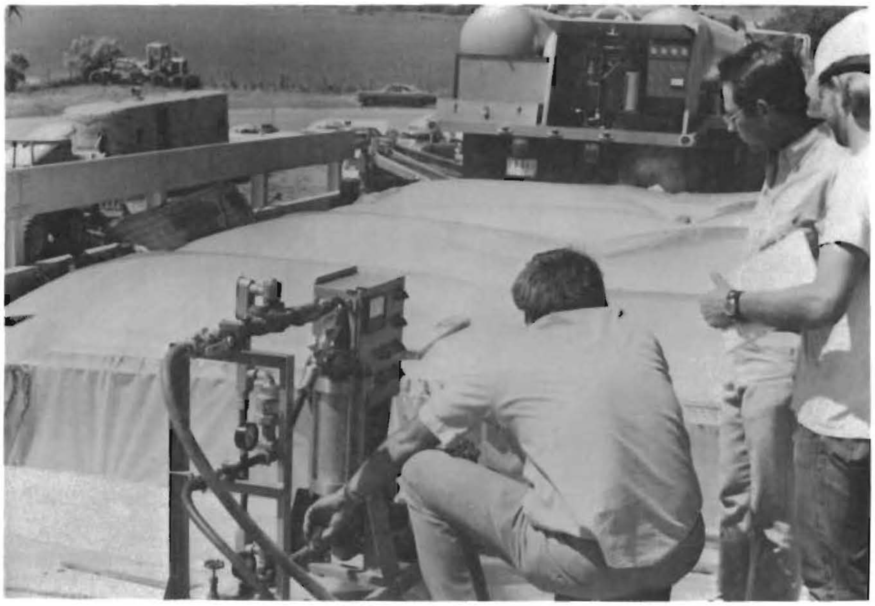


Fig. 4.12 Vapor Generator Used During Curing

When the steam vapor generator was turned on, the steam into the enclosure was kept moist, with an outlet temperature of 450°F (232°C), to minimize the danger of combustion of monomer vapor. After 30 minutes the temperature of the steam at the outlet was gradually increased to a maximum of 900°F (482°C) over a period of 1.75 hours. This corresponded to an increase in air temperature within the enclosure from 204°F (96°C) to 304°F (151°C). A gradual increase of the slab temperature was desired in order to prevent the monomer within the slab from heating up too quickly and possibly boiling out of the concrete. The slab reached a maximum temperature of 194°F (90°C). Approximately 15 gal (57 *l*) of propane were used in curing.

The entire curing operation required 2.5 hours to complete. As can be seen from the time-temperature log in Table 4.4 the surface temperature at most locations was approximately 140°F (60°C) within the first half-hour. Fig. 4.13 shows a plot of average slab surface temperature versus curing time. Only the average temperature was plotted because the range between high and low temperatures was small. The curve reflects the fact that the outlet steam temperature was decreased when it was observed that the thermocouple at location 2 was giving significantly higher temperatures than the other thermocouples. After it was determined that the readings at location 2 were not valid surface

Table 4.4
Curing Operation
Time-Temperature Log

Time	Temperature (°F)										
	Slab Surface							Air			Outlet
Sept. 27, 1975	1	2	3	4	5	6	Average	Air-1	Air-2	Average	Steam
1325	80	83	87	83	86	83	83	81	82	81	---
1340	146	178	144	124	155	124	138	206	196	201	450
1355	140	173	141	133	160	129	140	198	210	204	450
1410	174	198	160	135	160	132	152	218	230	224	600
1425	160	223	150	140	155	136	148	231	244	236	650
1440	160	255	157	150	160	144	154	241	257	249	700
1455	160	279	166	163	163	161	162	259	279	269	800
1510	170	297	181	177	172	177	175	284	302	293	900
1525	192	308	202	197	184	200	194	291	316	304	900
1540	193	261	193	194	183	198	192	259	259	259	500
1555	190	256	190	190	183	193	189	254	257	255	510
1600	Steam Vapor Generator Shut Off										

*Thermocouple readings at location 2 were invalid since steam was impinging directly upon the thermocouple.

