BRIDGE DECK REPAIR AND DEVELOPMENT OF PROCEDURES FOR EPOXY INJECTION GROUTING OF BRIDGE DECK DELAMINATIONS (Capital Avenue over I 496 in the City of Lansing, S10 of 33044D)

MICHIGAN
RESEARCH LABORATORY SECTION

MICHIGAN DEPARTMENT OF
STATE HIGHWAYS AND TRANSPORTATION

BRIDGE DECK REPAIR AND DEVELOPMENT OF PROCEDURES FOR EPOXY INJECTION GROUTING OF BRIDGE DECK DELAMINATIONS
(Capital Avenue over I 496 in the City of Lansing, S10 of 33044D)

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Testing and Research Division
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and 74 F-141
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INTRODUCTION

This project originated in mid-1974 when the Eisenhour Construction Company of East Lansing, Michigan, offered to do some bridge deck repair demonstration work for the State of Michigan. Eisenhour utilized the products of the Sinmast Company, a German based company that specializes in the production of epoxy adhesives. These products were being evaluated in the Research Laboratory under Research Project 73 NM-381. The repair work was to consist of replacing spalled concrete on a bridge deck with epoxy mortar or epoxy concrete. Eisenhour would furnish the labor and equipment for doing the work if the Department would pay for the epoxy materials required. Department personnel from the Maintenance and Testing and Research Division met with Eisenhour personnel and decided the deck most ideally suited for this type of work was on the bridge that carries Capital Ave over I 496 in the City of Lansing (S10 of 33044D).

Department experience, both in the laboratory and field, indicated that most epoxy patching materials were not satisfactory when used on concrete bridge decks. Work done in the Research Laboratory had shown that both the thermal coefficient and Young's Modulus for epoxy mortar were substantially different from concrete (1). This made epoxy mixtures unsuitable as a patching material when used to patch the load bearing concrete in bridge decks of composite design. Field verification of this incompatibility occurred on the bridge which carries I 96 over US 127 interchange ramps in the City of Lansing (S04 of 33083). In this case, epoxy mortar was used for extensive deep patching of spalled deck concrete and also as a wearing course overlay. This work was accomplished in June 1971. During the following year the deck concrete adjacent to the epoxy mortar patches was severely overloaded with stress concentrations and localized failure of the concrete resulted. This failure was reflected in the crack patterns which developed in the epoxy mortar overlay.

During subsequent meetings, the Department's Research Engineers explained the incompatibility problems to the Eisenhour representatives and encouraged them to consider the alternate repair procedure of epoxy injection grouting which was being used in the State of Kansas (2). The Department wished to see if it would be an effective and economical solution to our bridge deck deterioration problem. The Eisenhour people were generally receptive to trying the injection procedure, but were not convinced that their Sinmast Epoxy Binder had incompatibility problems. They had been assured by the Germans that this material was ideally suited for use with concrete. The understanding was reached that the Research Laboratory would determine the patching compatibility of Sinmast epoxy mortar

TABLE 1
SINMAST MORTAR BINDER VS.
GRADE 40S BRIDGE DECK CONCRETE
7 Sack

NO. 1 - THERMAL COEFFICIENT OF EXPANSION

Temperature Range Degrees F	Sinmast Epoxy Coefficient in./in./F	7 Sack Control Concrete in./in./F
0 - 35	9.1×10^{-6}	5.3×10^{-6}
35 - 70	11.8×10^{-6}	8.7×10^{-6}
70 - 120	15.9×10^{-6}	8.4×10^{-6}

NO. 2 - SHRINKAGE

Age (days)	Sinmast Epoxy Shrinkage Value mils/in.	Concrete Shrinkage Value mils/in.
7	0.47	0.23
28	0.57	0.41

NO. 3 - COMPRESSIVE MODULUS OF ELASTICITY

Compressive Load, psi	Modulus (Epoxy) psi	Modulus (Concrete) psi
500	2.54×10^{6}	4.45×10^{6}
1,500	2.50×10^{6}	3.82×10^{6}
2,500	2.46×10^{6}	3.78×10^{6}

NO. 4 - COMPRESSIVE LOAD CAPACITY (7 Day Moist Cure)

Sinmast Epoxy Mortar (psi)	7 Sack Control Concrete (psi)
8,440	4,180

with concrete and that Eisenhour would review the Kansas Report and determine the feasibility of equipping themselves to inject delamination planes.

A letter from H. L. Patterson to L. T. Oehler dated May 9, 1975, described Eisenhour's preparedness to begin injection, the patching incompatibility of Sinmast epoxy mortar with bridge deck concrete, and proposed plans for patching the spalled areas of the bridge. A table from that letter showing the test results on the Sinmast epoxy mortar is included with this report (Table 1). At this point it was decided to use the epoxy injection method to repair delaminated areas of both spans and then use an epoxy patching mix in half of one span. The remaining three-fourths of the deck was to be patched with hydraulic cement type mixes to be described.

Experimental Patching Concrete Development

In the fall of 1972, various experimental patching concretes were field tested on a bridge deck near Mason (3). Included among these materials was a moderately fast-setting product called "Embeco 411A" that was developed and sold by the Master Builders Co. It was a pre-mixed material that contained all required components except water. Because the material cost of this mixed concrete was extremely high ($15.90/cu ft), its application was limited to three patches with a combined total area of 30 sq ft. Subsequent inspections of these field applications indicated that it was performing very well and that it appeared to be free of the edge shrinkage that was typical of most of the other materials. It was known that the Embeco 411A concrete contained Master Builders' expansive component, "Embeco Metallic Aggregate." This material has been on the market for years and was included with some Type III cement as a control material in the evaluation of some patching mortars (4). In this application it was proportional in accordance with the producer's instructions for use with concrete. Laboratory test results gave the specious impression that it was ineffective in countering shrinkage in an air-entrained mortar.

With the knowledge that a field application had successfully countered shrinkage, a renewed interest was taken in the Embeco Metallic Aggregate and a more comprehensive laboratory evaluation was undertaken. Four different proportionings were employed in a regulated-set patching concrete and the resulting shrinkage prisms were given a simulated bridge deck cure followed by six months air drying. This work indicated that the Embeco Metallic Aggregate proportioned between 40 to 50 percent of the cement weight gave the best performance. It was also discovered that the bulk of the expansion occurred during the first 24 hours and therefore was not being recorded by the shrinkage prisms. A standard procedure (5), which utilized some special equipment for measuring initial expansion of concrete, was employed and the magnitude of the initial expansion was measured. After assimilating these facts, a patching concrete was designed with materials that would be readily accessible to our District Maintenance personnel. It contained eight sacks of Type I cement with 2NS fine aggregate, 25A crushed gravel coarse aggregate, an air-entraining agent, and the Embeco Metallic Aggregate. Two variations of this experimental concrete were created in the laboratory; one contained an amount of Embeco Metallic Aggregate equal to 40 percent of the weight of the cement, while the other employed an amount equal to 45 percent. These mix designs were evaluated against a control material that utilized the same materials, but without the Embeco Metallic Aggregate. The mix designs employed a nominal ratio of fine aggregate to total aggregate of 53 percent by volume. The 2NS fine aggregate that portion of the coarse aggregate passing a No. 4 sieve, and all the Embeco Metallic Aggregate were considered part of the fine aggregate.

The specimens used to evaluate this experimental patching concrete were; 4 by 8-in. cylinders, 3 by 3 by 14.5-in. shrinkage prisms, 4 by 5 by 16-in. flexure beams, 9 by 12 by 2.5-in. patching slabs, and 2 by 4-in. expansion cylinders.

