POLYMER CONCRETE OVERLAY
ON SH-51 BRIDGE DECK

ı and Development Divsion
ıa Department of Transportation

MARCH, 1982

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16. ABSTRACT

This report discusses OKLAHOMA's first polymer concrete bridge deck overlay. The objective of this project was to place a thin resinous overlay on a sound bridge deck and evaluate its performance over one year using various physical tests. The evaluation will show how well the overlay protects the reinforcing steel from corrosion due to deicing salts.

The steps leading to the construction of the overlay are detailed as well as the actual placing of the overlay. The results of various physical tests are reported for both before and after the overlay.

The protection of a bridge deck with a polymer concrete overlay appears to be a rather complicated procedure. Besides constraints of weather, temperature, aggregate and resin availability, machinery needs to be developed that can accurately and efficiently mix and lay polymer concrete.

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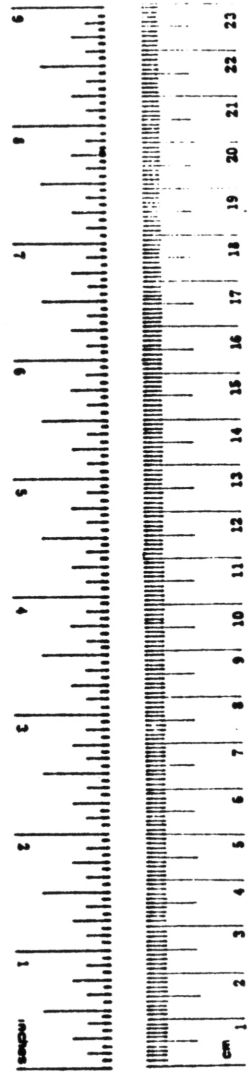
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

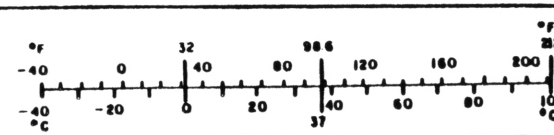
Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
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)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
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			
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)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
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)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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ACKNOWLEDGEMENT

The author wishes to thank R. L. Stringer, Division IV Engineer, S. C. "Pete" Byers, Division IV Maintenance Engineer, and the personnel of Division IV Headquarters, Perry, for their efforts in completing this project.

INTRODUCTION

The corrosion of bridge deck reinforcing steel has been one of the most severe problems facing bridge maintenance engineers. Corrosion occurs when salt (NaCl or $CaCl_2$) is applied to slick roadways to melt winter ice. The salt is dissolved by the melting ice and the resulting solution penetrates the deck through a continuous network of capillaries or bleed channels, voids and shrinkage cracks formed when the concrete was curing. A method is needed to protect the steel reinforcing bars from corrosion (and resulting damage to the concrete deck) since higher accident rates would occur without salt application.

In the development of quick setting, high-early strength plastic patching materials, polymer concrete was found to have a high adherence to sound Portland concrete and to be impervious to water. Polymer concrete uses a resin as the material binding the aggregate. It was the waterproofing characteristic of polymer concrete that prompted this project.

Photographs of the project are in Appendix A.

Objective

The objective of this project was to place a thin resinous overlay on a sound bridge deck and evaluate its performance over a year using various physical tests. The evaluation by the Research and Development Division of the

Oklahoma Department of Transportation (ODOT) will show how well the polymer concrete overlay protects the reinforcing steel from corrosion due to deicing salts. This project is authorized by the Federal Highway Administration Task Order No. 7, entitled, "Polymer Concrete Overlay" under Basic Agreement No. DOT-FH-11-9124. The FHWA contributed $20,000 toward this project. Interim User Manuals were distributed by the FHWA to inform engineers in highway agencies of the current state-of-the-art of polymer concrete overlays and to encourage field trials of these systems by state highway agencies.(1)

Background

The Oklahoma Department of Transportation has installed two types of systems to seal bridge decks that are similar. A single eastbound span of a SH 3 bridge east of Shawnee over the North Canadian River was poured with wax beads mixed in the Portland cement concrete.(2) On I-35, southbound, in Noble County, the bridge over Cow Creek had wax beads placed in the top 2 in (50mm) of the deck.(3) Using an electric blanket heating system provided by the FHWA, the wax beads were melted to seal the concrete, thus protecting the reinforcing steel from salt corrosion. Both appear to be working quite well.

Requirements

The FHWA recommended selecting a bridge that would be at least 100 ft (30.3m)long and carry 2000 to 4000 vehicles per day. Chloride content tests would have to show less than 2 lbs of chloride/yd^3 (1.2 kg/m^3) of concrete. Active corrosion of the reinforcing steel would be determined by measuring the electrical half-cell potentials. Wheel rutting measurement on the project bridge and an adjacent bridge would be needed. Eight corrosometer probes provided by the FHWA would have to be implanted in the deck to monitor corrosion on a monthly basis over the year. Skid tests in each lane would be repeated five times for an average skid number.

Immediately after the overlay, the skid tests were to be repeated. Chain-dragging the deck would identify any delaminations. Four 6 in (152 mm) cores were to be extracted and subjected to a 90 day chloride ponding test. Twenty 3 in (76 mm) cores were to be forwarded to the FHWA contact manager for testing of the overlay-Portland cement concrete interface shear bond strengths after zero, 50, 100, and 150 freeze-thaw cycles. The test results are shown in Appendix C. One year after completion of the overlay, the chain-drag, skid resistance, electrical half-cell potential test, wheelpath rutting measurements, and chloride content of the concrete tests are to be repeated.

PREPARATION

Test Bridge

A bridge in Division IV was sought as a test location as they had agreed to provide manpower and equipment to place the overlay. A test bridge was sought as close to the Central Office as practical to make frequent monitoring more convenient for the Engineering Test Branch of the Research and Development Division. In addition to the FHWA physical requirements for the structure, Division IV personnel suggested finding a bridge on a four lane, divided highway so traffic could be detoured easily.

The structure selected is the westbound bridge on SH 51 in Payne County, 5 mi (8 km) east of I-35. The bridge was built in 1975 as Project No. F-198(53), part of an improvement to widen SH 51 between I-35 and Stillwater from a two lane to a four lane, divided highway. Crossovers between roadways were at section mile roads on either side of the bridge. In 1981 the average daily traffic (ADT) was estimated at 5,000 vehicles on SH 51.

The structure was built as three spans supported by prestressed concrete beams. The deck was poured 7½ in (190 mm) thick with the top mat of reinforcing steel placed 2½ in (64 mm) below the surface. The bridge was skewed 45° to the left, was 138.53 ft (42 m) long, and designed with a clear roadway width of 40 ft and 9 in (12.4 m).

The chloride analysis at the existing steel level was found to be below the maximum 2 lbs/yd^3 (1.2 kg/m^3) requirement. The results of the chloride analysis can be seen in Appendix B.

At 307 locations on the deck, half-cell potentials were measured and found to have a mean of 176 millivolts with a standard deviation of 37 millivolts. A summary of results is presented in Appendix B. A plan of the deck showing the half-cell readings and their locations accompany the summary.

CONSTRUCTION MATERIALS

Polymer concrete uses a plastic to bind the aggregate instead of Portland cement and water. The plastic is made by combining a resin with other chemicals to harden the plastic. The resin is a viscous liquid plastic consisting of unconnected, long hydrocarbon molecule chains. The chemical reaction that connects the long hydrocarbon molecule chain to form a rigid plastic is called "polymerization".

Polymer

At the suggestion of the FHWA contract manager, the originally recommended polyester styrene was replaced by a vinyl ester resin. Vinyl ester had been found by the FHWA to perform as well as polyester styrene but to be less sensitive to water. Therefore, this vinyl ester (containing 50 percent styrene) was used to make polymer concrete for the project overlay. Moisture/compressive strength test comparisons can be seen in Table 1.

Table 1

Comparative Compressive Strengths, PSI*

% Moisture	Polyester Styrene	Vinyl Ester
0	9575	8140
1.5	4465	5210
3.0	2460	2720
4.5	1150	1590

*kPa = (PSI) (6.8948)

Promoter, dimethyl aniline, was added to the resin to enhance the chemical reaction. The promoter, when added to the resin, in combination with the initiator, causes polymerization at ambient temperatures. The amount of catalyst, 50 percent benzoyl peroxide dissolved in a tricresyl phosphate paste, added to the resin determined how quickly it hardened by connecting the long hydrocarbon molecule chains.(4)

To insure a bond between the existing Portland cement concrete and the polymer concrete overlay, a 15 mil (0.4 mm) tackcoat was applied prior to the overlay. It consisted of 500 lbs (225 kg) of resin mixed with two gallons (7.6 l) of silane.

The following items were purchased:

TABLE 2

Construction Materials

Purpose	Name	Quantity
Resin	Vinyl Ester	5800 lbs (2610 kg)
Promoter	Dimethyl Aniline	5 gal (19 l)
Catalyst	Benzoyl Peroxide	130 lbs (59 kg)
Tackcoat	Silane	2 gal (7.6 l)
Tackcoat	Vinyl Ester	500 lbs(225 kg)
Aggregate	Chip	15 tons (13.5 Mg)
Aggregate	Sand	13 tons (11.7 Mg)
Aggregate	Silica Flour	3600 lbs (1620 kg)

Aggregate

Vinyl ester polymer was tested with aggregate sources in Field Division IV. The quarry between Cushing and Drumright produces a durable limestone aggregate which failed to polymerize completely. The four hour cure compressive strength with dried aggregate was less than 2500 PSI(17.2 MPa). Microscopic examination of the limestone revealed many extremely fine clay lenses bedded in the matrix. It was suggested that clay has an absorbative effect on some of the chemical used to polymerize the vinyl ester resin, hence retarding the reaction.

An aggregate from a quarry 6 mi (10 km) northeast of Pawnee was tested and found to produce four hour cure compressive strengths in the 8000 PSI(55 MPa) range. This excellent result only occurred when the 3/8 in (10 mm) limestone chips and concrete sand were oven dried. The tolerable limit for moisture was held to one-half percent by weight, the measured moisture content of a sample of the 3/8 in (10 mm) limestone chips dried on an asphalt parking area.

The Chemical Engineering Department at the University of Oklahoma, Norman, assisted in formulating the correct portions of catalyst to be used with the vinyl ester. Also time-temperature curves were established to determine the relationship of temperature and catalyst concentrations to the amount of working time needed for the polymer concrete to gel.

Sieve analysis of the aggregates available in central Oklahoma, indicated that sufficient fines were not occurring naturally. Silica flour would have to be blended with the sand to meet the FHWA required gradation. The requirement could be met with a mixture of 50 percent limestone chip, 43.3 percent concrete sand, and 6.7 percent silica flour. The specifications were:

TABLE 3

Sieve Analysis of Aggregate Samples

% Passing Sieve	Chip	Sand	Flour	Mix	FHWA Req.
1/2"	100	100	100	100	100
3/8"	93	100	100	96.5	100-86
1/4"	57	100	100	78.5	85-71
No.10	2	89	100	46.2	47-40
No.40	1	34	100	21.9	23-18
No.200	0.8	0.7	100	7.4	8- 6

To cover the 209 yd^2 (167 m^2) deck with a 3/4 in (19 mm) overlay would require 350 ft^3 (10.5 m^3) of polymer concrete. To allow for waste and practice runs, the quantity estimated was increased by almost thirty percent. The density of successful test cylinders made at the University of Oklahoma were found to be as high as 143 lbs/ft^3 (2145 kg/m^3). Approximately 5470 lbs (2461 kg) of vinyl ester and 54,700 lbs (24.62 Mg) of aggregate were needed for the design mix of 10 percent by weight of dry aggregate. To each of 14 drums of vinyl ester resin, 1.7 pt (800 ml) of dimethyl aniline was added as a promoter.

Fifteen tons (13.5 Mg) of 3/8 in (10 mm) limestone chip were purchased from a local Perry concrete plant in July and spread on an asphalt paved parking area in the Division IV yard to dry in the sun. After turning the aggregate daily for three consecutive days, a sample had a moisture content of 0.2 percent. It was then loaded into two surplus dump beds set on wood blocks. Each chip loaded bed was then covered with a plastic sheet and heavy canvas.

Thirteen tons (11.7 Mg) of Class "A" concrete sand were purchased from the same source and similarly spread to dry. By mid-week, the daily turning had sufficiently dried the sand. A sample of the sand had a 0.2 percent moisture content. The silica flour was then blended with the concrete sand at the rate of 50 lbs (22.5 kg) of flour with 325 lbs (146 kg) of sand. Blending was done with a portable drum concrete mixer prior to storage. A third surplus dump bed had been modified with side boards to hold the sand mixture.

When all the chemicals had arrived, samples of the aggregate were taken from the dump beds. Using the actual chemicals ordered for construction of the deck and the aggregate, test cylinders were made at the University. Their four hour cure compressive strengths were found to be in the high seven and low eight thousand pounds per square inch range.

Concrete-Mobile

To mix the polymer concrete on the bridge deck, it was decided to use a Daffin "Concrete-Mobile." Essentially, a Concrete-Mobile is a truck-mounted, continuous mix, concrete plant. Two large bins hold the sand and stone, another bin contains Portland cement and a tank supplies the water. A conveyor belt runs under the bins, with gates at the end of the bins controlling the rate at which aggregate is discharged. The cement is sifted onto the aggregate before water is pumped onto the dry mix. At the end of the truck, the conveyor belt discharges the mix into the end of a trough. Inside the trough is an auger which mixes the concrete as it lifts it to the end of the trough.

