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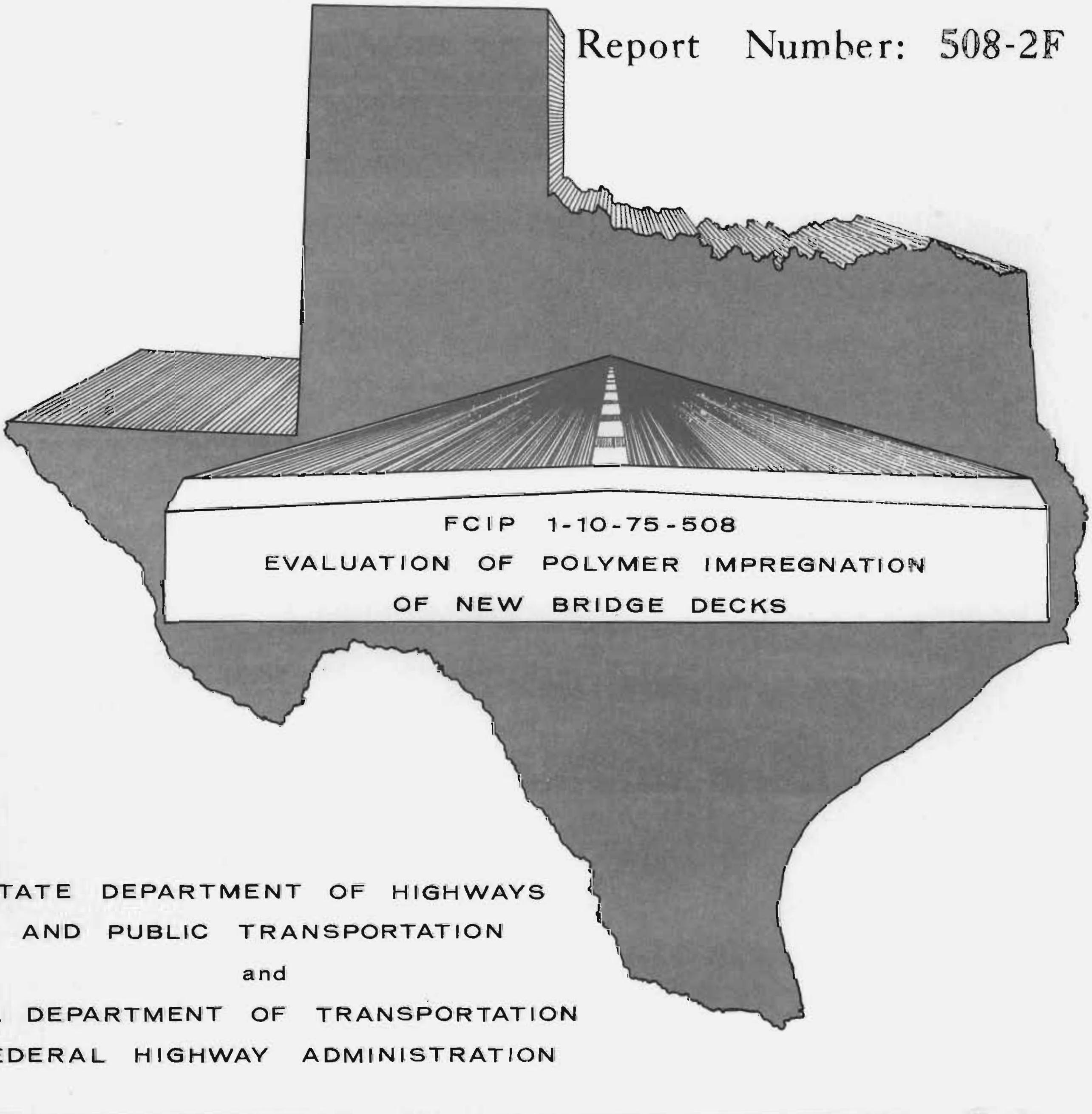
POLYMER IMPREGNATION
OF
NEW CONCRETE BRIDGE DECKS

Report Number: 508-2F



FCIP 1-10-75-508
EVALUATION OF POLYMER IMPREGNATION
OF NEW BRIDGE DECKS

STATE DEPARTMENT OF HIGHWAYS
AND PUBLIC TRANSPORTATION
and
U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

NOTICE

There was no invention or discovery conceived or first actually reduced to practice in the course of or under this contract, including any art, method, process, machine, manufacture, design or composition of matter, or any new and useful improvement thereof, or any variety of plant which is or may be patentable under the patent laws of the United States of America or any foreign country.

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16. Abstract

With the continued use of deicing salts coupled with the small amount of cover constructed over the top mat of steel in many bridge decks badly deteriorated concrete bridge decks are becoming an increasing problem. To prevent this in the future on structures being constructed now, some means of positively sealing the surface of the concrete deck against the intrusion of moisture and deicing salts is needed. Linseed oil treatments and asphalt seal coats are not 100% effective and improved methods are needed. Researchers under cooperative research study 3-9-71-114, *Concrete-Polymer Materials for Highway Application*, developed in the laboratory and field tested a method of "polymer impregnating" concrete bridge decks.

This report describes in detail the method of polymer impregnating a new 64'8"x751' bridge deck at Big Spring, Texas. A drying method using gas fired infrared radiant heaters for drying the deck and polymerizing the monomer system was developed by the contractor. This method did not require an insulated enclosure, provided uniform heat on the deck and was considered to be an efficient economical construction method.

The impregnation depths achieved were generally the 1/2" - 5/8" range. While some minor cracking of the concrete was observed, it did not appear to be more than normal from aging and weathering and while heating and cooling of the deck may have been a contributing factor, cracking was not directly attributed to the heating process by project personnel.

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Polymer-Impregnation, Bridge Decks,
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METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

LENGTH

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

AREA

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

MASS (weight)

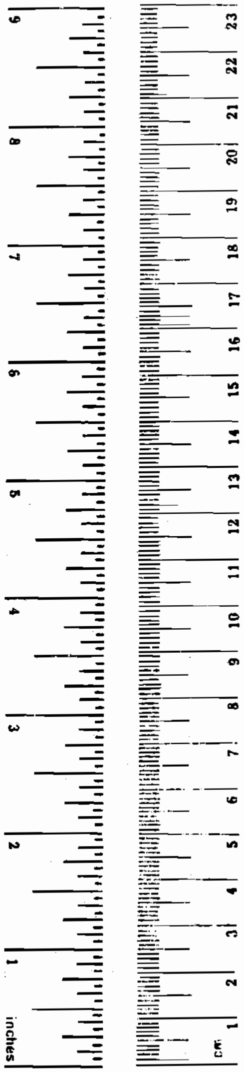
Symbol	When You Know	Multiply by	To Find	Symbol
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t

VOLUME

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

TEMPERATURE (exact)

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



Approximate Conversions from Metric Measures

LENGTH

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

AREA

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

MASS (weight)

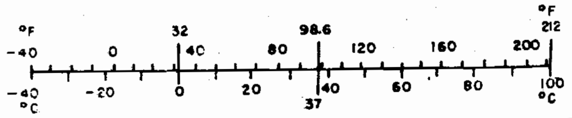
Symbol	When You Know	Multiply by	To Find	Symbol
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	

VOLUME

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

TEMPERATURE (exact)

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



POLYMER IMPREGNATION OF NEW CONCRETE BRIDGE DECKS

by

Temple R. Kennedy
Study Supervisor

State Department of Highways and Public Transportation

Texas

Research Report 508-2F

"Evaluation of Polymer Impregnation of New Bridge Decks"

Research Study No. FCIP 1-10-75-508

Sponsored by the
U.S. Department of Transportation
Federal Highway Administration

October 1977

SUMMARY

The polymer impregnation of the Owens Street Railroad Overpass structure on State Highway 350 in Big Spring, Texas was the first major application of this type deck sealing against intrusion of moisture and de-icing salts in Texas. As this type project had not been done in the State before it was necessary for the construction contractor to devise and develop methods for drying the deck, soaking with monomer and polymerizing the monomer system. The construction specification used provided adequate leeway for him to improvise with methods and equipment.

With the required test slab an insulated enclosure was constructed. A gas-fired-forced-hot-air draft was used to dry the slab. Problems of uniformly heating the slab within the enclosure and poor economics of fuel utilization necessitated that another method of drying be developed. In the test he used a gas-fired portable steam generator to polymerize the monomer. Due to a possible equipment malfunction, satisfactory heat was not developed and polymerization was unsatisfactory.

The contractor elected to reject completely the methods attempted on the test slab. He obtained gas-fired radiant heaters for both drying the slab and polymerization. With this system no enclosure was needed, energy consumption was nominal and polymerization complete.

This report describes the procedures used in the successful impregnation of the bridge deck which was 64' 8" wide and 751' long.

PREFACE

This report is the second on field application of partially polymer impregnated concrete bridge decks. The author is appreciative of the cooperation and assistance provided by District 8 SDH&PT personnel and the construction contractor, J.H. Strain and Sons, Tye, Texas. Of particular appreciation was that provided by Messrs. Bobby R. Lindley, Assistant District Engineer, Abilene; Joseph H. Smoot, Supervising Resident Engineer and Billy Ray Grimes, Project Inspector, Big Spring; and Construction Superintendent, T. A. Mussett, Tye, Texas. Also the able assistance of Mr. David Hustace, Senior Research Engineer in taking and helping analyze the photographs for the crack survey is gratefully acknowledged. Acknowledgement is made to Mr. A. M. Seely, Bridge Construction Engineer, for his activities and influence in initiating the polymer impregnation project and monitoring its progress. The examination and laboratory testing of the cores and the report thereon was performed by Mr. Tom S. Patty, Materials and Tests geologist. His work is gratefully acknowledged and appreciated.

October 1977 Temple R. Kennedy

IMPLEMENTATION STATEMENT

Research work under the State Department of Highways and Public Transportation Cooperative Research Program has developed a method for protecting existing and new concrete bridge decks from the intrusion of moisture and deicing chemicals. Laboratory analysis has shown that partially impregnated concrete is practically impervious to moisture. Strength tests indicate much greater strength than unimpregnated control concrete and freeze thaw cycling attest to the impregnated concrete's durability.

Phase I of this project saw the impregnation of a 12' X 24' section of the center point bridge over IH 35 south of San Marcos, Texas. Report Number 508-1, *Polymer Impregnation of Existing Concrete Bridge Decks*, described the procedure. On this work, butane-fired "pear burners" were used in an insulated enclosure to dry the deck and steam heat in the same enclosure was used for polymerization.

In Phase II of this project a new bridge deck of approximately 50,000 square feet was partially polymer impregnated. The laboratory work, proven by these two field construction projects, adequately demonstrates that upon consideration of recommendations made herein polymer impregnation is ready for immediate implementation.

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CHAPTER I

INTRODUCTION

For the past several years more and more deteriorating bridge decks have been detected which require heavy maintenance repairs and in some cases complete replacement. Most of the concrete delamination and deterioration can be attributed to moisture and chemicals from deicing salts penetrating to the reinforcing steel which corrodes and expands. Freeze-thaw cycles take their toll on the concrete. Most bridge decks constructed during the late forties, through the fifties and early sixties were a five-cement-sack concrete mix. Too, a minimum of concrete cover over the top mat of steel was provided. This was usually only two inches from the center of the top steel mat to the surface. The concrete decks in most cases had been overlaid with asphalt surface treatments or hot-mix asphaltic concrete pavements. These asphaltic layers no doubt held the mositure and chemicals thus hastening deterioration.

In the middle sixties the department realizing the shortcomings of those bridge designs, went to a six-sack concrete design with a low water-cement ratio for all direct traffic bridge decks, required air-entraining and increased the cover over the top steel mat. To further deter the penetration of moisture and chemicals into the concrete, a concrete surface treatment of boiled linseed oil and mineral spirits was specified to be applied to all new bridge decks. Later with FHWA approval the type treatment was changed to two course asphalt surface treatment. These treatments, while being definite improvements, were never considered completely satisfactory in positively sealing the concrete against intrusion of moisture and chemicals over the life span of the structures. However, under the Cooperative Research Program, researchers at the Center for Highway Research in research study 3-9-71-114 had developed a method to partially impregnate a concrete bridge deck with polymer. Laboratory tests showed the impregnated concrete to be virtually impervious, strong by both flexural and compressive tests and durable by freeze-thaw cycling. A very limited field demonstration had been made on Berry's Creek west frontage road bridge to IH 35 in Williamson County. With this research work, lab and field demonstration, the procedure was ready for implementation.

District 8, Abilene, Texas, has historically had problems with damage to bridge concrete decks caused by deicing salts and the many prevalent freeze-thaw cycles. Over the years an average of 39 freeze-thaw cycles have been recorded in that area. At the time the State Department of Highways and Public Transportation was promoting implementation of and publicizing the work of Research Study 114, District 8 was designing a structure for the Texas and Pacific Railroad Owen's Street Overpass in Big Spring, Texas. The structure on State Highway 350 was to be 751 feet long, 64 feet 8 inches wide parapet wall to parapet wall with a pedestrian sidewalk on the west side. Being a railroad overpass, it was to be a high structure with a fairly steep grade of up to 6.5 percent. Due to the height there will be considerable ice forming and braking action required. The grade prohibited the use of an asphaltic pavement overlay. They felt they had to have a direct surface type structure. The Owen's Street Overpass is a large structure and with accelerating costs of construction, the district felt they had to take all precautions to insure preservation of the structure. To replace the deck in 10 - 15 years would most likely cost three times or more than the original construction cost. With these factors in mind, they investigated using partial impregnation of the concrete with polymer. Another advantage which they anticipate gaining from the use of polymer impregnation was that research showed that skid resistance was usually higher and the surface more wear-resistant. After their investigation, they decided with the Bridge Division and FHWA concurrence, to seal the deck with partial depth polymer-impregnated concrete.

CHAPTER II

SPECIFICATION DEVELOPMENT AND CONTRACTOR ORIENTATION

2.1 Specification Development

Though the methods and ability to polymer impregnate hardened concrete had been developed by research and demonstrated on a small scale in both the laboratory and the field by researchers it had not been done in Texas by construction contractors nor on the scale of a 50,000 square feet structure.

In order to design and prepare the plans, specifications and estimate (PS&E) for bid receipt and contract letting, it was necessary that a construction specification be developed. On this "new" work it was decided that an end product or performance type specification would not be in the best interest of the State nor the successful bidder. A prescription type specification was deemed to be desirable. Heavy reliance was placed upon the Center for Highway Research researchers to provide the technical information as types of chemicals to specify, mixture formulas, temperature ranges for deck drying and polymerization, time span for drying and soaking with monomer and polymerization. The appropriate values and limits had been developed and tested by the researchers in study 114. The intent of the specification was to assure one-half inch of polymer impregnation in the concrete deck though the researchers felt as little as one-quarter inch would provide satisfactory protection for the concrete and steel. The technical data provided by the researchers was taken by District 8, Materials and Tests and Bridge Division Engineers and melded into a complete specification with inspection controls, safety features of storage and handling materials, methods of measurement and payment, etc. Of two important features of the specification, one was that the contractor would submit detailed plans and procedures for polymer impregnation at least 60 days prior to a demonstration which was also required by the specification. The submission was to 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. The second was that a demonstration impregnation would be made. The specification required that:

> *"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."*

The contractor's plan and the complete Special Specification Item 4127, Polymer Impregnation of Concrete Slabs are exhibited in APPENDIX A.