The 4 by 8-in. cylinders were used to determine Young's modulus, specific gravity, and compressive strength of the concrete in sets of three after one, three, seven, and twenty-eight days of continuous moist room cure and also after a twenty-eight day special cure which consisted of seven days moist room curing followed by twenty-one days of air drying in the laboratory. This latter cure was a more realistic simulation of a twenty-eight day field cure.

Three shrinkage prisms were given the simulated bridge deck cure (SBDC) which consisted of one week moist room curing followed by alternating three-week intervals of air drying and moist room curing for a total cure time of thirteen weeks. The cure time was followed by six months of air drying and then a four-week period in the moist room where length recovery was measured. Length and weight measurements were made at key intervals throughout the cure, dry out, and recovery periods.

Flexure beams in sets of three were tested after one and seven days of continuous cure and after the twenty-eight day special cure.

The experimental patching concrete and its control were each cast as a patch within two diked patching slabs; these were given the twenty-eight day special cure and were tested in freeze-thaw where fresh and 3 percent salt water were alternately ponded within the dikes in respective four and three cycle repeating intervals. The patching slabs were closely monitored for signs of shrinkage and scaling. At 42 and 105 cycles, one slab from each set was sawed into two 3.75 by 4-in. blocks. These blocks were then tested in single shear where the patch was sheared off the slab substrate.

Two, 2 by 4-in. expansion cylinders were placed under a micrometer bridge and carefully measured for expansion during the initial 24-hour period; this gave important supplemental information to the shrinkage prism measurements.

This patching concrete work established that an insignificant difference existed between the performance of the 40 and 45 percent mixes. Hence, the one containing 40 percent Embeco Metallic Aggregate was given primary consideration. Laboratory test data for this mix and its control are shown in Table 2 and Figure 1. These data indicate the experimental laboratory patching concrete was superior to the control concrete in strength and shrinkage characteristics, and, as expected, maintained compatibility with structural concrete's compressive modulus of elasticity. However, it was much more vulnerable to freeze-thaw inflicted scaling. Because the laboratory freeze-thaw testing was much more severe than normal field conditions, this problem was not considered too serious. However, it was observed that the scaling, which advanced rapidly at first, ceased when it reached the top surface of the coarse aggregate (Fig. 2). This seemed to indicate that the mortar, which had little means of vertical restraint, was being disrupted by the expansive forces of the Embeco Metallic Aggregate. Mortar with adequate restraint, such as that between embedded coarse aggregate particles, effectively impeded disruption. It was observed that although this possibility of scaling would detract from the aesthetics of a patch surface, it would not severely impair its functional value.

This patching concrete was then recommended for a field application with the Type I cement rather than the regulated-set cement because the Type I reaches design strength just as fast and shrinks less.

Injection Technique Development

From the Kansas report, which concerns itself mostly with the failures and successes of various stages of development work, it was noted that the hollow vacuum drill for drilling the injection ports and the rubber stopper seal on the injection nozzle were the key to their success. Though differing with some of its contents, we were able to use it as a general guide in understanding many of the problems we encountered.

TABLE 2
PATCHING CONCRETE DATA
(Experimental Laboratory Patching Concrete With Embeco Metallic Aggregate)
Eight Sack/Cu Yd Mixes

Cubic Yard Composition Data

Type of Concrete		Mix Water	W/C Ratio	Type I Cement	E/C Ratio	Fine Aggregate: Embeco Metallic Aggregate	Fine Aggregate: 2NS Sand	Fine Aggregate: 25A Crushed Gravel Passing No. 4 Sieve	F.A./T.A. Ratio	Coarse Aggregate 25A Crushed Gravel Retained on a No. 4 Sieve	6.5 Percent Entrained Air (MBVR) 1 fl oz/sack
Control	wt(lb)	286	0.38	752	--	--	1,259	182	--	1,337	--
	vol(ft³)	4.58	--	3.83	--	--	7.91	1.07	0.53	7.85	1.76
Experimental Laboratory Patching Concrete	wt(lb)	286	0.38	752	0.40	301	1,115	182	--	1,337	--
	vol(ft³)	4.58	--	3.83	--	0.90	7.01	1.07	0.53	7.85	1.76

Test Data

Type of Concrete	Compressive Strength, psi					Flexural Strength, psi			Patching Slab Shear Strength, psi		Dry Bulk Specific Gravity 28 Day Continuous Cure	Compressive Modulus of Elasticity, psi 28 Day Continuous Cure
	Continuous Cure				28 Day Special Cure	Continuous Cure		28 Day Special Cure	Freeze-Thaw			
	1 Day	3 Day	7 Day	28 Day		1 Day	7 Day		42 Cy.	105 Cy.		
Control	2,870	4,020	3,330	6,080	4,800	490	915	640	300	630	2.26	4.0×10^6
Experimental Laboratory Patching Concrete	3,170	4,120	5,960	7,230	7,380	555	825	860	435	705	2.33	4.1×10^6