By plugging the water tank and shutting off the Portland cement bin, resin could be pumped into the mix instead of water and polymer concrete would result. One advantage of this machine was the ability to make only as much polymer concrete as is needed at a time. Aggregate was loaded onto the Concrete-Mobile from the protected dump beds. Using a freight scale, the rock and then sand gates were set to deliver aggregate at a pre-determined rate of 90 lbs (40 kg) per minute of each material.

An agreement was made with U.S. Concrete in Norman to supply their machine and operator for $640 per day. This was the only available machine in Oklahoma to our knowledge.

Two resin pumps and a rheostat were shipped from the FHWA in Washington. They were to be used to transfer the resin into the Concrete-Mobile. The resin pump was calibrated to deliver 18 lbs (8.1 kg) of resin/minute (10 percent of the delivery rate of aggregate) to the Concrete-Mobile. The other pump, a constant speed pump, removes resin from the barrels into an open holding tub. It is in this tub that the catalyst (benzoyl peroxide) is added. Also a Bidwell paving machine was loaned for the project by the Bureau of Land Management in Denver. The paver, modified for use with polymer concrete, was trucked in by common carrier.

PRE-CONSTRUCTION

All equipment and materials were stored at the Division IV Headquarters in Perry. The week of October 19 through October 23, 1981 was chosen by FHWA, Research Division, and Field personnel for completion of the overlay.

Test Run at Division Headquarters

On Monday, October 19, representatives of the FHWA discussed duties with the Field Division's maintenance personnel and with the Research Division's engineering technicians. The chemical engineer from the University of Oklahoma would supervise mixing the chemicals on the bridge.

On a gravel area on the back lot of the Division yard, the paving machine was set on its riding rails. With all personnel attending, catalyst was added to the resin and blended in the Concrete-Mobile to produce polymer concrete.

However, the polymer concrete was entirely too rich in resin. An entire 450 lb (202 kg) drum was then wasted along with the corresponding aggregate. During the test setup, the calibrated resin pump had been inadvertently exchanged for the resin transfer pump. The constant speed transfer pump delivered resin at a higher rate than the calibrated resin pump. Tri-chloroethane solvent was used to flush the pumps, hoses and clean out the Concrete-Mobile.

Preparation

While personnel were staging in the Division yard, other maintenance workers and traffic control personnel were preparing the bridge.

The detour crossovers between the eastbound and westbound roadways were not sufficient for large trucks to turn. Using motor graders, the radii of the crossovers were widened with asphalt. Also, maintenance personnel throughly sand blasted the bridge deck on Tuesday, October 20.

Traffic control was provided by Division IV personnel. Sign posts were erected and the necessary detour signs readied.

CONSTRUCTION

First Pass

On Wednesday, October 21, 1981, work commenced. Westbound traffic was detoured as the equipment arrived at the bridge from the Division Headquarters. The pipe rails were set up on the north parapet wall and on the deck to pave the right shoulder first. Boards wrapped in plastic sheeting were nailed to the deck to contain the 16 ft (4.9 m) wide lane of polymer concrete as it was being laid. The paving machine was lifted from a flat bed trailer by a crane and lowered onto the pipe rails. Directly ahead of the paver was the Concrete-Mobile. Next to the Concrete-Mobile was a large, single unit flat bed truck carrying all the resin and related equipment. The tackcoat drum had a valve installed so it could be laid on its side. Pre-measured amounts of benzoyl peroxide were provided to the tackcoat man to make him independent of the chemical personnel on the flat bed truck.

Coarse bristle push brooms were used to spread the tackcoat. These brooms, however, proved to be slow, messy and to waste tackcoating material.

After the first lane was paved, rubber squeegees were substituted for the brooms. After the paver had been adjusted to lay a 3/4 in (19 mm) overlay, work began. On the chemical truck, two open top tubs were alternately kept filled with resin. The chemical engineer from the University of Oklahoma weighed the benzoyl peroxide catalyst using one-half percent catalyst by weight to resin. Laboratory experiments had suggested that one-half percent benzoyl perxoide catalyst on a 50°F (10°C) day would give approximately thirty minutes of working time. As it was determined that more catalyzed resin was needed, catalyst was added to a tub, and stirred with a wooden paddle. When the previous tub was emptied, the hose from the calibrated resin pump was transferred to the waiting tub. Hence, polymer concrete production at the Concrete-Mobile could continue uninterrupted. Polymer concrete was discharged onto the tackcoated deck immediately in front of the paver. The tackcoat mixer and his two broom men worked beneath the long mixing trough of the Concrete-Mobile.

The vibrating screeds of the paver could not work directly against the parapet wall; therefore, a man with a tamping tool stood on the back of the paver, compacting and leveling a 4 in (100 mm) wide section of overlay along the parapet. The paver could not finish the last 3 ft (.9 m) of the lane because of the 45 degree skew. The parapet wall stopped before the paver could pass over the end of the lane. The remaining area in the right lane was placed and compacted by hand. After paving the right lane, the Concrete-Mobile was flushed with solvent along with the resin pumps. This removed residual catalyzed resin before it hardened.

Second Pass

The pipe rails were moved to the inside lane and the plastic-wrapped boards were placed as soon as the concrete in the right lane had set. With the Concrete-Mobile, front-end loader and chemical truck in position, pouring the inside lane was ready to begin. This time the tackcoat was spread with the originally planned rubber squeegees. They spread the tackcoat more neatly, rapidly and uniformly than the coarse bristle brooms.

It was obvious that the limestone chip supply was not sufficient to finish the deck. A truck of limestone chip was ordered from Perry and the chip spread on the roadway to dry.

Quality control became a problem as work proceeded in this lane. The polymer concrete would alternate between being too rich or too lean. The lag time between adjusting the rheostat controlling the calibrated resin pump and the discharging polymer concrete was too great. The effect was to over compensate.

Early in the afternoon, well before the planned quitting time, a rain shower appeared. Over 60 ft (18 m) of the inside lane (measured from the west end of the bridge) had been paved. The limestone chip, spread on the road to dry, was quickly put into a dump truck and covered. The open bins of the Concrete-Mobile also were covered. After a four hour cure, the detour was removed and traffic returned to the bridge.

Delay

Thursday, October 22, was spent in the Division yard. By afternoon, the sky had cleared and temperatures returned to the high 50°F (10°C). The afternoon was spent re-calibrating the resin pump and discharge gates of the Concrete-Mobile in an attempt to improve the quality of the polymer concrete.

Return to the Bridge

Early Friday morning, October 23rd, crews and equipment returned to the bridge. Paver rails were set up to finish the inside lane. In the remaining portion of this lane, pump failure occurred five times. Three times, clots of gelled resin from previously emptied tubs jammed the impellers of the pump. Once, a fuse in the rheostat burned out, and finally, a clot was discovered so large that it clogged the 3 in (75 mm) diameter delivery hose. When the resin failed to be pumped to the Concrete-Mobile, it usually was not discovered until quantities of too dry and bone-dry polymer concrete were discharged onto the deck. This aggregate was unusable and was thrown over the side of the bridge.

Center Section

With the two 16 ft (4.8 m) wide passes on the inside and outside lanes of the bridge completed, the remaining

8.5 ft (2.5 m) wide center section was ready for overlaying. It was obvious that there was not enough aggregate to finish the pass, so the extra chip drying on the roadway was loaded into the Concrete-Mobile. Sand, which was in even lower supply, was supplemented with 2½ tons (2250 kg) of bagged, dried coarse sandblasting flint. Paving was begun and ran continuously until the sand and resin were exhausted simultaneously about 30 ft (9 m) from the east end of the bridge.

Problems

The first pass had a very shiny appearance due to excess resin ponding on the surface. This likely was due to excessive tackcoat. During the period that coarse bristle brooms were substituted for the planned squeegees, the workman used more resin because it would not spread very easily. In fact, the 55 gallon drum of tackcoat resin allotted for the entire deck was used in just the right lane.

After the right pass was laid, the remainder of the bridge suffered with dry spots and wet "ponds" at totally random locations. Before the "ponds" set hard, sandblasting flint was sprinkled onto the surface for traction after it gelled.

The problem of an inconsistent ratio of resin to aggregate may have been due to variations in the delivery rate of the resin pump or to the inability of the Concrete-Mobile to consistently deliver the specified rate of aggregate. Perhaps it was a combination of both.

POST-CONSTRUCTION

The week after completing the overlay, a delamination test revealed over 200 ft^2 (18 m^2) of overlay that did not bond to the deck. Also, in the center pass about 10 ft (3 m) from the west end of the bridge, a portion of the overlay 8 ft (2.5 m) long failed to harden completely. However, skin about 1/4 in (6 mm) thick on top of the overlay did harden, probably due to ultra-violet radiation from the sun. A plan of the deck showing the location and relative size of the delaminated areas and resulting patches is shown in Appendix C.

Expansion Joints

Sand had been used to fill the two expansion joints as paving proceeded across the deck. A concrete saw and crew sawed out the 2 in (50 mm) wide excess material resting on the sand. Allied Jet Seal 9020, a two component rubber compound, was poured into the joint to keep out contaminants. It has not tracked and has bonded very well.

First Patching Attempt

Impending cold weather prompted attempts to get more of the same vinyl ester (DOW 411-C-50) quickly in order to repair the rough riding bridge. However this was not possible; suppliers were out of stock and the factory was delayed in getting production started. However, Shell Development in Houston donated 55 gal (209 l) of their vinyl ester resin (DPV-706) to the project.

The aggregate used in patching was surplus silica gravel which passed a 1/4 in (6.4 mm) sieve but was retained on a No. 6 sieve. Coarse flint and very fine silica sand were combined with the No. 6 for aggregate. Fearing a drop in temperature that would prohibit the patching attempts, the hastily acquired aggregate did not meet the FHWA required gradation.

On Wednesday, November 4th, the delaminations were removed with jackhammers. To mix the polymer concrete, a portable drum mixer was used. As before, one half percent by weight of benzoyl peroxide was added as catalyst.

After the first batch had been placed and work proceeded, it was noticed that the polymer concrete was not setting up. While the concentration of catalyst should have been sufficient to gel the resin during the upper 40°F (4°C) day, it was not gelling. The next batches were made with one percent benzoyl peroxide. As work progressed, it became apparent that one and one-half percent benzoyl peroxide would be needed. One or two of the last patches received polymer concrete with the strong concentration of catalyst.

The polymer concrete that would not set was disposed of. Only a couple of small patches appeared to have hardened. But, within a couple of days under traffic, they began to erode badly. It was as though the polymer resin was failing to adhere to the aggregate.

Hardened clumps of polymer concrete among the soft material lead us to believe that a major problem was insufficiently dissolved benzoyl peroxide in the resin. The clumps could have been concentrated areas of catalyst.

Second Attempt

After the failure of the Shell vinyl ester resin to harden when used in original formulation, an order was placed with the local supplier for the Dow product. Additional silane was ordered to provide sufficient tackcoat material. To assure a sufficient supply of the benzoyl peroxide catalyst, more catalyst was ordered. At this time the FHWA suggested using a type of benzoyl peroxide which contains a dispersant agent. Besides the different type of catalyst, a shaft mounted mixer was purchased which could be immersed in bucket of resin and agitated with a power drill.

Sun drying the sand and chip in late November was out of the question. A supplier of speciality sands in Oklahoma City was able to oven dry and bag silica gravel and sands directly corresponding to the FHWA gradation. While the cost of the dried, bagged aggregate was $60.80 per ton ($67.56 per Mg) as compared to only $14.19 per ton

($15.77 per Mg) for the wet aggregate from the original source, only 7 tons (6.3 Mg) of bagged aggregate was purchased as opposed to 30 tons (27 Mg) originally acquired to make a practice run and overlay the bridge. Test cylinders exceeded 4000 PSI(27.6 MPa) in four hours.

Anticipating the low 40^{o}F (4^{o}C) weather, the barrels of resin and trucks of bagged aggregate were stored inside heated garages. While the hardening would be slowed by the cold deck, the use of warm materials could counteract that effect.

A screed was made by bolting a common electric vibrating concrete "snake" to an 8 in (200 mm) I-beam. Though heavy, four men were able to utilize the device most successfully.

On Tuesday, December 1st, Research Division personnel using air hammers, removed all the overlay that was not securely bonded to the deck. The deck was carefully sounded and over 400 ft^2 (36 m^2) of overlay was removed. These areas were then sand blasted.

The next two days, December 2 and 3, these areas were patched while traffic was detoured. The original one half percent benzoyl peroxide gelled in 30 to 40 minutes as planned. The hand screed had a tendency to tear the surface more than the power screed on the paver because the contact surface had not been carefully machined smooth.

When the patching was completed, the remaining 10 gal (38 l) of resin was catalyzed and squeegeed onto the deck. Besides treating the patches to seal any tears, the center and left lanes were squeegeed anywhere the surface aggregate looked dry or some popout had occurred.

The next week Division IV maintenance personnel from Cushing feathered the approaches. Asphalt was laid on both the leading and trailing edge of the 3/4 in (19 mm) overlay to improve the ride.

Cores were taken on December 21st as part of the requirements for evaluation. The core holes were refilled with Duracal.

PRELIMINARY TEST RESULTS

Skid Tests

Five skid tests were performed in each of the westbound lanes of the bridge at 40 mph (64 kph) in March of 1982. The results are shown in Table 4. The test conform to ASTM E274. Inconsistency in the polymer concrete (rich, lean, or patches) could account for the variations in skid resistance.

