POLYMER IMPREGNATION
OF
EXISTING CONCRETE BRIDGE DECK

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16. Abstract

Procedures used for polymer impregnation of a section of bridge deck are described in detail in this report. Insulated enclosures are used for drying the slab for a specified time. Monomer application rates were varied in specified test sections to determine the optimum rate of application for sufficient impregnation depths. Concrete sand was used to prevent rapid evaporation of the monomer during soaking.

Steam heat was the method selected to polymerize the monomer. This procedure required approximately two hours for complete polymerization.

The depth of impregnation varied based on the rate of monomer loading used. The higher the application rate, the thicker the impregnated layer. The depths ranged from 1 inch to 1.9 inches.

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Summary

Polymer impregnation of bridge decks is becoming a leader in the many methods constructed to render a bridge deck impervious to the intrusion of moisture and de-icing chemicals. Structural damage which can occur from these unwanted substances may be costly to repair and dangerous to the traveling public.

Procedures used for polymer impregnation of a section of bridge deck are described in detail in this report. Insulated enclosures were used for drying the slab for a specified time. Monomer application rates were varied in specified test sections to determine the optimum rate of application for sufficient impregnation depths. Concrete sand was used to prevent rapid evaporation of the monomer during soaking.

Steam heat was the method selected to polymerize the monomer. This procedure required approximately two hours for complete polymerization.

The depth of impregnation varied based on the rate of monomer loading used. The higher the application rate, the thicker the impregnated layer. The depths ranged from 1 inch to 1.9 inches.

Implementation Statement

The results of much polymer impregnation research indicated this would successfully render impervious the top of concrete bridge decks. Field trials indicate that successful procedures for polymer impregnation of concrete slabs have been developed. The strength and durability of slabs are increased as polymerization depths are increased Therefore, it is suggested that implementation proceed by the use of this method to render entire bridge decks impervious to intrusion by water and de-icing chemicals and for structural repair of spalled or badly cracked concrete slabs.

The first contract polymer impregnation project in Texas has been let. The bridge is a large bridge in square feet surface area and the entire deck will be polymer impregnated before opening to traffic.

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CHAPTER 1 - INTRODUCTION

Introduction of moisture and de-icing chemicals into bridge deck concrete has for many years been a nationwide problem. The steel corrosion which results from the moisture and chemicals has caused scaling, spalling, and even structural damage to many of the Nation's bridge decks.

Several methods have been employed in various locations in an attempt to retard the intrusion of undesirable chemicals into the concrete. Some methods have proven effective for short durations, others have shown to be effective in rendering a bridge deck virtually impervious to moisture and de-icing chemicals for long periods of time.

Investigation under Texas Cooperative HPR Research Study 3-9-71-114 indicates that polymer impregnation of bridge decks is a successful, long lasting procedure for preventing and/or retarding steel corrosion from water and deicing chemicals introduced from a concrete bridge deck surface. Previous small scale explorations in Texas and larger applications in other areas indicated that the polymer impregnation process had advanced to the point that a larger-scale field trial installation on a complete bridge deck was desirable.

CHAPTER 2 - TEST SITE LOCATION AND HISTORY

In order to provide adequate field evaluation of the polymer impregnation process, Texas State Department of Highways and Public Transportation included this process in the plans and specifications for the construction of two bridges. One is the Owen's Street Railroad Overpass structure on State Highway 350 at Big Springs, Texas, consisting of 48,564 square feet of deck surface area. The other is a 26,082 square foot structure on I.H.-27 at Lubbock, Texas. The companion twin structure will have the Iowa method dense concrete on the deck surface. These bridges are currently under construction.

To further evaluate some of the equipment such as the insulated enclosure, the propane burners and the portable steam generator prior to impregnating the larger areas of the above two structures, it was deemed desirable to perform a smaller field test giving the various construction contractors the opportunity to observe this work. Also, various monomer application rates could be applied to verify the range of quantity specified in the two construction contracts. The bridge selected for this field application is located approximately three miles southwest of San Marcos, Texas (figure 1) and is the crossing of Centerpoint Road over I.H.-35. Centerpoint Road bridge has a roadway width of 24 feet and is 310 feet long, consisting of six prestressed concrete beam and slab units with the following lengths: 40-50-65-65-50-40. The slab thickness is 6¼ inches. Construction began in 1957 with the last slab being placed in December of 1957. Early 1958 brought about the opening of this bridge to traffic. Traffic since opening has been light (automobiles and farm trucks) and the average daily traffic has remained very low.

The concrete used in the slab was "five-sack"/cubic yard Class A transit mix with partially crushed limestone gravel as aggregate. The water-cement ratio for the mix was 6.5 gallon/sack. The average slump of the mix was 3½ inches. No admixtures were used in the mix. The slab was belt finished.