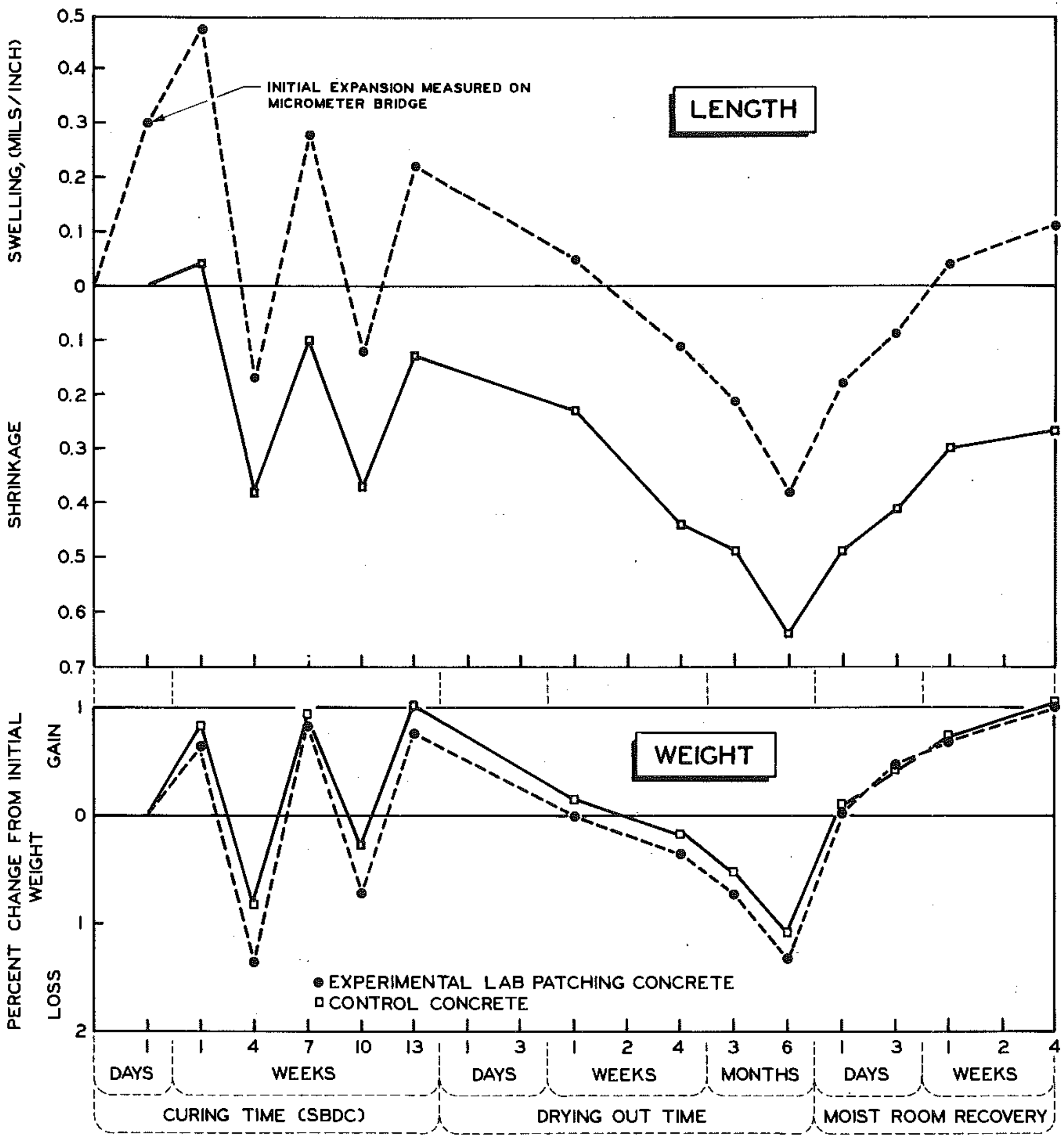
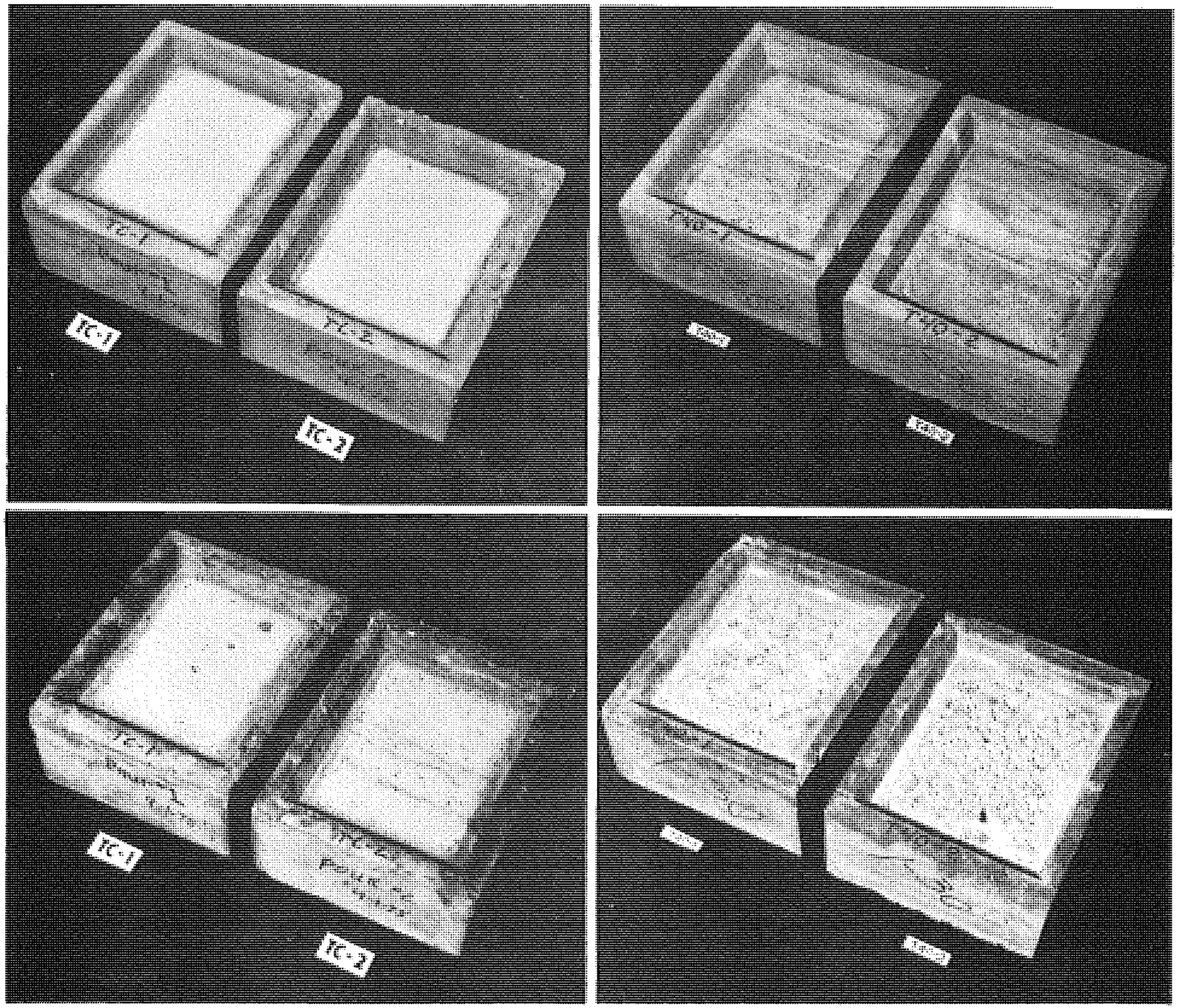


Figure 1. Length and weight variations of 3 by 3 by 13.5-in. shrinkage prisms during and following the 13-week simulated bridge deck cure (SBDC).



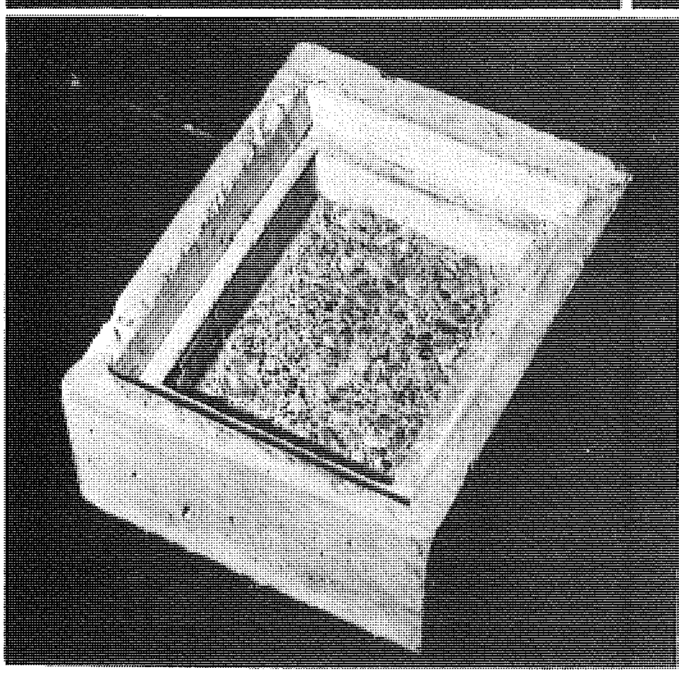


Figure 2. Before and after views of patching slabs that were tested through 42 freeze-thaw cycles. Surface condition of control slabs on left shows contrast of scaling vulnerability of experimental laboratory patching concrete on right. The inset view is of a patching slab block before patching concrete is placed.