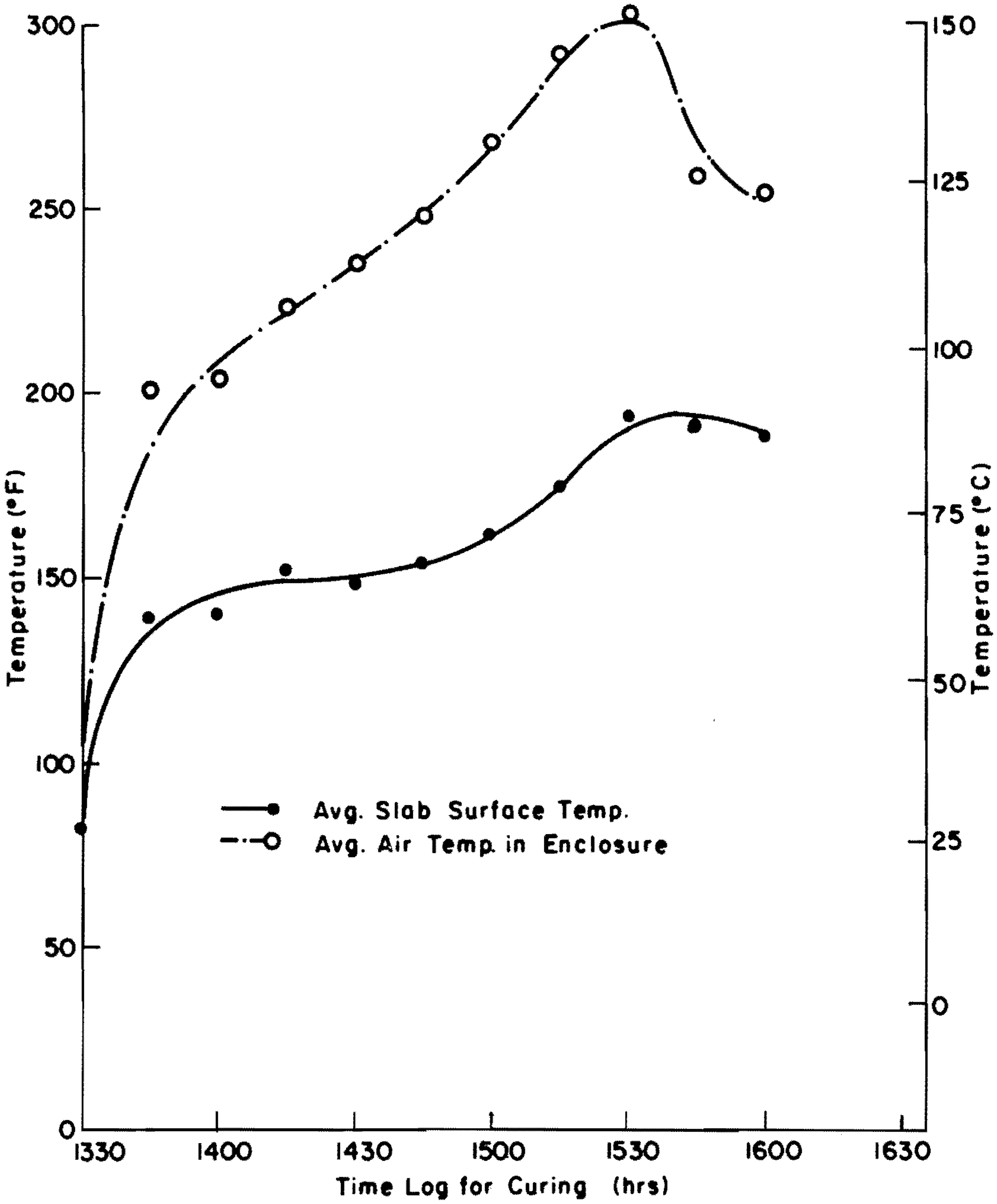


Figure 4.13 Curing Temperature vs. Time

temperatures because steam was being sprayed directly onto the thermocouple which had become exposed to the air, the steam temperature was increased.

5.0 Results of Polymer Impregnation

5.1 Appearance of Surface

The top panels of the enclosure were left in place until Monday, September 29, when they were removed. It was observed that the steam had melted many small holes 0.5 to 3 in. (1.2 to 7.5 cm) in diameter in the polyethylene, which had been left in place over the sand during curing. In the NE section several large holes one to three ft (0.3 to 0.9 m) in diameter were noted. In this quadrant, about one-half of the sand cover had been blown off the surface. Several other exposed areas were noted. Later examination of cores from these areas indicated no absence of polymer at the surface, which would have resulted if the monomer had been evaporated.

After the surface had been allowed to cool, the enclosure was removed and the sand was swept from the deck. The deck did not show any visible signs of polymer on the surface, i.e., there was no change in color of the slab surface. A careful visual examination was made of the narrow initial cracks that were in the slab surface, but it did not appear that the polymer had sealed them.

The sand cover, which had been left on during the curing, did not bond to the deck at all (Fig. 5.1). It was, in fact, very dry and loose and there was only slight evidence of polymerized monomer within the sand.

5.2 Effects of Drying on Deck

The impregnated area was carefully examined for cracks before and after the deck was impregnated. No additional cracks were found in the impregnated area after impregnation. However, some cracking occurred in the region between the expansion joint and the test area (Fig. 5.2). These cracks were noticed during drying. After the deck cooled, most of the cracks closed and were not visible to the naked eye.

The cracking is believed to have been caused because the thermal expansion of the test area was resisted on the east end only by the 3-ft (0.91-m) section of concrete between the joint and the test area. The 3-ft (0.91-m) section did not heat up nearly as much as the concrete inside the enclosure and, as a result, was subjected to tensile stresses. On the west end where a 13-ft (3.96-m) section resisted the thermal expansion, no cracking was observed.

From the results of the drying, it can be concluded that (1) for this application the 300°F (149°C) and higher temperatures were not excessive and (2) a greater distance should be left between the area being dried and the edge of the slab unless the enclosure extends all the way to the edge of the slab.