2.2 Contractor Orientation

As polymer impregnation was something new to Texas highway construction contractors, extensive preparation was made to orient and inform them of the work done in Research Study 114, "Polymer Impregnated Concrete for Highway Applications." Such an information program could serve to show that there was nothing exotic nor mysterious about polymer impregnation, enlist their assistance and benefit from their experiences in developing equipment and methods for drying concrete and polymerization of monomer for use on large scale construction projects and to hopefully produce reasonable bid prices for the upcoming contract letting for the Big Spring project.

On August 21, 1974, Dr. Clyde Lee, Director of the Center for Highway Research and Dr. David Fowler, Principal Investigator, Research Study 114, made a presentation to the Structures Committee of Associated General Contractors, Highway Heavy Branch in Austin, Texas. There were fifteen contractors present who are involved in heavy construction related to structures. The presentation which was fairly basic consisted of a sixty-minute slide presentation followed by a question and answer type discussion. The Structures Committee later expressed further interest and made a field trip inspection on October 16, 1974 to the Center for Highway Research laboratory to observe their work.

The Owens Street, Texas and Pacific Railroad Overpass structure in Big Spring, Texas was scheduled for receipt of bids and contracting July 23, 1975. Also in the design and plan preparation stage at that time was an IH 27 structure in District 5, Lubbock, Texas, which was to be polymer impregnated. In order to further brief prospective bidders on polymer impregnation developments and techniques, Drs. Fowler and Paul of CFHR conducted a workshop on July 10, 1975. It was designed to give contractors information on materials, methods, requirements and handling precautions for impregnation of bridge decks. The purpose was to remove the fears or unknowns regarding a new process so that bidders could intelligently formulate a bid for the Owens Street structure in Big Spring which was scheduled for July 23, 1975 letting. Materials and equipment suppliers were present and on the program. Cost figures were presented, safety precautions enumerated and construction procedures outlined. Widespread interest was exhibited. Thirty-five people attended the workshop session of which twelve were people representing nine contracting firms.

At the July 23rd bid opening, seven bids were received for constructing the project in Big Spring which provided for impregnating a concrete bridge deck with polymer. Six of the seven contractors submitting bids had attended the July 10, 1975 workshop. It is believed that the conferences held with the AGC Structures Committee and prospective bidders materially contributed to the bidding competition and lower costs for that work. Bids for the polymer impregnation item varied from $5.00 per square yard to $15.00 per square yard. The successful low bidder on the complete project was J. H. Strain & Son, Inc. of Tye, Texas. Their bid for the polymer impregnation portion of the project was $10.00 per square yard.

CHAPTER III

MONOMER SYSTEM AND MATERIALS

3.1 Monomer System

A polymer is a large molecule made up of many smaller molecules in a regular pattern. Some of the familiar polymers are plastics, fibers, and rubber. Some natural polymers are wool, cotton, hair and animal flesh. Some synthetic polymers are nylon, polyester, poly vinyl chloride, and plexiglas. A monomer is a small molecule from which large molecules (polymer) can be made. The monomers of use to us have double bonds which permit them to be polymerized. In order to begin the chain reaction required for polymerization, an initiator must be added to the monomer. The initiator is sometimes called a catalyst. It starts the chain reaction of polymerization. The rate of polymerization is dependent upon the temperature. The cross-linking agent which is a monomer with more than one double bond,results in a polymer which is harder and more heat and chemical resistant. The use of trimethylolpropane, trimethacrylate (TMPTMA) increases the rate of polymerization of MMA or in effect reduces the cure time. An inhibitor is added to monomers to prevent polymerization from occurring during transportation and storage. The specifications require that the MMA 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 must also be inhibited. The specifications require that it shall contain not less than 80 ppm nor more than 100 ppm of HQ (hydroquinine) inhibitor.

The monomer used was a system of methyl methacrylate (MMA) in combination with a cross linking agent trimethylolpropane, trimethacrylate (TMPTMA) and a polymerization initiator Azobis (isobutronitrile) (AIBN). This was the system developed previously in cooperative research study 114 at the Center for Highway Research and recommended for use on this project by Dr. Fowler and Dr. Paul.

3.2 Materials

For this project the liquid monomer system was a mixture of the following chemicals:

1. *Monomer* - MMA with an Inhibitor - MEHQ
2. *Crosslinking Agent* - TMPTMA with an Inhibitor - HQ
3. *Initiator* - AIBN

The proportions of these chemicals in the monomer system mixture are very important. The job mixture batch consisted of:

1. 20 gallons of MMA
2. 0.9 gallons of TMPTMA
3. 0.8 pounds of AIBN

Two of the batches were required to provide sufficient liquid to be applied to each 9' 6" X 64' 8" section. The specification restricted the amount of mixture which could be prepared at one time to batches of not greater than thirty gallons.

Additional data relative to the chemicals, source of supply, representatives, packaging quantities and prices are contained in APPENDIX B.

CHAPTER IV

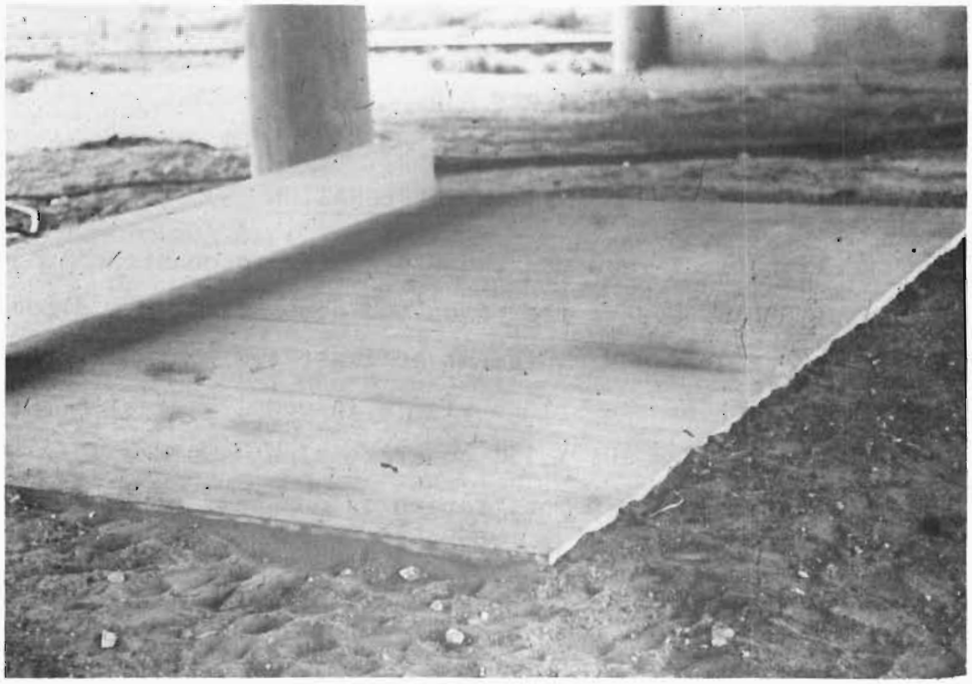
DEMONSTRATION IMPREGNATION

The specifications required the contractor to construct a concrete slab of a minimum 150 square feet area and demonstrate his proposed impregnation procedures and equipment at least two weeks prior to beginning impregnation of the bridge slab. In compliance with this, the contractor constructed a 10' X 15' concrete slab. On May 16-17, 1977 the contractor performed a demonstration on one-half of the test slab. As provided in his approved work plan (see APPENDIX A). The contractor had previously prepared a sheet metal enclosure with 4" insulated walls. For drying the slab he used space heaters with blowers rated at 300,000 Btu's per hour each. The hot air was ducted into the enclosure through insulated sheet metal ducts. Three-eights inch thickness of clean sand had been screeded onto the concrete slab to be dried. During drying, monitoring of the thermocouples showed that deck temperature was not uniform with those in corners being consistently lower. Some means of out-draft for air circulation would also be needed. Air temperature in the enclosure was quite high, being in the 600°F range while the concrete was relatively cool by comparison. The contractor concluded from his demonstration that this was not a practical economical method of drying. See Figures 1 - 4.

For the curing phase of the demonstration the contractor used a Gray Vapor generator Model HLC 100 for generation of steam. For unknown reasons the contractor was apparently unable to obtain steam or suitable temperature steam from his equipment to uniformly heat the test slab to the desired temperature. Upon removal of the enclosure there was considerable water present on the slab and sand inside the enclosure.

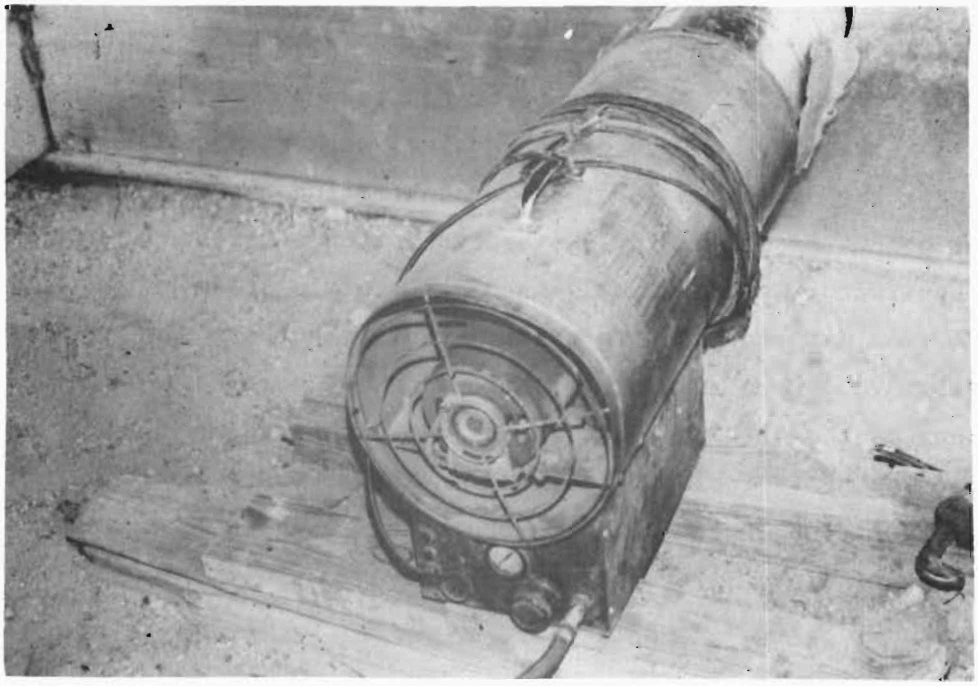
With these problems occurring on the demonstration to impregnate a small test slab, the contractor began to search for and investigate other means and equipment to dry the slab and cure (polymerize) the monomer.