Procedural development work on injection techniques took place on the Capitol Ave deck during eight days between May and September. During this time various types of equipment and procedures were repeatedly tested and revised. Injection work carried out prior to August was done with a tapered plastic injection nozzle inserted through the single hole of a rubber stopper. To build pressure up to 40 psi, the operator had to press the hand held injection gun down so that the rubber stopper, which was compressed between the concrete and the gun, would create an effective seal. Due in part to operator fatigue, the success of this technique was very qualified and the overall view toward the whole procedure had been discouraging. Another technique was then tried, which was much more encouraging. As usual, the delamination and reinforcing bar locations were marked, as were locations for the injection and vent ports. Holes for both of these ports were drilled with a hand-held 3/8-in. impact drill. Those intended for injection were reamed with a 1/2-in. hollow bit that was hooked to a vacuum line. The reamed injection ports were then inspected closely. On some, the holes were nearly perfect; on others, the holes were either elongated or had major chips broken away from their edges. It was felt that the rubber stopper would provide a sufficiently good seal for injecting the near-perfect holes, but that grouted-in "tees" would probably be required for the others. Five hours later, after the epoxy paste had securely grouted-in the plastic tees, the injection work started. Using a rubber stopper seal some of the delaminations were successfully injected, but others were vitiated by even the tiniest chips around the injection hole. In general, the plastic tees gave results which were much more satisfactory. The injected epoxy seemed to flow into the delaminations, fill them, and then appear at the vent ports. At one location, where there were two delaminations in close proximity, epoxy from one injection port began flowing from the tee in the adjacent one; indicating that an effective procedure had been developed. On September 8, 1975, cores were taken in these successfully injected locations (Figs. 3 through 5).

Figure 3 shows the results of injection on one side of a reinforcing bar that has a crack over it. The rust build-up on the bar apparently blocked the flow of epoxy and very little was able to cross over the bar and none escaped from the crack. It was difficult to recover the full drilled length of this core because of an embedded tie-wire protruding up from the bottom steel. In attempting to recover this partial-depth core, the first fracture occurred at the bottom of the top steel and the remainder of the core was recovered with great difficulty. It was noted that moisture seeped from the exposed bottom of this rebar for 60 hours after it had been returned to the laboratory. Apparently, there were tiny reservoirs along the bar that harbored this corrosive moisture.

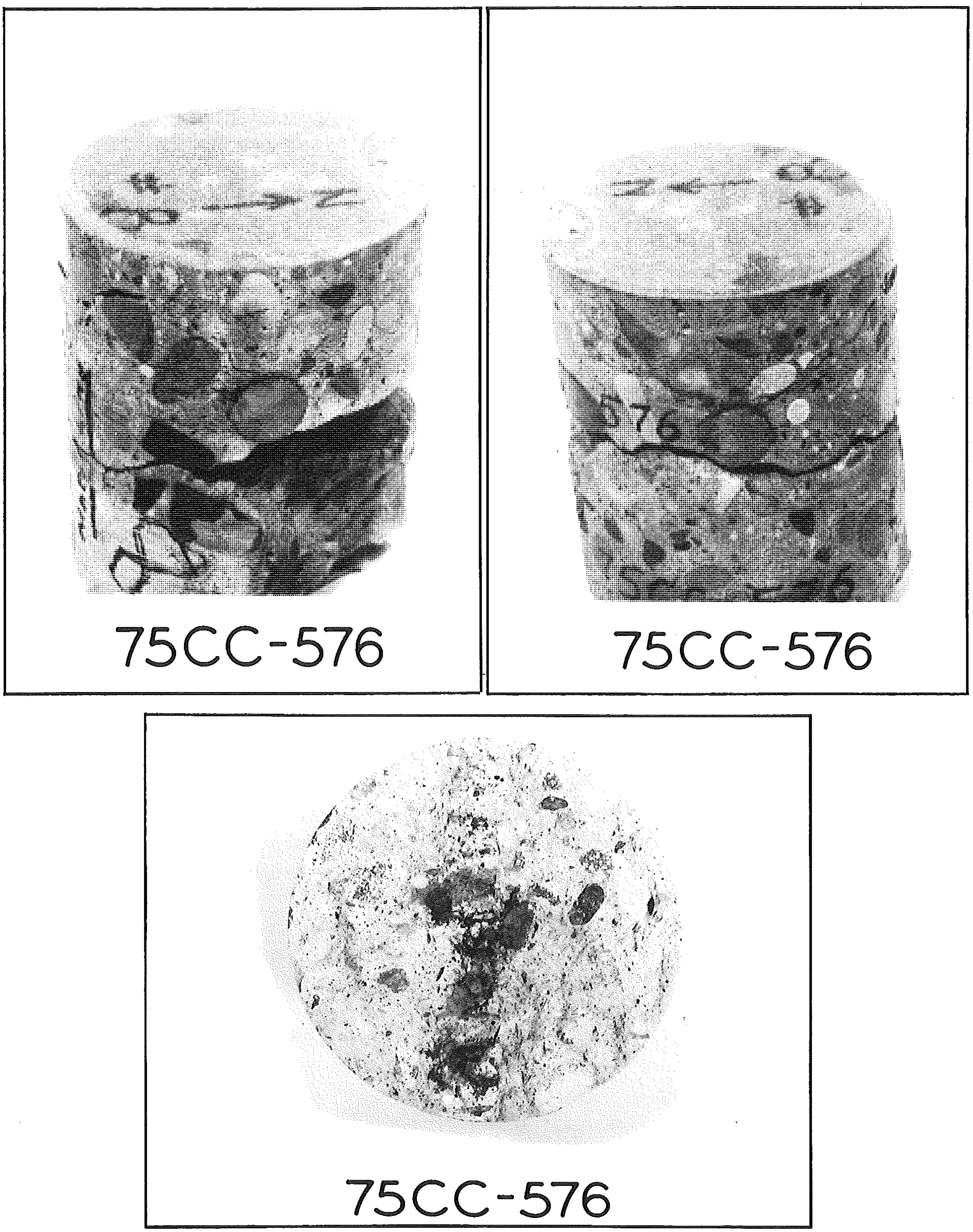


Figure 3. Views of both sides of a core cut through a delaminated area over a transverse bar. Pressure injection epoxy resin came from one injection port only. Views show how rust build-up impeded epoxy flow over bar. Inset photo shows fracture at bottom of bar from which moisture seepage of 60 hour duration was observed.

Figure 4. Delaminated area between transverse bars that was restored with pressure injected epoxy resin.

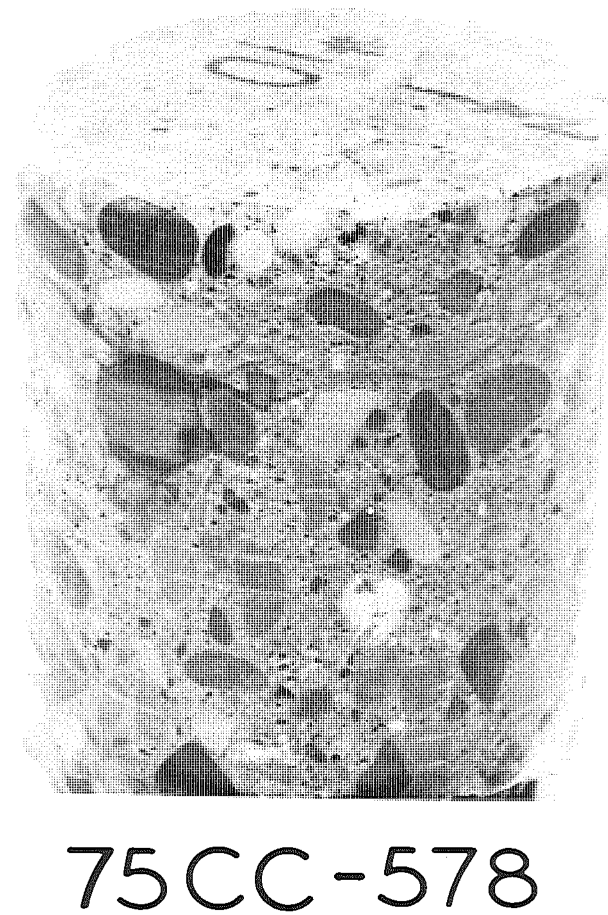


Figure 5. Delamination over a transverse bar that was restored with pressure injected epoxy resin from injection ports on either side of the bar.