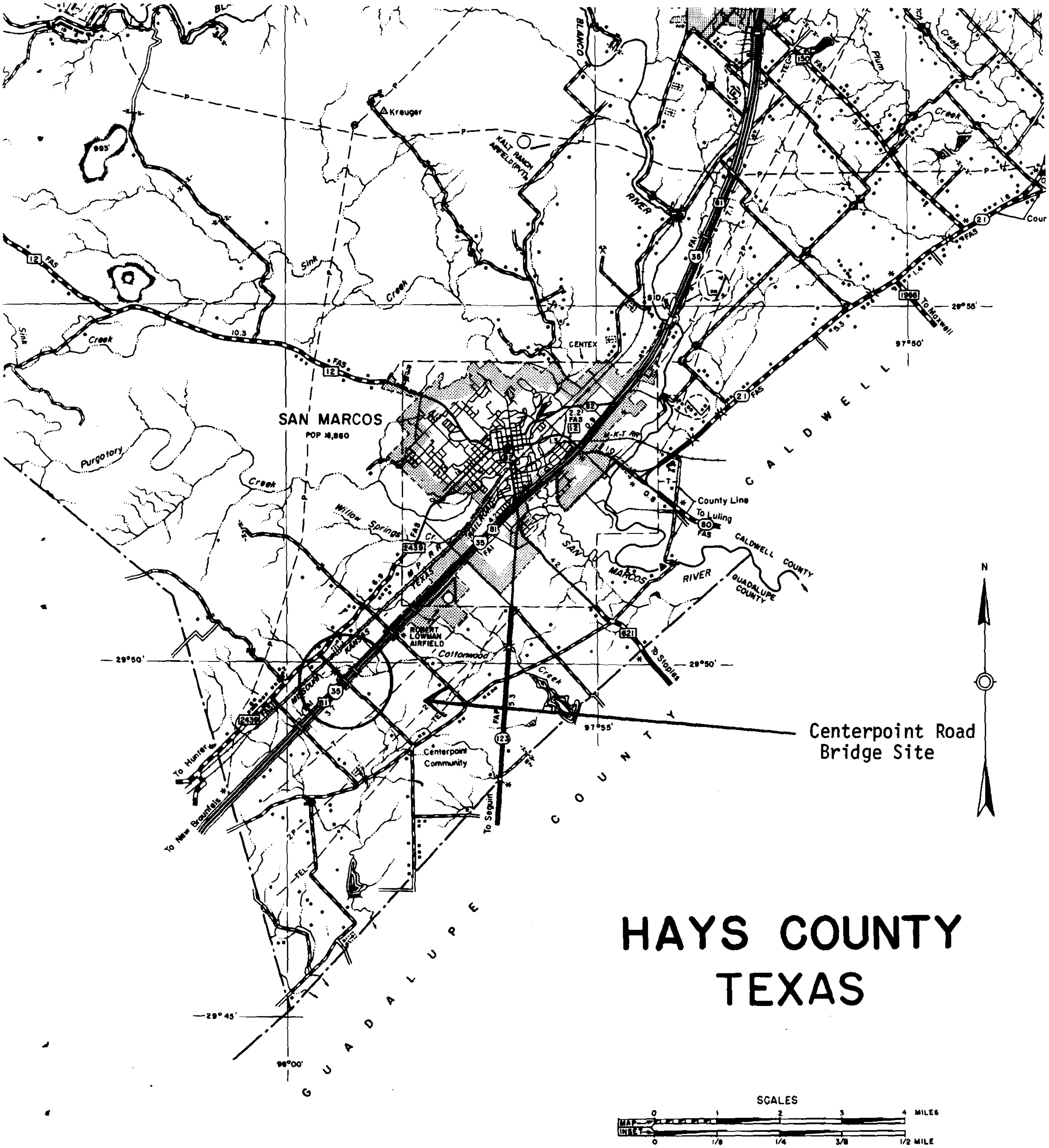

HAYS COUNTY
TEXAS
Centerpoint Road Bridge Site
SAN MARCOS
POP 18,860
Kreuger
KALT RANCH AIRFIELD (PVT)
CENTEX
Sink Creek
Purgatory Creek
Willow Springs Cr.
Plum Creek
BLANCO RIVER
SAN MARCOS RIVER
M-K-T RR
ROBERT LOWMAN AIRFIELD
Cottonwood Creek
Centerpoint Community
County Line
To Luling
To Maxwell
To Staples
To Seguin
To New Braunfels
To Hunter
CALDWELL COUNTY
GUADALUPE COUNTY
CALDWELL
GUADALUPE COUNTY
29°55'
29°50'
29°45'
97°50'
97°55'
98°00'
N
SCALES
MAP
INSET
0
1
2
3
4 MILES
0
1/8
1/4
3/8
1/2 MILE

Figure 1

No linseed oil or any other sealer has ever been applied to this deck. Two de-icing salt treatments have been applied. These were both applied shortly after opening to traffic and none have been applied since. State Department of Highways and Public Transportation maintenance personnel inspected this bridge and found a number of leaking cracks in the surface indicating that it should be sealed.

The section chosen for the polymer impregnation treatment was the 40-foot span on the west end of the bridge. The cross slope of the bridge deck about the center line is 0.83% and the average grade of the bridge in this span is approximately 4%.

CHAPTER 3 - TEST SITE PREPARATION AND EQUIPMENT SET-UP

In an attempt to achieve a symmetrical drying pattern, the area to be tested was located equally around the centerline and was 12 feet wide and 24 feet long (figure 2).

In order to achieve successful polymer impregnation of concrete, the area to be treated must be totally clean and free of dirt, leaves, oil and all debris. This bridge deck was thoroughly swept with a broom to accomplish a complete surface cleaning.

Accuracy in temperature monitoring during the drying phase is extremely important to accomplish deck drying and to prevent any additional structural deterioration which might result from excess heat being applied to the concrete. To adequately monitor these temperatures, eight thermocouples were placed (figure 3). Six of these thermocouples were used to monitor the deck temperatures and two were used to keep check on the air temperature within the drying enclosure.

In order to dry the concrete deck evenly, a 3/8 inch layer of undried concrete sand was spread over the area to be treated. This also allows the sand to be thoroughly dried prior to monomer application. Extra sand was placed on the wires leading to the thermocouples to further insulate them from the heat (figure 4). Past experience has shown excessive heat will burn the insulation from the thermocouple rendering it ineffective in the temperature monitoring.

Proper drying can only be accomplished within controlled conditions so a drying enclosure was assembled and placed on the test section (figure 5). The enclosure is constructed of light steel framework covered with panels made of sheet metal and fiberglass insulation and is constructed so that it can be easily assembled and disassembled by bolts. The enclosure used consisted of two 12 foot x 12 foot x 1½ foot sections bolted together. The enclosures can be prefabricated and as many as desired connected together to "treat" practically any desired area, within reason.