Figure 1



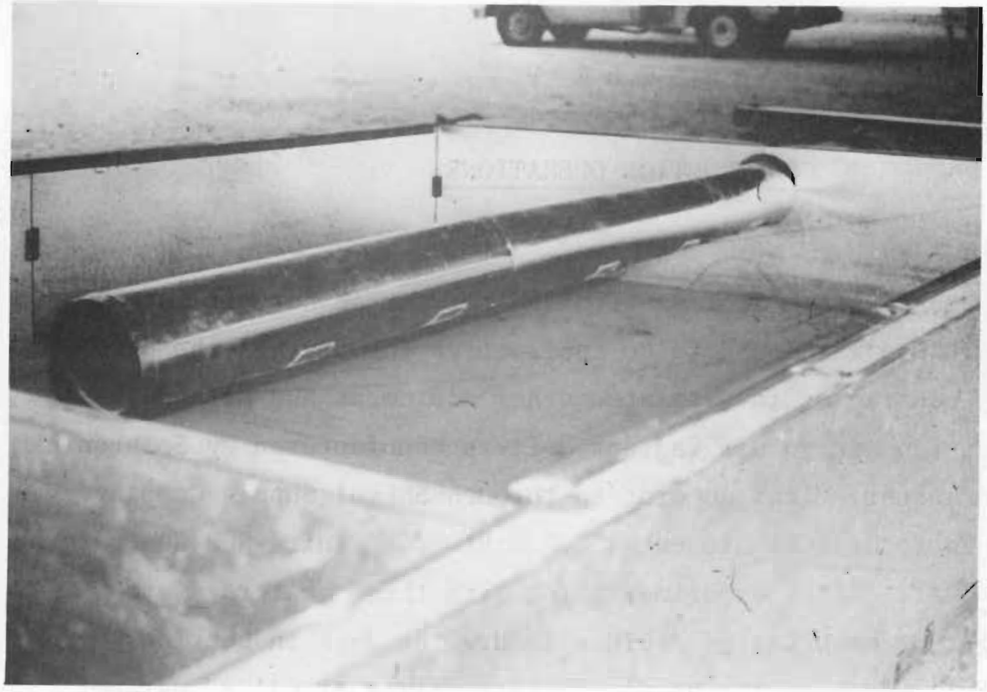
DEMONSTRATION SLAB

Figure 2



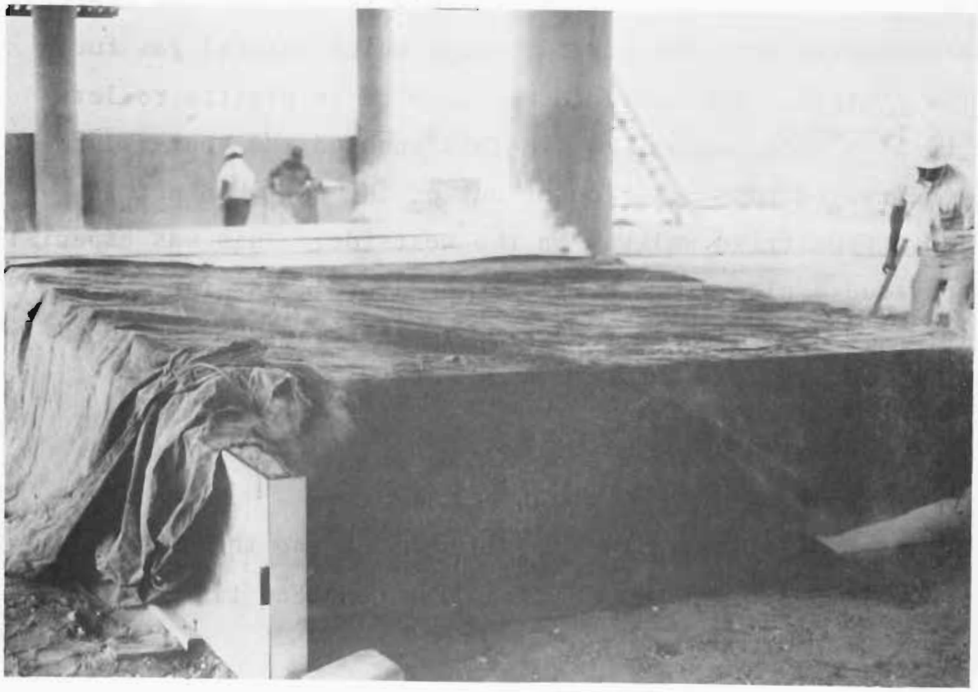
HOT AIR BLOWER

Figure 3



HOT AIR DUCT FOR DEMONSTRATION SLAB

Figure 4



COVERED ENCLOSURE FOR DEMONSTRATION SLAB

CHAPTER V

CONSTRUCTION OPERATIONS

5.1 General

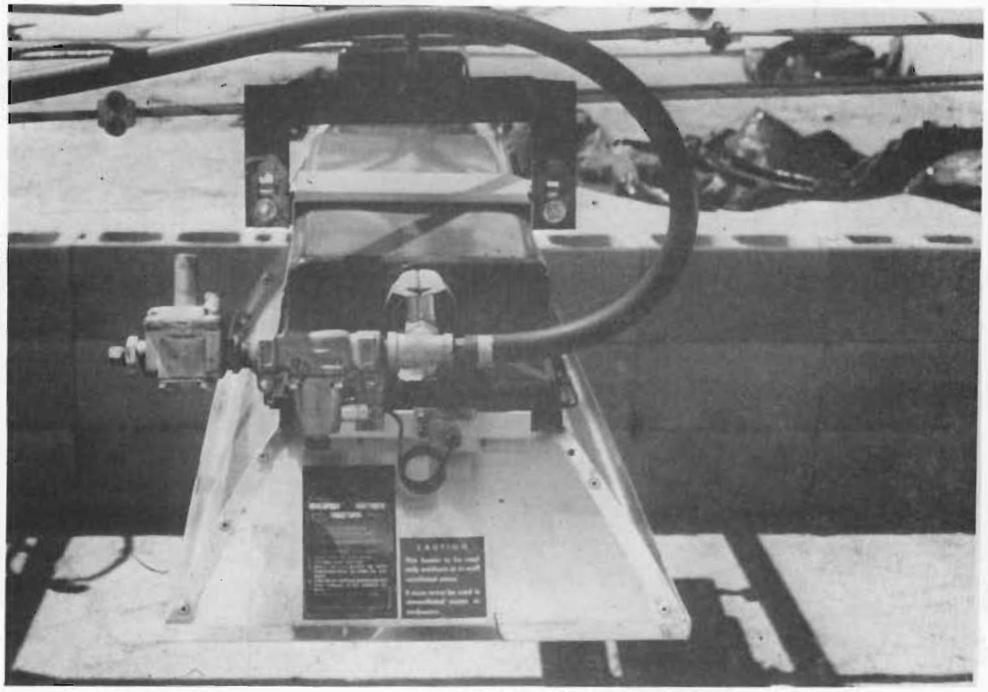
After the demonstration impregnation and the forced hot-air into an insulated enclosure was found to be ineffective for drying the deck, the construction contractor investigated other equipment and methods. His ultimate decision was to use radiant heaters manufactured by Solaronics Incorporated, Rochester, Michigan ordered through Shovel Supply Company, Dallas, Texas. These heaters are each 50,000 Btu Gas Infra-Red Generators Model Number MU 60AY. After experimentation with these heaters as to spacing and height of mounting he decided to dry the deck in sections which were the full width of the bridge deck travelway of 64' 8" parapet wall to parapet wall and 9' 6" longitudinally. To dry that section would require 32 of the heaters. As he elected to dry two sections at one time, 64 heaters were required. Figure 5 shows an individual heater and Figure 6 shows a bank of 32 heaters mounted on a truss scaffold.

The contractor constructed a truss type scaffold to support the heaters. The two lower outside chords were the pipes through which natural gas fuel was supplied for the heaters. The scaffold was mounted on plastic rollers or wheels which rode atop each parapet wall. This enabled the heaters and supports to easily be rolled into position or out of the way when not in use. The bridge had a pedestrian walkway on the westside. This was especially convenient as it provided a place for the flexible natural gas line, water hoses, and circulation for workmen from one side to the other of section being impregnated. See Figure 7.

5.2 Drying the Concrete Deck

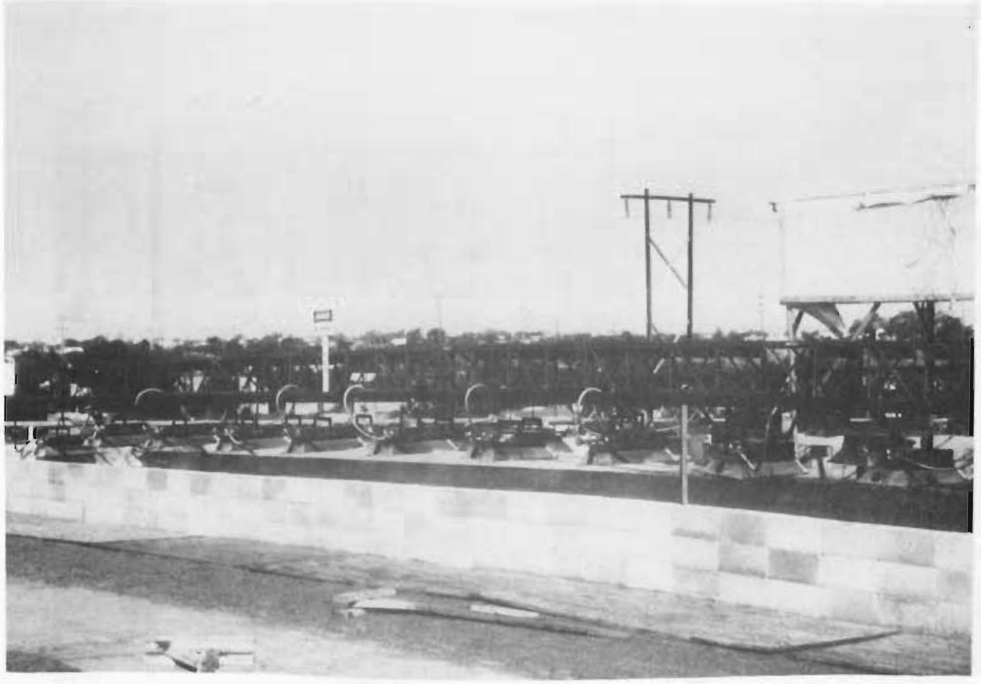
Since an insulated enclosure was not required, by using the radiant heaters the contractor elected to place a dry-wall of hollow concrete tile, three tiles

Figure 5



RADIANT HEATER

Figure 6



BANK OF RADIANT HEATERS

Figure 7

PEDESTRIAN SIDEWALK AND NATURAL GAS AND WATER LINES

Figure 8

LIGHTING THE RADIANT HEATERS

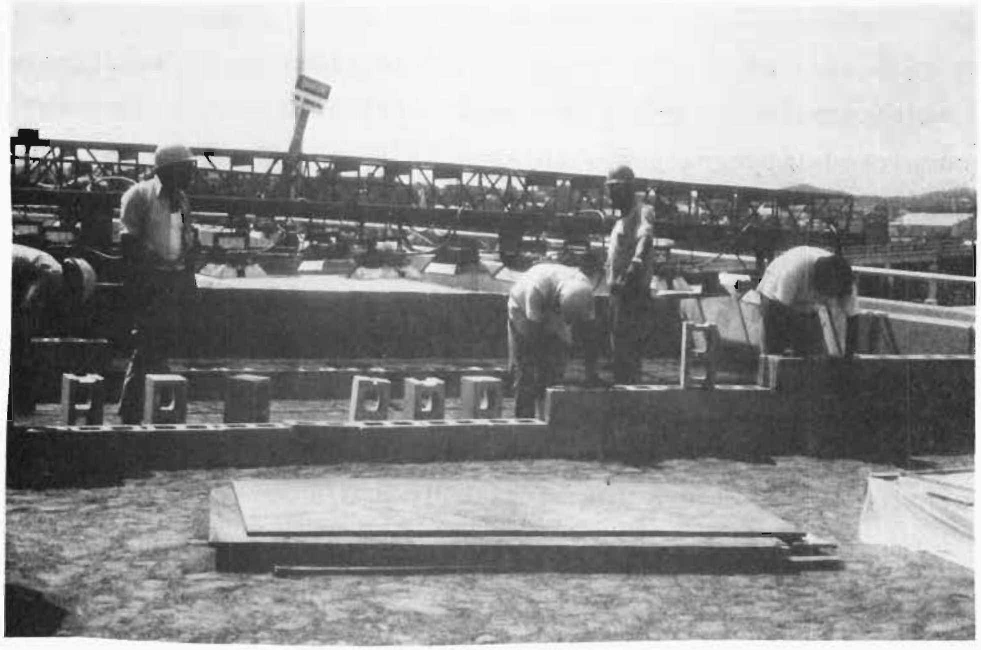
high along each side of the 64' 8" by 9' 6" sections to be impregnated. The 9' 6" width provided for a three-inch overlap on each side resulting in 9' of completed impregnation with each section. The tile wall protected against wind and supported wood-frame canvas covered panels which were used to aid in keeping moisture out during the cooling phase and as a shade against heat and actinic light from sunrays during the soaking phase. Figure 9 shows the tile wall and Figure 11, the canvas covered panels.

Prior to beginning drying, a thin layer of concrete sand was spread over the section. See Figure 10. Initially a 3/8" thickness was placed. After experimentation with 3/8", 1/2" and 5/8" thicknesses it was decided that 5/8" was preferable. The primary purpose of the sand was to serve as a wick or a medium to hold the monomer system during soaking. It was essential that it be dry for that purpose. Too, it acted as an insulation to the concrete preventing the radiant heat from directly striking the concrete and was believed to aid in attaining uniform heat distribution onto the concrete.

In order to monitor the heating and rate of drying of the concrete, six thermocouples were placed in the deck for each section. The locations for the thermocouples were previously made and small holes about 1/4" deep drilled in the concrete. The thermocouple was inserted in the drilled hole and secured with a lead fabric. The wires from the thermocouples were connected to a potentiometer which would accommodate twelve lines. By turning a dial to each, an instantaneous temperature reading could be obtained for the concrete at that location. Figures 12 and 13 show the thermocouples and potentiometer.

With the tile walls, the sand layer and the thermocouples in place, the section was ready to be heated for the drying phase. Each of the gas heaters was lit using a small butane hand torch and regulated prior to rolling the scaffold and heater into position. See Figure 8. The heaters were located 32" above the sand layer with the end ones being 28". Figure 14 illustrates the site during the heating process.

Figure 9

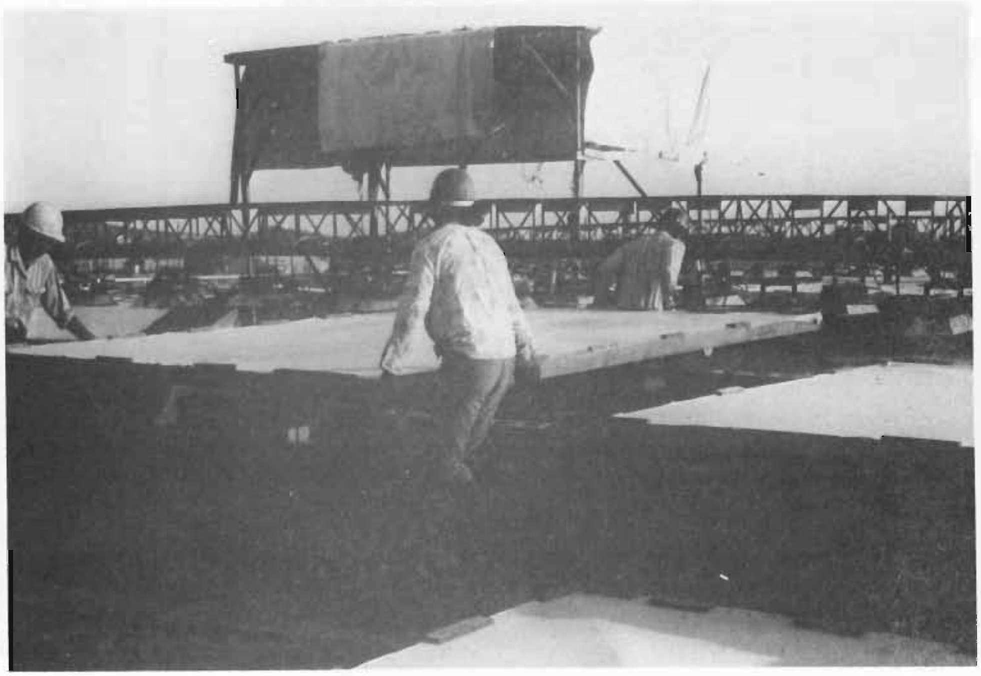


BUILDING THE DRY TILE WALL

Figure 10

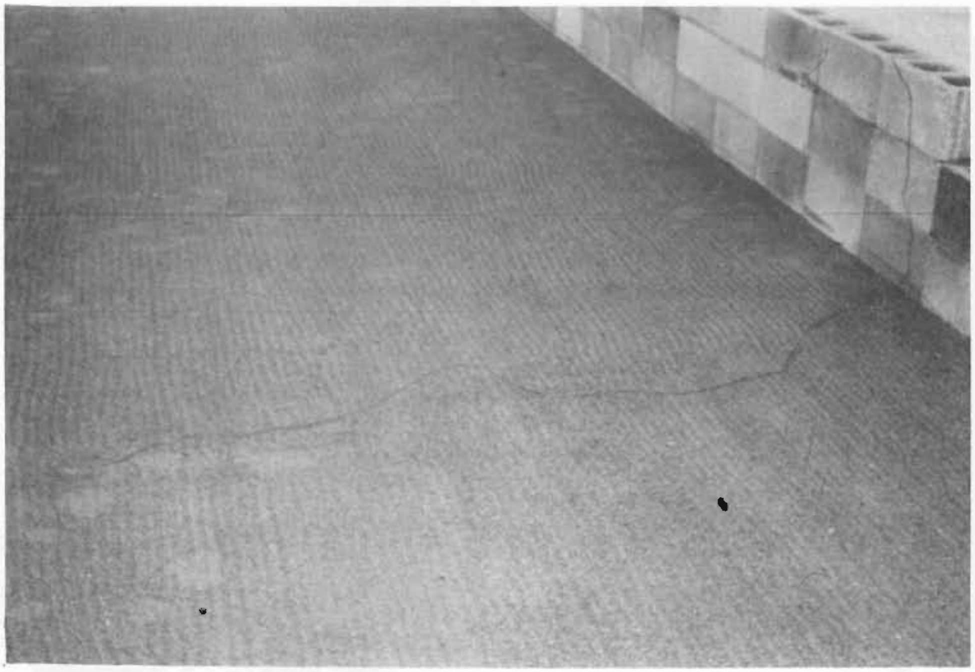
SPREADING THE SAND LAYER

Figure 11



CANVAS COVERED SHADE PANELS

Figure 12



THERMOCOUPLE AND WIRE IN PLACE

Figure 13

POTENTIOMETER

Figure 14

HEATERS IN POSITION FOR DRYING

The specifications require that the rate of rise of the deck temperature shall not exceed 2° F per minute. The temperature was read and recorded every 5 minutes during the buildup of temperature. When the concrete temperature generally stabilized, readings were made and recorded on 15 to 30 minute intervals. The required drying temperature was within the range 225° - 260° F which must be maintained for five hours. A typical polymer impregnation cycle began the morning of August 30, 1977. The heaters were lit and rolled into position at 11:30 a.m. At 1:30 p.m. the minimum required temperature of 225° F for the concrete was attained and drying began. The concrete was dried until 6:30 p.m. at which time the gas heaters were turned off and rolled out of the impregnation section area. See Figure 15 for record of temperatures for the drying cycles.