Sounding for delaminated or 'hollow' areas.

Locating position of reinforcing bars in delaminated area.

Three-eighths in. holes are drilled for injection and vent ports.

A vacuum cleaner is used to remove drill dust from around ports.

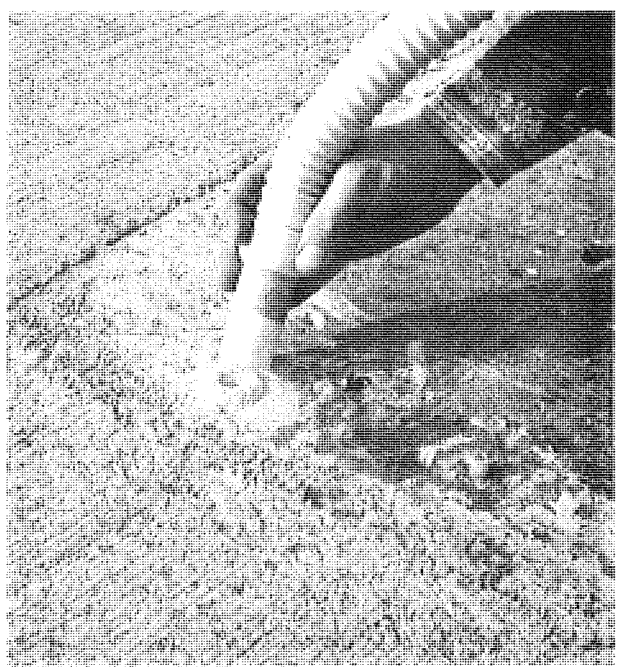


Figure 6. Sequence of operations for epoxy grouting procedure.

In the previously described area of the two adjacent delaminations where there was the interconnected flow of epoxy, a core was taken through a crack and the rebar that initiated it. This core shows the complete penetration that results in a delamination when injection occurs from either side of a crack (Fig. 5).

A summary of the facts learned during this work from May through August follows, and a photographic sequence of injection operations is shown in Figure 6.

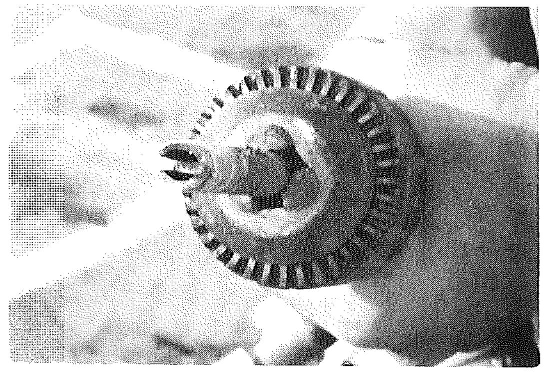
1) Drilling injection ports - Because drill dust would plug up the intersection of the hole with the delamination plane, it had to be removed while the hole was being drilled. Initial drilling of the port with the hollow bit was too slow. An acceptable port could be obtained in the distinctly hollow delamination plane by drilling two holes with an impact drill. Air pressure at 50 psi held on the first hole blew dust out while the second hole was being drilled. The first hole was then plugged while the second was used as the injection port. The best injection port was made by impact drilling a 3/8-in. hole and reaming it carefully with a 1/2-in. hollow bit hooked to a vacuum so as to remove all drill dust.

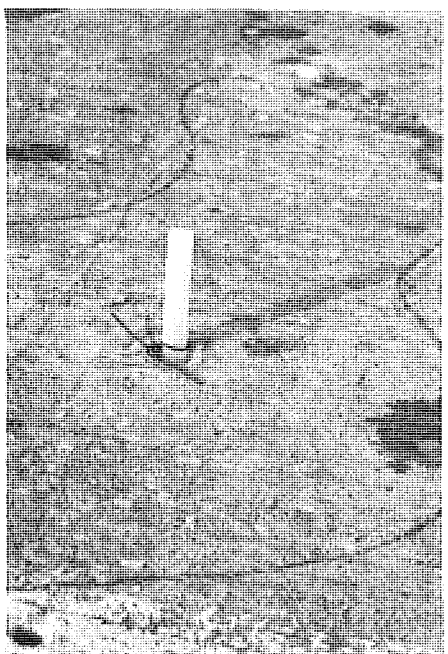
2) Drilling vent ports - Acceptable vent ports could be made by simply impact drilling 3/8-in. holes.

3) Nature of Delamination Planes - Delamination planes vary in size, shape, and hollow prominence. Limits can be best defined by sounding with a steel handled hammer. Delaminated areas vary in size from less than 9 in. to 24 in. across or larger; they are generally irregular in shape, and their sounds from tapping vary from a snare-drum prominence to an obscure, slightly hollow sound. Surface cracks through a delaminated plane are always over a heavily rusted reinforcing bar.

4) Pressure Injection of Epoxy Resin - Early injection attempts utilized a pressure pot from a paint sprayer apparatus, mixed epoxy, and a rubber stopper seal on the injection nozzle. This system worked well on distinctly hollow delaminated areas only. Laminar flow of epoxy through lines, however, caused layers of epoxy to progressively harden and eventually ruin the hoses. The rubber stopper seal at injection ports worked well only at low pumping pressures (10 to 20 psi) and only if the injection port was perfectly drilled with no chips around the edge. The best injection of all types of delamination planes occurred when a two-component pump operating at 25 to 40 psi pumped into a plastic tee which had been grouted into the injection port with a high-viscosity epoxy paste. Air vent

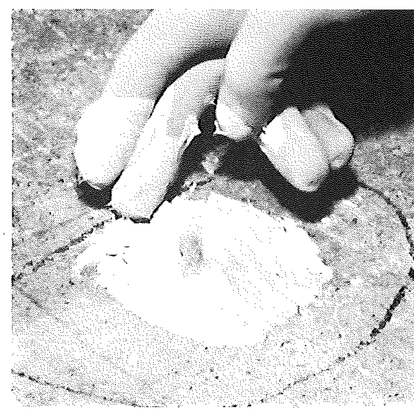
Injection ports are reamed with a 1/2-in. hollow bit vacuum drill to prevent plugging of the opening.





The polyethylene 'tee' is held in place with a support wire.

The polyethylene 'tee' is grouted with epoxy bonder.



Operator pumps grout into 'tees.'

Figure 6 (Cont.). Sequence of operations for epoxy grouting procedure.

ports were necessary for the injection of some delamination planes while not necessary for others.

Recommended Procedure for Injecting Delamination Planes

The procedures recommended for injecting bridge deck delamination planes by the techniques that were found to be the most effective during this work are as follows.