TABLE 4

Skid Test Results

Westbound Roadway	Avg. Skid No.	Std. Deviation
Right Shoulder, left wheelpath	31.2	1.3
Right Lane, Left wheelpath	52.4	1.5
Left Lane, Right wheelpath	30.0	6.4
Left Lane, Left wheelpath	46.2	1.8

Ninety Day Chloride Ponding Test

The 6 in (152 mm) cores were tested according to AASHTO T-259 by the Materials Division of the Oklahoma Department of Transportation. The chloride content of the deck immediately adjacent to the core location was taken to provide a basis for comparison of the relative impermeability of the overlay. The results, shown in Table 5, are expressed as pounds of chloride per cubic yard. A statistical analysis of the results are presented in Appendix C.

TABLE 5

Chloride Content

(pounds of chloride per cubic yard)*

	Upper Level		Steel Level	
	Adjacent	Core	Adjacent	Core
	4.6	4.3	2.1	2.1
	1.6	2.1	2.3	2.2
	4.0	1.9	1.8	1.4
	5.8	2.1	2.3	1.5
Average	4.0	2.6	2.1	1.8
Std. Dev.	1.8	1.2	0.2	0.4

*$kg/m^3 = (lbs/yd^3)(0.593)$

COST ANALYSIS

These estimates were based on quarterly summary billing reports to the end of February 1982. Costs from work performed after the end of February were estimated by comparing charges of work performed before February.

Estimated Cost of Entire Research Project

Payroll (plus additives)	$46,865	
Materials Actual construction materials plus incidental supplies.	$16,639	
Equipment Rental Concrete-Mobile ($640/day) plus ODOT equipment rental rates.	$10,475	
Travel Room & board for Research Division personnel in Perry (6 nights).	$ 1,426	
Tests & Professional Fees Field testing by Division IV personnel, lab testing by Materials Division, and consulting by University of Oklahoma.	$ 7,031	
TOTAL		$82,436

Typical Overlay Cost

Costs that reflect only the placement of the deck and subsequent delamination repair will give an approximation of the cost of a production type overlay.

Payroll	\$ 7,890
Equipment Rental	\$ 7,944
Materials	\$12,516
	\$28,350

The aggregate and resin used should have produced approximately 21.5 yd^3 (16.3 m^3) of polymer concrete. This represents a cost of \$1,257/yd^3 (\$1,654/m^3) or \$2.91/ft^2 (\$32/m^2) for placing a 3/4 in (19 mm) overlay.

SUMMARY AND CONCLUSIONS

The objective of this project was to place a thin, resinous overlay on a sound bridge deck to protect the steel reinforcing bars from corrosion. This method of protection has led to several observations.

1. The resin is sensitive to the aggregate content. Clay in the limestone or in poorly washed sand inhibits the reaction of the chemicals. Using sandblasting flint, acquired from lead mine chat piles, also appeared to inhibit the reactions and produce a very weak concrete. The lower the moisture content of the aggregate, the stronger the concrete. The problem of drying and storing aggregate is a handicap.
2. Meeting the optimum gradation of the aggregate sizes by using a two component aggregate to reduce the amount of resin needed was not possible.
3. The 40°F to 90°F (4°C to 32°C) range of ambient temperature in which the polymer concrete can be laid restricts the scheduling of construction. July and August, two of the most desirable months of the construction season, are virtually eliminated.
4. The supply of resin and catalyst was not reliable, orders must be made far in advance of construction. This problem would diminish if polymer concrete were a common construction material. The resin also has a limited shelf life of only three months.

5. A more efficient method of blending the catalyst and resin is needed. The system used was too labor intensive. Also, the reliability and calibration of the two resin pumps leave something to be desired.
6. The polymer concrete did not remain consistent throughout production. The mixture alternated between being lean to rich in resin content. Whether it was the fault of the resin pump or Concrete-Mobile can not be established. The Concrete-Mobile is capable of mixing 27 ft^3 (0.8 m^3) of concrete per minute while only 1.5 ft^3 (0.05 m^3) per minute was made on the bridge deck. Restricting the flow of aggregate so drastically undoubtedy affected its accuracy. Changing the shape of the discharge gate of the Concrete-Mobile to a square might have helped the limestone ship to flow more uniformly. The 3/8 in (10 mm) chip had to flow through an opening about 9 in (23 mm) wide and only about 1/2 in (12 mm) high. Alternately, the Concrete-Mobile could be allowed to operate closer to the capacity for which it was designed, if the paving machine were designed to move more rapidly.
7. Use of a portable concrete mixer during hand patching showed that accurate polymer concrete could be accurately blended. A bank of portable mixers with a power delivery buggy could probably produce sufficient concrete having accurate resin portions, except this would be more labor intensive than the method used.

8. It would be unfair to draw any conclusions as a result of the patching attempts with the Shell product. No experiments had been conducted with the Shell resin to verify the promoter and catalyst concentrations for the best results as had been done with the Dow product at the University of Oklahoma. Also no test had been done to verify the use of flint as an alternate aggregate.

The protection of a bridge deck with a polymer concrete overlay appears to be a rather complicated procedure. Beside constraints of weather, temperature, aggregate, and resin availability, machinery needs to be developed that can accurately and efficiently mix and lay polymer concrete.

REFERENCES

1. "Polymer Concrete Overlays, Interim User Manual, Method A", J. C. Jenkins, G. W. Beecroft and W. J. Quinn, Oregon State Highway Division for FHWA, Office of Research and Development, December 1977, pp. 43.

2. "Internally Sealed Concrete (Wax Beads)", Gary Hamacher, Oklahoma Department of Transportation, June 1976, pp. 16.

3. "Internally Sealed Concrete at Cow Creek, Oklahoma", Jack Stewart and Ghasem Pourkhosrow, Oklahoma Department of Transportation, August 1981, pp. 91.

4. "Polymer Concrete Patching User's Manual", Chris Root, Dauda Ismalia, and Dr. Carl E. Locke, University of Okalhoma, April 1980, pp. 33.

APPENDIX A

PROJECT PHOTOGRAPHS

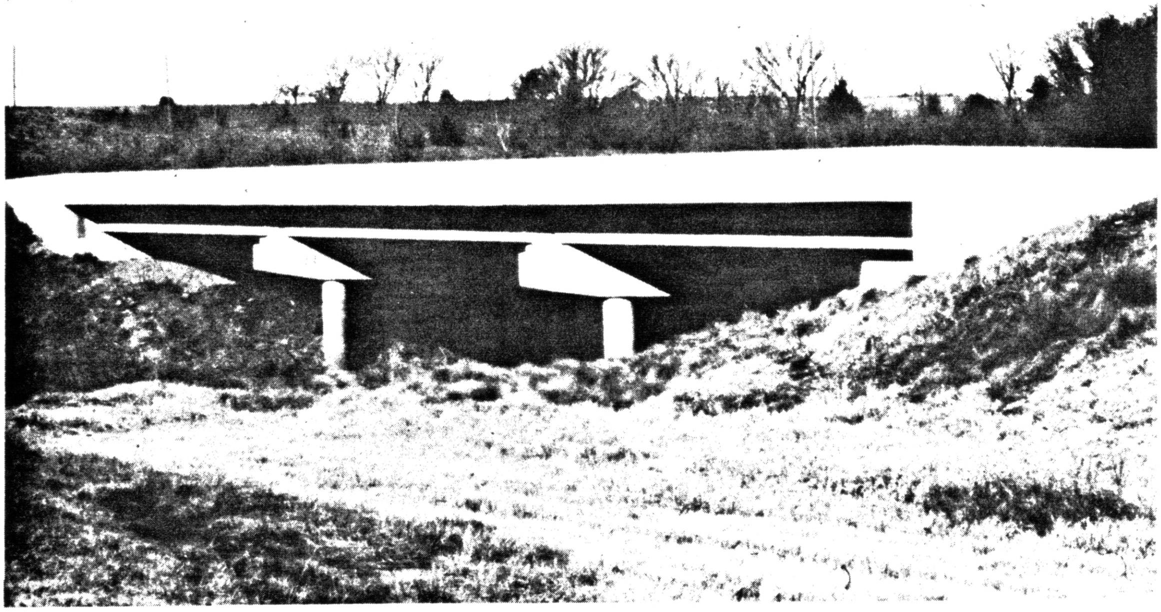


Figure 1. The original bridge on westbound SH 51, Payne County.

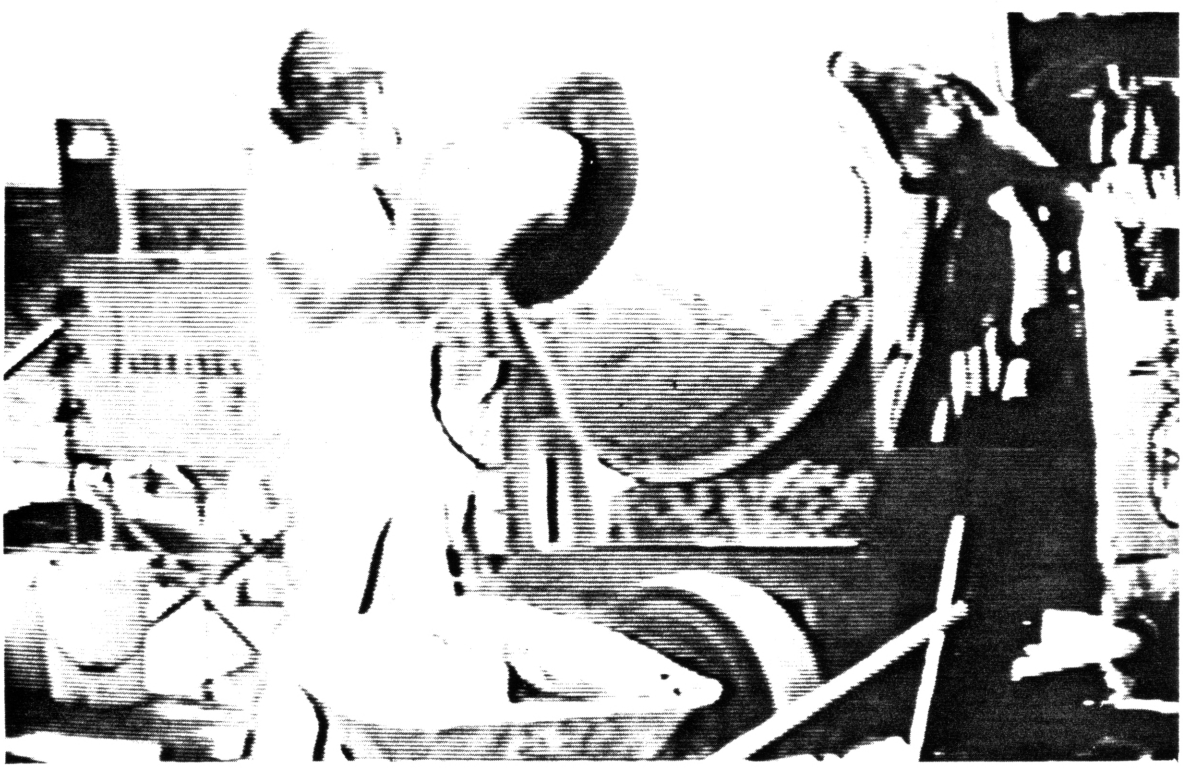


Figure 2. Dried sand was blended with silica flour.

Figure 3. Corrosometer probe locations were marked and probes installed.

Figure 4. Concrete-Mobile was loaded with the dried aggregate.

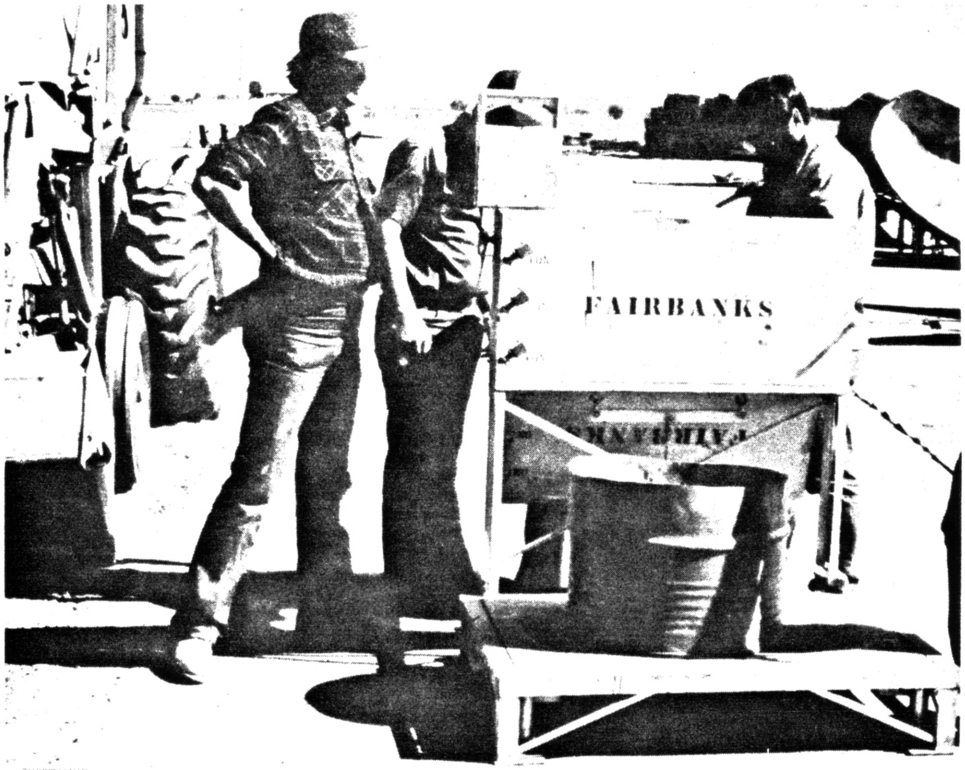


Figure 5. Sand, then chip, discharges were calibrated.