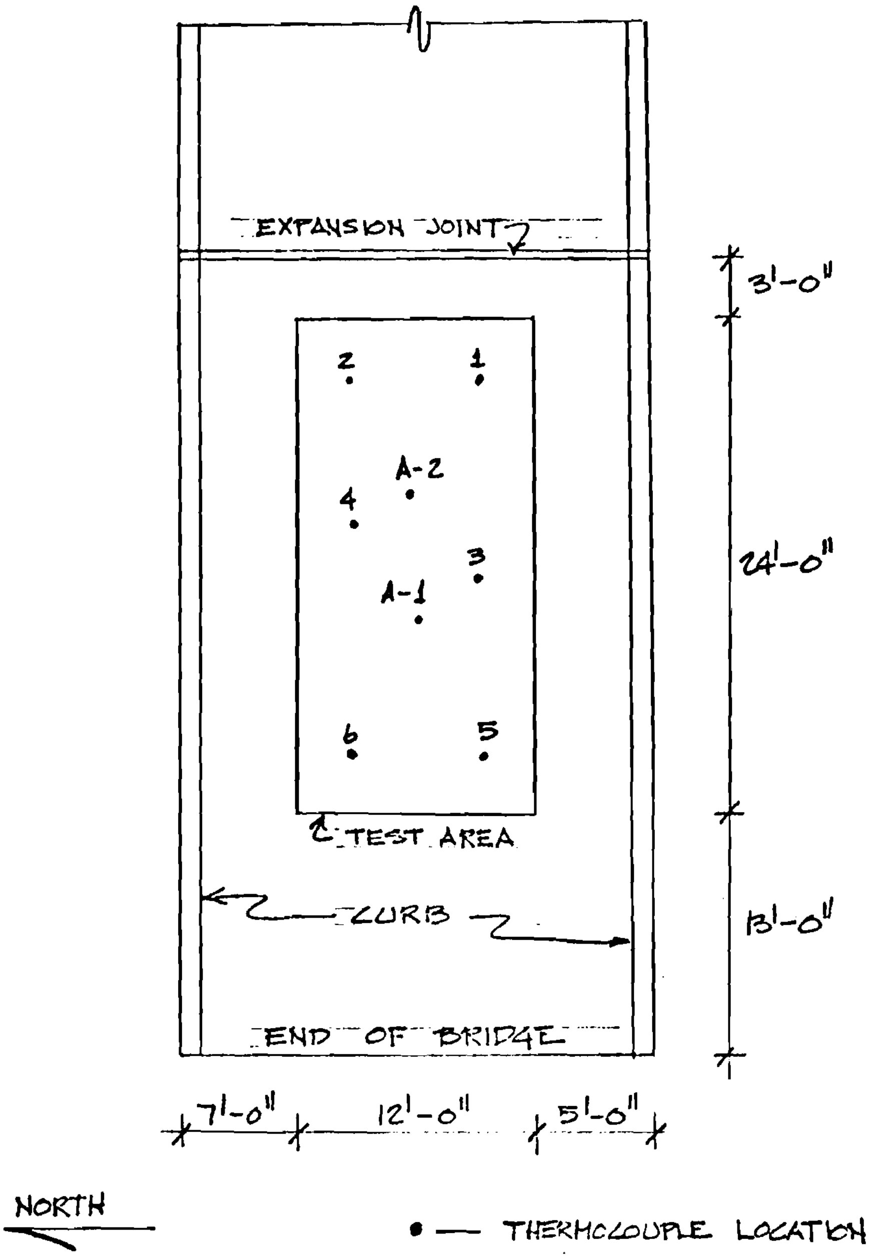


Figure 2 Location of Test Area

Figure 3 - Installation of Thermocouples

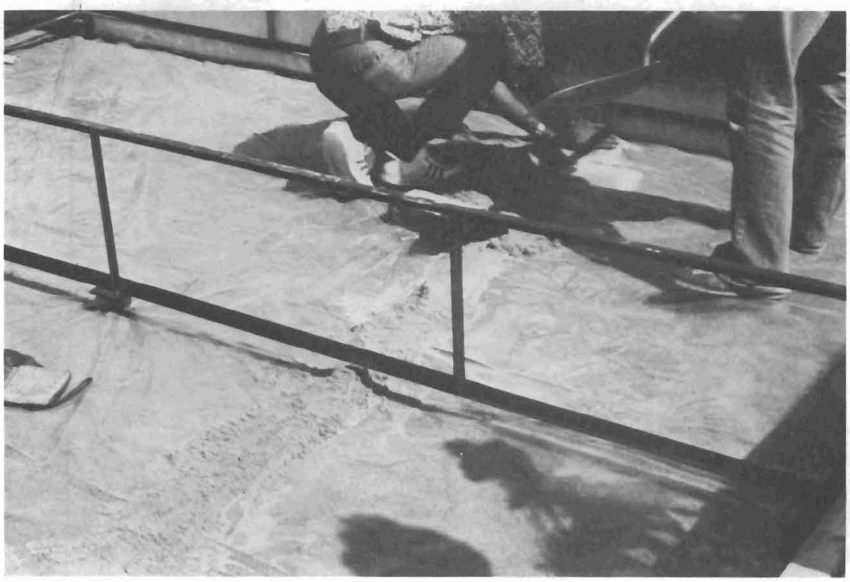


Figure 4 - Placing Sand on Thermocouple Wires

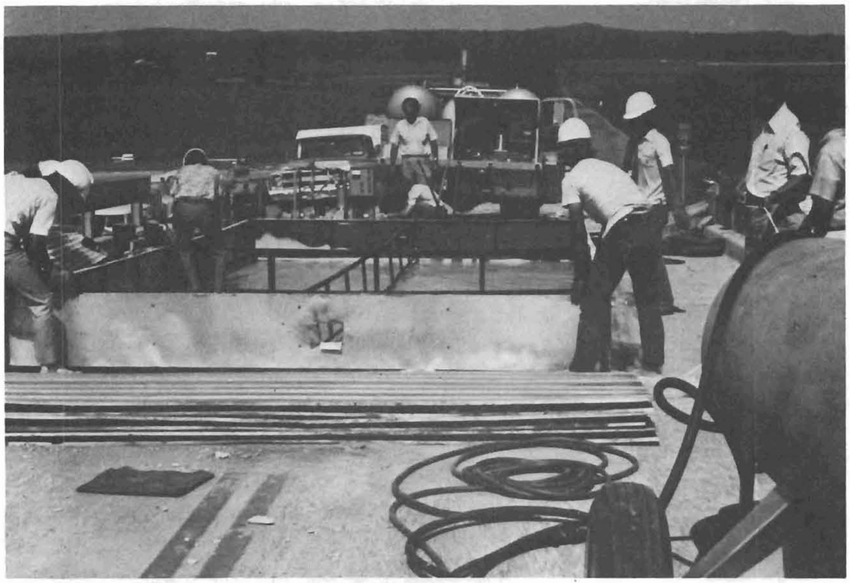


Figure 5 - Installation of Drying Enclosure

The burners, one in each end of the enclosure were installed and connected to the propane supply. To prevent localized hot spots resulting from the burner flame directly contacting the sand cover, a piece of sheet metal approximately 2 foot x 4 foot was placed on the sand under the burners. The burners used for the drying operation are similar to the type used by ranchers to burn the spines or thorns from prickly pear leaves for use as a livestock feed (figure 6). The final required step is to cover the drying enclosure with the sheet metal, fiberglass insulated panels so that controlled drying may begin (figure 7).

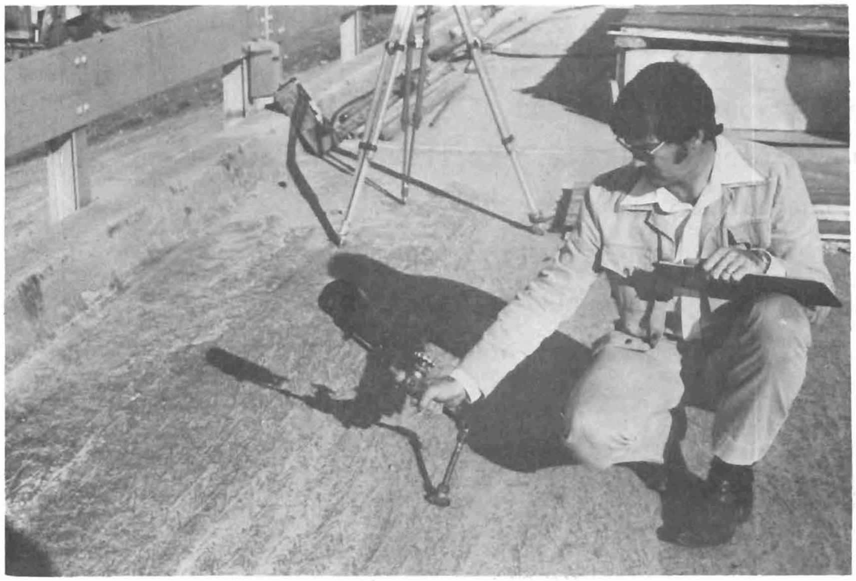


Figure 6 - Burner Used for Drying Operation

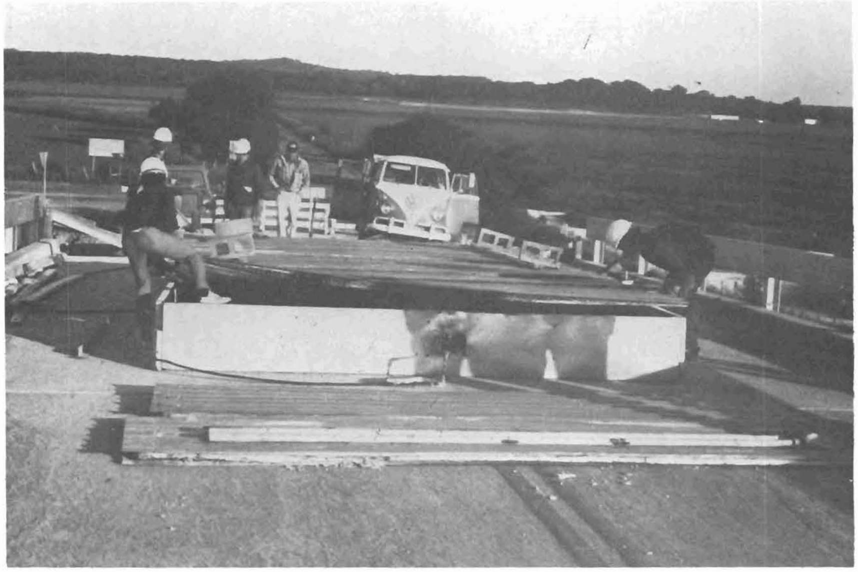


Figure 7 - Covering the Drying Enclosure

CHAPTER 4 - DRYING OF THE SLAB

The deck drying operation was accomplished using the 400,000 BTU/hr. propane fired burners mentioned in Chapter 3, and was comprised of two stages.

The first stage consisted of lighting only one burner in the enclosure and gradually increasing the concrete surface temperature to the range of 240^{0} Fahrenheit to 260^{0} Fahrenheit. This was done to minimize thermal gradients and stresses in the slab. A heating rate of 1^{0} Fahrenheit per minute was determined preferable for this job. Initial deck temperature was about 75^{0} Fahrenheit. During this stage, the temperatures emitted from the thermocouples were constantly monitored to insure the maximum specified limit of 2^{0} Fahrenheit per minute was not exceeded (figure 8).

After the bridge deck temperature reached 260^{0} Fahrenheit, the second step of the drying operation began. This step allowed the slab to dry for 5½ hours at a temperature range of 260^{0} to 300^{0} Fahrenheit. This temperature range was maintained for the five hours by lighting the other burner when the heat rate leveled off.

Due to the location of the burners, "hot" and "cold" spots developed on the surface. In order to assure even surface temperature the lower edges of the enclosure were sealed with sand at the base (figure 9) and the top panels of the enclosure were opened slightly to cool the high temperature areas (figure 10). The results of the thermocouple temperature readings at various times are shown for the six different deck readings and the two air readings in figure 11. The maximum deck temperature at the end of the drying cycle was 336^{0} Fahrenheit. When the two burners were turned off, an increase in average temperature of the surface readings to 300^{0} Fahrenheit was measured.

The drying operation required approximately nine hours with temperature build up requiring approximately 3½ hours and drying requiring approximately 5½ hours.