5.3 Cooling the Dried Concrete Deck

Cooling the concrete after drying was a most tedious chore in the impregnation process. The concrete temperature had been elevated to about 245° - 255° F during drying. Specifications required cooling to 90° F before the monomer system could be applied for the soaking cycle. In the hot Texas weather during July and August, it proved most difficult to cool the concrete that low. This requirement was eventually modified to 100° F. By cooling overnight, 100° F could be attained. As the concrete cooled to about 200° F polyethylene sheeting was placed on the section to prevent absorption of moisture from the atmosphere. To aid in this, canvas covered panels were placed atop the tile walls. It was necessary that the concrete cool to the required temperature to assure that there was not sufficiently high temperature to prematurely cause polymerization of the liquid monomer system when applied.

5.4 Soaking with the Monomer System

In order to apply the liquid monomer before the sun and ambient temperature were high, the monomer system was usually mixed and applied between 6:00 and 7:00 a.m. after the concrete had cooled overnight as was done on August 31, 1977.

DRYING SLAB # 79
STATION 16+64.16 - STATION 16+73.13
August 31, 1977

TIME p.m.	THERMOCOUPLE #/TEMPERATURE °F					
	#7	#8	#9	#10	#11	#12
12:55	110	110	110	112	110	110
1:02	130	138	132	150	140	130
1:10	155	155	150	165	160	145
1:15	165	165	165	175	170	165
1:20	180	180	178	185	183	190
1:30	182	190	185	192	195	211
1:45	215	215	215	215	219	240
* 2:00	240	241	229	230	235	248
2:30	255	262	255	250	255	260
3:00	267	280	269	262	275	275
3:30	265	290	262	262	280	275
4:00	251	259	250	245	251	260
4:30	249	252	250	242	250	255
5:00	250	255	259	247	249	255
5:30	250	253	254	248	249	260
6:00	250	259	253	249	249	259
6:30	250	259	259	249	249	261
** 7:00	250	259	255	245	249	261

*Start Drying Time

**Turned Off Heaters

Figure 15

The amount of monomer required to be placed was 0.65 gallons per square yard of surface area. A total of about 40-42 gallons was used for each section. As the specifications required that not more than 30 gallons should be mixed at one time, two batches were used for each section. A typical batch of monomer system was:

20 gallons of monomer
0.8 pounds of initiator
0.9 gallons of cross linking agent

The monomer was drawn from a 55 gallon drum into two-gallon plastic buckets and poured into a large kettle. The powdered initiator was mixed in the last bucket by stirring with a wooden paddle then poured into the kettle. The cross-linking agent was added last. As a safety precaution a wooden paddle was used to prevent sparks. The kettle also had a wooden top. A mobile crane elevated the kettle to provide adequate gravity flow of the monomer which was applied through a connecting hose with a pipe sprinkler head. As one batch was being applied to one-half the section the second batch was being mixed. As placing the monomer proceeded it was immediately covered with polyethylene sheeting to retard evaportation. When the monomer had been applied to the entire section and covered with plastic sheeting, the canvas covered panels were placed atop the tile wall to provide shade. The monomer was to soak for 4 to 6 hours according to specifications. The sand was checked for dampness as an indication of when the monomer had soaked in. As experience was gained a typical soak time of 2 1/2 to 3 hours evolved. See Figures 16, 17, 18 & 19 for mixing and applying the monomer for soaking.

5.5 Polymerization

When the monomer has soaked into the concrete the polymerization phase should begin at once. The plastic sheeting was removed and the sand layer lightly sprinkled with water. See Figures 20 & 21. The water served to prevent or retard evaporation from the concrete surface and also afforded a safety measure against possible igniting of the monomer.

Figure 16

MIXING THE MONOMER SYSTEM

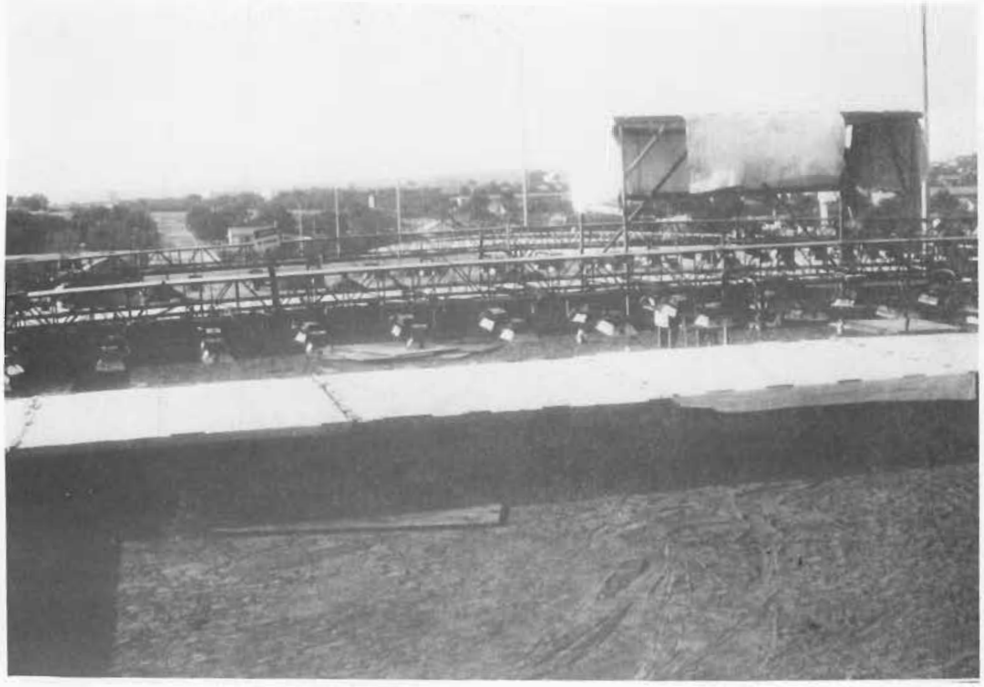
Figure 17

PLACING MONOMER

Figure 18

PLACING MONOMER AND COVERING
POLYETHYLENE SHEETING

Figure 19



SOAKING PHASE WITH CANVAS COVERED PANELS

Figure 20

SPRAYING MONOMER SOAKED DECK WITH WATER
JUST PRIOR TO POLYMERIZATION

Figure 21

REMOVING POLYETHYLENE SHEETING AND SPRINKLING
WITH WATER AFTER SOAKING

The heaters were lit, regulated and rolled into position. As required by specifications, the temperature of the concrete deck was brought to 140° F. A temperature of 140° - 175° F was then maintained for two hours. The temperature was checked and recorded at suitable intervals for control. See Figures 22 & 23 for a typical temperature record. This completed a cycle. When the area had cooled down so workmen could handle the tile blocks, they were moved to a new section and another cycle commenced.

5.6 Miscellaneous

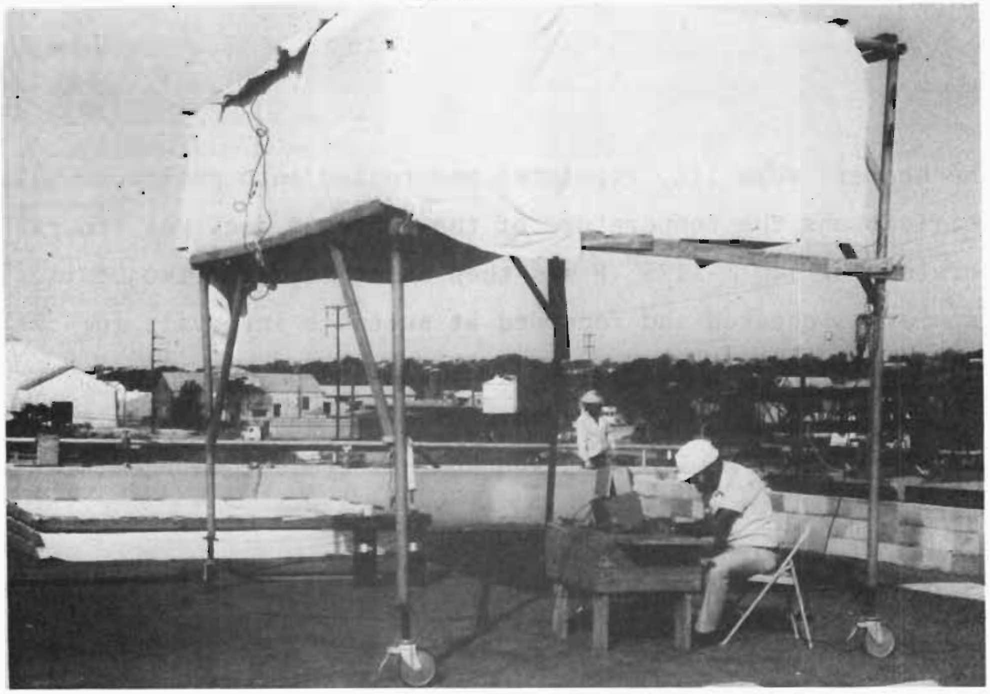
Due to the experimental nature of this first polymer impregnation project, variations in construction methods were tried on some sections. Section number 49 (Station 13+94.24 - Station 14+03.46) was dried at a lower temperature. When the concrete temperature reached 170° F, the five hour drying time was started. The temperature got up as high as 210° F during the full five hour drying period. Penetration of the polymer was one-quarter inch as measured on cores from section 49.

A shorter drying period was tried on section number 50 (Station 14+03.46 - Station 14+12.62). The specification temperature of 225° - 260°F was held and recorded for only 2 1/2 hours instead of the full five hours normally used. Polymer impregnation depths in this section was three-eights inch.

On section number 51 (Station 14+12.69 - Station 14+22.0) the required temperature for drying had been attained and the concrete drying for two hours thirty minutes when rain came. It was necessary to cut off the heaters and stop drying. This section was redried the next day. Core showed the polymer impregnation depth to be 3/8" - 1/2".

To evaluate the long term effectiveness of polymer impregnated concrete to resist the intrusion of moisture and de-icing chemicals, three sections were not impregnated. Those sections are number 8 (Station 10+29.94 - Station 10+38.92), number 61 (Station 15+02.72 - Station 15+11.69) and section number 83 (Station 17+00.03 - Station 17+09.00). Having these three untreated sections should afford a performance comparison of durability or resistance to chemical intrusion and subsequent steel corrosion.

Figure 22



MAKING TEMPERATURE RECORDINGS FROM THERMOCOUPLE AND POTENTIOMETER

SOAKING & CURING SLAB #79
STATION 16+64.16 - STATION 16+73.13
September 1, 1977

TIME	THERMOCOUPLE #/TEMPERATURE °F						
	#7	#8	#9	#10	#11	#12	
6:05a.m.	92	100	110	100	100	100	
8:20	90	95	100	92	95	92	Polymer applied to right half
8:37	90	95	100	92	95	92	Polymer applied to left half
10:45	100	100	110	100	100	95	Heat applied (2 hours & 8 minutes soaking)
10:50	120	110	130	110	110	110	
10:55	130	120	130	120	120	135	
11:00	140	130	138	130	130	142	
11:05	150	140	145	140	140	155	Start Curing Time
11:20	150	190	148	140	140	160	
11:30	158	145	152	145	150	170	
11:45	160	150	160	150	152	170	
12:00	165	151	162	155	162	180	
12:30p.m.	175	161	171	160	162	190	
1:05	185	170	170	158	175	190	

5/8" sand cover over all of slab. Used canvas cover for cool down. Sprayed water on sand before heat was applied for curing. Used 40 gallons of monomer.

Figure 23

CHAPTER VI

EXAMINATION AND TESTING OF CORES

In order to determine the depth of penetration of the polymer impregnation cores were taken of finished sections. In all, 51 cores were taken. They were four inches in diameter and about two inches deep or to the top mat of reinforcing steel. All core holes were patched with polymer concrete.

With some cores the depth of polymer could be noted by the darker color. However for a positive determination of the polymer depth, the cores were dipped in a 10% hydrochloric acid solution for 60 second etching. The specimen is then rinsed and blown dry with compressed air. The acid attacks the mortar and not the polymer. The depth can then be readily noted and measured.

The thickness of the polymerized layer varied throughout the deck and within a section. The range of thickness was from 1/16 inch to 3/4 inch. This variation was believed to be due more to variations in density of the concrete than to polymer impregnation construction procedures. Cement content, air entrainment percentage, mixing variables, and concrete consolidation all may have contributed to concrete density variation in the concrete bridge deck. Some differences in color or shade of the concrete from cores could be detected. See APPENDIX C for a tabular listing of individual core locations and polymer impregnation thickness.

In an effort to evaluate the imperviousness of the polymer layer, the SDH&PT Materials and Tests Division experimented with and developed a method to determine this. The water sealing or waterproofing qualities are apparently related to the quality of the polymer impregnation. The test method and results of cores tested are in APPENDIX C.

Comparison of an impregnated layer to untreated concrete was made by freeze-thaw cycling in Phase I of this study by study 114 investigators. Two 4-inch diameter cores were subjected to the test by ponding 0.25 inches of water in steel rings bonded to the surface and cycled between -20° F and 73° F. The control specimen failed after 12 cycles. The impregnated specimen was subjected to 42 cycles and tested further. Each core had fine cracks on the surface. Those in the impregnated specimen were apparently sealed. However, those in the control specimen probably contributed to its early failure.

Figures 24, 25, 26, and 27 illustrate the coring operation and the cores.

Figure 24

CORING THE DECK

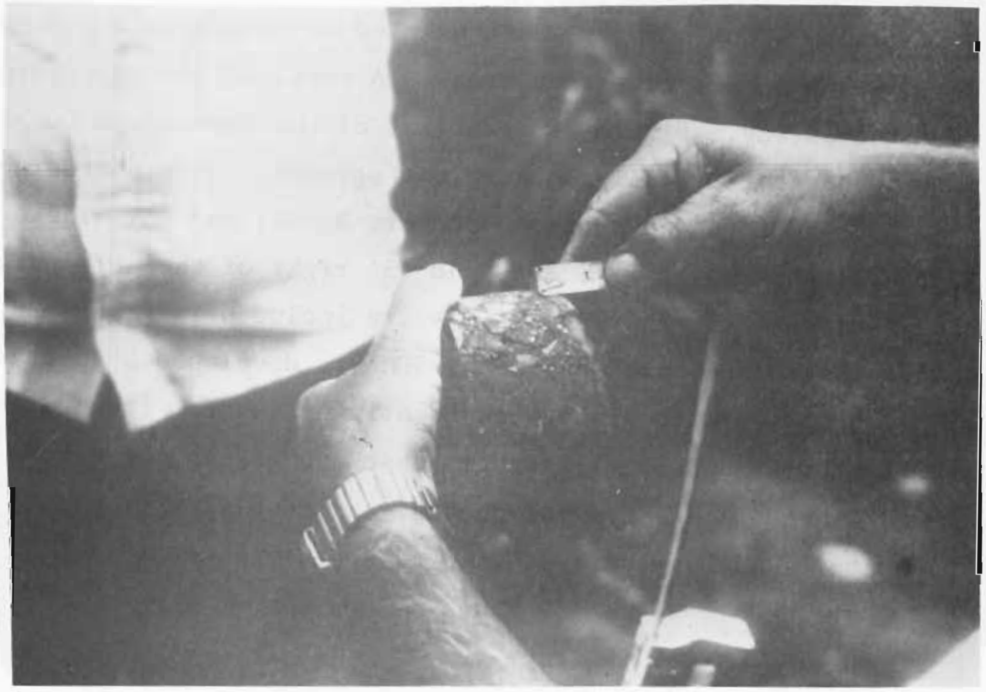
Figure 25

TYPICAL CORE

Figure 26

ACID ETCHING OF CORE

Figure 27



POLYMER DEPTH MEASUREMENT

CHAPTER VII

CRACK SURVEY

There had been some concern exhibited that the heat of drying and polymerization might damage or cause cracking of the concrete. Laboratory investigation and field impregnation demonstrations had not borne this out. However, to perform a more complete investigation and evaluation of possible heating related cracking on this project, before and after impregnation photographs were taken for analysis purposes. Initially, it was felt that ten photographs selected randomly and five photographs taken at selected sites where cracks existed prior to impregnation would be sufficient to monitor the deck for additonal cracking. After considerable discussion with CFHR and FHWA personnel, it was decided that about one-hundred photographs of 12" by 12" deck sections, randomly selected, would be desirable. Too many photographs could result in too much data to analyze but 100 would be suitable to reveal any cracking tendency. To select the sites for the additional photographs, the portion of the structure which had not yet been polymerized was stratified into 8' transverse by 50' longitudinal sections. These sections were divided into 1' squares. A table of random numbers was then used to determine a photograph location within each of the stratified areas. A total of 114 photographs were taken for the survey. Figure 28 is a list of the photograph locations. In addition to these statistically located photographs, seven photographs were taken in the unimpregnated sections numbers 8, 61, and 83. These photographs were generally taken at 15', 30', and 45' right of the left parapet wall in the section center. These locations are included in Figure 28.