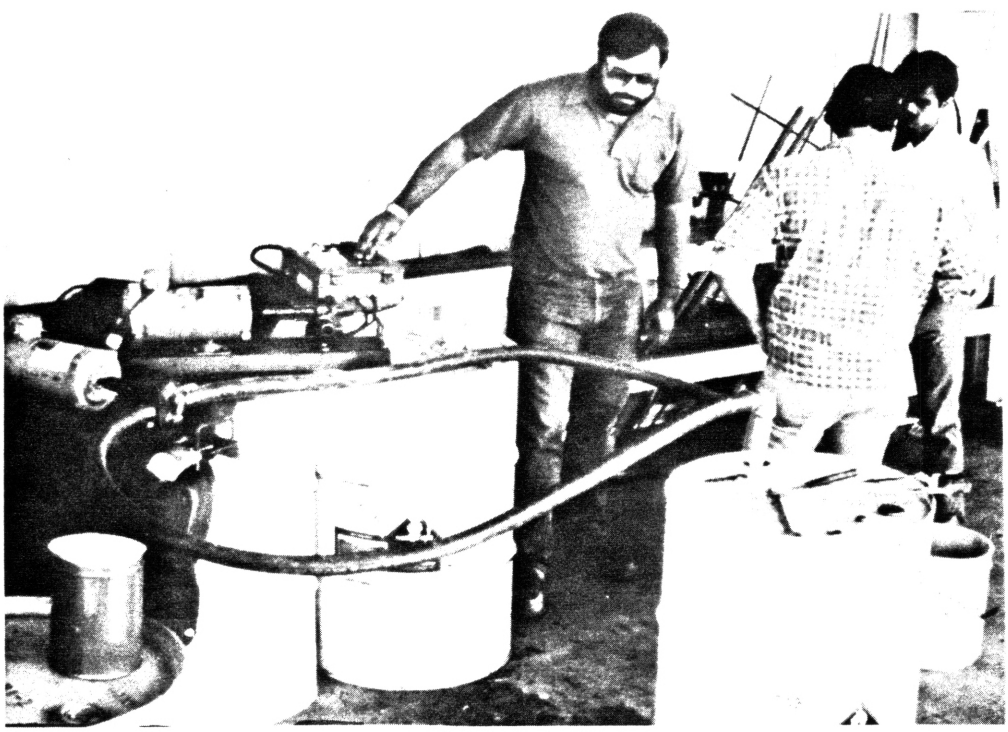


Figure 6. The resin pump was calibrated to deliver the specified amount.

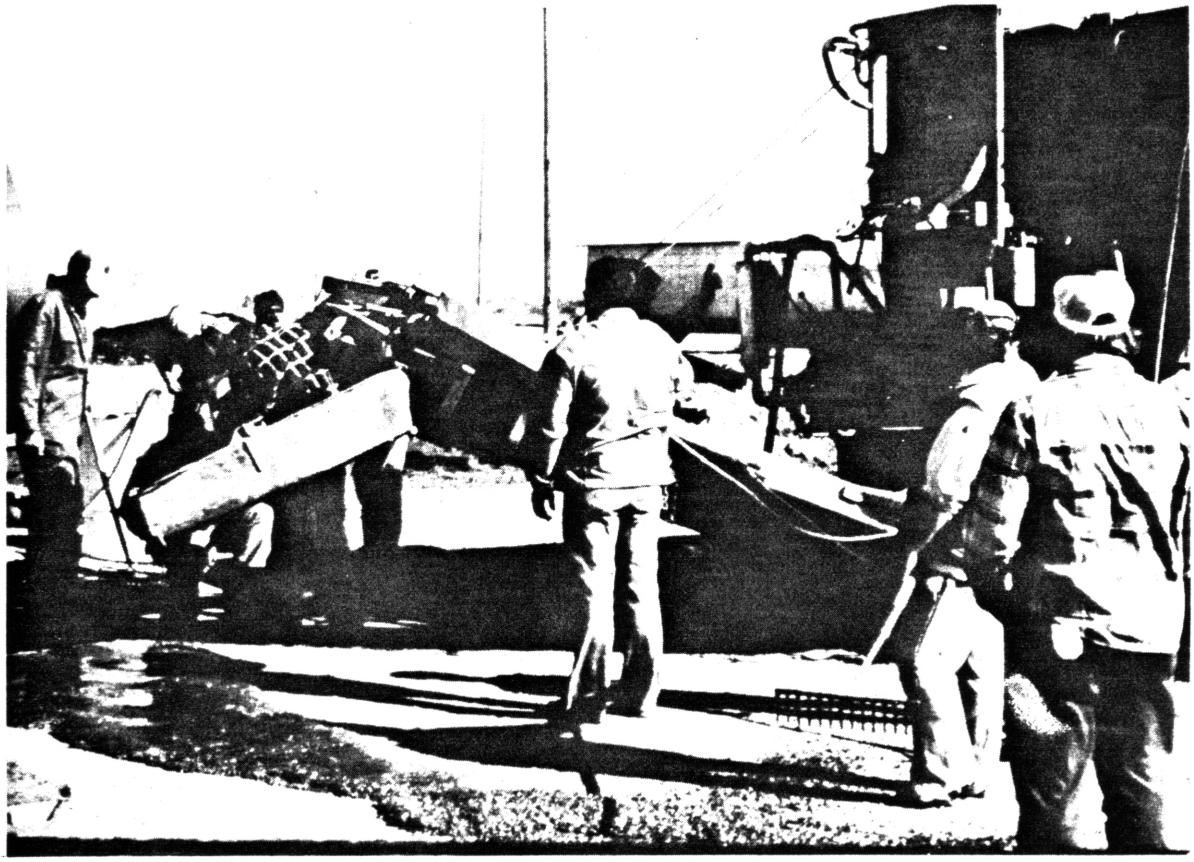


Figure 7. A trial run was made in the yard.

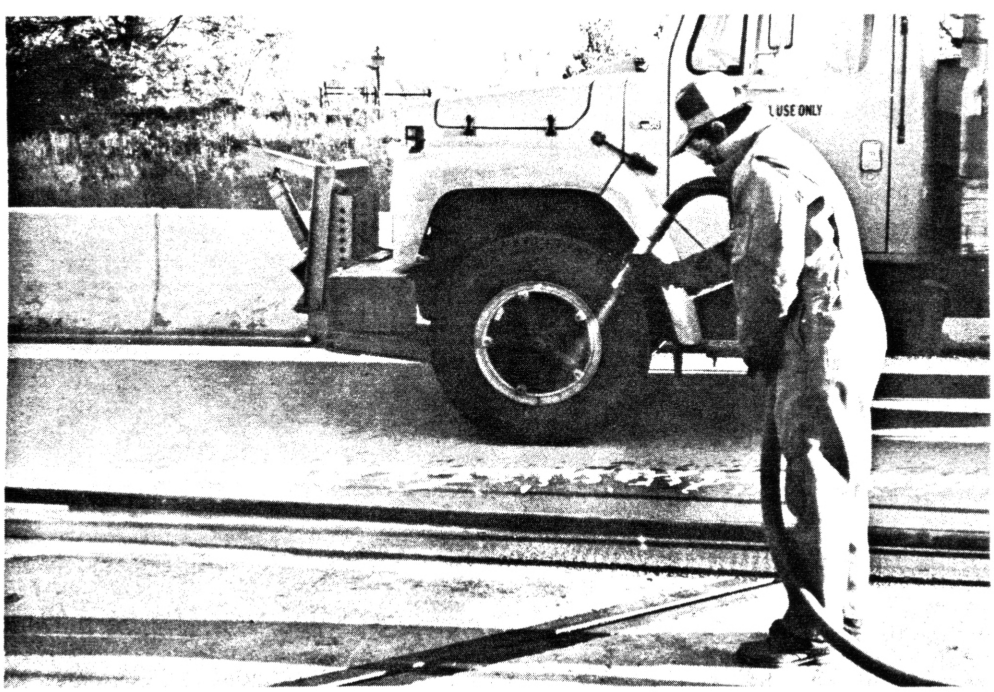


Figure 8. The deck was thoroughly sandblasted clean.

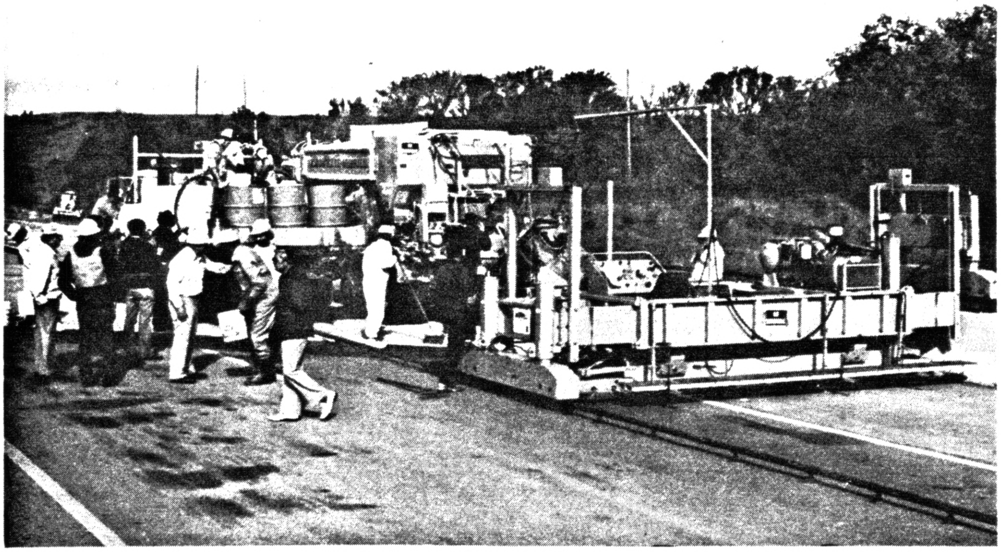


Figure 9. The paving train was first assembled in the right lane.

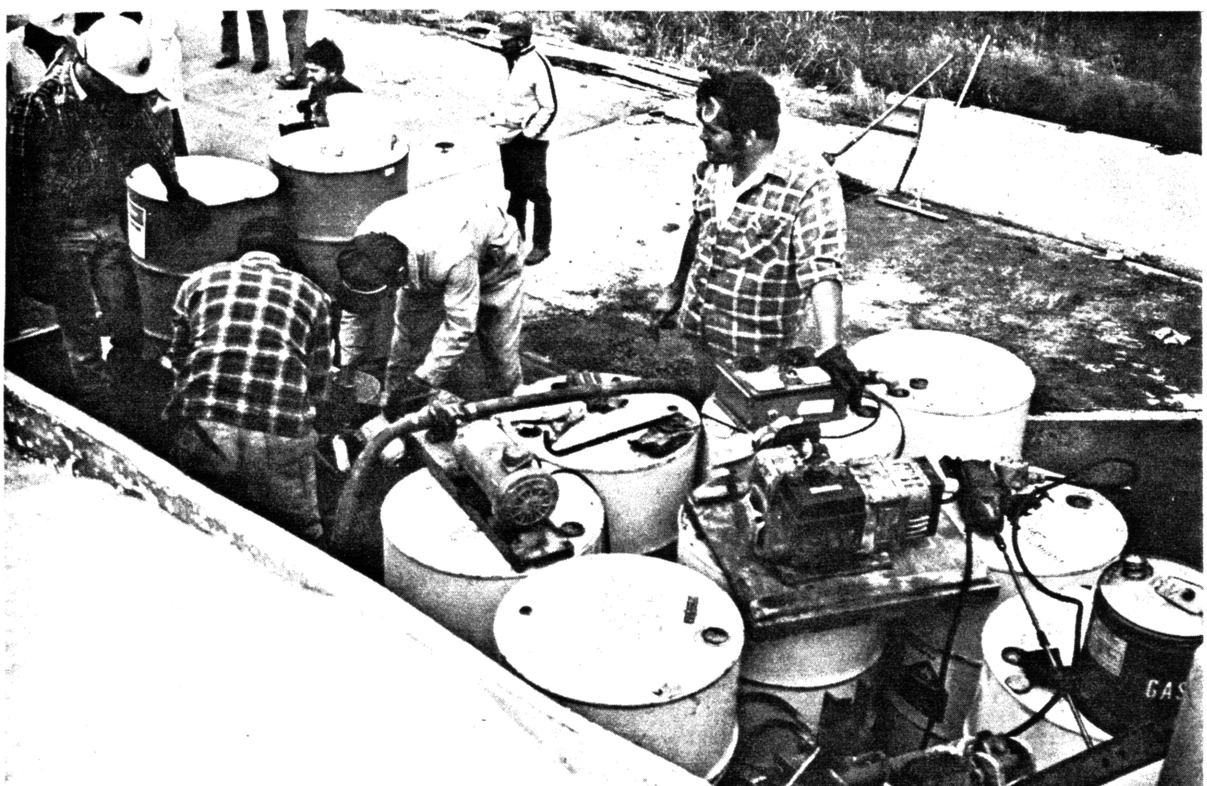


Figure 10. The chemical truck held the resin, catalyst and pumps.