Figure 8 - Monitoring the Temperature

Figure 9 - Sealing Lower Edge of Enclosure with Sand

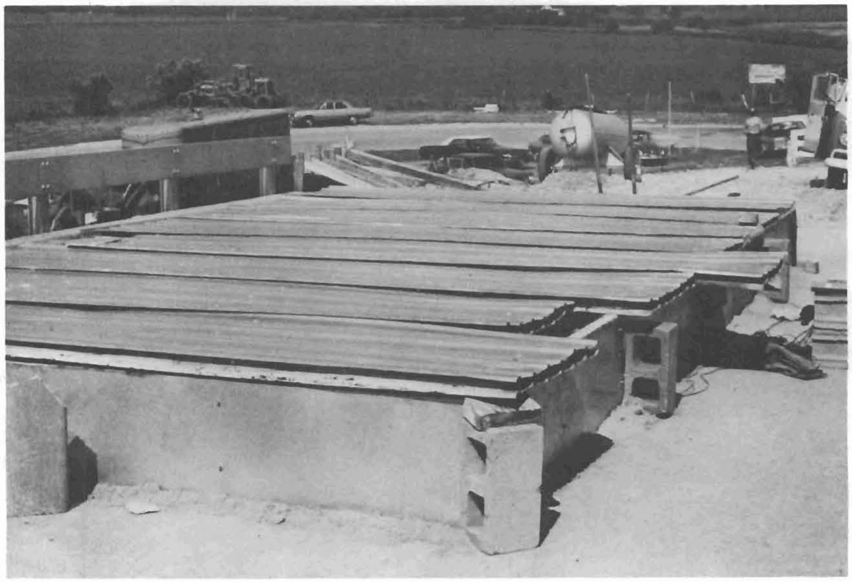
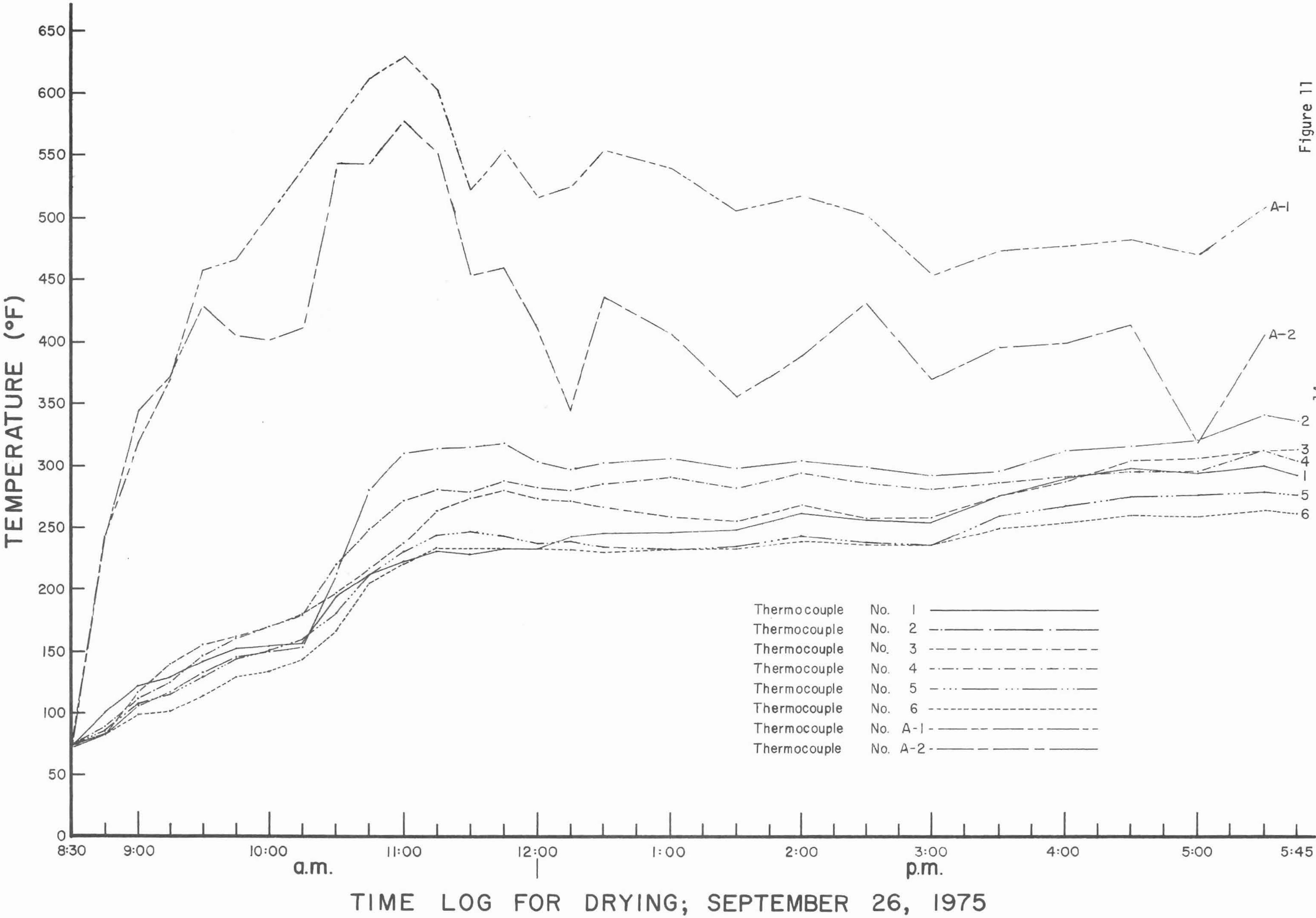


Figure 10 - Top Panels of Enclosure Left Slightly Open

Figure 11



TEMPERATURE (°F)
650
600
550
500
450
400
350
300
250
200
150
100
50
0
8:30
9:00
10:00
11:00
12:00
1:00
2:00
3:00
4:00
5:00
5:45
a.m.
p.m.
TIME LOG FOR DRYING; SEPTEMBER 26, 1975
A-1
A-2
2
3
4
1
5
6
Thermocouple No. 1
Thermocouple No. 2
Thermocouple No. 3
Thermocouple No. 4
Thermocouple No. 5
Thermocouple No. 6
Thermocouple No. A-1
Thermocouple No. A-2

CHAPTER 5 - COOLING THE SLAB

Successful soaking of the monomer into the slab required the deck temperature to be "cool", approximately 90^{0} Fahrenheit. In order to achieve this cooling, the top panels of the drying enclosure were removed until early evening when the humidity began to increase. When the significant increase in humidity was noted the top panels were replaced and the entire drying enclosure was covered with a sheet of polyethylene film. This was done to prevent the return of moisture to the slab.

Temperature monitoring indicated the polyethylene sheet retained too much warm air causing the slab not to cool properly. The polyethylene film was removed from each end of the enclosure, insulated top panels were propped up with bricks (figure 12) and one end of the enclosure was propped up on bricks to facilitate the flow of air over the surface of the sand cover. The remainder of the night the slab cooled sufficiently.

The time versus temperate relationship for each of the six deck thermocouples is shown in figure 13. This plot indicates that the deck cooled constantly and gradually from the time the polyethylene was removed from the ends until completion of the cooling period. At this point preparation of the test area for monomer soaking was begun.