1) No work shall be started unless the weather has been dry, without any rain for two consecutive previous days and the daily high air temperatures are predicted to reach or exceed 65 F. Work should begin early in the morning if possible.

2) Experienced Highway Department personnel should sound out the bridge deck surface and outline the delaminated areas with lumber crayons. These areas should then be rated as to whether they are distinctly hollow, moderately hollow, or slightly hollow. Locate these areas on a bridge deck diagram and label them respectively, H, M, or S. Injection work will be done on the distinct and moderately hollow areas first.

3) Transverse and longitudinal reinforcing bars in the delaminated areas should be located with a Pachometer, and lines drawn on the concrete to locate their position. Check the concrete over the reinforcing bars for cracks which would indicate heavy corrosion of the bar.

4) At the hollowest part of the delamination area, usually near the center, locate an injection port so as to avoid hitting any reinforcing bars; the location is shown with a felt tip marker. If a transverse rebar crack runs through the delamination, locate an injection port on either side of the bar such that the two ports are somewhat laterally offset.

5) Locate four or more vent ports around the delaminated area and mark them. Vents located between the same transverse reinforcing bars as an injection port should be positioned about 1 in. outside the defined limits of the delaminated area. Other vents should be located at the defined limits. Adjacent vent ports should not be less than 6 in. apart.

6) With a rotary impact drill, bore 3/8-in. holes at both the injection and vent port locations to a depth that will intercept the delamination plane. The drill most often will make a hollow sound above the plane and a solid sound below. A maximum depth of 2 in. will generally be sufficient. All drill dust should be removed by either a vacuum cleaner or blown away with

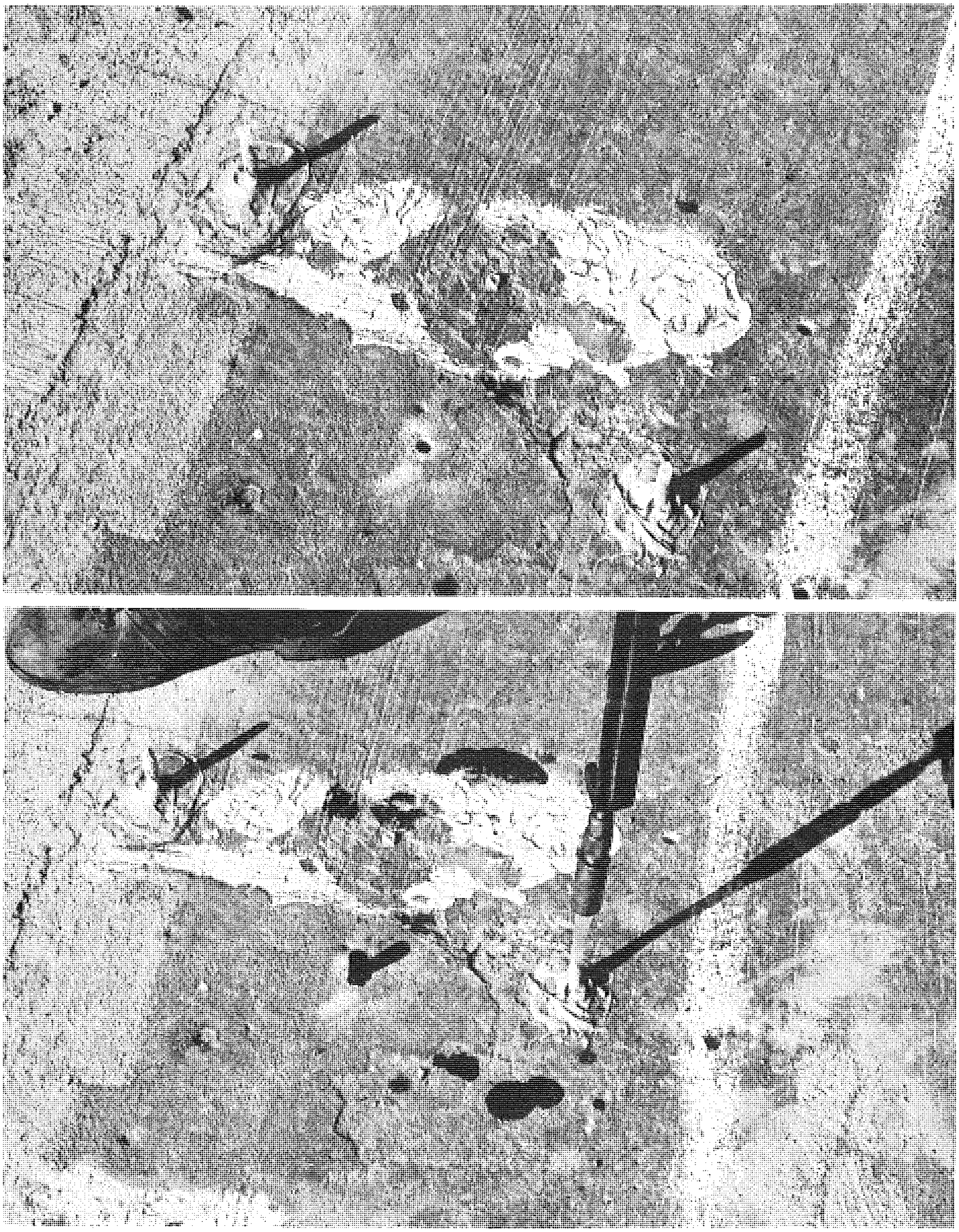


Figure 7. Close-up before and after views of epoxy injection of a delaminated area. Note stoppered vent port and fissures where epoxy escaped.

a blast of compressed air. The injection ports should now be reamed with a 1/2-in. hollow vacuum bit that is hooked to a heavy duty vacuum cleaner. The vacuum bit is required to remove all the drill dust from the hole so as to leave a clean entrance into the delamination plane. It is not necessary to ream the vent ports with the vacuum drill.

7) Mix sufficient epoxy paste to grout in all required injection tees and to seal all blemishes or spalls adjacent to a delaminated area. The paste shall be a fast-setting epoxy that contains sufficient filler (50 percent by weight) to make a "Grade C Grout" (Federal Spec. MMM-G-G50a) or equivalent. The contractor shall have prepared a table showing how long a time is required for a quart of the mixed epoxy to set at 70, 60, and 50 F. The mixed epoxy shall then be allowed to set through an "induction period" equivalent to 67 percent of the time required to set before it is used. This induction period will greatly reduce the time required for the epoxy to harden after it has been applied. The epoxy grout components to be used shall be kept warm overnight and then mixed prior to the time it is required for use by the length of time required for induction.

8) The injection tees shall be 3/8-in. in outside diameter, and shall be of polyethylene (type "Weatherhead PT-240") or copper tubing. They shall be approximately 3 in. long with a bevel cut at the end that goes into the hole and a square cut at the injection end. Wire supports shall be tightly wrapped around the tee in such a fashion that the ends will lie on the deck surface and keep the tee vertical in the hole.

9) The mixed epoxy shall then be spread around to seal the tees in their injection holes and to seal all obvious blemishes around the delaminated area from where epoxy could escape. The epoxy grout shall then be allowed to set until it has hardened.