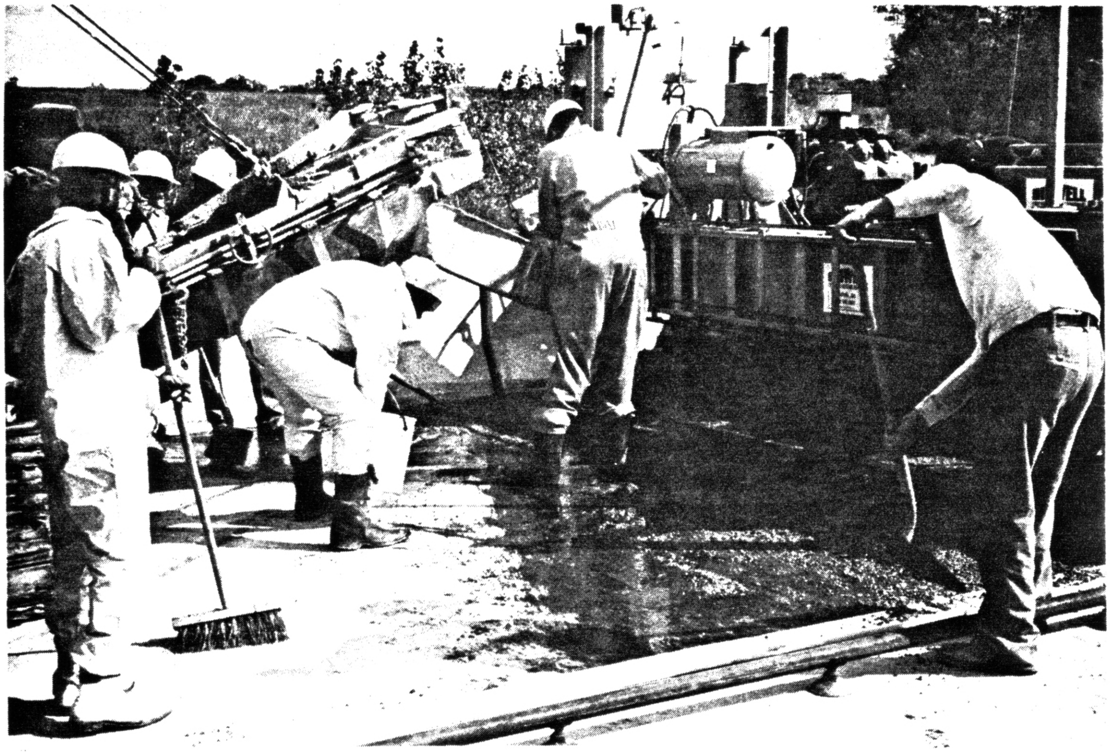


Figure 11. Polymer concrete was discharged onto a tackcoated surface before the paving machine.

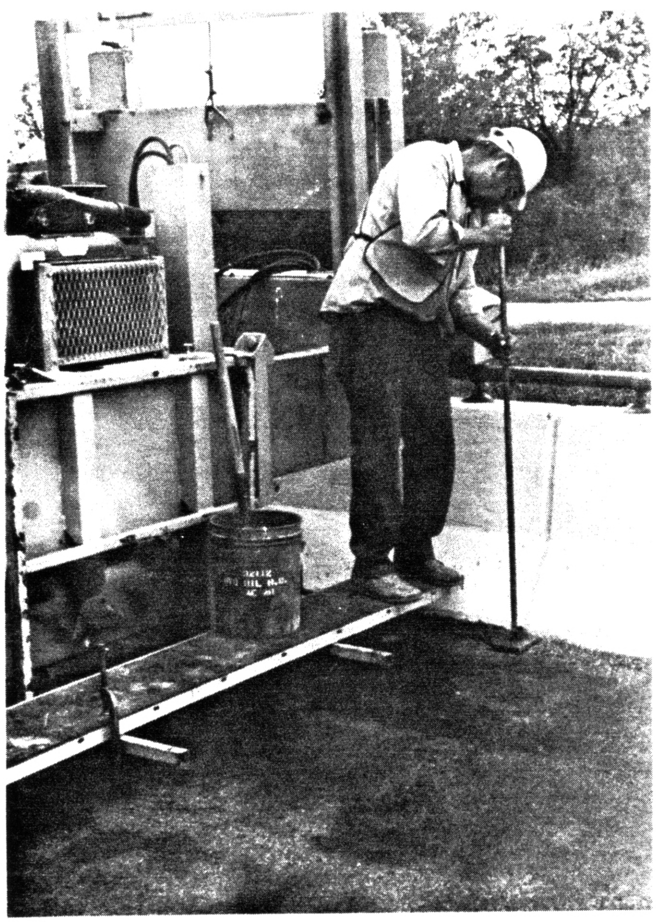


Figure 12. The paving machine could not compact the last 4 in (10cm) against the parapet wall.

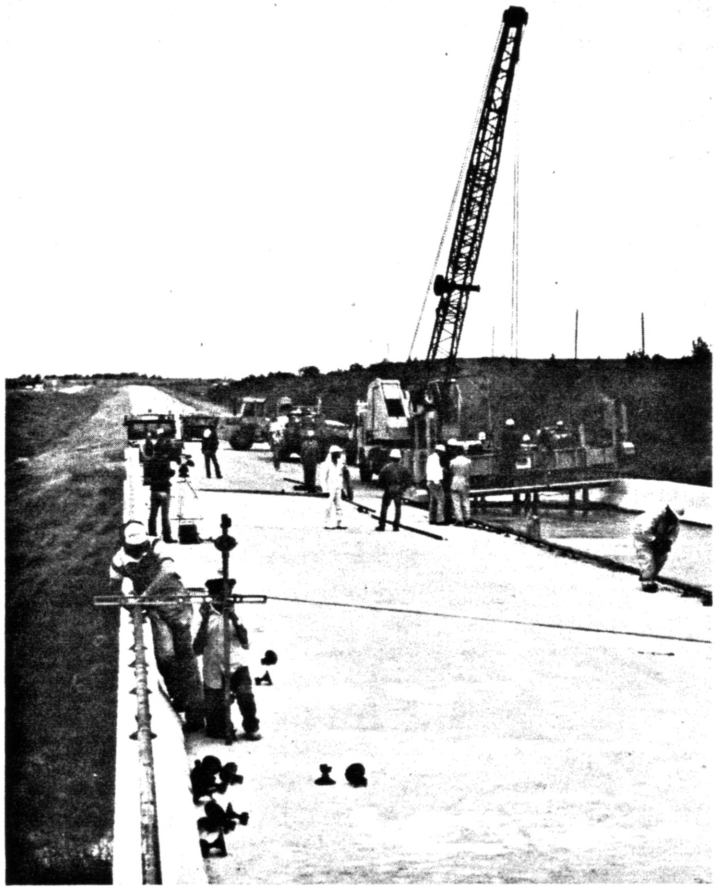


Figure 13. With the right lane paved, the equipment was moved to the left lane.

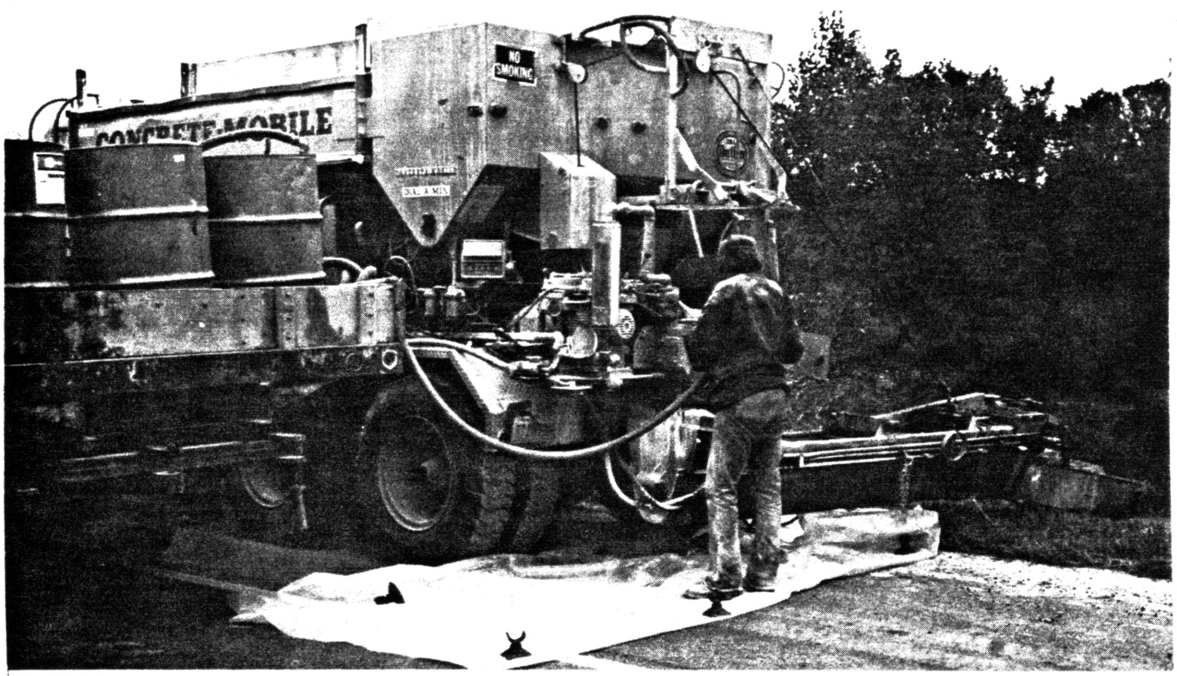


Figure 14. After each extended shutdown, the Concrete-Mobile and resin pumps were flushed.

Figure 15. Areas having lean resin content were squeeged with additional resin.

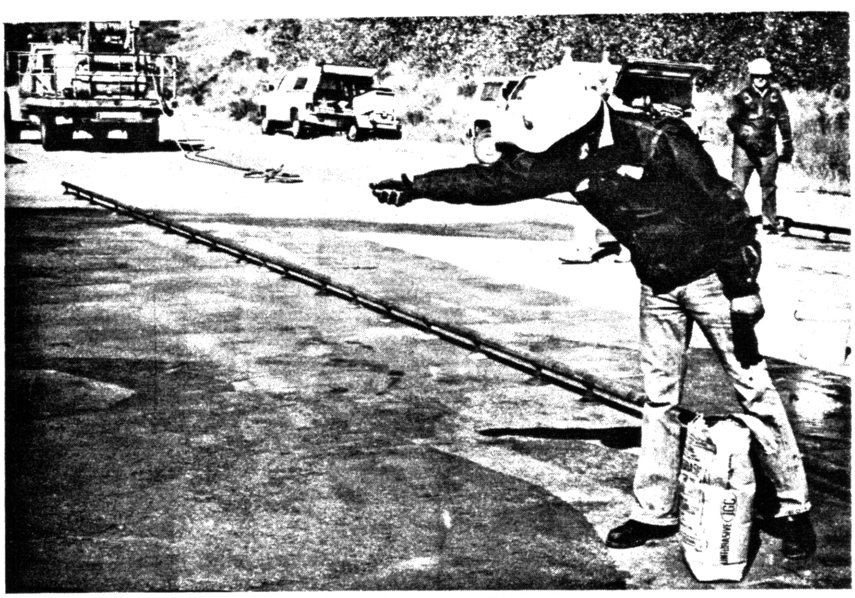


Figure 16. Additional sand sprinkled on the gelled surface provided traction.

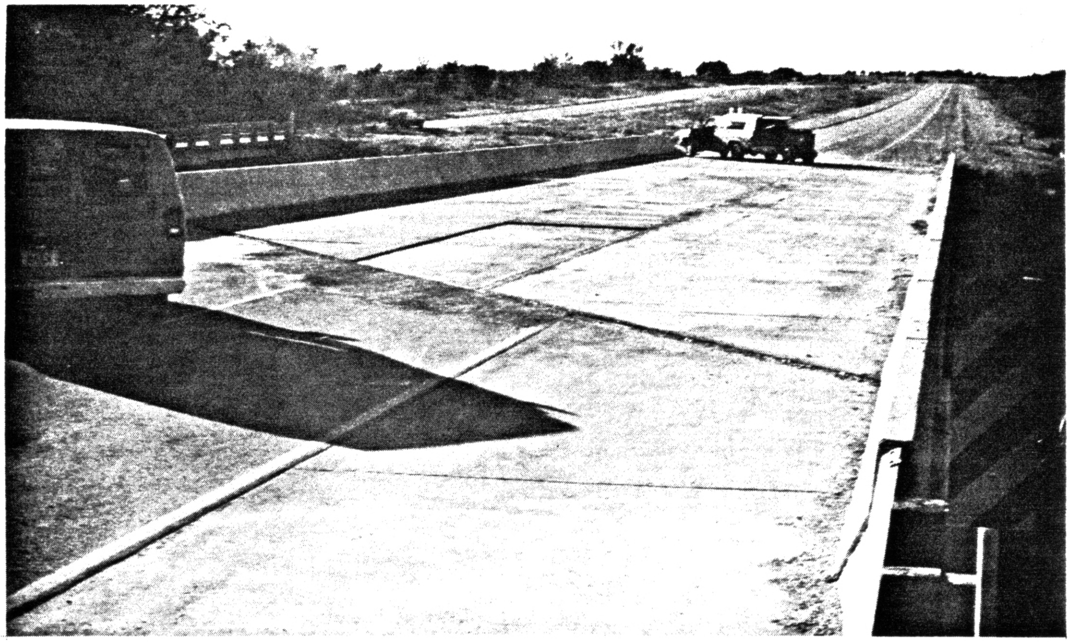


Figure 17. The bridge was nearly completed.