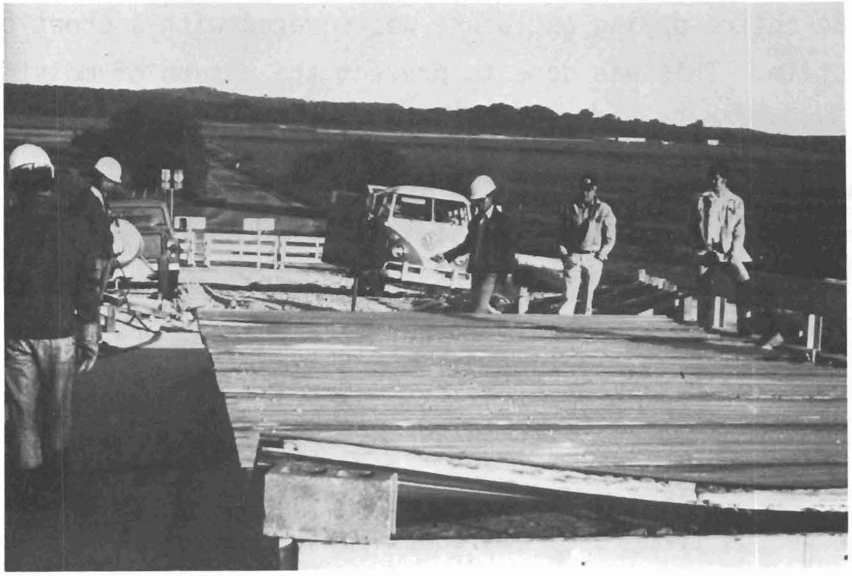
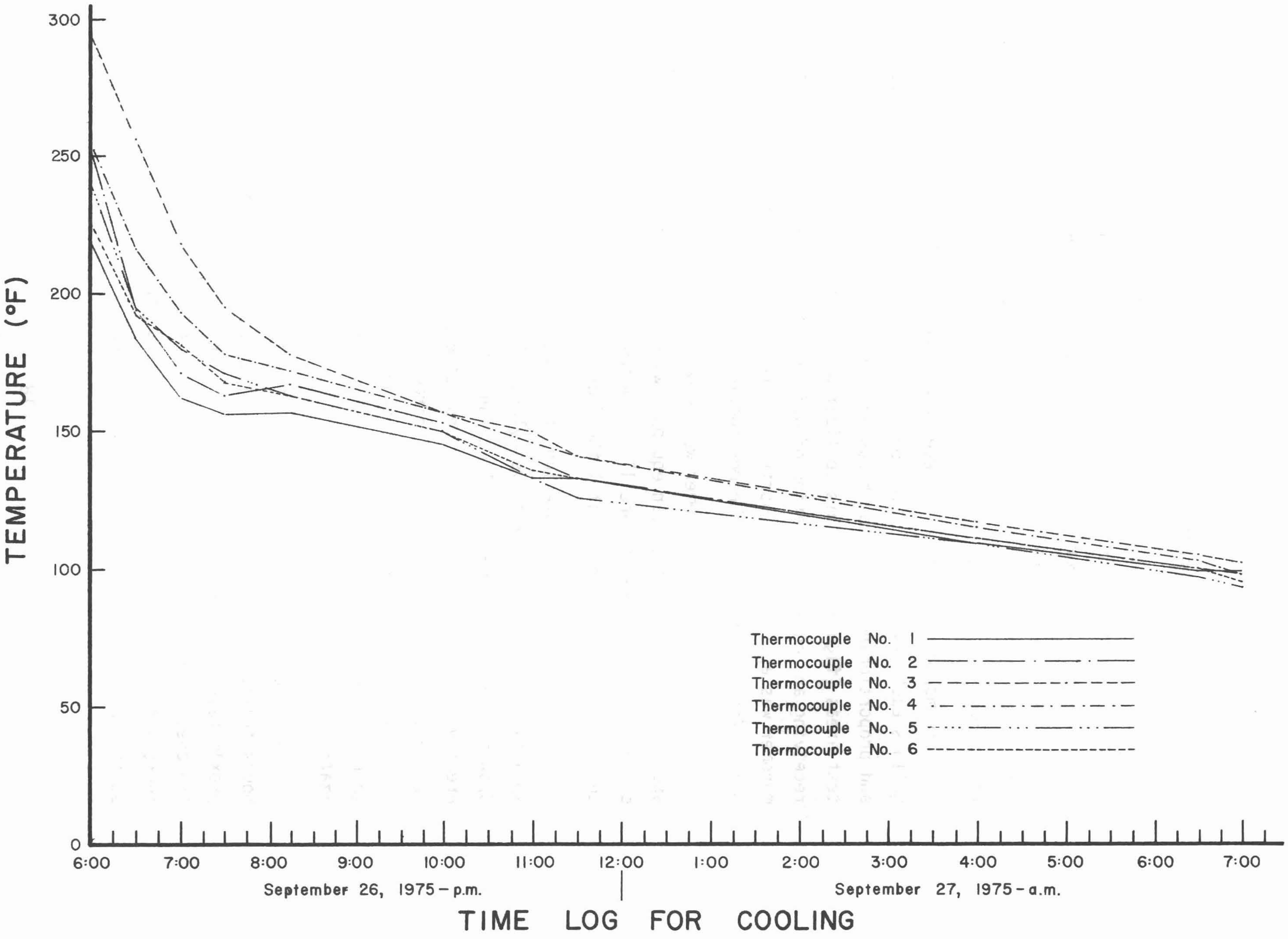


Figure 12 - Cooling the Slab



TEMPERATURE (°F)
300
250
200
150
100
50
0
6:00
7:00
8:00
9:00
10:00
11:00
12:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
September 26, 1975 – p.m.
September 27, 1975 – a.m.
TIME LOG FOR COOLING
Thermocouple No. 1
Thermocouple No. 2
Thermocouple No. 3
Thermocouple No. 4
Thermocouple No. 5
Thermocouple No. 6

Figure 13

CHAPTER 6 - MONOMER APPLICATION

After removal of the drying enclosure from the test area, the thermocouples were removed and the sand screeded smooth (figure 14). To test the rate of monomer application the surface area to be impregnated was divided into six test areas of approximately 46 square feet each. With the monomer application equipment on hand, the small area made uniform monomer application easier.

The monomer was mixed in seven equal batches of approximately four gallons each (figure 15). See appendix A for monomer mixing procedure and proportioning. Each batch was applied to one of the six premarked test areas (figure 16). This application resulted in each test area receiving an equal application of 0.6 lb./sq.ft. The last batch of monomer was applied to the north side areas resulting in an increase of 0.2 lb./sq.ft. or a total monomer application of 0.8 lb./sq.ft.

Application of the monomer was accomplished through the use of a special built five-gallon can equipped with a spray bar attached to the can by a plastic hose (figure 17). The monomer compound was sprayed over the sand (back and forth) until the four-gallon batch was used.

Immediately after completion of monomer application, the area sprayed was covered with a polyethylene film to prevent evaporation. Upon completion of monomer application and covering the last of the six areas with polyethylene film, the insulated panels were placed over the entire test area to shield it from direct sunlight. This operation was performed to allow sufficient soaking and penetration of the monomer and to provide protection from sunlight which can cause premature polymerization.

A faster than expected drying of the sand after approximately two hours indicated the need for additional polymer to be applied to approximately one-third of the test area. An identical batch of monomer to the ones mixed earlier was applied to this area. This additional monomer increased the application rate on one of the six test areas to 1.1 lb./sq.ft. and to 0.9 lb./sq.ft. on another area. The remaining four test