Fig. 5.1 Bridge Deck Surface After Impregnation

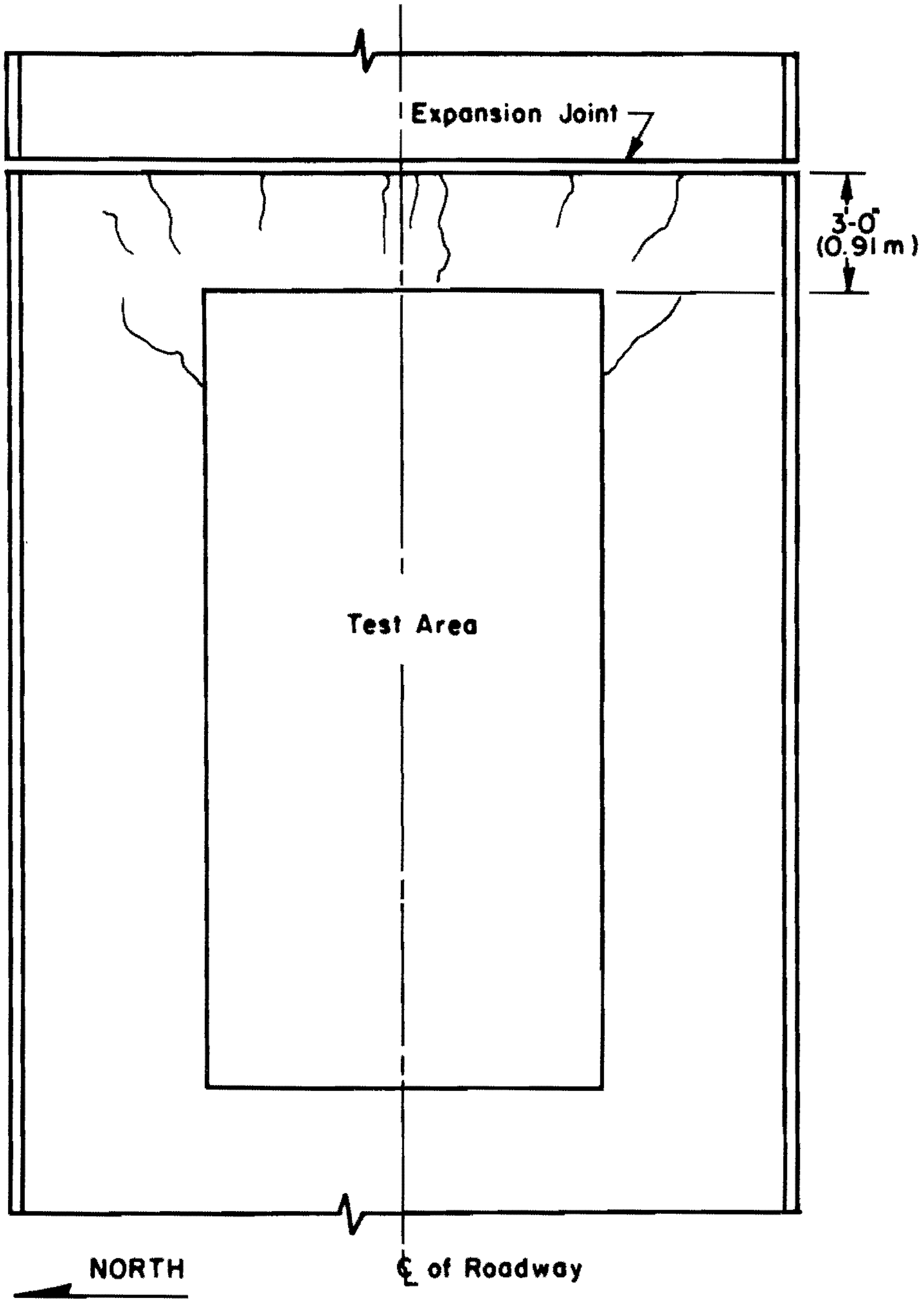


Figure 5.2 Cracking Caused by Drying

5.3 Depth of Impregnation

5.3.1 Core Samples

Six days after the impregnation of the deck had been completed, core samples were taken at various locations in the test area to determine the depth of polymer impregnation. Cores were taken from the center of each of the six areas shown in Fig. 5.3. In addition a core was taken from outside the test area to serve as a control specimen. Most of the cores taken were 2 in. (5.08 cm) in diameter, but a few 4-in. (10.16-cm) cores were taken for freeze-thaw tests to evaluate the effectiveness of the polymer impregnation.

5.3.2 Polymer Depth

The depth of polymer impregnation was determined by splitting the cores to observe the depth of penetration. A summary of the polymer impregnation depths is presented in Table 5.1. It will be noted that the minimum depth of impregnation was 1 in. (2.5 cm) with a maximum of 1.9 in. (4.8 cm). Except for the area with a monomer application of 1.1 lb/sq ft (52.7 N/sq m) the depth of polymer throughout the test area was constant. The only difference from one area of application to the next was in the color of the polymer. From a close visual examination of the split cores there was no evidence of any loss of monomer at the surface due to evaporation. Photographs of some of the cores are shown in Fig. 5.4. A penciled line indicates the lower limit of polymer.