10) After the epoxy grout has set and is hard, injection shall start by inserting the injection nozzle into the tee and turning on the flow at a pressure between 25 and 40 psi. The nozzle shall be held in each tee up to four minutes duration or until epoxy begins to flow from all the vent ports. As epoxy appears and begins filling each vent that vent shall be sealed with a cork or rubber stopper and pumping continued. If epoxy begins a strong flow from a previously unnoticed blemish, pumping shall be discontinued. If there are two or more injection tees in one delamination and pumping at one for four minutes has produced no results, the injection gun should be systematically moved to each of the other tees and then returned to the resistant ones. If pumping at one tee causes epoxy to flow from another tee, that tee should be sealed with a cork or stopper and pumping continued.

Figure 7 shows before and after views of a delamination where two tees were required. It shows where epoxy emerged both from vent ports and obscure blemishes in the deck. Heavy flow from the one vent port was plugged with a rubber stopper.

BRIDGE DECK REPAIR SEQUENCE

The plans proposed for patching the bridge deck recommended limiting the epoxy mortar patching to half of one span. It suggested that the experimental patching concrete developed in the laboratory be field tested on this bridge against the reliable control material Embeco 411A that performed so well on the Mason test bridge.

Sawing Perimeter of Patch Areas

In early September, the spalled areas on the deck where the concrete would have to be patched were located and outlined with black paint stripes. Bridge Maintenance personnel sawed around the perimeter of these areas in preparation for that portion of the patching work to be done by the Department.

Final Injection of West Half

On September 15, the Sinmast Division of the Eisenhour Construction Co. followed the injection procedure described in this report and injected all the distinctly and moderately hollow delaminations on the west side of the bridge. The delaminations had been located, assessed, and marked by personnel of the Research Laboratory who also monitored the injection work.

Chipping and Patching on East Half

On October 6 and 7, Bridge Maintenance personnel moved onto the east half of the bridge deck and chipped out the concrete within the areas designated with black paint stripes to an average depth of 1-3/4 in. On October 8, Research Laboratory personnel set up their equipment to mix concrete for the patching work on the east half of the bridge deck. The cool cloudy weather was ideal for patching work because the lower temperatures slowed down the hydration of the cement and effected a reduction in the water-cement ratio. This was desirable because it would minimize the shrinkage of the concrete. All component materials for the 4 cu ft batches were weighed out in the laboratory into containers which were then marked with a felt pen so that subsequent measurements could be made by volume. Four

1-1/2 bushel galvanized sheet steel baskets were used with the aggregate while pails were used with the other components. The concrete used in these areas was the experimental laboratory patching concrete that was previously described. It was finished to a surface 1/8 in. higher than the contour of the deck to compensate for possible scaling problems. One set of test specimens was made from this concrete; consisting of six 4 by 8-in. cylinders and three 3 by 3 by 15-in. shrinkage prisms. The measurements and test data obtained from these specimens are included in Table 3 and Figure 8. The field proportioning used for this concrete is given in Table 4.

TABLE 3
PATCHING CONCRETE FIELD APPLICATION
TEST DATA

Type of Concrete	Pour Date	Slump, in.	Entrained Air, percent	Compressive Strength, psi		Dry Bulk Specific Gravity	
				7 Day	28 Day	7 Day	28 Day
Experimental Laboratory Patching Concrete	October 8, 1975	3-1/4	5.5	5,100	7,100	2.287	2.313
Embeco 411A Patching Concrete (Control)	October 16, 1975	1-1/2	8.0	5,000	4,950	2.130	2.148

Research Laboratory personnel had outfitted the Maintenance crew's flat-bed truck to carry all the cement and aggregate. Plywood sides, fashioned to form a box at the rear of the bed, created bins for the sand and gravel while the cement was stacked on a pallet at the front. The two longitudinal bins were arranged so that when the hoist tilted the bed, the aggregate would pour out through access gates at the rear. The mix water was carried in a tank mounted on another truck. Carrying all the concrete component materials on trucks permitted the mix area to be spotted close to the patch areas, eliminated the nuisance of locating aggregate stockpiles in a congested urban area, and eliminated the variation in aggregate moisture that is so characteristic of outdoor stockpiles.

Chipping and Patching on West Half

On October 14, Maintenance personnel began breaking out the punky concrete in the west half within the designated areas in the northwest quadrant. Simultaneously, Eisenhour's personnel mixed an epoxy concrete using Sinmast epoxy binder with fine and coarse aggregate and patched the spalled areas in the southwest quadrant of the bridge. The mix designs for

TABLE 4

8 SACK TYPE I WITH 40 PERCENT EMBECO AND 25A CRUSHED GRAVEL C.A.

PATCHING CONCRETE FIELD WORK SHEET

Components For Two Cubic Feet

Date	Time	Fine Aggregate							Peerless Type I	Admixtures	
		A	B		C		D	E			
			Required Absorption Water (+)		Actual Moisture Content (-)		B - C	A + C			
		Oven Dry Weight, lb	Percent	Weight, lb	Percent	Weight, lb	Moisture Adjustment (±)	Wet Weight, lb	Cement, lb	MBVR, ml	Embeco, lb
		82.59	0.85	0.70	1.15	0.95	-0.25	83.54	55.70	17.5	22.30

Coarse Aggregate							Water				Priming Slurry	
F	G		H		J	K	L	D	J	M		
	Required Absorption Water (+)		Actual Moisture Content (-)		G - H	F + H				L ± D ± J		
Oven Dry Weight, lb	Percent	Weight, lb	Percent	Weight, lb	Moisture Adjust-ment, (±)	Wet Weight, lb	Required Mix Water, lb	F.A. Moisture Adjust-ment (±)	C.A. Moisture Adjust-ment (±)	Total Water Required lb	Cement, gm	Water, gm
112.51	0.64	0.72	0.62	0.70	+0.02	113.21	21.18	-0.25	+0.02	20.95	5,114	2,148