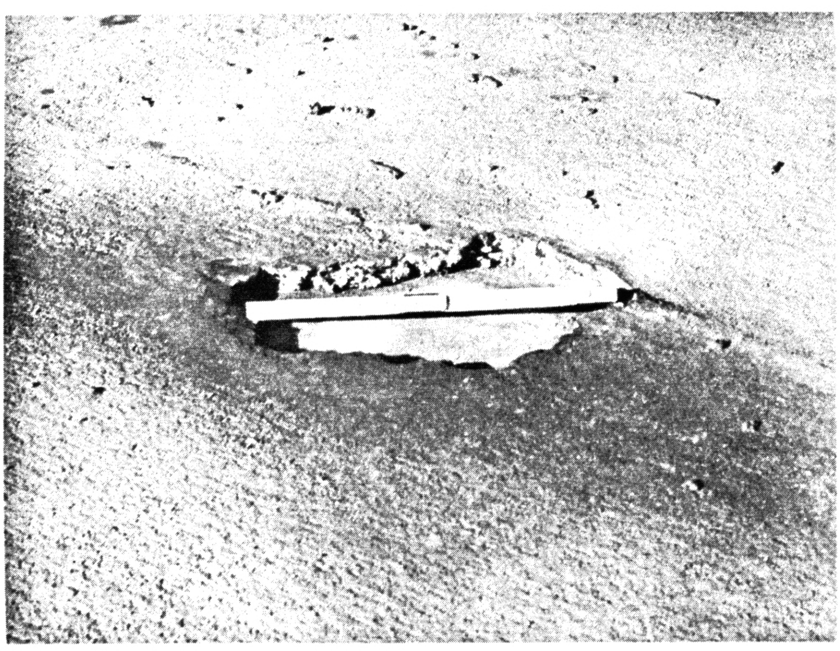


Figure 18. Delaminations ranged from small to large.

Figure 19. Some delaminations were very large; an 8 ft (2.4m) measuring stick.

Figure 20. Expansion joints were filled with a rubber-like material.

Figure 21. Unsound polymer concrete was jackhammered away.

Figure 22. For patching, polymer concrete was mixed with a portable mixer and placed by hand.

Figure 23. Delaminations were generously tackcoated.

Figure 24. A shopbuilt screed compacted the patches.

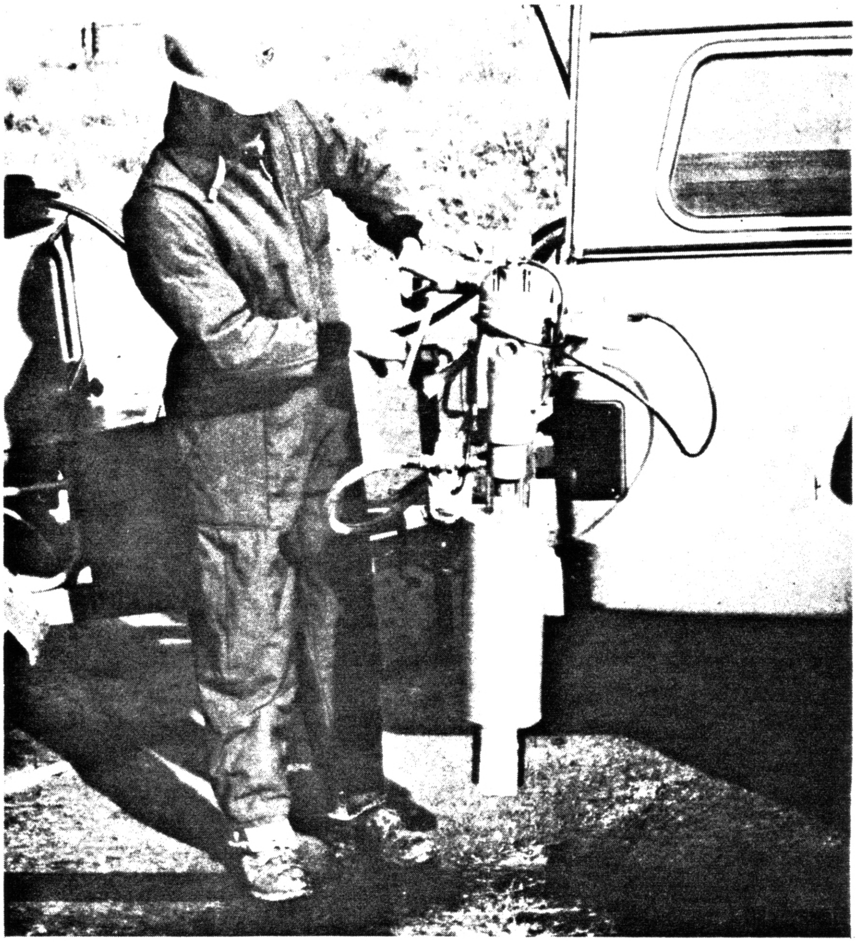


Figure 25. Core samples were taken from the deck.

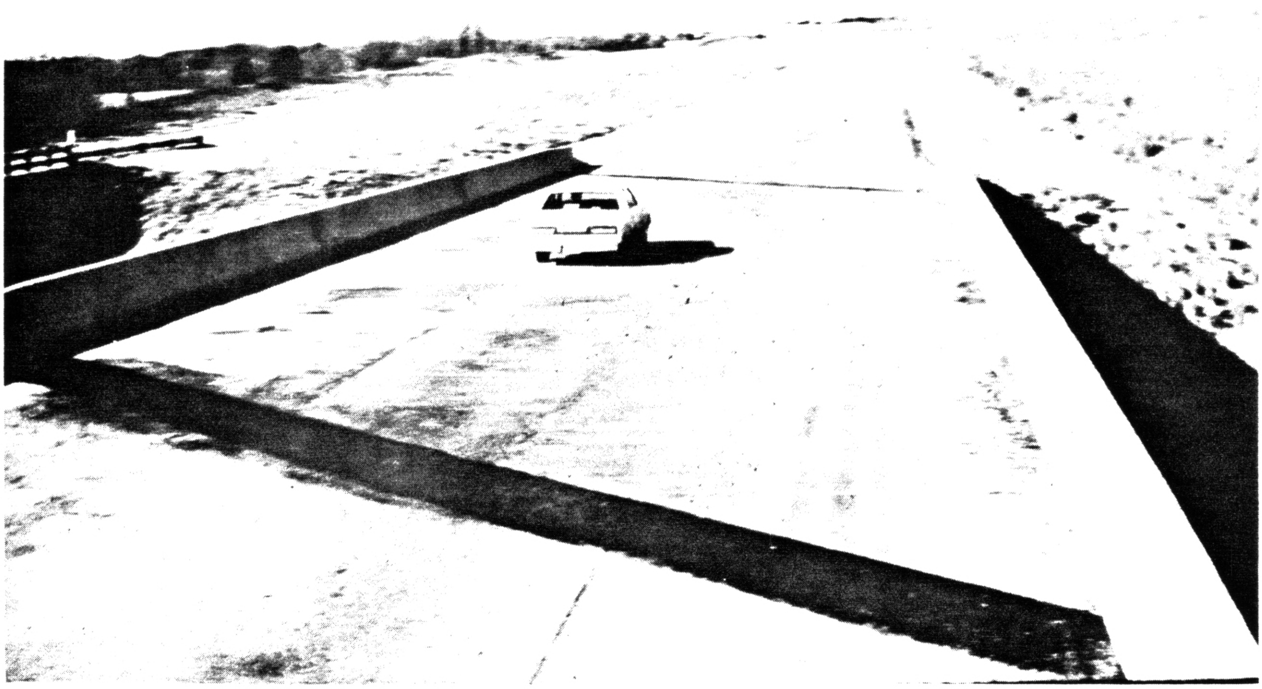


Figure 26. The bridge with its multi-colored patches as it appeared three months after initial construction.

APPENDIX B

PRE-OVERLAY TEST RESULTS

MATERIALS DIVISION

CHLORIDE ANALYSIS

PROJECT NO.: FAP 198(53) REPORT DATE ...09-08-81
DATE RECEIVED : 7-17-81
DATE SAMPLED : N.A.
COUNTY : PAYNE
BRIDGE : 18-NX0560
COMMENTS : S.H. 51 LOCATION: 5.6 MILES EAST OF LOGAN COUNTY LINE.

% LOSS(<.625) = 0.0 % LOSS(>0.625) = 0.0 % LOSS(ALL DEPTHS) = 0.0

SAMPLE (1)	STA.	LANE (2)	HALF CELL	SAMPLE DEPTH	STEEL DEPTH	% CL- (RECD)	% CL- (DRY)	% H2O	% LOSS	ADJ. % CL- (3)	CL-LBS. / CU.YD. (3)
1A	406+40	1	126	0.375 TO 1.375	1.750	0.0802	0.0821	2.370	14.77	0.0680	2.6603
1B	406+40	1	126	1.375 TO 2.375	1.750	0.0415	0.0427	2.924	14.04	0.0363	1.4193
2A	406+30	1	128	0.625 TO 1.625	2.000	0.0415	0.0427	2.787	12.13	0.0430	1.6828
2B	406+30	1	128	1.625 TO 2.625	2.000	0.0312	0.0321	2.814	11.65	0.0328	1.2850
3A	406+75	1	158	0.750 TO 1.750	2.125	0.0485	0.0500	3.064	11.57	0.0515	2.0149
3B	406+75	1	158	1.750 TO 2.750	2.125	0.0381	0.0392	2.766	12.41	0.0376	1.4717
4A	406+85	1	158	0.500 TO 1.500	1.875	0.0635	0.0654	3.036	11.21	0.0714	2.7941
4B	406+85	1	158	1.500 TO 2.500	1.875	0.0415	0.0426	2.535	13.23	0.0383	1.5006
5A	407+15	1	188	0.375 TO 1.375	1.750	0.0369	0.0380	2.998	13.04	0.0356	1.3950
5B	407+15	1	188	1.375 TO 2.375	1.750	0.0288	0.0298	3.483	10.99	0.0323	1.2646

(1) THE NUMBER IS THE HOLE FROM WHICH THE SAMPLE WAS TAKEN. THE LETTER IS THE POSITION WITHIN THE HOLE. A=TOP OR FIRST. B=SECOND ETC.
(2) LANES ARE NUMBERED FROM LEFT TO RIGHT FACING IN THE DIRECTION OF STATIONING.
(3) THE VALUES ARE ADJUSTED FOR DIFFERENCES IN THE AMOUNT OF AGGREGATES IN INDIVIDUAL SAMPLES.

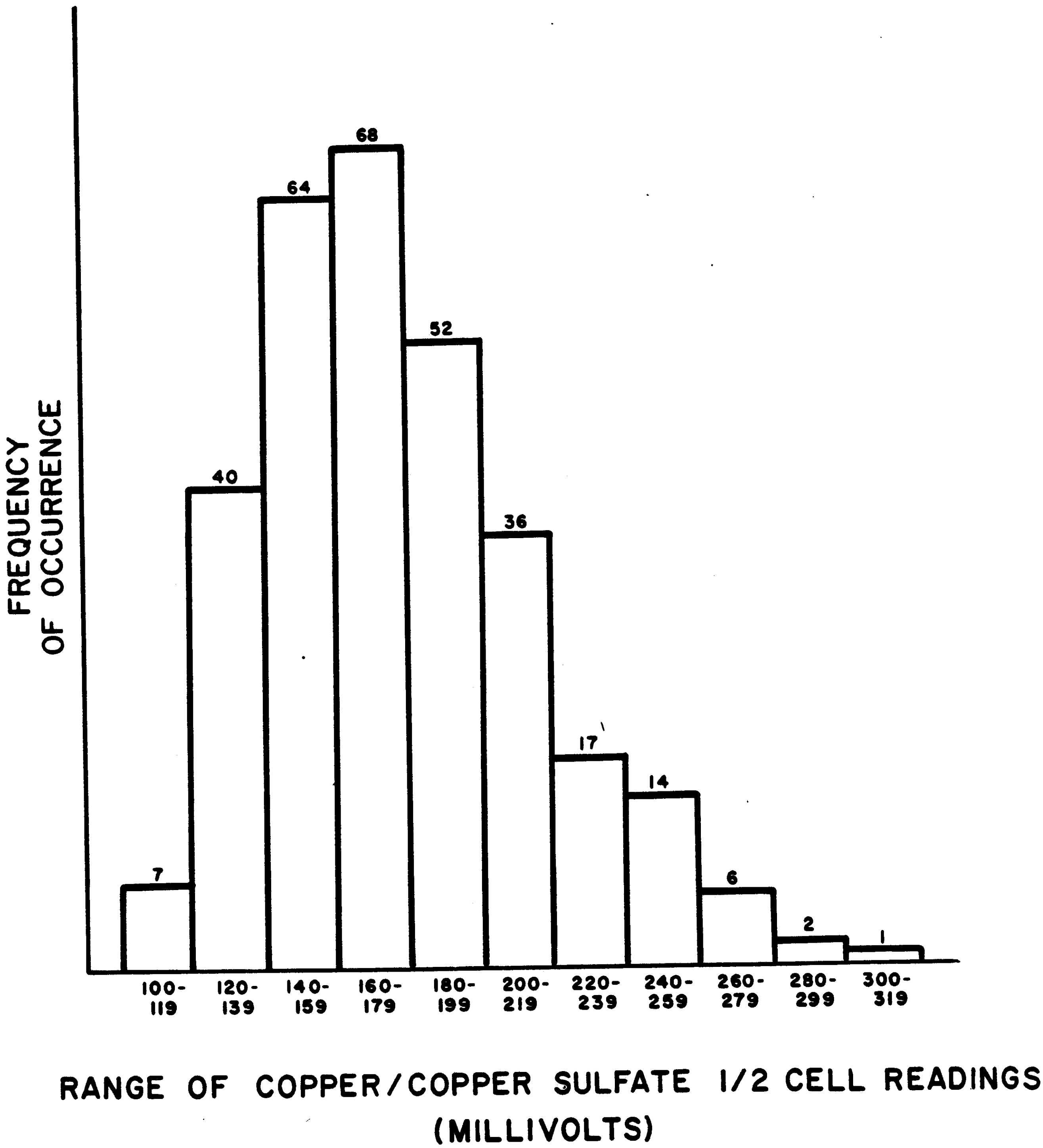
% LOSS(<.625) = 0.0 % LOSS(>0.625) = 0.0 % LOSS(ALL DEPTHS) = 0.0