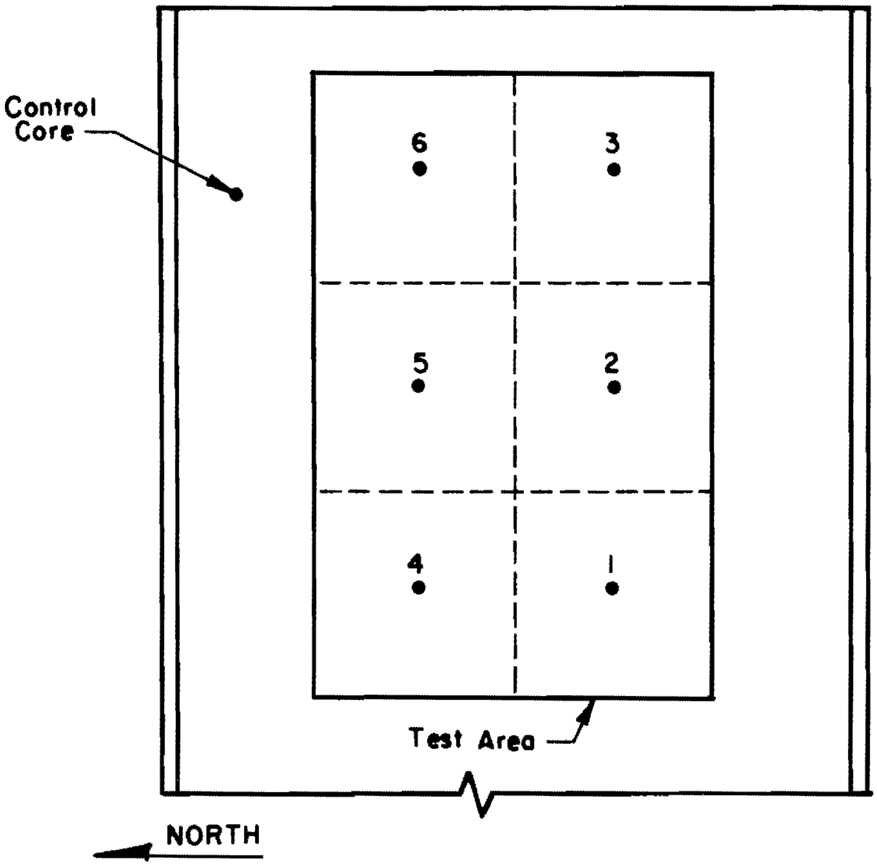


Figure 5.3 Core Locations

Table 5-1

Summary of Polymer Depth

Core Location	Monomer Loading (lb /sq ft)	Depth of Impregnation (inches)	Color of Polymer
1	0.6	1.0-1.25	Very light, splotchy
2	0.6	1.0-1.25	Very light, splotchy
3	0.9	1.0-1.25	Medium
4	0.8	1.0-1.25	Light to medium
5	0.8	1.0-1.25	Light to medium
6	1.1	1.5-1.9	Medium to dark