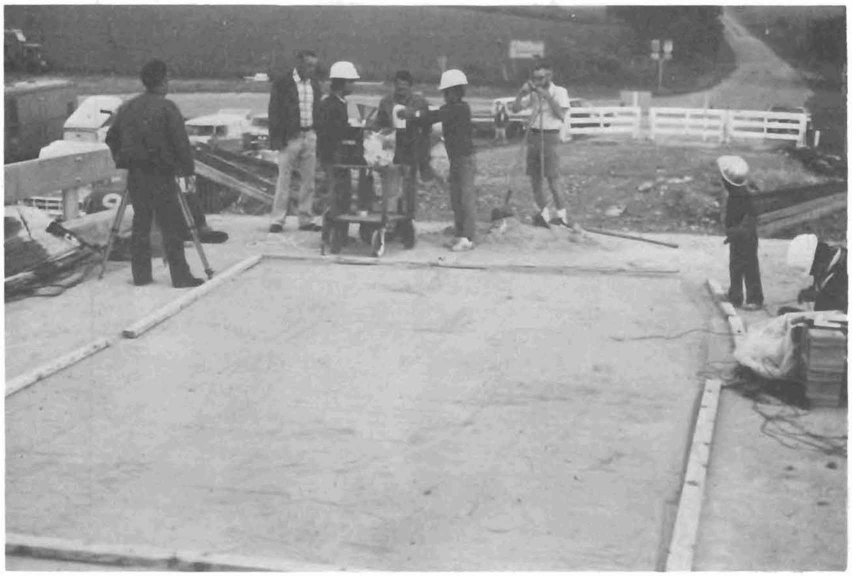


Figure 14 - Screeding the Sand

Figure 15 - Mixing Monomer

Figure 16 - Application of Monomer to Test Area

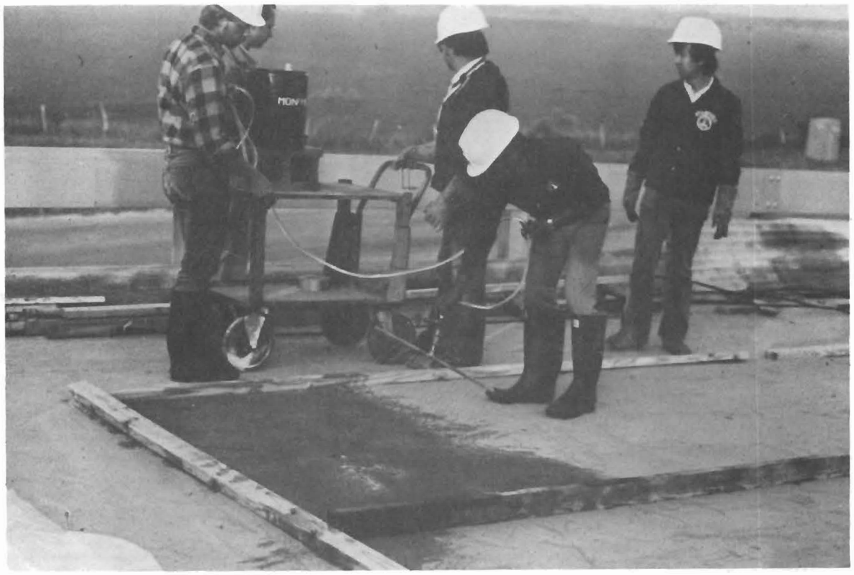


Figure 17 - Monomer Application Equipment

areas were unchanged.

The monomer was allowed to soak in excess of six hours, with four plus hours for the first soaking and two additional hours after applying the additional monomer.

CHAPTER 7 - MONOMER SYSTEM CURING OPERATION

Polymerization of the monomer was accomplished by steam, which was injected into the enclosure thereby heating the slab causing polymerization of the monomers.

The polyethylene film and sand were left in place. When the drying enclosure was returned to the proper position on the test area, the steam distribution system was assembled within the curing enclosure (figure 18) and the six thermocouples were placed on the surface of the bridge deck through slits in the polyethylene sheet.

The steam distribution manifold system consisted of 1½ inch pipe with holes ¼ inch in diameter drilled into both sides of the pipe on 11-inch centers. The hole configuration used was such that the area of the holes (combined) was equal to the cross sectional area of the pipe. The steam distribution system was designed to allow use of a steam generator at both ends of the enclosure to insure polymerization. Steam lines were equipped with a bypass valve to allow for ease in steam temperature and steam flow adjustment.

To minimize heat loss the top of the enclosure was put in place and the bottom edges sealed with sand, the top edges were sealed with tarps (figure 19). The entire enclosure was then covered with polyethylene film to eliminate heat loss during the curing operation (figure 20).

The steam generator used was an all purpose portable steam generator available on the commercial market (figure 21). It was operated on propane, a local water supply and a 125 C.F.M. air compressor. The automated equipment provides instant steam at the push of a button. For this application the decision was made to keep the steam very moist.

The danger of monomer vapor combustion required the outlet temperature of the steam to be maintained at 450° Fahrenheit for approximately thirty minutes. At this point the outlet temperature of the steam could then be