Mr. Hustace, Senior Research Engineer, SDH&PT, developed a special camera stand and template with photograph identification for taking the photographs. Figures 29 and 30 illustrate these and making the cracks survey. Figures 31 and 32 are typical photographs resulting from the crack survey. Details and analysis of results appear in APPENDIX D.

FIGURE 28

CRACK SURVEY PHOTOGRAPH DATA

PHOTO NO.	STATION	DISTANCE RIGHT OF LEFT PARAPET WALL	CRACKED BEFORE	CRACKED AFTER	DATE BEFORE	DATE AFTER
1	9+80	33	yes	yes	6/21/77	7/14/77
2	10+34	15		yes	none	8/31/77
3	10+34	30		no	none	"
4	10+34	45		no	none	"
5	10+59	18.5	yes	yes	6/21/77	7/14/77
6	10+61	15	no	no	"	"
7	11+40	1		no	none	8/31/77
8	11+46	19	yes	yes	7/14/77	"
9	11+50	60	yes	yes	"	"
10	11+60	10	no	no	"	"
11	11+68	24	no	no	"	"
12	11+70	2	yes	yes	"	"
13	11+73	16	yes	yes	"	"
14	11+76	59	no	no	"	"
15	11+82	52	no	no	"	"
16	11+85	40	no	no	"	"
17	11+93	38	no	no	"	"
18	11+97	16	no	yes	"	"
19	12+07	51	yes	yes	6/21/77	"
20	12+08	2.5	yes	yes	"	"
21	12+12	23	no	yes	"	"
22	12+24	43	no	no	7/14/77	"
23	12+32	55	no	no	"	"
24	12+33	27	no	yes	"	"
25	12+34	1	yes	yes	"	"
26	12+38	34.5	yes	yes	6/21/77	"
27	12+46	7	yes	yes	"	"
28	12+48	9	no	no	7/14/77	"
29	12+56	17	yes	yes	"	"
30	12+58	59	yes	yes	"	"

FIGURE 28
(con't.)

CRACK SURVEY PHOTOGRAPH DATA

(continued)

PHOTO NO.	STATION	DISTANCE RIGHT OF LEFT PARAPET WALL	CRACKED BEFORE	CRACKED AFTER	DATE BEFORE	DATE AFTER
31	12+66	36	no	no	7/14/77	8/31/77
32	12+72	37	no	no	"	"
33	12+72	42	no	no	"	"
34	12+72	45	no	no	6/21/77	"
35	12+80	6	no	no	7/14/77	"
36	12+86	61	no	no	"	"
37	12+88	31	no	no	"	"
38	13+00	10	yes	yes	"	"
39	13+01	18	no	no	"	"
40	13+10	54	no	no	"	"
41	13+18	29	no	yes	"	"
42	13+25	8	no	no	"	"
43	13+28	38	no	no	"	"
44	13+37	58	no	no	"	"
45	13+46	14	no	yes	"	"
46	13+47	21	no	no	"	"
47	13+53	48	no	no	"	"
48	13+53	49	no	no	"	"
49	13+65	8	no	no	"	"
50	13+73	29	no	yes	"	"
51	13+74	10	yes	yes	"	"
52	13+79	24	no	no	"	"
53	13+90	64c	no	no	"	"
54	13+93	0c	no	no	"	"
55	14+01	45	yes	yes	"	"
56	14+01	52	no	no	"	"
57	14+16	38	no	no	"	"
58	14+45	31	no	no	7/14/77	"

FIGURE 28
(con't.)

CRACK SURVEY PHOTOGRAPH DATA

(continued)

PHOTO NO.	STATION	DISTANCE RIGHT OF LEFT PARAPET WALL	CRACKED BEFORE	CRACKED AFTER	DATE BEFORE	DATE AFTER
59	14+46	0c	no	no	7/14/77	8/31/77
60	14+47	18	no	no	"	"
61	14+51	64c	no	no	"	"
62	14+53	33	yes	yes	"	"
63	14+57	8	yes	yes	"	"
64	14+57	43	no	no	"	"
65	14+58	48	no	no	"	"
66	14+70	42	no	no	"	"
67	14+72	21	yes	yes	6/21/77	"
68	14+73	8	no	no	7/14/77	"
69	14+75	60	no	no	"	"
70	14+84	56	no	no	"	"
71	14+85	33	no	no	"	"
72	14+88	3	no	no	"	"
73	14+91	20	no	no	"	"
74	14+99	62	no	no	6/21/77	"
75	15+07	15		no	none	"
76	15+07	45		no	none	"
77	15+10	26	no	no	7/14/77	"
78	15+25	40	no	no	"	"
79	15+26	8	no	no	"	"
80	15+27	21	no	no	"	"
81	15+30	55	no	no	"	"
82	15+42	25	no	no	"	"
83	15+44	42	no	no	"	"
84	15+51	1	yes	yes	"	"
85	15+67	59	no	yes	"	"
86	15+68	23	yes	yes	6/21/77	"
87	15+75	14	no	no	7/14/77	"
88	15+75	63	no	no	"	"
89	15+95	41	no	no	"	"

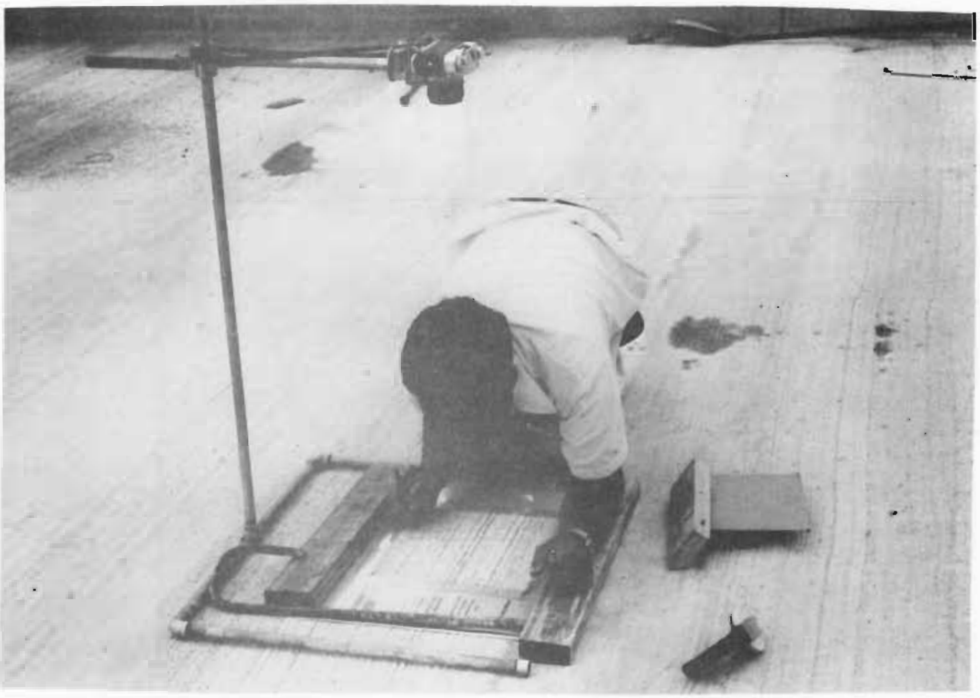
FIGURE 28
(con't.)

CRACK SURVEY PHOTOGRAPH DATA

(continued)

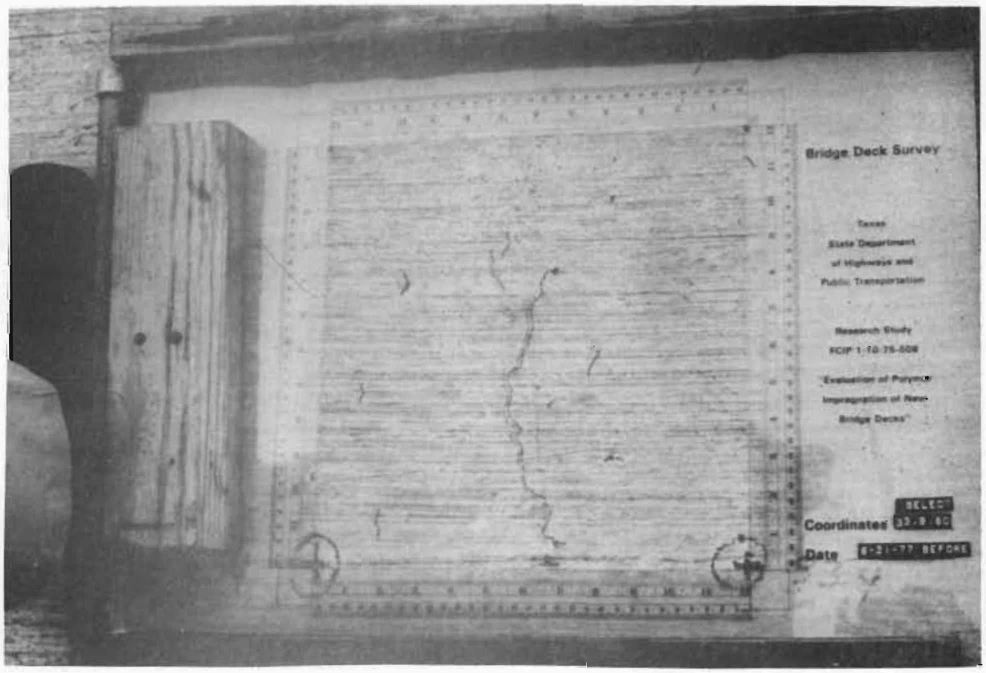
PHOTO NO.	STATION	DISTANCE RIGHT OF LEFT PARAPET WALL	CRACKED BEFORE	CRACKED AFTER	DATE BEFORE	DATE AFTER
90	15+98	56	no	no	7/14/77	8/31/77
91	15+99	18	no	no	"	"
92	16+06	26	no	no	"	"
93	16+14	4	no	no	"	"
94	16+16	3	no	no	6/21/77	"
95	16+17	37	no	no	7/14/77	"
96	16+22	54	no	no	6/21/77	9/16/77
97	16+35	9	no	no	7/14/77	"
98	16+37	57	no	no	"	"
99	16+45	0c	no	no	"	"
100	16+49	29	no	no	"	8/31/77
101	16+60	42	no	no	"	"
102	16+65	48	no	no	"	9/16/77
103	16+66	32	no	yes	"	"
104	16+67	21	no	no	"	"
105	16+86	32	no	no	"	"
106	16+88	40	no	no	"	"
107	16+98	38	no	no	"	"
108	17+02	56	no	no	"	"
109	17+04	15		no	none	8/31/77
110	17+04	30		no	none	"
111	17+07	48	no	no	7/14/77	9/16/77
112	17+10	18	no	no	"	"
113	17+12	16	no	no	"	"
114	17+14	2	no	no	"	"

Figure 29



MAKING CRACK SURVEY AND PHOTOGRAPH

Figure 30



TEMPLATE USED IN CRACK SURVEY

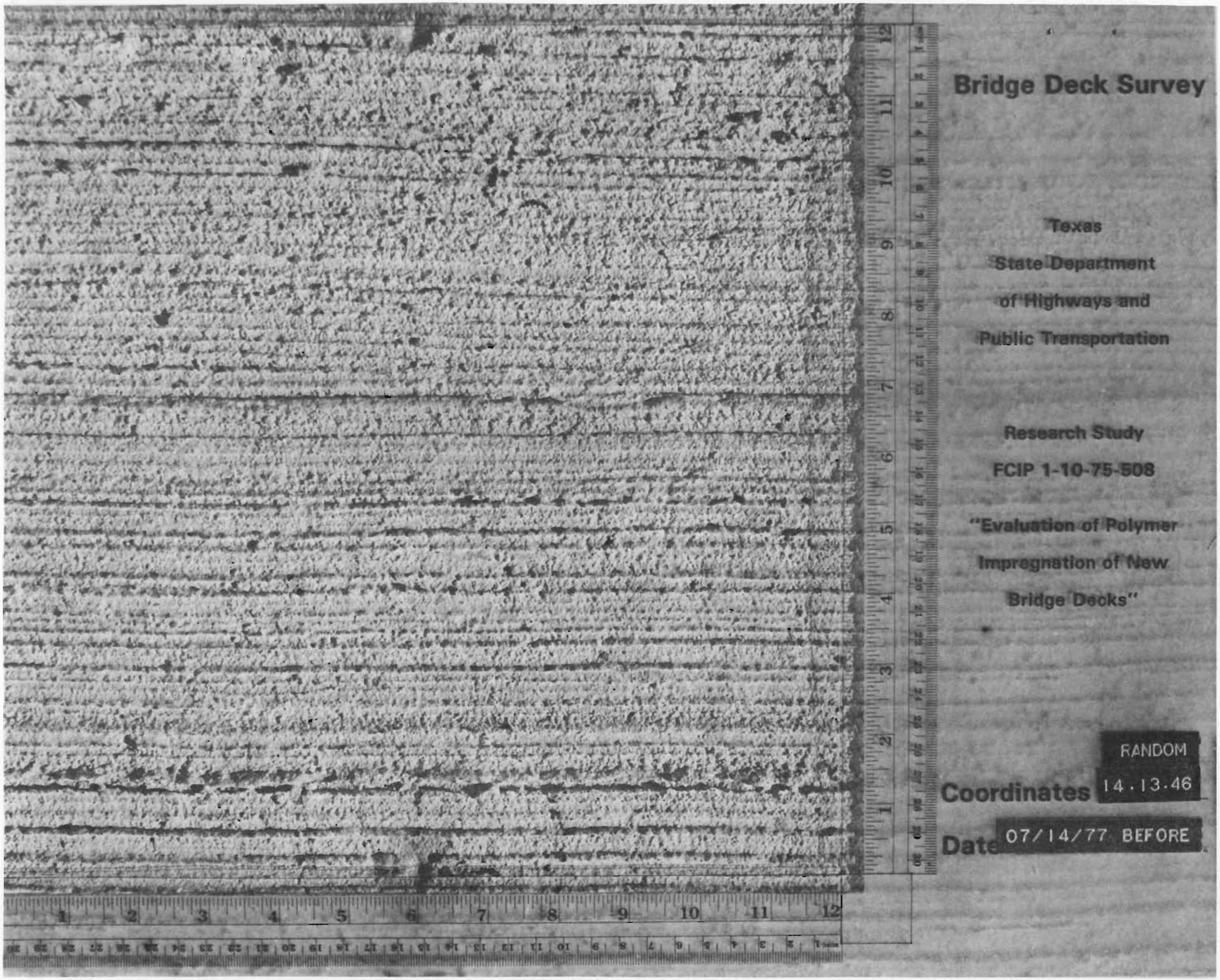

Bridge Deck Survey
Texas
State Department
of Highways and
Public Transportation
Research Study
FCIP 1-10-75-508
"Evaluation of Polymer
Impregnation of New
Bridge Decks"
RANDOM
Coordinates 14.13.46
Date 07/14/77 BEFORE