1 lb/sq ft = 47.9 N/sq m
1 in. = 2.54 cm

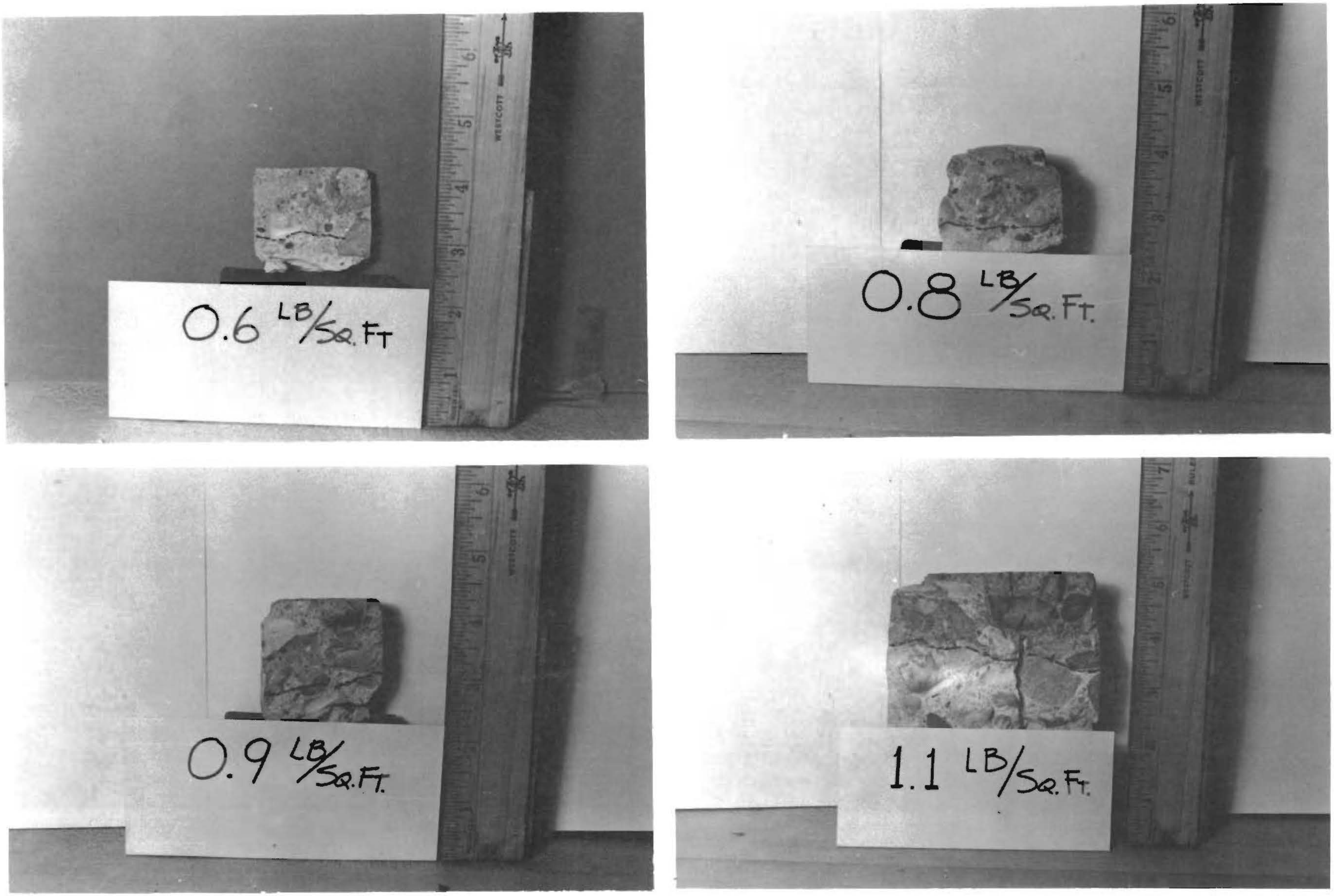


Fig. 5.4 Photographs of Cores from Areas of Different Monomer Application Rates

The polymer zone in the concrete was brown in color and was easy to distinguish from the unimpregnated concrete. The shade of brown varied from one area of polymer loading to another and was darker for higher monomer application rates. It has not yet been determined conclusively how much effect the variation in polymer loading has upon the durability properties of polymer-impregnated concrete. Previous tests on poor quality polymer-impregnated slabs have shown very good resistance to freeze-thaw deterioration and corrosion, however (4-7).

5.3.3 Water Penetration Test

A water penetration test was conducted to determine the depth of impregnation. This test is based upon the fact that once the concrete pores have been filled with polymer, water is no longer able to penetrate significantly into the concrete.

The procedure used was to cut open a core with a water-lubricated saw and then soak the cut face with water for 15 to 20 seconds. The sample was then removed from the water and the cut surface was quickly blown dry with an air hose. The unimpregnated portion of the concrete, having absorbed more water, could be clearly differentiated from the polymer-impregnated concrete.

This test showed that four distinct zones existed in each of the cores. The top two zones were clearly defined before the surface was wetted and dried. The third and fourth zones became apparent after the surface had been dried (Table 5.2).

The first or top zone is a layer of carbonation, or weathering, which was 0.25 to 0.4 in. (0.6 to 1 cm) in depth in all of the samples tested. This layer of carbonation is a weathered layer in the concrete which exists in concrete which is usually about ten years, or more, old. It is brought about by a reaction between the concrete and the environment. There was no evidence of loss of polymer in this layer due to evaporation and the layer appeared to be completely filled with polymer.

The next zone was a layer of darker polymer, compared to the one below it. This zone varied in depth depending upon monomer loading, but was not less than one in. in depth. The third zone was also a layer of polymer which was lighter in color than the layer above it. The fourth zone was simply the unimpregnated portion of the core.

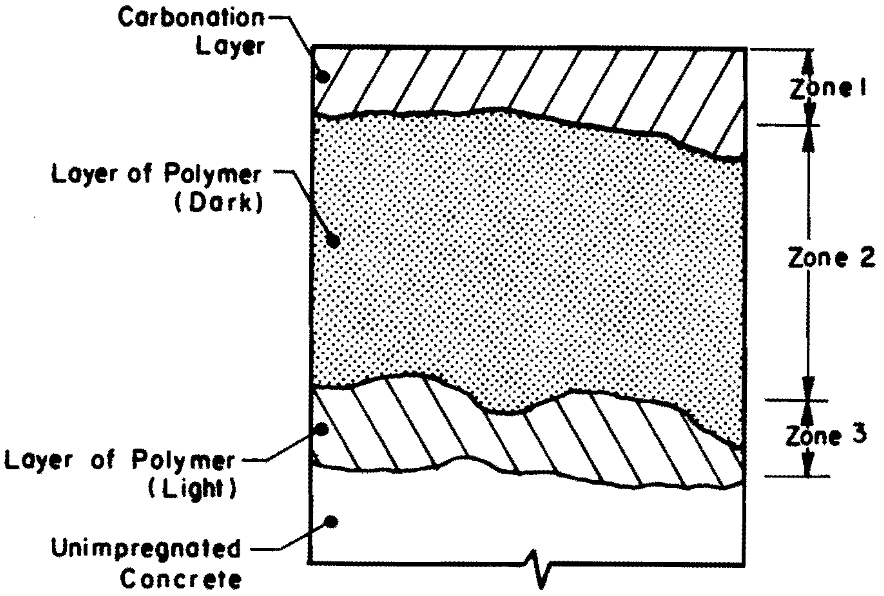
5.4 Freeze-Thaw Durability

Two 4-in. (10.16 cm) diameter cores were subjected to freeze-thaw tests by ponding 0.25 in. (0.64 cm) of water in steel rings bonded to the surface and cycling between -20°F (-6.7°C) and 73°F (22.8°C). The control specimen failed after 12 cycles. The impregnated specimen (monomer loading: 0.8 lb/sq ft (38.3 n/sq m)) has been subjected to 42 cycles and is still undergoing testing. Each core had fine cracks on the surface (Sect. 3.4). The cracks in the impregnated specimen were apparently sealed while those in the control probably contributed to its early failure.