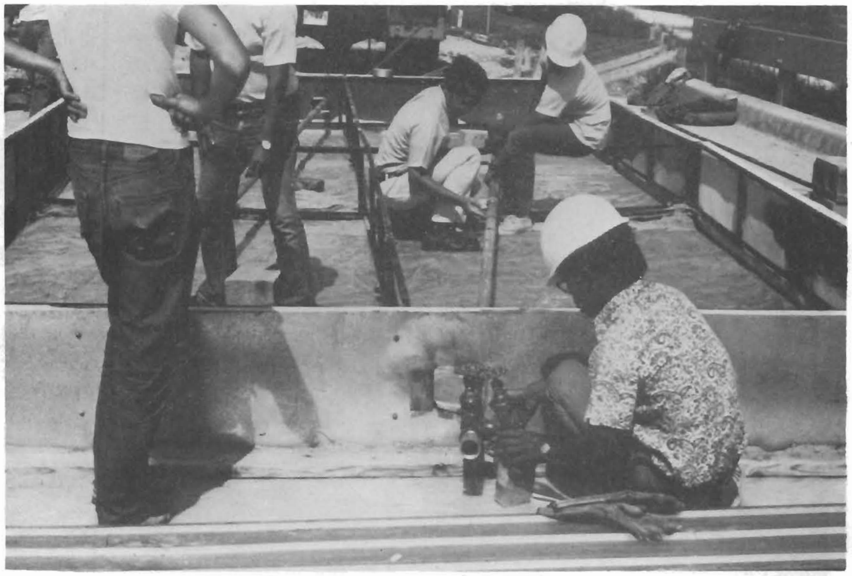


Figure 18 - Installation of Steam Distribution System

Figure 19 - Covering Enclosure

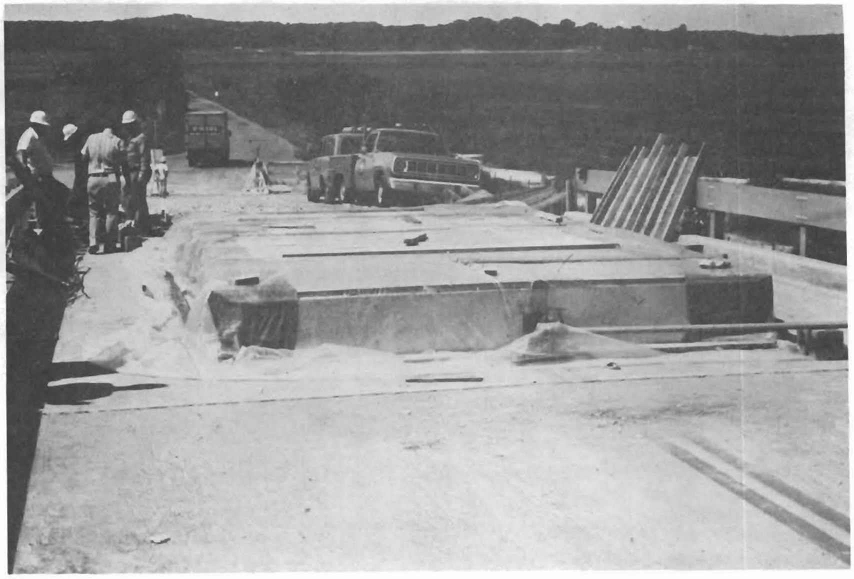


Figure 20 - Enclosure Covered with Polyethylene Sheet

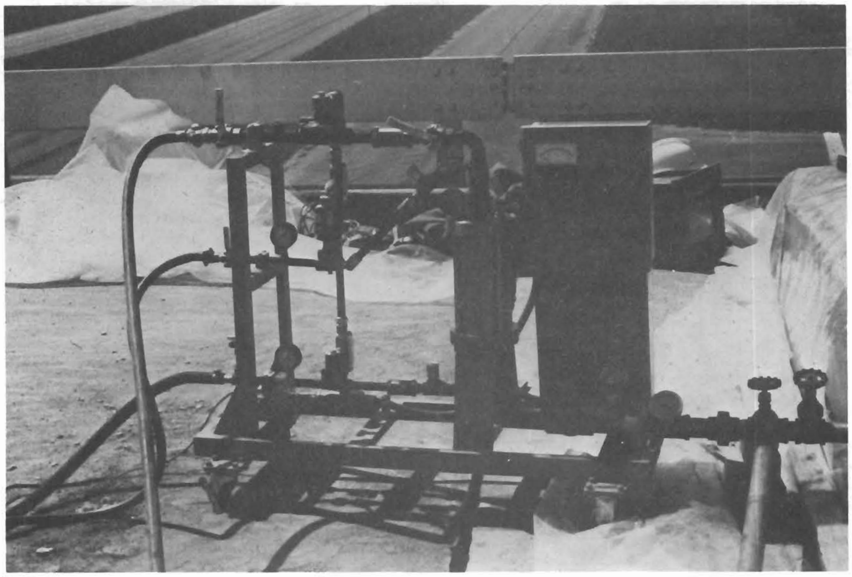
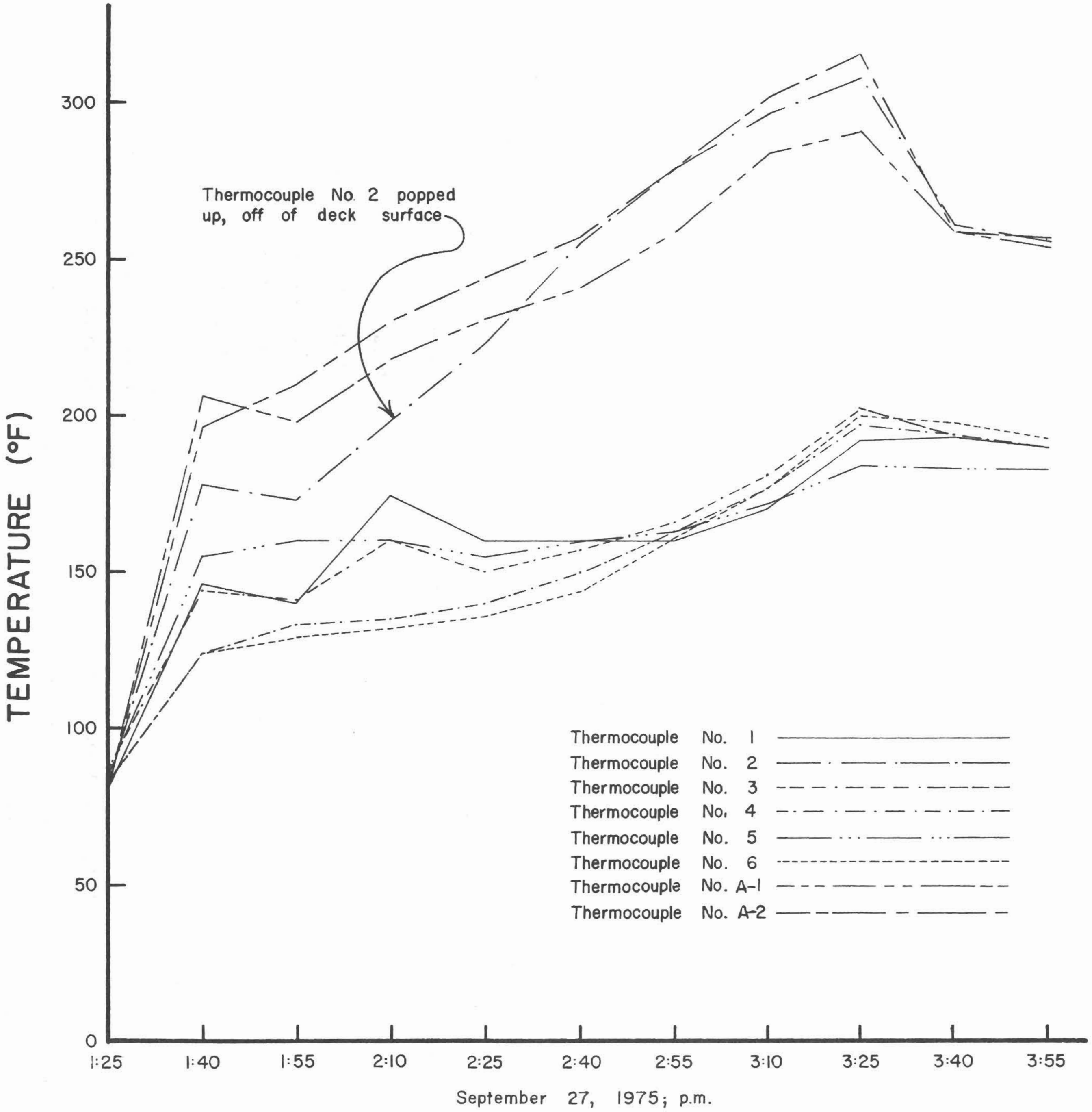


Figure 21 - Portable Steam Generator

gradually increased to the required maximum of 900° Fahrenheit. This was accomplished in less than two hours. The increase in steam temperature increased the air temperature within the enclosure to 304° Fahrenheit, an increase of approximately 100° Fahrenheit. A gradual increase in air temperature allowed the slab temperature to slowly increase preventing excess heating of the monomer and the possibility of it boiling out of the concrete.

The plot in figure 22 indicates the gradual increase in temperature with time discussed above. Note the higher temperature reading for thermocouple number 2. This is due to the release of the thermocouple epoxy from the deck, therefore, not giving true slab temperature readings. As shown in this figure, the entire curing time was approximately 2½ hours.

The enclosure was left in place for another thirty-six hours after the steam was shut off. This time delay was for convenience so that removal would not have to be effected on Sunday and was not a project requirement.



TIME LOG FOR CURING

Figure 22

CHAPTER 8 - TEST AREA CLEAN UP

Removal of the polyethylene sheeting, tarps and insulated top panels from the enclosure showed that a slight rotation in one of the steam manifolds had occurred. That is, one steam distributor pipe had rotated such that one line of openings pointed slightly downward. This direct flow of steam had melted many holes in the polyethylene film under the manifold (figure 23). In the area of this direct steam blast, approximately 50% of the sand was exposed. Also, it was noted that there were seven areas of exposed concrete surface caused by the direct steam blowing the sand away (figure 24). Examination of these seven areas indicated no appreciable evaporation of monomer had occurred.

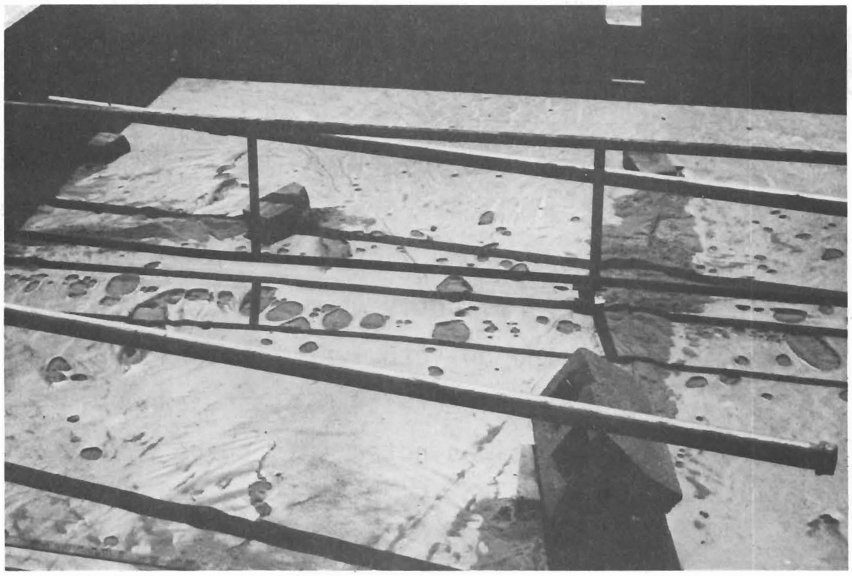


Figure 23 - Holes in Polyethylene Film

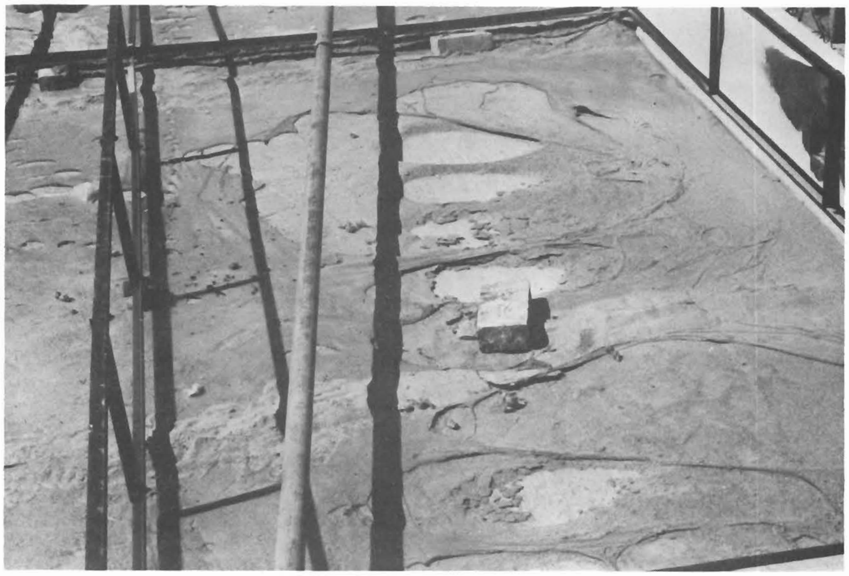


Figure 24 - Exposed Concrete Surface

CHAPTER 9 - RESULTS

The researchers were concerned with the possibility of the monomer polymerizing before totally soaking into the slab and bonding the sand to the surface. When the sand was swept away (figure 25), no polymer was in evidence on the surface and in no place did the sand bond to the slab.