SAMPLE (1)	STA.	LANE (2)	HALF CELL	SAMPLE DEPTH	STEEL DEPTH	% CL- (RECD)	% CL- (DRY)	% H2O	% LOSS	ADJ. % CL- (3)	CL-LBS./ CU.YD. (3)
6A	407+35	1	214	0.125 TO 1.125	1.500	0.0623	0.0643	3.284	11.48	0.0685	2.6816
6B	407+35	1	214	1.125 TO 2.125	1.500	0.0323	0.0333	3.162	12.93	0.0307	1.2023
7A	406+10	2	150	1.000 TO 2.000	2.375	0.0346	0.0359	3.724	11.72	0.0365	1.4280
7B	406+10	2	150	2.000 TO 3.000	2.375	0.0224	0.0231	2.914	12.75	0.0215	0.8432
8A	406+25	2	159	1.125 TO 2.125	2.500	0.0300	0.0310	3.255	12.01	0.0307	1.2029
8B	406+25	2	159	2.125 TO 3.125	2.500	0.0309	0.0318	2.924	13.09	0.0289	1.1331
9A	406+55	2	174	0.125 TO 1.125	1.500	0.0743	0.0761	2.453	13.37	0.0696	2.7260
9B	406+55	2	174	1.125 TO 2.125	1.500	0.0381	0.0392	2.896	12.10	0.0386	1.5117
10A	406+70	2	145	0.750 TO 1.750	2.125	0.0323	0.0336	4.023	8.29	0.0483	1.8917
10B	406+70	2	145	1.750 TO 2.750	2.125	0.0231	0.0239	3.514	10.82	0.0263	1.0311
11A	407+ 0	2	214	0.500 TO 1.500	1.875	0.0322	0.0333	3.563	9.58	0.0426	1.6665
11B	407+ 0	2	214	1.500 TO 2.500	1.875	0.0151	0.0157	3.643	11.67	0.0160	0.6256
12A	407+20	2	201	1.250 TO 2.250	2.625	0.0415	0.0430	3.701	12.23	0.0419	1.6420
12B	407+20	2	201	2.250 TO 3.250	2.625	0.0369	0.0387	4.832	11.06	0.0417	1.6314

(1) THE NUMBER IS THE HOLE FROM WHICH THE SAMPLE WAS TAKEN. THE LETTER IS THE POSITION WITHIN THE HOLE. A=TOP OR FIRST. B=SECOND ETC.
(2) LANES ARE NUMBERED FROM LEFT TO RIGHT FACING IN THE DIRECTION OF STATIONING.
(3) THE VALUES ARE ADJUSTED FOR DIFFERENCES IN THE AMOUNT OF AGGREGATES IN INDIVIDUAL SAMPLES.

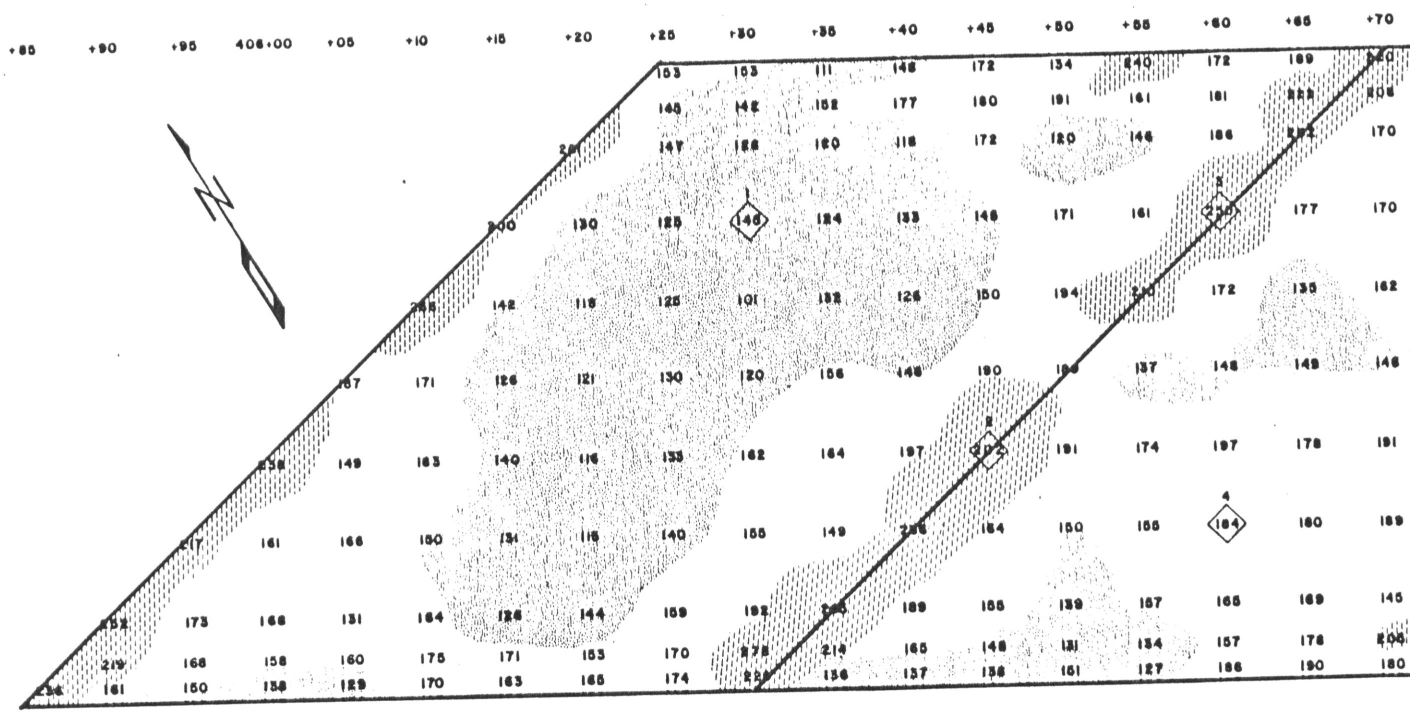
Range of Copper/Copper Sulfate Half-Cell Readings
(Millivolts)

Range	Frequency	Cum. Freq.	Percent	Cum. Percent
100-119	7	7	2.3	2.3
120-139	40	47	13.0	15.3
140-159	64	111	20.8	36.2
160-179	68	179	22.2	58.3
180-199	52	231	16.9	75.2
200-219	36	267	11.7	87.0
220-239	17	284	5.5	92.5
240-259	14	298	4.6	97.1
260-279	6	304	2.0	99.0
280-299	2	306	0.7	99.7
300-319	1	307	0.3	100.0

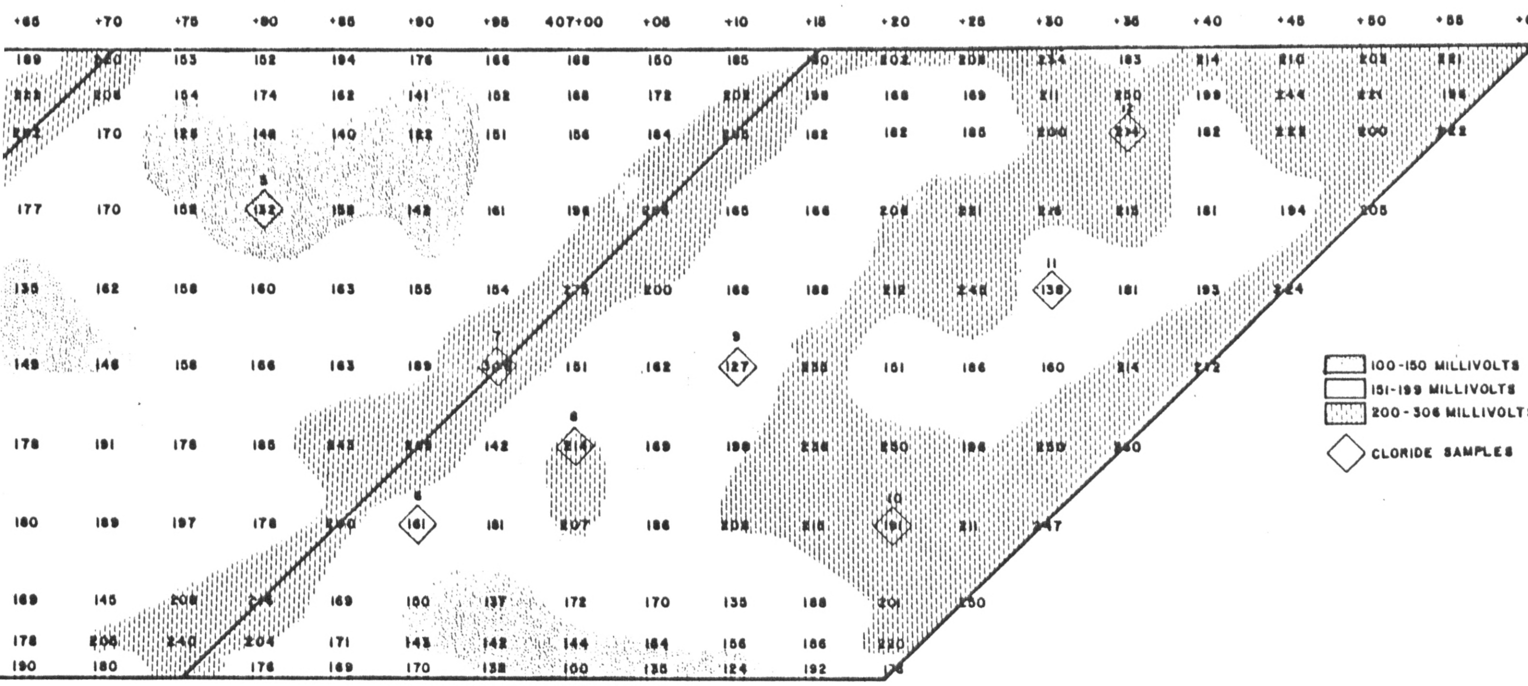


FREQUENCY OF OCCURRENCE
7
40
64
68
52
36
17
14
6
2
1
100-119
120-139
140-159
160-179
180-199
200-219
220-239
240-259
260-279
280-299
300-319
RANGE OF COPPER/COPPER SULFATE 1/2 CELL READINGS (MILLIVOLTS)