Table 5-2

Summary of Depth Determined By Water Penetration Test

Core Location	Depth Zone 1 (inches)	Depth Zone 2 (inches)	Depth Zone 3 (inches)	Monomer Loading (lb /sq ft)
4	0.25	1	0.1	0.8
3	0.25	1	0.1	0.9
6	0.4	1	0.5	1.1



Core Profile

1 lb/sq ft = 47.9 N/sq m
1 in. = 2.54 cm

6.0 Cost for Polymer Impregnation of Bridge Decks

6.1 Available Options

The success of the polymer impregnation treatment for highway bridge decks will ultimately depend upon several factors: cost, benefits, and practicability, especially as compared to other available options. For existing bridge decks, polymer-impregnation appears to be the most promising means of providing durability. For new construction, other options will probably be available including epoxy-coated reinforcing bars and internally-sealed concrete using wax beads, although these methods do not have all of the advantages of polymer-impregnated concrete. Internally-sealed concrete will not provide increased strength although the resistance to water absorption should be comparable. The use of epoxy-coated bars should minimize corrosion problems but will have no effect on freeze-thaw durability.

6.2 Cost of Polymer Impregnation

The establishment of a reliable unit cost for polymer impregnation of bridges will require an initial learning period by contractors. The experience gained in the first few projects will undoubtedly lead to modifications in specifications.

The cost of monomer, catalyst, and cross-linking agent in the proportions used in the Center Point Road bridge demonstration is about $0.30/sq ft or $2.70/sq yd ($3.23/ sq m) at an application rate of 0.60 lb / sq ft (28.7 N/sq m) at 1975 prices. The application rate may have to be increased for more porous concrete. The cost of equipment as used in this demonstration is relatively low and should be adequate for many re-uses. It is likely that more sophisticated equipment will be developed to minimize labor requirements and to more efficiently utilize fuel and monomer.

The optimum use of labor and equipment would seem to dictate simultaneous and/or multiple operations. Using a checkerboard arrangement, one or more areas could be dried while soaking, and curing could be underway in other areas of the bridge.

Bids have been taken by the SDHPT on two new bridges to be polymer-impregnated as part of the construction contract. Prior to the bid opening, a workshop sponsored by the Center for Highway Research and the SDHPT was held to educate contractors on the materials, procedures, and safety requirements for polymer impregnation.

The first bridge, to be built in Big Spring, is 751 ft (229 m) long with a 64-ft (19.5-m) roadway and has a maximum grade of about 6%. The unit prices for the complete impregnation process are given in Table 6.1 in order of the overall low bidders for the entire project. The unit prices include the demonstration of the contractor's impregnation procedures on a slab-on-grade built on the site.

The second bridge, located in Lubbock, is much smaller, with a length of 207 ft (63 m) and a roadway 42-ft (12.8-m) wide. The prices, shown in Table 6.2, are higher than for the Big Spring bridge, apparently because of the much smaller size. For example, the firm that bid $13.35/sq yd ($15.97/ sq m) for the Big Spring bridge bid $50/sq yd ($59.80/sq m) for the Lubbock bridge. It should be noted that in general the bidders were not the same for the two bridges.

It is probable that contractors will amortize the cost of their equipment on the first job. Neglecting inflationary trends, future jobs may be bid for lower unit prices for comparable size bridges.

Table 6.1 Unit Bid Prices on Big Spring Bridge[a]

Bidder[b]	Unit Price, $/sq yd[c]
1	10.00
2	9.00
3	5.00
4	11.00
5	13.35
6	14.00
7	15.00

[a] 5396 sq yds (4512 sq m)

[b] In order of low bidders on entire project

[c] $1.00/sq yd = $1.20/sq m

Table 6.2 Unit Bid Prices on Lubbock Bridge[a]

Bidder[b]	Unit Price, $/sq yd[c]
1	15.00
2	15.00
3	50.00
4	40.00
5	17.50
6	50.00
7	10.00
8	35.00
9	14.00
10	35.00

[a] 966 sq yds (808 sq m)

[b] In order of low bidders on entire project

[c] $1.00/sq yd = $1.20/sq m

7.0 Summary and Recommendations

7.1 Summary

A portion of a bridge deck was successfully impregnated using procedures developed as part of Research Study 114 at the Center for Highway Research at The University of Texas at Austin. The bridge was 17 years old and in good condition.

The bridge deck was initially evaluated by means of a monomer penetration test to determine if the concrete required cleaning prior to impregnation. Cleaning was not required.

A thin layer of sand was applied to the bridge prior to drying. With the use of an insulated enclosure, the bridge was dried for 5.75 hours after the average surface temperature reached 260°F (127°C). The concrete was allowed to cool overnight to 90°F (32°C).

Monomer was applied to the concrete at rates ranging from 0.6 lb / sq ft (28.7 N/sq m) to 1.1 lb / sq ft (52.7 N/sq m). The test area was shaded during the soaking period. The monomer soaking time was five hours.

The monomer was polymerized by steam injected into the enclosure. The maximum concrete surface temperature attained was 194°F (90°C). The entire curing operation required 2.5 hours.

The impregnated depth ranged from 1 in. (2.5 cm) to 1.9 in. (4.8 cm), with the greatest depth occurring in the area where the largest amount of monomer was used. Sand did not bond to the concrete surface, nor was there any other change in appearance of the surface.

Costs of polymer impregnation based on bids received by the State Department of Highways and Public Transportation are given. For the largest of the two bridges which has an area of 5396 sq yds (4512 sq m), the bids ranged from $5/sq yd ($6.00 sq m) to $15.00/sq yd ($18.00/sq m).

7.2 Recommendations

Specific recommendations regarding the impregnation process are as follows:

1. A minimum drying time of five hours at a temperature of the range of 250°F (121°C) to 300°F (149°C) is recommended.
2. The perimeter of the drying enclosure should either be positioned at the edge of expansion joints or curbs or be a minimum distance of 10 feet (3.1 m) away from joints or curbs to minimize the danger of cracking due to tensile stresses caused by thermal expansion.
3. Monomer application rates should be increased from 0.6 lb/sq ft (28.7 N/sq m) for concrete with high water-cement ratios.
4. Soaking times of five hours are adequate to obtain a penetration greater than 0.5 in. (1.27 cm).