Figure 31

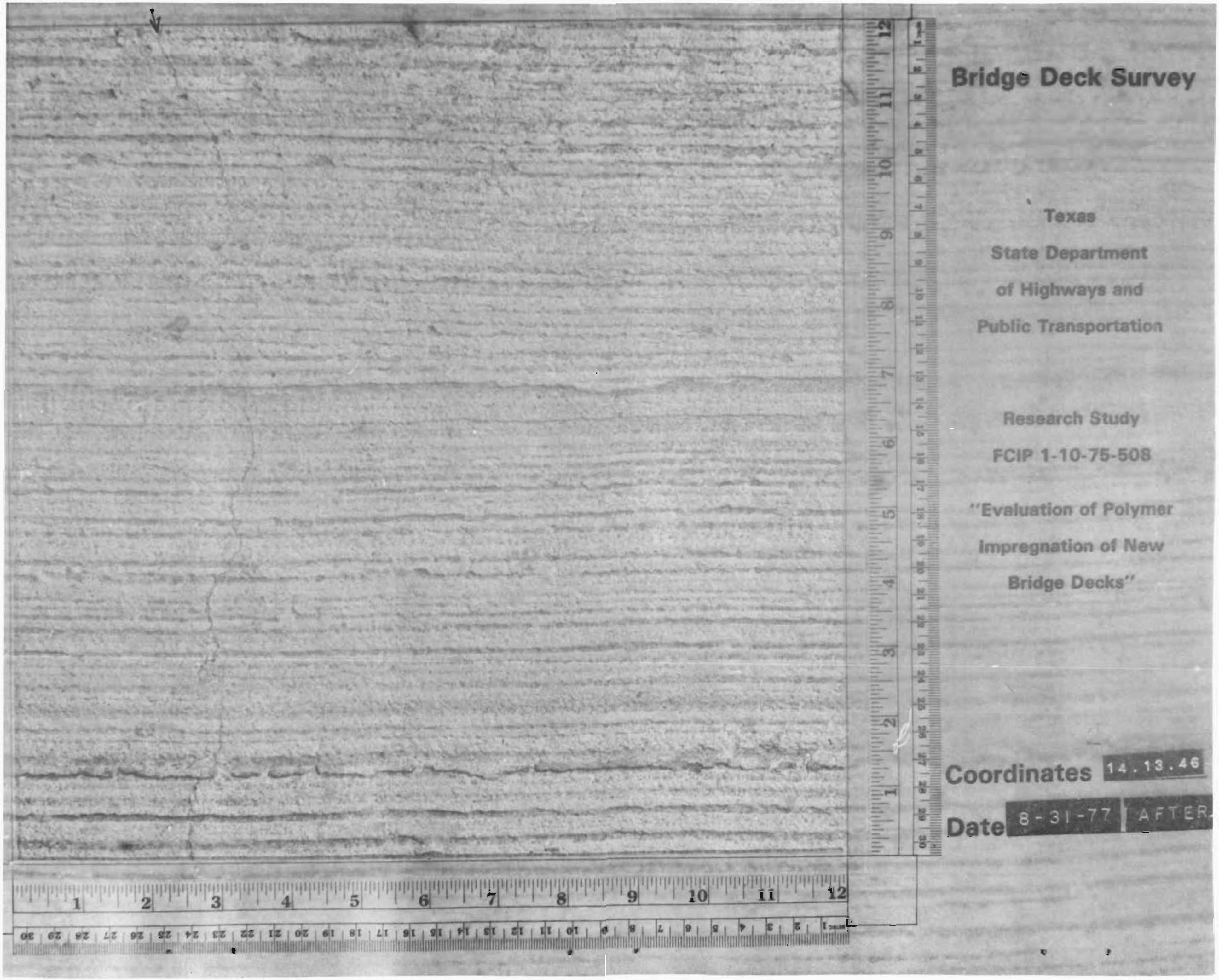

Bridge Deck Survey
Texas
State Department
of Highways and
Public Transportation
Research Study
FCIP 1-10-75-508
"Evaluation of Polymer
Impregnation of New
Bridge Decks"
Coordinates 14.13.46
Date 8-31-77 AFTER

Figure 32

There was some additional cracking of the deck concrete noted after polymerization. As analyzed by the crack survey photographs, the increase was estimated at 6.1 percent more cracks than before the survey. The cracks were generally of the "hair-line" type with insufficient width for practical measurement. They could not be positively attributed to heating of the concrete nor could they be positively not attributed to the heating. Bear in mind that the deck had been placed in the fall in near ideal conditions of an exceptionally wet fall and winter. The deck had not been subjected to the expansive conditons created by an extremely hot, dry Texas summer when the before photos were taken. The resulting cracks may have been those normal for weather and expansion cracking from experiencing its first Texas summer.

Some of the additional cracking was in the longitudinal direction. The resident engineer on the project theorized that this was common on wide roadway structures of this type, as slab action in the transverse direction can result on wide structures and unresisted lateral expansion contributes to the longitudinal cracking. The overall width including the pedestrian sidewalk is 70' 9".

CHAPTER VIII

COST DATA AND ECONOMICS

The cost or economics must always be a design consideration in any engineered construction. Methods of waterproofing and protecting a multimillion dollar bridge against deicing chemicals is no exception. The engineer's estimate for polymer impregnation of 5,396 square yards of concrete bridge deck was $9.00 per square yard or $48,564.00. This estimate of $1.00 per square foot was recommended by Dr. David Fowler and Dr. Donald Paul, Center for Highway Research. When bids were opened on July 23, 1975, seven bids were received. The following contractors and their bid price per square yard for the polymer work are listed in their order of low bid on the complete project.

Low Bidder	J. H. Strain & Sons, Inc.	$10.00/s.y.
2nd Low Bidder	Zack Burkett Co.	9.00/s.y.
3rd Low Bidder	Bailey Bridge Co.	5.00/s.y.
4th Low Bidder	Hensel Phelps Construction Co.	11.00/s.y.
5th Low Bidder	Austin Bridge Co.	13.35/s.y.
6th Low Bidder	Ross Anglin Co.	14.00/s.y.
High Bidder	Border Road Construction Co.	15.00/s.y.

The low bidder was about 12.9 percent under the total project estimate or approximately $268,000.00 including engineering and contingencies. The total contract amount was $1,815,930.55 including E. & C. The polymer impregnation price of $53,960.00 was less than 3 percent of the contract and considered very satisfactory.

The radiant heaters used by the construction contractor to dry the concrete bridge deck and to polymerize the monomer usually sell for about $180 per unit. By purchasing in the off season and in quantity they were obtained for about $155 each. The heaters used approximately 9,000 cubic feet of natural gas for a complete cycle of drying and polymerization of two sections. Two sections include 128 square yards of bridge deck. The cost of natural gas to the contractor was $1.80 per 1,000 cubic feet. Therefore, the fuel cost for polymer impregnation was $0.125 per square yard.

The prices of the various materials FOB Dallas, Texas are:

Monomer	$0.44/lb.
Cross-linking agent	1.36/lb.
Initiator	2.22/lb.

The ingredients for batches covering an approximately 64 square yard section and costs are:

Monomer:	313.2 lbs.	@	$0.44	=	$137.808
Cross-linking agent:	15.894 lbs.	@	1.36	=	21.615
Initiator:	1.6 lbs.	@	2.22	=	3.552
TOTAL FOR 64 S.Y.					$162.975

(OR $2.546 per s.y. for materials)

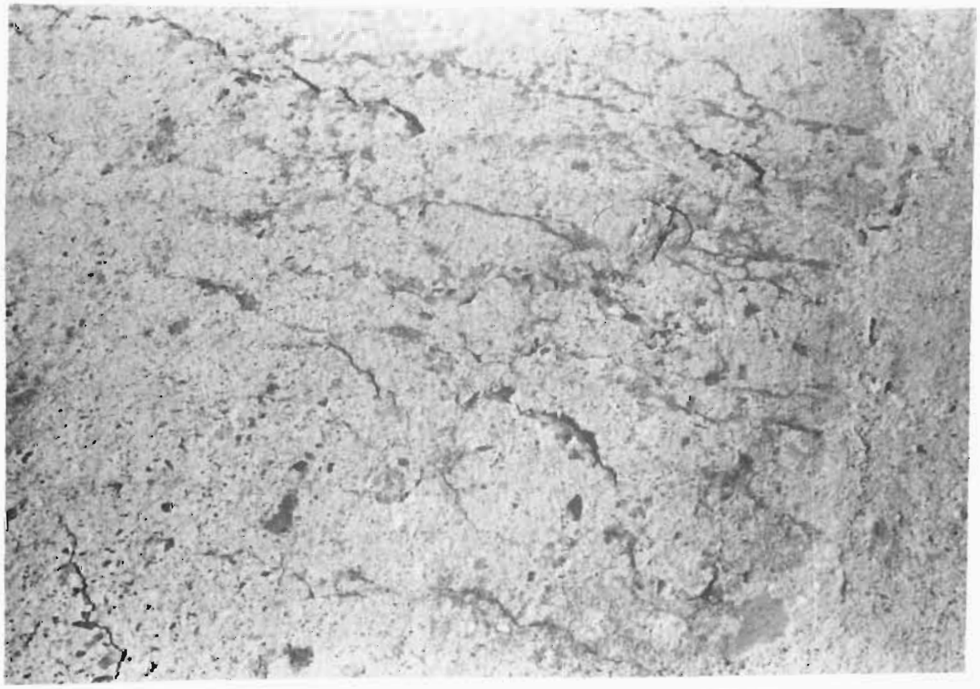
Costs for labor, other equipment and contingencies are not available. However, the contractor indicated at a field day meeting at Big Spring, Texas, on July 26, 1977, that future work of this type could be done for the same or possibly even less money per square yard.

Even though the cost of $53,960 to polymerize this $1,815,930.55 bridge may appear expensive, it may in reality be economical compared to extensive maintenance or replacement cost if the concrete deteriorated. None of the usual conventional concrete sealing methods have proven entirely satisfactory. From research results and laboratory tests and investigation with field trials, polymer impregnation appears to meet the requirements. Figures 33 and 34 illustrate badly deteriorated concrete in two Texas bridge decks. We can ill afford to continue to construct expensive bridge structures and decline to provide the best protection against moisture and chemical intrusion available.

Figure 33

DAMAGED CONCRETE IN CURB FROM CHEMICALS AND FREEZE THAW

Figure 34



CRACKED AND DELAMINATED BRIDGE DECK CONCRETE

CHAPTER IX

CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusions

The Owens Street, Texas and Pacific Railroad Overpass on State Highway 350 in Big Spring, Texas was the first full-scale polymer impregnation project in the State. J. H. Strain and Sons, Inc. Tye, Texas, the successful bidder, devised a practical and economical procedure for doing the work. He showed that a cumbersome enclosure requiring high temperatures was unnecessary. The procedure using gas-fired radiant heaters which he devised has revitalized interest in polymer impregnation nationwide within FHWA.

When properly dried, and soaked with monomer, desired depths of polymer impregnation can be obtained in new concrete bridge decks. With a slow build-up of temperature of the concrete and drying at specification temperature unusual or damaging cracking of the concrete from the heating was not apparent. Acid etching and microscopic examination of concrete cores illustrate satisfactory polymer impregnation of the bridge deck. Apparently future polymer impregnation work may be performed as economically as this was. No doubt other innovative methods of performing the work will be developed by successful contractors.

9.2 Recommendations

A. Close adherence to drying and soaking times with additional monomer being added where needed will insure desired depth of impregnation.

B. Consideration should be given to polymer impregnation along with other possible protective systems for each new concrete bridge deck constructed in the colder region of the State and particularly where deicing chemicals are used for snow and ice control.

C. Consideration should be given to polymer impregnation of existing concrete bridge decks where apparent poor quality material in all or portions are resulting in maintenance problems.

D. Studies to compare imperviousness and durability of concrete specimens of the conventional sealing methods as linseed oil treatment, asphalt surface treatments and hot-mix asphaltic concrete pavement with partial polymer impregnation are recommended.

E. It is recommended that a committee composed of CFHR principal investigators, Research Section personnel, Maintenance Division and Bridge Division personnel conduct regional conferences to transfer the technology developed under research study 114 and this project to the field for information and implementation. The participants should be design engineers, materials engineers, construction and maintenance engineers.

APPENDIX
A

CONTRACTOR'S WORK PLAN
AND
CONSTRUCTION SPECIFICATIONS

Control 695-1-19
State 350
Howard County
PD No. 8392
March 18, 1977

J. H. Strain & Sons, Inc., Contractor

PROCEDURE AND EQUIPMENT PROPOSAL FOR POLYMER IMPREGNATION OF SLABS ON OWENS STREET OVERPASS IN BIG SPRING, TEXAS

DESCRIPTION: This report is the plan and procedure for polymer impregnation of concrete slab in accordance with the plans and Special Specification, Item 4127, State Department of Highways and Public Transportation, which will be used on the Texas and Pacific Railroad overpass and State Highway 350 in Howard County, Project M-F203(1), etc.

At least two weeks prior to impregnation of the bridge slab, a demonstration of this procedure will be performed on a 10 x 15 foot slab of concrete cast on the ground. This slab is 7 3/4 inches thick with reinforcement, No. 4 bars on 6 inch centers in both directions approximately 2 inches below the top of the slab. The slab was cast on a vapor barrier with the same concrete mix design and has the same finish and texture as the bridge slab. This slab will be used to evaluate the equipment and procedures as described herein.

MATERIALS: We propose to use the chemicals required for this project produced by Rohm and Haas Company, with the exception of the initiator (Vazo 64) to be supplied by DuPont Company*.

The monomer solution shall consist of 100 parts by weight of monomer, Methyl Methacrylate, MMA, 5.0 parts by weight of a crosslinking agent, Trimethylolpropane Trimethacrylate, TMPTMA (X-980), and 0.5 parts by weight of the polymerization initiator Azobis (isobutyronitrile), AIBN (Vazo 64).

The MMA will have a minimum purity of 99.8%, and shall contain an inhibitor, MEHQ (Methyl ester of hydroquinine) in an amount of 10 ppm. The TMPTMA shall have a minimum purity of 95% and contain 100 ppm of HQ (hydroquinine) inhibitor. AIBN shall have a minimum purity of 96%.

or Poly-Zole AZDN supplied by Stepan.