COPPER/COPPER SULFATE

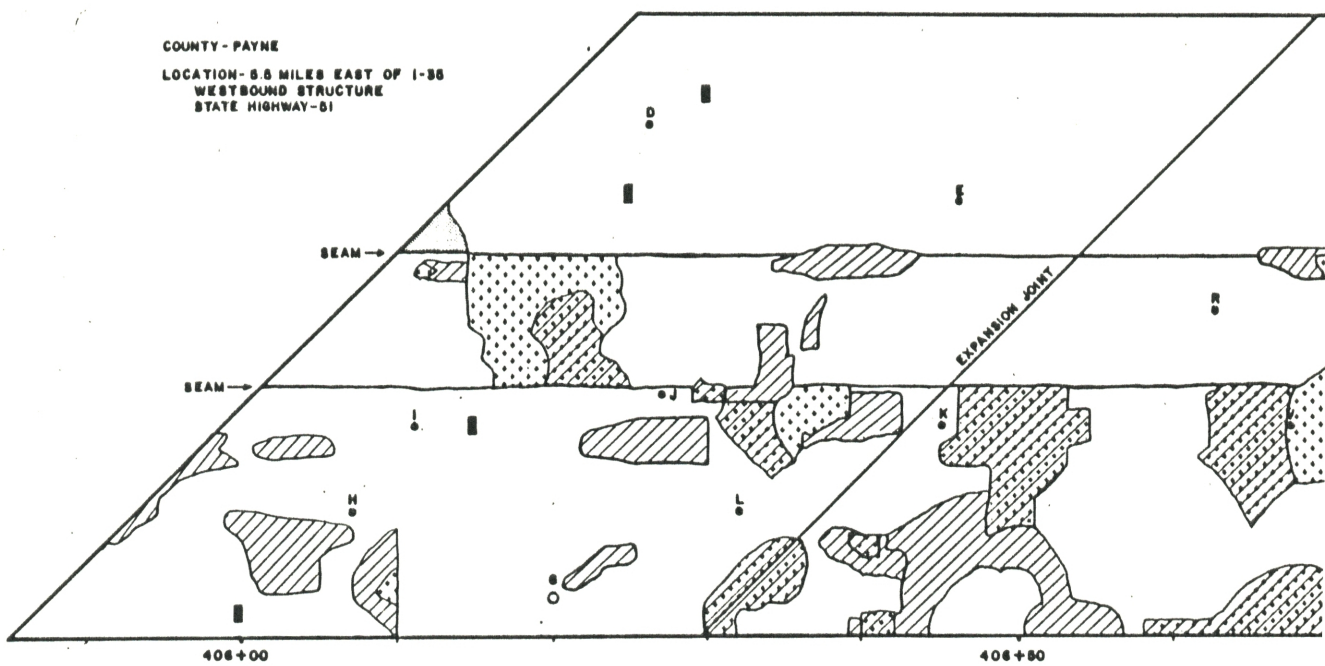


R SULFATE HALF CELL READINGS



APPENDIX C

POST-OVERLAY TEST RESULTS



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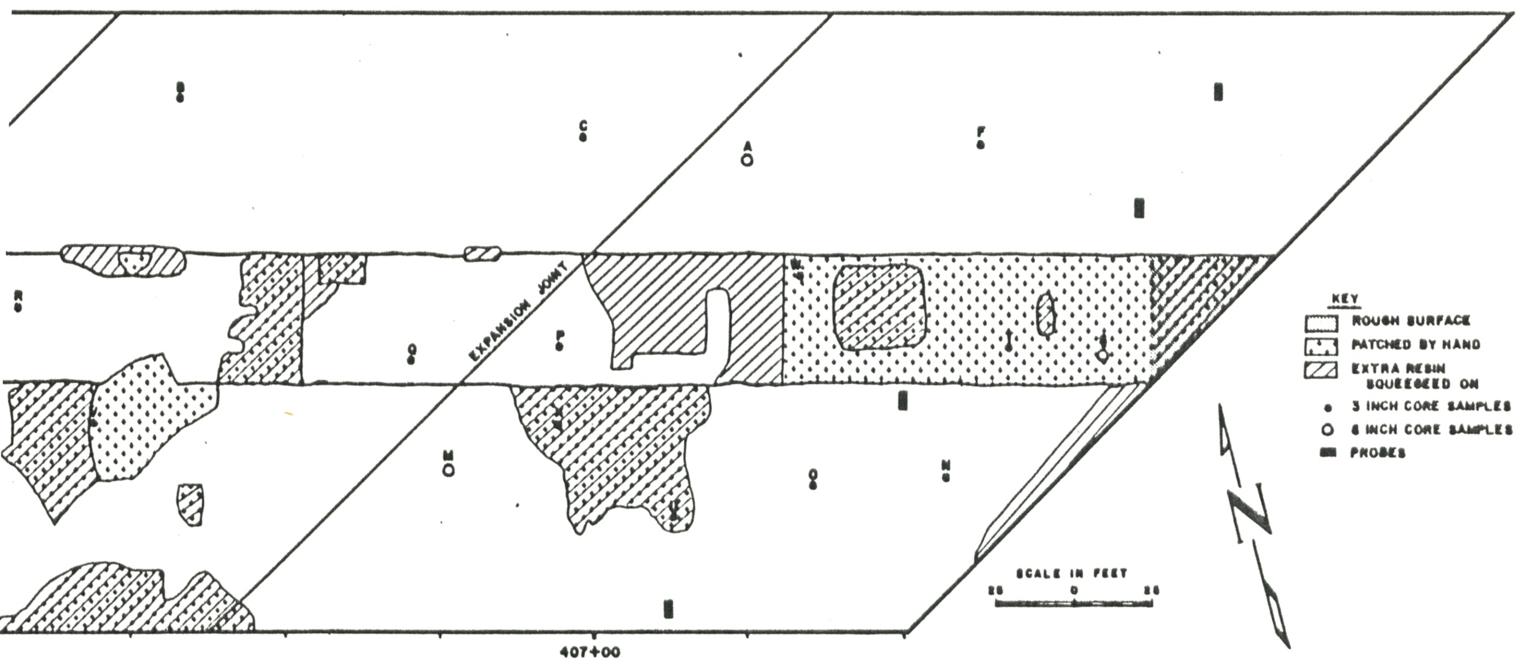

AND PROBE LOCATIONS

S OF DELAMINATIONS

Results of 90 Day Chloride Ponding Test
(Pounds of Chloride per Cubic Yard of Concrete)

Upper Level

Adjacent to Core	Core after Test
4.6	4.3
1.6	2.1
4.0	1.9
5.8	2.1
$\overline{X}_1 = 4.0$	$\overline{X}_2 = 2.6$
$S_1 = 1.8$	$S_2 = 1.2$
$N_1 = 4$	$N_2 = 4$

Test Hypothesis: that the mean of the two populations is equal. $\mu_1 = \mu_2$

At 90% confidence level, the critical region for six degrees of freedom is $T < -1.943$ and $T > 1.943$

$$Sp = \sqrt{\frac{(N_1-1)(S_1^2) + (N_2-1)(S_2^2)}{(N_1+N_2-2)}} = 1.53$$

$$T = \frac{(\overline{X}_1-\overline{X}_2) - d_o}{S_p\sqrt{1/N_1 + 1/N_2}} = 2.80$$

Conclusion: There is insufficient evidence to indicate a difference in the means of the two sample populations. Hence, we are 90% confident that there was a change in the chloride content of the concrete at the level above the steel.

At Steel Level

Adjacent to Core	Core after Test
2.1	2.1
2.3	2.2
1.8	1.4
2.3	1.5
$\bar{X}_1 = 2.1$	$\bar{X}_2 = 1.8$
$S_1 = 0.2$	$S_2 = 0.4$
$N_1 = 4$	$N_2 = 4$

Test Hypothesis: that the mean of the two populations is equal. $\mu_1 = \mu_2$

At 90% confidence level, the critical region for six degrees of freedom is $T < -1.943$ and $T > 1.943$

$$Sp = \sqrt{\frac{(N_1 - 1)(S_1^2) + (N_2 - 1)(S_2^2)}{(N_1 + N_2 - 2)}} = 0.32$$

$$T = \frac{(\bar{X}_1 - X_2) - d_o}{Sp\sqrt{1/N_1 + 1/N_2}} = 1.34$$

Conclusion: Since the T value falls within the critical region, we accept the hypothesis that the chloride content of the concrete at the steel level did not change.

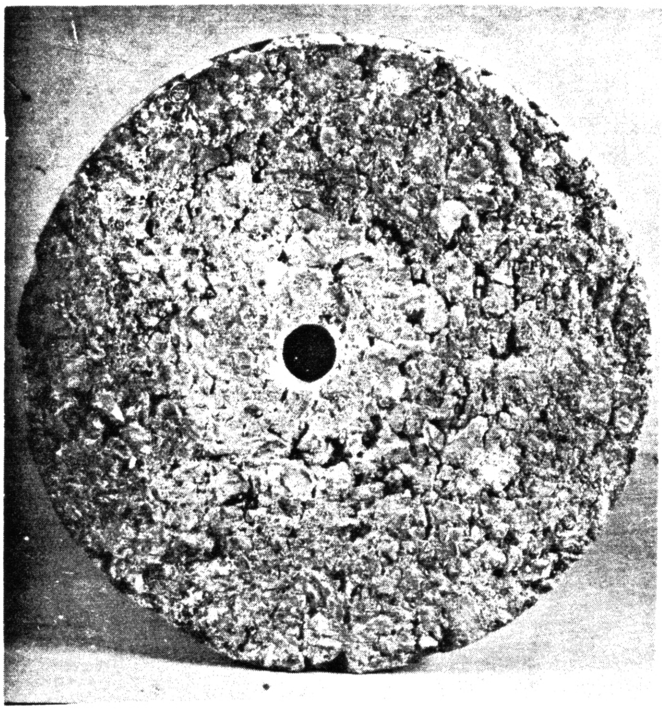

Figure 1. Resin Lean Polymer Concrete

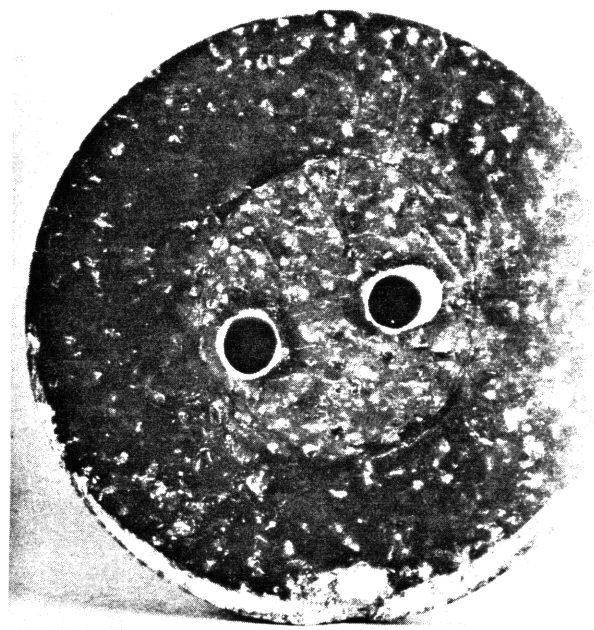

Figure 1. Resin Rich Polymer Concrete

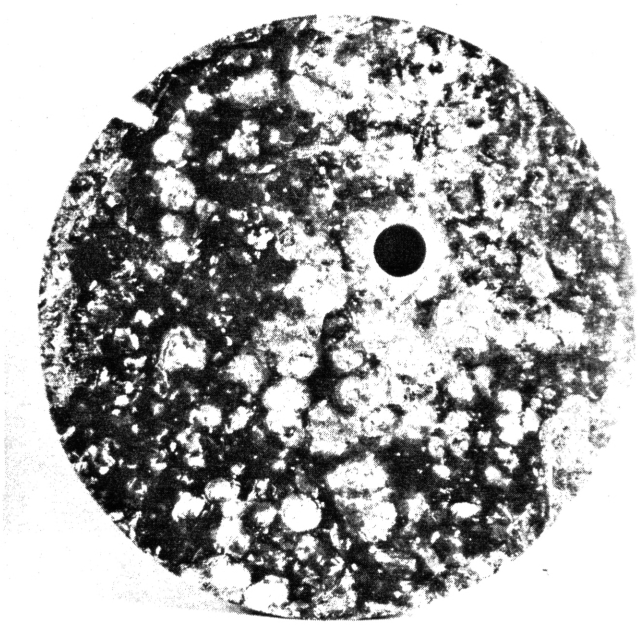

Figure 3. Polymer Concrete Patch

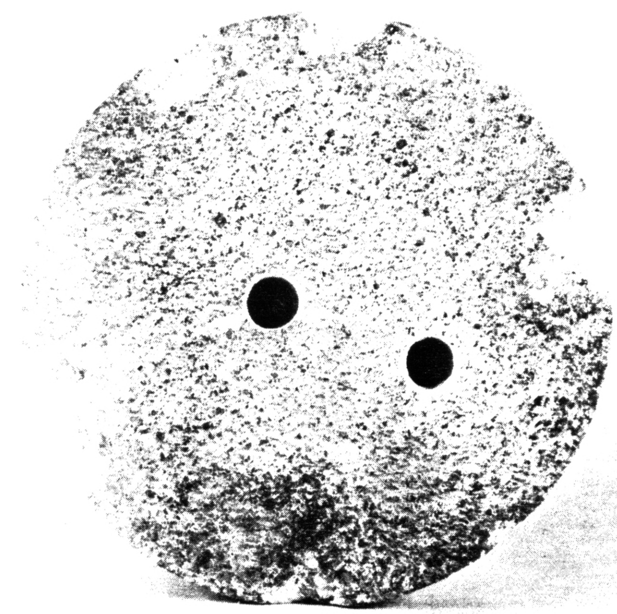

Figure 4. Excellent Polymer Concrete

The four cores taken from the bridge deck for the 90 day chloride ponding test.

SHEAR-BOND STRENGTH TEST
TYPE B POLYMER CONCRETE
STATE HIGHWAY NO. 51 WB BRIDGE
5.5 MILES EAST OF I-35
(AMOUNTS IN P.S.I.) ****

CORE	NO. OF FREEZE-THAW CYCLES	BOND STRENGTH	CONC. STRENGTH	AVERAGE BOND STRENGTH	AVERAGE CONC. STRENGTH
B	0	909	781	890	822
D	0	606	714	-	-
F	0	1232	*	-	-
K	0	941	909	-	-
N	0	761	882	-	-
H	50	303	663	453	704
I	50	337	882	-	-
O	50	438	485	-	-
R	50	357	581	-	-
T	50	832	909	-	-
C	100	488	628	161	559
J	100	**	540	-	-
L-2	100	**	522	-	-
P	100	318	566	-	-
W	100	**	540	-	-
E	150	***	***	269	485
L-1	150	**	451	-	-
Q	150	236	488	-	-
U	150	303	838	-	-
V	150	835	731	-	-
X	150	239	401	-	-

* CORE TOO SHORT TO TEST
** TOP OFF DUE TO FREEZE-THAW CYCLING
*** CORE DESTROYED DUE TO FREEZE-THAW CYCLING
**** kPa = (PSI) (6.8948)

SHEAR-BOND STRENGTH TEST
TYPE B POLYMER CONCRETE
STATE HIGHWAY NO. 51 WB BRIDGE
5.5 MILES EAST OF I-35

CORE	DESCRIPTION OF BOND BREAK
B	CLEAN BREAK AT BOND
C	CLEAN BREAK AT BOND
D	CLEAN BREAK AT BOND
E	*
F	CLEAN BREAK AT BOND
H	CLEAN BREAK AT BOND
I	CLEAN BREAK AT BOND
J	**
K	CLEAN BREAK AT BOND
L-1	**
L-2	CLEAN BREAK AT BOND
N	CLEAN BREAK AT BOND
O	CLEAN BREAK AT BOND
P	CLEAN BREAK AT BOND
Q	CLEAN BREAK AT BOND
R	CLEAN BREAK AT BOND
T	10% OF BREAK IN CONCRETE
U	5% OF BREAK IN CONCRETE
V	80% OF BREAK IN CONCRETE
W	**
X	CLEAN BREAK AT BOND

* CORE DESTROYED DUE TO FREEZE-THAW CYCLING
** TOP OFF DUE TO FREEZE-THAW CYCLING