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APPENDIX

Appendix A

A.1 Burners

The burner units used in the drying system were No. 356 Lightweight Torches, purchased from Blackwell Burners of San Antonio, Texas. The No. 356 torch has a rated heating capacity of 500,000 BTU.

The original jet orifice was found to be too large to allow a stable gas flow. The orifice was replaced by a smaller one, which was drilled out until a stable flow was obtained. The burner unit was equipped with a globe valve for regulation of gas.

A.2 Vapor Generator

The steam source used during curing was a Gray Vapor Generator, manufactured by GCOE Corporation of Dallas, Texas. The steam generator has a capacity of 500,000 to 3,000,000 BTU per hour with a temperature range of 180°F to 1400°F. Support equipment required for the operation of the generator included : a 125 ft^3/min (3.5 m^3/min) air compressor, a 300 gal (1135 l.) propane tank, water [40 psi (27.6 N/cm^2) and 2 to 10 gpm (7.6 to 37.8 l./min)], and 110 V electricity. The generator should be equipped with a bypass valve when the steam is injected into an enclosure to prevent the initial uncombusted gas from igniting. For curing larger areas, a larger air compressor is required.

TEXAS HIGHWAY DEPARTMENT

SPECIAL SPECIFICATION

ITEM 4127

POLYMER IMPREGNATION OF CONCRETE SLABS

4127.1. Description. This item shall govern for the materials and the construction methods required for polymer impregnation of concrete slabs in accordance with the plans and these specifications.

4127.2. General. The Contractor shall submit detailed plans and procedures for polymer impregnation at least 60 days prior to the demonstration required herein. This submission shall include materials to be used, type and size of equipment and apparatus, provisions for storage of monomer ingredients, mixing of monomer solution, the proposed impregnation pattern of the deck, and necessary safety precautions.

4127.3. Demonstration Impregnation. A minimum of two weeks prior to impregnation of the bridge slab, the Contractor shall demonstrate his proposed procedures and equipment on a reinforced concrete slab cast on the ground at the site. The reinforcement shall be No. 4 bars on 6 inch centers, in both directions at approximately 2 inches below the top of the slab. The slab shall have the same thickness used in the bridge, have a minimum area of 150 square feet, and be of the same mix design to be used in the bridge slab. The slab shall be placed on a vapor barrier and shall have a 5 percent grade in one direction. The surface texture shall be the same as that used on the bridge. Cores will be taken to evaluate the depth and the quality of impregnation. The demonstration shall also be used to evaluate equipment and procedures.

4127.4. Materials. The monomer solution shall consist of 100 parts by weight of monomer, Methyl Methacrylate, MMA, as produced by Rohm and Haas Company or an approved equal; 5.0 parts by weight of a crosslinking agent, Trimethylolpropane Trimethacrylate, TMPTMA (X-980), as produced by Rohm and Haas Company or an approved equal; and 0.5 parts by weight of the polymerization initiator, Azobis (isobutyronitrile), AIBN (VAZO 64), as produced by E.I. Dupont Company or an approved equal.

The MMA shall have a minimum purity 99.8 percent, and shall contain an inhibitor, MEHQ (methyl ester of hydroquinine) in an amount not less than 9 ppm nor more than 12 ppm as supplied by the manufacturer.

The TMPTMA shall have a minimum purity of 95 percent and contain not less than 80 ppm nor more than 100 ppm of HQ (hydroquinine) inhibitor.

AIBN shall have a minimum purity of 96 percent.

The Contractor shall furnish certification from the materials supplier that the materials meet the requirements of this specification. Further testing, as required, will be done by the Department.

4127.5. Storage and Handling. The Contractor shall obtain from the manufacturer detailed information on safe practices for storage, handling and disposal of these materials and also their explosive and flamability characteristics, health hazards and recommended fire fighting equipment.

Individual materials shall be stored in accordance with the manufacturer's recommendations and in a manner that prevents the materials from becoming contaminated in any way by foreign substances. The AIBN shall not be stored in the same structure or vehicle as the MMA, or the TMPTMA, until just prior to mixing, and then only the specific amounts to be used for a given batch shall be brought into the same area.

Once these ingredients have been mixed, the resulting mixture shall be regarded as a highly reactive material which is more dangerous than any of the individual ingredients separately. Suitable fire extinguishers shall be located near the mixing and application area. Further information on fire safety may be found in "Chemical Safety Data Sheet", SD-79, from Manufacturing Chemists Association, 1825 Connecticut Avenue, N. W., Washington, D.C. 20009.

4127.6. Mixing. The individual ingredients for the monomer solution shall be premeasured to yield 100 parts of MMA, 5 parts of TMPTMA and 0.5 parts of AIBN, proportioned by weight, in the final mixture.

All mixing shall be done in an unenclosed, shaded area. Mixing shall proceed by introducing the MMA into a suitable container. The AIBN shall then be added and mixed until no undissolved particles of AIBN are evident. The TMPTMA should then be added and mixed. In no case shall the mixing time be less than 5 minutes. Samples will be taken for testing to insure that the mixture will polymerize at the desired rate.