Upon completion of the clean up operation, the test area was surveyed by a visual examination. The small existing cracks were apparently not closed by the process. No additional cracking of the bridge deck could be detected after clean-up.

Approximately one week after completion of the job, cores were taken from the various pre-designated test areas (figure 26). One core was also taken from the slab outside the test area to serve as a control specimen.

The normal core taken was 2-inch diameter with three 4-inch cores taken (figure 27) to allow freeze thaw tests to be performed. Cores were also taken from two of the areas where the steam had blown the sand away.

The depth of polymer impregnation was determined by splitting the cores and measuring the depth. In all areas except the 1.1 lb./sq.ft. area, the depth of penetration varied very little. See table 1. As the concentration of monomer increased, the color or darkness of the treated area also increased.

TABLE 1

Polymer Concentration lb./sq.ft.	Depth of Penetration in inches
0.6	1-1.25
0.8	1-1.25
0.9	1-1.25
1.1	1.5-1.9

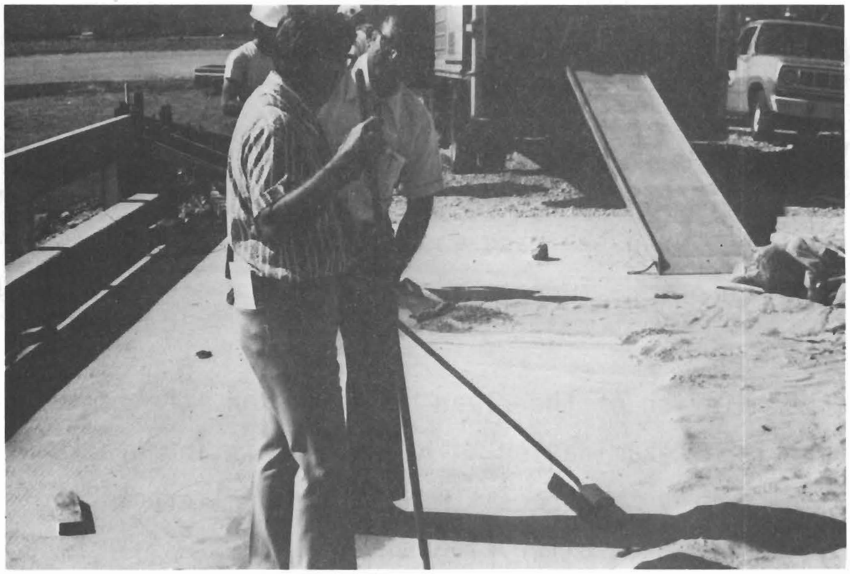


Figure 25 - Sweeping Sand from Surface

Figure 26 - Coring of Test Area

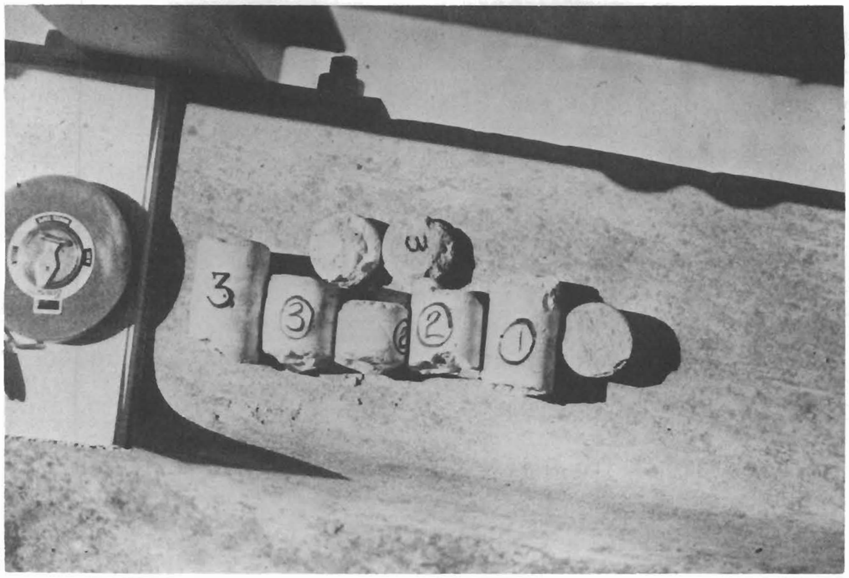


Figure 27 - 2" & 4" Cores

Water penetration tests were also performed on the cores mentioned above. This tested the ability of the various concentrations of polymers to restrict the intrusion of water into the bridge deck. The micropores in the top portion of each core were filled with polymer. The depth of this portion varied with monomer concentration, Table 2.

TABLE 2

Monomer Loading (lb./sq.ft.)	Impervious Zone Depth (inches)
0.8	0.25
0.9	0.25
1.1	0.40

The 0.6 lb./sq.ft. monomer loading was not tested due to the cores being destroyed during the coring operation.

See Appendix B for Water Penetration Test procedure.

CHAPTER 10 - CONCLUSIONS

1. Monomer loading used had little to do with depth of polymer impregnation. Sufficient depths were obtained with all loadings.
2. The higher the monomer concentration, the darker the color, resulting in possibly a more dense polymer layer which should logically be more impervious to water and de-icing chemicals intrusion.
3. Sufficient depths of impervious layers were developed with all loadings used.
4. Drying and curing methods used caused no apparent structural damage to the bridge deck surface.
5. Equipment used for all phases was satisfactory to obtain the desired results. More or larger capacity equipment could be necessary or more practical for impregnation of larger areas.

CHAPTER 11 - RECOMMENDATIONS

1. Large scale field trials should begin as soon as possible.

2. Careful control and monitoring of heating cycle length and temperatures should be required, with particular attention to rate of temperature increase of the concrete deck.

3. As reflected in Table 1, sufficient depth of penetration of monomer was achieved with 0.6 lb/sq.ft. application. Monomer loadings of at least 0.6 lb./sq.ft. with a minimum five hours soak time should be specified to obtain satisfactory depths of polymer impregnation.

4. Formulation of monomer used is satisfactory to develop sufficient depths of impervious layers and should be used on future jobs with similar surface characteristics.

5. Control of minimum curing time should be maintained as specified based on the monomer formulation used. Variations in monomer formulation will require variations in curing time.

APPENDIX A

MONOMER SOLUTION FORMULATION

The monomer solution used for this job was mixed on the job site in the following amounts:

(1) Monomer
100 parts by weight of Methyl Methacrylate, MMA.

(2) Cross Linking Agent
5 parts by weight of Trimethylol propane, Trimethacrylate, TMPTMA

(3) Polymerization Initiator
0.5 parts by weight of Azobis (isobutronitrile), ABIN

APPENDIX B

PROCEDURE FOR WATER PENETRATION TEST

1. Saw core in half. Exposing the interior surface of the core for its entire length.
2. Polish interior surface of core with Number 220 silicone carbide grit to remove saw marks.
3. Soak core half in warm water for 15-20 seconds.
4. Remove from water and air spray the surface dry.
5. Mark water penetration zones on core surface. Zones can be identified by color. Dark color indicates more water absorption.

APPENDIX C

METRIC REFERENCE

OMITTED