STORAGE OF MATERIALS: The MMA solution is to be stored in a concrete storage unit provided by Clyde McMahon Ready Mix. These units are within 1300 feet of the overpass structure and are very suitable for temperature control and ventilation. They are also well isolated from other storage buildings, business structures, or dwellings. The TMPTMA and AIBN will be stored at the engineers' lab building on the jobsite. Both of these storage structures can be temperature controlled. The Big Spring City fire department will be advised of the type of chemical stored in each location.

MIXING: The individual ingredients for the monomer solution will 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. The MMA and TMPTMA will be measured by the gallon and the AIBN will be measured by the pound.

The mixing of the monomer ingredients will be done in steel drums with wooden paddles manually operated. We will use two drums in the mixing operation, approximately 22½ gallons to keep within the maximum quantity of 30 gallons to be mixed in a single container, and be able to have sufficient quantity ready for distribution at the same time. The mixing operation will be done on the bridge slab at a safe distance from any drying or other operation that might endanger men or equipment. The operation shall be done under a portable canopy of sufficient area to insure shade for storage and mixing of the chemicals involved. The monomer will be kept away from flame or spark and given the same care as gasoline.

The temperature of the mixture during preparation and application will be between 40° F and 80° F. The mixture must be applied within 30 minutes after completion of mixing.

Portions of a batch which become unsatisfactory for use will be burned under controlled conditions in an open area north of the bridge within the highway right-of-way.

TREATMENT AREA: All slabs have been in place over 28 days. Immediately after placement of concrete the slabs were sprayed with Type I Curing Compound and then covered with wet blankets for a minimum of six days. The surface of the concrete to be treated will be thoroughly cleared of any curing compound or foreign material. Substance such as oil or grease which cannot be removed by sweeping shall be cleaned with an approved solvent or sandblasting. Any solvents used shall be allowed to evaporate completely prior to heat application.

The area we propose to impregnate at one time shall be approximately 64 square yards. This area to be the full transverse length of the slab 64 feet and 9 feet longitudinally, avoiding open joints by ~~three~~ Seven feet or ~~more~~ Coming up to the open Joint. The parapet wall will become the ends of the enclosure and should the heat, during the drying process, appear to damage the wall, it will then be insulated from the heat by the use of a panel. By allowing the wall to be part of the enclosure, will make it possible to seal the joint between the wall and slab with polymer.

The area to be treated will be enclosed with panels two feet high and four inches thick constructed on a frame made of 1/2 inch angles. Each side is to be sheeted with 20 gauge sheet metal and insulated with full thickness fiberglass. We will provide all necessary increments to give a completely enclosed area. Also, the top cover sections which are to be provided in the same dimensions and insulation will be removable to allow for ventilation when necessary.

DRYING: We propose to use hot air to accomplish the drying operation on slab and sand cover. This operation is to be done by two space heaters with blowers rated at 300,000 BTUs per hour each. The hot air is to be ducted into enclosed insulated area through insulated sheet metal ducts 10" in diameter. Each blower is to be set at quarter point on opposite side of the enclosed area to be dried and will be teed into perforated sheet metal ducts (10" dia.) set above slab surface approximately 12" and each one to be 1/2 the distance of longitudinal length and set approximately at centerline of enclosure.

TEMPERATURE CONTROL: We propose to use a Barber-Colman Millivolt Potentiometer, Model PA-11-1 with thermocouple sensors fastened to the concrete surface at locations which will show the maximum and minimum expected temperatures. A Minimum of 6 sensors will be used with the proposed enclosure of 64 square yards, which will provide a continuous reading of the surface temperature.

We will hold the temperature rise of the concrete surface, not to exceed 2 degrees per minute, and not less than ~~to exceed~~ 225°~~.~~ or more than 260°F. This temperature is to be held approximately 5 hours. ~~If this drying can be accomplished at a lower temperature by using more time, we would like to hold expansion to top surface at a minimum.~~ Due to low humidity in this area, that is normal, we think that this would be less cause for any spalling on the surface of the slab. We also propose to cover the surface of the area to be treated with clean sand at approximately 3/8" thickness before drying operation is started. The sand cover is to remain in place until polymerization has been completed. The surface temperature of concrete will be allowed to cool to 90° or below, but not under 40°, before monomer is applied.

While the slab is being cooled, a polyethylene cover will be placed over the treatment area to protect the dry sand from moisture during periods of high humidity.

MONOMER DISTRIBUTION: The monomer solution shall be applied uniformly to the surface at the approximate rate of sixtyfive one-hundredths (0.65) gallons per square yard. The monomer solution will be carefully sprayed so as not to erode the sand cover. The sand surface will 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 distributor shall consist of 55 gallon drum with three 1/2" outlets in bottom, with cut-off valves placed in line immediately after line is out from under bottom. Then a plastic flexible hose which will be attached to a 1/2" teed pipe. The horizontal part of the teed pipe shall be approximately three feet long and perforated with 5/64" 1/16" holes on 2" 4" centers. This assembly will be mounted on a section of "Spanit" bridging and placed on dollies to ride on tracks outside enclosure sides and travel transversely to length of slab. The spray bar assembly will be arranged to be used from either side of bridge, and be able to adjust for height above slab as desired. The drum shall have a wooden cover that can be securely held in place during the distribution operation of each section being impregnated. The ~~plastic~~ hose will be Opaque Plastic and built of such material that will not react with the monomer.

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

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

Excess monomer solution will not be permitted to run down the bridge deck or through expansion joints or holes in the deck. Inert material will be used to soak up excess runoff.

Suitable fire precautions will 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.

CURING: Immediately after the soaking period, the impregnated surface shall be cured by application of heat. We propose to use steam to attain the temperature of 140° F. in the 2 hour time limit and maintain at this temperature but not above 175° for 2 hours. We propose to use a Gray Vapor generator Model HLC 100 for generation of steam. We will cover the area being impregnated immediately after distribution with polyethylene sheeting.

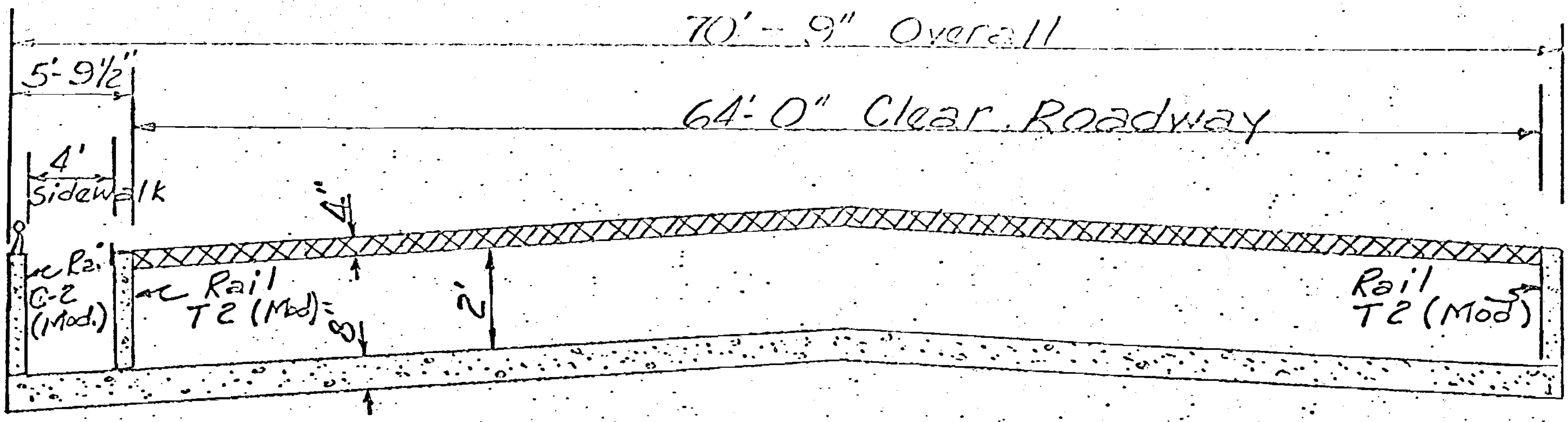
The method of heat application and distribution will be such as to insure uniform surface temperature and avoid localized hot spots. During heat application, the polyethylene sheeting shall remain in place on the surface to minimize evaporation.

The sand cover will 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 will be removed.

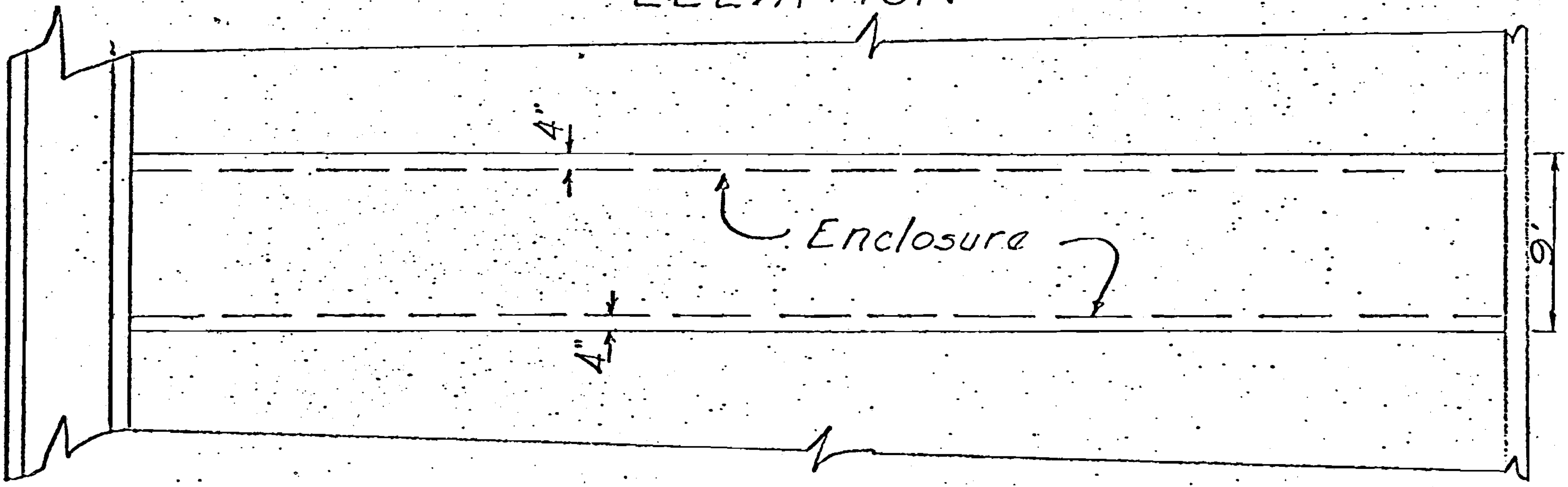
Most of the foregoing equipment will be built by our own forces because we know of no manufacturer producing such equipment, so we will have some adjustments and alterations to be made as we set up in the field.

We propose to begin on the south end of the structure and proceed north with the strip pattern for each enclosure used for drying, cooling, soaking, and curing operation. The enclosures will be spaced at least 25 feet apart, while one enclosure is in the drying process another enclosure would be in either soaking or curing.

The adequacy of the drying and curing operation will be tested on the ground with a full scale enclosure for adjustments of ducts and uniformity of heat prior to starting on the bridge slabs.



ELEVATION



PLAN

SKETCH SHOWING ENCLOSURE TO BE USED FOR POLYMER IMPREGNATION OF CONCRETE SLABS.

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.

APPENDIX
B

MONOMER AND MATERIALS DATA

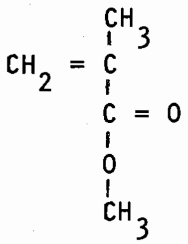
SOURCES FOR CHEMICALS FOR BRIDGE DECK IMPREGNATION

A. MONOMER:

Chemical Name: Methyl Methacrylate

Abbreviation: MMA

Formula:



$CH_2 = C(CH_3) - C(=O) - O - CH_3$

Source:

Rohm and Haas Company
Independence Mall West
Philadelphia, PA. 19105

Regional Office: 4585 Simonton Road
Dallas, Texas 75240
(214) 233-1021

Ordering: Margret Pursel

Technical Representatives: Tom Purcell
Ron Young

For contact with Philadelphia Order Dept:
Call Dorothy Dondici (215) 592-3236

September 1977
Price Structure:

Bulk	$0.38/pound
Truckload (54 drums minimum)	0.44
30-53 drums	0.45
15-29 drums	0.46
5-14 drums	0.47
3-4 drums	0.49
1-2 drums	0.51

Orders should specify the inhibitor type and amount to be

MEHQ - 10 ppm

Other Potential Suppliers:

E. I. DuPont de Nemours
Wilmington, Delaware

Polysciences, Inc.
Paul Valley Industrial Park
Warrington, Pennsylvania 18976

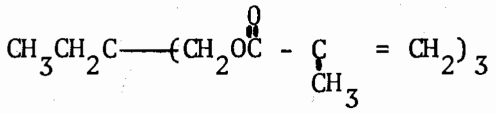
B. CROSS-LINKING AGENT:

Chemical Name: Trimethylolpropane Trimethacrylate

Abbreviation: TMPTMA

Rohm and Hass Designation: X-980

Formula:



$$CH_3CH_2C{-}(CH_2O\overset{\overset{O}{\|}}{C}-\underset{CH_3}{\underset{|}{C}}=CH_2)_3$$

Source: Rohm and Haas
(all information same as for MMA)

September 1977 Price Structure:

Bulk	$1.15/pound
Truckload	1.18
10 drums	1.20
4-9 drums	1.31
1-3 drums	1.36

Order should specify inhibitor type and amount to be

HQ - 100 ppm

Other Potential Suppliers:

Ware Chemical Corporation
P. O. Box 262
Stratford, Connecticut 06497
"Chemlink 30"

Celanese Plastics Company
26 Main Street
Chatham, NJ 07923

Haven Chemical Company
5000 Langdon Street
Philadelphia, Pennsylvania 19124

C. INITIATOR:

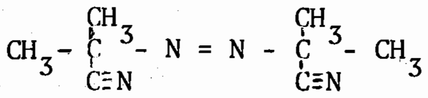
Chemical Name: 2,2' - Azobis(isobutyronitrile)

Abbreviation: AIBN

Common Trade Names:

VAZO 64	(DuPont)
BUTOCEL	(Fairmount)
POLY-ZOLE AZDN	(Stepan)

Formula:



$$CH_3-\overset{CH_3}{\underset{C\equiv N}{C}}-N=N-\overset{CH_3}{\underset{C\equiv N}{C}}-CH_3$$

Source:

Stepan Chemical Co.
Polychem Dept.
5151 Eames St.
Wilmington, MA 01887
(617) 933-4240

Sales Coordinator: Sheila Quinno

Technical Representative: Bill Landry

September 1977
Price Structure:

50 lbs	$2.62/lb FOB
100 - 250	2.22
300 - 1200	1.96
1250 - up	1.85

APPENDIX
C

CORE TEST PROCEDURES AND RESULTS

ACID ETCHING
RECORD OF CORE POLYMER DEPTH

SLAB NUMBER	CORE NUMBER	DEPTH OF POLYMER	REMARKS
1	1-1	1/2"	Using forced hot air and enclosure
	1-2	1/2"	
	1-3	5/8"	
	1-4	1/2"	
2	2-1	1/8"	
	2-2	1/8"	
	2-3	1/2"	
	2-4	3/8"	
3	3-1	1/8"	
	3-2	1/4"	
	3-3	1/8"	
4	4-1	1/2"	Began using radiant heaters
	4-2	3/8"	
	4-3	3/8"	
	4-4	1/2"	
5	5-1	3/8"	
	5-2	3/8"	
	5-3	1/4"	
6	6-1	1/2"	
7	7-1	5/8"	
9	9-1	3/8"	
	9-2	3/8"	
10	10-1	1/2"	
12	12-1	1/2" - 1/8"	Edge of slab line or lap joint
	12-2	5/8"	
13	13-1	1/16"	Edge of slab line or lap joints
	13-2	3/8" - 1/2"	

ACID ETCHING
RECORD OF CORE POLYMER DEPTH
(continued)

SLAB NUMBER	CORE NUMBER	DEPTH OF POLYMER	REMARKS
14	14-1	5/8"	
	14-2	5/8"	
	14-3	5/8"	
15	15-1	1/8" on S. 1/2" on N.	Construction joint
	15-2	3/8" - 1/2"	
16	16-1	1/2"	
17	17-1	1/2"	
18	18-1	1/2"	
19	19-1	1/2"	
20	20-1	3/4"	
	20-2	1/16" - 1/8"	Lap joint
21	21-1	5/8"	
22	22-1	5/8"	
48	48-1	5/8"	
	48-2	1/2"	
49	49-1	1/4"	
	49-2	5/8"	
50	50-1	3/8"	
	50-2	1/2"	
51	51-1	1/8"	
	51-2	3/8" - 1/2"	Slab redried after rain
55	55-1	3/4"	
57	57-1	3/4"	
59	59-1	5/8"	

SUMMARY

Number of cores - 51
Average polymer depth using smaller measurements - 0.35"
Average polymer depth using larger measurements - 0.38"

LABORATORY DETERMINATION OF POLYMER PENETRATION IN CONCRETE BRIDGE DECK CORES

by

Tom S. Patty
Geologist III

Materials and Tests Division
State Department of Highways and Public Transportation

February 1978

INTRODUCTION

Cores removed from polymer impregnated Owens Street overpass structure Big Spring, were subjected to several laboratory methods including acid etching, staining and microscopical analysis, as part of the research program to evaluate the polymer system. Examinations over the past 5 years of cores extracted from old and new concrete bridge decks show that cores provide adequate samples to demonstrate how well a polymer system has been introduced, the depth of penetration and the relative consistency of the system.

METHODS

A quick and simple technique to determine the relative depth of a polymerized monomer in concrete involves total or partial submersion of a core or a vertical section cut from a core in 10% HCl for 60 seconds. If a monomer has sufficiently polymerized in situ to encapsulate the cement paste, the zone of polymer saturation is easily differentiated from normal paste after an acid-etch treatment. This etching technique is especially suited for on-site evaluation because it does not require elaborate equipment and can be performed as quickly as cores are taken. Acid etching of vertical sections cut from cores is not necessary for quick field evaluation.

The cores being evaluated are submerged top-down into a glass or plastic container of sufficient size and depth to allow the acid to etch about two inches of the core's height. The cores should be rinsed well with water and dried. When blown dry with compressed air, the polymer saturated paste quickly turns white or generally it is lighter in color than the non-treated cement paste. The etching quickly dissolves certain portions of the cement paste from around the coarse aggregate and sand particles resulting in a marked change in relief at the boundary between the polymer treated and non-treated paste. If cores are poorly impregnated, an extended acid treatment (2-3 minutes) may be necessary to clearly show where the polymer has encapsulated the cement paste.

Staining or color enhancement to further delineate the penetration depth of polymer after acid etching is accomplished by applying phenolphthalein. The phenolphthalein solution reacts to the pH of the concrete and stains the cement paste where the polymer is absent. The core should be washed in deionized water to neutralize any rinse water with relatively high pH which would affect the results of a phenolphthalein application. The indicator quickly shows areas of a core which may have microcracks or zones where the monomer may have evaporated or diffused prior to polymerization. Polymer impregnated paste will not stain. In addition, phenolphthalein will not stain carbonated or weathered cement paste such as generally found in concrete older than roughly five years.

A soaking period of at least 24 hours with a phenolphthalein solution ponded on top of a core is normally adequate to show if any leakage occurs through the polymer treatment. The indicator solution will stain unsealed microcracks and any unprotected cement paste which allows migration of the dye through interconnected voids and capillaries. Discontinuities, which may not clearly be discernible after a core or a section through a core has been acid-etched, are usually more distinguishable after a phenolphthalein color-enhancement treatment. If microcracks and interconnected capillaries are sealed no migration of the indicator dye will occur.

Ponding of the indicator solution on top of the cores using plastic cylinders and a caulking sealer has demonstrated that a polymer treatment can prevent solutions from penetrating concrete cores which have been removed from a bridge deck.

Vertical sections cut from 4-inch cores permit a number of examinations from the same sample. Parallel slices about 1/4-inch thick allow several comparative studies to be made from a single core. They also show slight variations which may exist in the polymer system resulting from aggregate size and gradation and porosity of the paste. Microscopical examination of the paste and capillary system for the presence of polymer requires polished-sections prepared from slices cut about 1/4-inch thick and one-inch square. These examinations substantiate the findings of acid etching treatments and provide a more accurate picture of the polymer system.

Petrogrpahic identification of polymer in treated concrete can be made from mirror-like polished sections at magnification ranges of 200 to 400 times. Examinations show that the apparent index of refraction of the cement hydration products is significantly changed when impregnated with polymer. The unhydrated cement grains are unaffected by the polymer but the cement paste changes to almost an isotropic condition and is easily differentiated from the polymer-free paste when viewed under reflected polarized light.

RESULTS

A total of fifteen 4-inch cores taken from the Owens Street Overpass were subjected to laboratory examination in an effort to identify the impregnated polymer system, determine its depth of penetration and evaluate the relative effectiveness of the polymer in sealing the concrete from solutions.

The following is a summary of the observations:

Owens Street Overpass Cores, Big Spring

Core #	Top Surface Observations	Depth of Polymer	Phenolphthalein Penetration Test	Petrographic Examination
3-4	No microcracks apparent	Trace on surface.	No staining observed, no penetration of solution.	No polymer noted below top surface.
4-5	Sand mat on surface, some microcracks	0.5 inch	Stain in vertical microcrack to 1.4-inch depth, no stain in polymer saturated zone. Lateral migration of dye in fracture system below polymer zone.	Well-defined polymer system to 0.5 inch depth. Polymer observed to 0.8 inch depth with some discontinuities adjacent to air voids and microcracks.
5-4	Surface very dark and glazed, no microcracks	0.5 inch	Minor stain in microcrack over large aggregate near surface. No other staining noted in polymer zone.	Well-defined polymer system to 0.5 inch depth. Polymer glaze layer on top.
40-2	Some microcracks	0.4 inch	Staining along vertical microcrack to depth of 1.2 inch. Lateral staining from crack below polymer treatment. No staining in polymer zone.	Evaporation areas in polymer zone to 0.2 inch depth, other discontinuities in polymer zone noted near voids.
42-1	Top surface cracked when cored	0.5 inch	Test not conducted.	Poorly-developed polymer system from 0.1-0.3 inch level. Very irregular polymer from 0.3-0.5 inch depth. Isolated traces of polymer to 0.8 inch depth.
48-2	Some microcracks	0.5 inch	Staining restricted to microcracks and minor evaporation areas.	Polymer system with some minor discontinuities below large aggregates and near voids. Microcracks noted with phenolphthalein stain. Traces of polymer to 0.7 inch depth.

Core	Top Surface Observations	Depth of Polymer	Phenolphthalein Penetration Test	Petrographic Examination
49-2	No microcracks noted	0.6 inch	No staining observed.	Polymer well-defined between 0.1-0.6 inch depth. Some traces to 0.8 inch depth. Evaporation or diffused zone to 0.1 inch level.
50-2	Microcrack noted	0.5 inch	Staining restricted to vertical crack and adjacent to coarse aggregate near to surface. Lateral migration of dye in fractures below polymer zone.	Polymer well-defined to 0.5 inch depth with evaporation zone to 0.2 inch. Discontinuities associated with some coarse aggregate.
55-1	Microcrack noted	0.7 inch	Staining along vertical microcrack to depth of 1.1 inch and around large aggregates near top surface.	Polymer well-developed between 0.2-0.7 inch level.
57-1	Top surface damaged when cored.	0.7 inch	Phenolphthalein soak test not conducted because of damaged surface.	Good polymer system between 0.2-0.5 inch depth. Irregular diffused zone from 0.1-0.2 inch. Polymer observed to 0.2 inch.
59-1	Top surface damaged when cored.	0.6 inch	Test not conducted.	Poorly-developed polymer system from surface to 0.3 inch depth. Fair system at 0.3-0.6 inch depth but very irregular boundaries.
79-1	Microcracks noted	0.5 inch	Staining restricted to vertical microcracks and lateral cracks around coarse aggregate. Staining below level of polymer due to lateral cracks.	Evaporation zone to 0.2 inch level. Good polymer system from 0.2-0.5 inch depth. Traces of polymer to 0.6 inch level.

Core #	Top Surface Observations	Depth of Polymer	Phenolphthalein Penetration Test	Petrographic Examination
80-1	Microcracks noted	0.7 inch	Extensive staining along several microcracks and very pronounced lateral migration of dye below polymer zone but all staining restricted to fracture planes.	Polymer to 0.7 inch level somewhat irregular boundaries and some diffused areas to 0.1 inch zone.
81-1	Microcracks noted	0.4 inch	Staining along several microcracks to depth of about 0.5 inch.	Very irregular polymer system to 0.4 inch.
82-1	No microcracks noted but surface chipped when cored.	0.6 inch	Soak test not conducted.	Well-developed polymer system to 0.6 inch depth.

DISCUSSION

All but one of the fifteen cores taken from the Owens Street Overpass showed that a polymer system was present at depths ranging from 0.4 to 0.7 inches. In some cores petrographic examination revealed that traces of polymer were found slightly deeper. However, most of the cores exhibited a system of surface microcracks which often could be traced to depths greater than 1.0 inch. In the majority of cores which had unsealed microcracks, a 24-hour soaking test with a phenolphthalein indicator showed that penetration of a solution was inevitable and signs of the stain could be traced along the length of the cracks.

Lateral migration of solutions occurred if the vertical crack passed through the polymer-treated zone and into unprotected paste. No instances were found where the dye solution penetrated a continuous polymer-saturated zone. Several cores had coarse aggregate which occurred near the top surface (less than 0.2 inches) and the dye solutions would generally penetrate evaporation areas in the topmost part of the impregnated zone and migrate along the aggregate-paste boundary. However, microscopic examination showed that migration of the phenolpthalein at these boundaries was always associated with separations or unsealed microcracks and that the observed staining would be restricted to the crack and not the adjacent polymer-saturated paste.

Two extremes of treatment appeared to be exemplified by Core 3-4, which had only a surface trace of polymer, and Core 5-4, which reportedly had a "double" application of polymer. Both were subjected to a 24-hour soak period with phenolphthalein with essentially the same results; no evidence of solution penetration. Control samples of the Class C concrete were set up and subjected to the same soak test. The control samples, which had also been examined and found free of microcracks, had perhaps 0.1 inch of penetration of the indicator after 24 hours. A 72-hour soak showed only about 0.3 inch depth of stain and after 144 hours about 0.7 inch. Thus, if the concrete is sound and free of microcracks it should be relatively impervious to any solutions. Where unsealed microcracks were present some penetration of solutions could be expected, at least to the extent of the unsealed crack itself. Since no penetration was noted through continuous polymer-treated paste, the polymer no doubt contributes to sealing the concrete.

Petrographic studies show that often a polymer treated paste might appear to be continuous in a visual inspection of an acid etched surface but at high magnifications minute discontinuities are commonly found near aggregate particles and air voids. Under the microscope zones of diffused polymer or evaporation areas are easily distinguished. Normally, within the anticipated penetration zone, minute traces of polymer are present in the evaporation areas suggesting that the monomer was there but that it either diffused by capillary action or evaporated before polymerization took place.

Owens Street Overpass Cores, Big Spring

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81-1	Microcracks noted	0.4 inch	Staining along several microcracks to depth of about 0.5 inch.	Very irregular polymer system to 0.4 inch.
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APPENDIX
D

ANALYSIS OF CRACK SURVEY

SUMMARY OF CRACK SURVEY
PHOTOGRAPH RESULTS

CRACKS OBSERVED BEFORE TREATMENT	UNCRACKED OBSERVATIONS	CRACKS OBSERVED ONLY AFTER TREATMENT	TOTAL OBSERVATIONS
28	79	7	114
		Percent increase in cracks	6.1%

UNCRACKED OBSERVATIONS BEFORE TREATMENT
CRACKED AFTER TREATMENT

PHOTOGRAPH NUMBER	STATION	DISTANCE RIGHT OF LEFT PARAPET WALL
18	11+97	16
24	12+33	27
41	13+18	29
45	13+46	14
50	13+73	29
85	15+67	59
103	16+66	32

CRACKED OBSERVATIONS BEFORE TREATMENT

PHOTOGRAPH NUMBER	STATION	PHOTOGRAPH NUMBER	STATION
1	9 + 80	26	12 + 38
2	10 + 34 15' Rt.	27	12 + 46
5	10 + 59	29	12 + 56
8	11 + 46	30	12 + 58
9	11 + 50	38	13 + 00
12	11 + 70	51	13 + 74
13	11 + 73	55	14 + 01 45' Rt.
17	11 + 93	58	14 +45
19	12 + 07	62	14 + 53
20	12 + 08	63	14 + 52 08' Rt.
21	12 + 12	67	14 + 72
22	12 + 24	84	15 + 51
23	12 + 32	86	15 + 68
25	12 + 34	105	16 + 86

UNCRACKED OBSERVATIONS BEFORE AND AFTER OBSERVATIONS.

PHOTOGRAPH NUMBER	STATION	PHOTOGRAPH NUMBER	STATION
3	10+34, 30' Rt.	64	14+57, 43' Rt.
4	10+34, 45' Rt.	65	14+58
6	10+61	66	14+70
7	11+40	68	14+73
10	11+60	69	14+75
11	11+68	70	14+84
14	11+76	71	14+85
15	11+82	72	14+88
16	11+85	73	14+91
28	12+48	74	14+99
31	12+66	75	15+07, 15' Rt.
32	12+72, 37' Rt.	76	15+07, 45' Rt.
33	12+72, 42' Rt.	77	15+10
34	12+72, 45' Rt.	78	15+25
35	12+80	79	15+26
36	12+86	80	15+27
37	12+88	81	15+30
39	13+01	82	15+42
40	13+10	83	15+44
42	13+25	87	15+75, 14' Rt.
43	13+28	88	15+75, 63' Rt.
44	13+37	89	15+95
46	13+47	90	15+98
47	13+53, 48' Rt.	91	15+99
48	13+53, 49' Rt.	92	16+06
49	13+65	93	16+14
52	13+79	94	16+16
53	13+90	95	16+17
54	13+93	96	16+22
56	14+01, 52' Rt.	97	16+35
57	14+16	98	16+37
59	14+46	99	16+45
60	14+47	100	16+49
61	14+51	101	16+60