The mixture shall be prepared in batches of not greater than 30 gallons.

The temperature of the mixture during preparation and application shall be between 40F and 80F.

The mixture must be applied within 30 minutes after completion of mixing. A longer time before application will be permitted at lower temperatures provided the Contractor can demonstrate that the procedure is safe and that adequate depth of impregnation is obtained.

Portions of a given batch or batches which have become unsatisfactory for use shall be disposed of by incineration under controlled conditions in a safe open area, or incorporated into a land fill, all in accordance with applicable federal, state and local regulations.

4127.7. Construction Methods. Not sooner than 28 days after placement of the concrete to be treated, the monomer solution shall be applied to the concrete surface within the limits shown in the plans.

The surface of the concrete shall be swept clean to remove all foreign material. Substances such as oil or grease which cannot be removed by sweeping shall be cleaned with an approved solvent and/or sandblasting. The surface shall be cleaned not more than 4 hours prior to application of heat for drying. Any solvents used shall be allowed to evaporate completely prior to heat application.

The deck shall be dried by a method determined by the Contractor. The heat source may include, but not necessarily be limited to, open flame burners, infrared heaters, warm forced air, or heat lamps. Adequate enclosures shall be provided to concentrate and confine the heat.

The intensity of heat application shall be rigidly controlled to insure that the rate of temperature rise of the concrete surface shall not exceed 2 degrees per minute, and in no case shall there be evidence of sooting, charring, spalling or cracking of the concrete. The drying temperature on the surface of the concrete shall be uniform and maintained between 225F and 260F for 5 hours. Caution shall be exercised to prevent localized temperatures in excess of 260F.

The Contractor shall install heat sensing devices on the concrete surface, one per 100 square feet, at locations approved by the Engineer, which will continuously record the surface temperature.

The sand cover required herein may be applied to the surface before the application of heat in order to dry the sand.

As nearly as possible, the areas to be dried at one time shall be approximately symmetrical with respect to the structure centerline to minimize the unsymmetrical longitudinal expansion of the deck.

Any surface damage caused by the drying process shall be repaired by approved methods prior to monomer impregnation.

The monomer solution shall be applied within 24 hours after completion of drying and while the temperature of the surface of the concrete is between 50F and 90F. Cooling of the surface to within the above temperature range may be accelerated by blowing <u>dry</u> air over the surface.

Clean <u>dry</u> concrete sand or blast sand shall be applied to the surface to a depth of three eighths to one half of an inch prior to application of the monomer solution. (The sand may be damp if applied prior to drying.) The purpose of the sand is to hold the monomer solution on the surface during the soaking period. Other materials such as <u>dry</u> burlap or blankets may be used if they are shown to perform adequately.

While the slab is being cooled and during the time the monomer solution is being applied and soaking into the concrete, the surface area being impregnated shall be shaded and protected from sunlight and moisture by an enclosure. In addition, a polyethylene membrane shall be placed on the surface of the concrete or sand during cooling and the sand during soaking for the purpose of preventing moisture from high relative humidity and other sources from entering the dry sand covering and/or the concrete.

The monomer solution shall be applied uniformly to the surface at the approximate rate of sixty five one-hundredths (0.65) gallons per square yard. The monomer solution shall be carefully sprayed so as not to erode the sand cover. The sand surface shall be covered with polyethylene sheeting as soon as possible after application of the monomer solution. The polyethylene shall be weighted to hold it in place.

The monomer solution shall be allowed to soak into the concrete from 4 to 6 hours. If the sand cover becomes dry, additional monomer solution shall be applied.

During application and soaking, the monomer solution shall be confined to the area being impregnated. It shall not be allowed to run or be sprayed onto previously impregnated surfaces. A slight overlap of areas will be permitted to insure that the bridge deck is impregnated throughout the designated limits.

Excess monomer solution shall not be permitted to run down the bridge deck or through expansion joints or holes in the deck. Inert material, such as dry sand, shall be used to soak up excess runoff.

Suitable fire precautions shall be taken during the application and soaking period, during which time no open flame, drying or otherwise, shall be closer than 25 feet to the area being impregnated or to the mixing area.

Immediately after the required soaking period, the impregnated surface shall be cured by application of heat. The surface temperature of 140F for curing shall be attained in not more than 2 hours and maintained between 140F and 175F for 2 hours. The heat source may be steam, ponded hot water or forced warm air. Open flame heat will not be permitted.

The method of heat application and distribution shall be such as to insure uniform surface temperature and avoid localized hot spots. During heat application, the polyethylene sheeting shall remain in place on the surface to minimize evaporation.

The cover shall be removed after curing is completed. Any sand which has bonded to the slab to a depth of one fourth of an inch or more, or where a rough riding surface results, shall be removed to the satisfaction of the Engineer.

4127.8. Measurement. The work required for polymer impregnation of the concrete slab will be measured by the square yard. This includes sixty five one-hundredths (0.65) gallons of monomer solution, 5 hours drying time, 4 to 6 hours soaking time and 2 hours curing time, per square yard.

4127.9. Payment. Payment for polymer impregnation of concrete slabs will be at the unit price bid per square yard, measured as prescribed above, which payment shall be full compensation for the demonstration impregnation; for all testing; for furnishing and applying monomer solution, sand, blankets, membranes and enclosures; for all cleaning, drying and curing; for all labor, tools, materials, equipment and incidentals necessary to complete the work and for all special facilities and equipment for storage of materials and fire precautions.