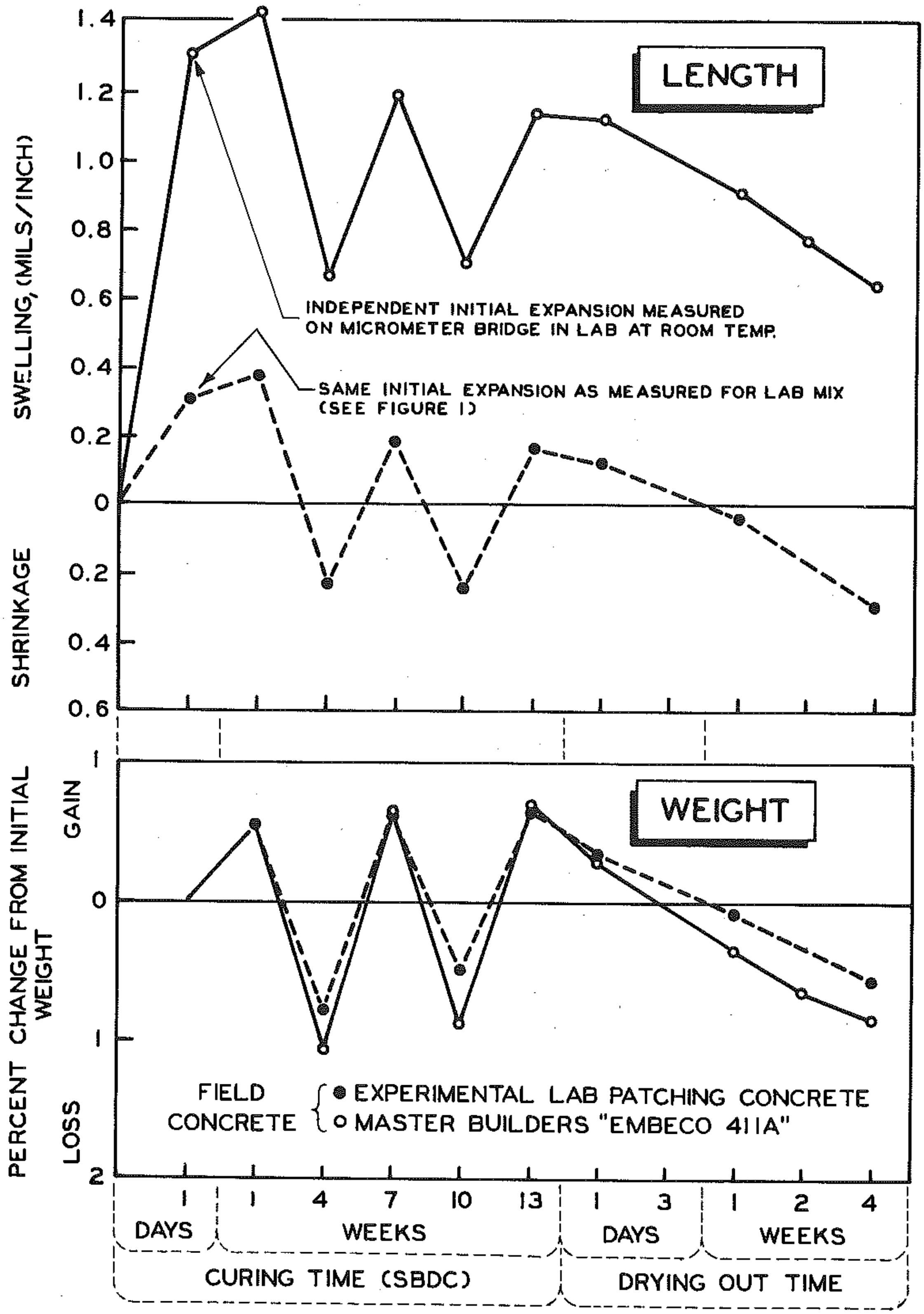


Figure 8. Length and weight variations of 3 by 3 by 15-in. shrinkage prisms during and following the 13-week simulated bridge deck cure (SBDC).

TABLE 5

EPOXY CONCRETE MIX
1 cu ft Volume

Mix	Coarse Aggregate, lb		Fine Aggregate, lb		Aggregate Binder Ratio by Weight	Sinmast Epoxy Binder Product No. 4, lb		
						Part	A	B
	A	B	C	D		Specific Gravity	1.124	0.993
I	46.70	46.70	26.67	13.39	12/1	--	8.90	2.23
II	47.25	47.25	27.00	13.54	15/1	--	7.26	1.82

AGGREGATE PHYSICAL PROPERTIES

Aggregate	Sieve Analysis (percent retained)									Dry Bulk Specific Gravity
	1/2	3/8	No. 4	No. 8	No. 16	No. 30	No. 50	No. 100	Pan	
A	--	12.3	72.3	14.9	0.5	--	--	--	--	2.637
B	--	--	30.0	65.0	4.7	0.3	--	--	--	2.602
C	--	--	--	--	--	1.2	95.0	3.6	0.2	2.634
D	--	--	--	--	--	--	72.4	22.4	5.2	2.637

this epoxy concrete are given in Table 5. Two mix designs were used; one, with an aggregate-epoxy ratio of 12 to 1 by weight, and the other with a 15 to 1 ratio. The first, designated "I" in the table, was placed in the south half of the largest patch. The other designated "II" was placed in the remainder of the largest patch plus both of the smaller patches. This mix design was changed because there was some initial doubt as to whether mix design II had sufficient binder to fill the aggregate voids. However, when mix design I appeared to have ample epoxy, they switched to the second design. The patch areas were given a prime coat of pre-mixed epoxy binder just prior to placing the epoxy concrete mixes.

On October 16, the temperature was cool and ideal for working with the fast-setting Embeco 411A patching concrete. Cool temperatures retard the set far better than any chemical retarder. This material was developed by the Master Builders Co. and is sold in 55-lb bags as a complete mix which requires only the addition of water. It contains a moderately fast-setting cement, both fine and coarse aggregate, Embeco Metallic Aggregate for expansion, and a powdered air entraining agent. The steel was sandblasted in the morning, and by 1:00 p.m. the temperature was 56 F and mixing the concrete began. The mixer charge of 4 cu ft consisted of 10 bags of Embeco 411A (55 lb/bag) with approximately 56 lb of water. The first batch was mixed to a higher slump and used as a priming slurry on the pre-wetted substrate of the patch areas. The mixing, placing, and finishing of this material proceeded smoothly with very little variation between batches. From one of the batches, test specimens were cast; they consisted of six 4 by 8-in. cylinders and three 3 by 3 by 15-in. shrinkage prisms. Test results from these specimens are shown in Table 3 and Figure 8. These results show performance comparisons between the experimental eight-sack concrete and the commercial Embeco 411A concrete; of these data the shrinkage characteristics are the most important. The field proportioning used for this concrete is shown in Table 6. The series of photos in Figure 9 shows the mixing, placing, and finishing of this concrete.

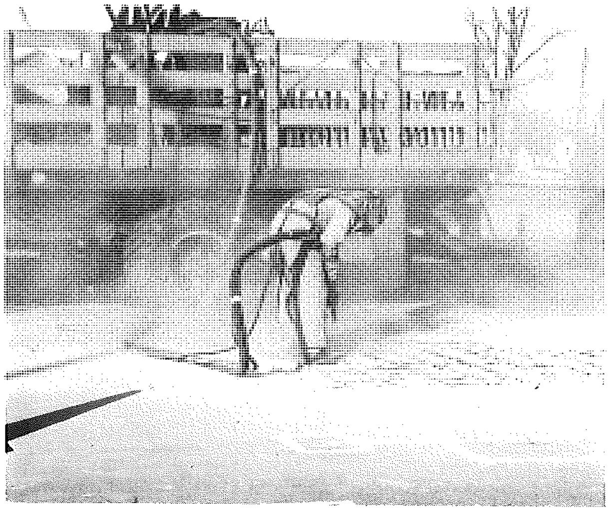
Final Injection on East Half

It was requested that the Eisenhour Construction Co. return and, using the previously described technique, inject those delaminations on the east half of the bridge. On October 22, the weather had been dry for several days and Eisenhour personnel drilled the injection and vent ports. At 10:00 a.m. when the bonding paste epoxy was mixed, the temperature was 55 F; it was allowed a 10-minute induction period before it was used to grout-in the injection tees. By 3:00 p.m. the temperature was 72 F, but the bonding paste had not yet set enough to permit injection. At 4:00 p.m. the temperature began to drop and it was realized that soon it would be too cool to secure the optimum penetration of the injected epoxy; thus the east half of the bridge was kept closed to traffic overnight. By 1:00 p.m. the temperature was in the mid-seventies, the deck was warm, and the injection work started at the north end of the bridge. There were about 30 delaminated areas with 40 tees; larger areas crossing a rusted bar had two injection ports. The pressure was held at about 25 psi for most of the tees with excellent results at about 25 of the 30 areas. Injection in some areas was impeded by surface blemishes or unseen fissures that allowed epoxy to escape in spite of attempts to seal them off. Pressures higher than 30 psi seemed

TABLE 6
EMBECO 411A (3 MINUTE TOTAL MIX TIME)
PATCHING CONCRETE FIELD WORK SHEET
Components For Two Cubic Feet

Date	Time	Fine Aggregate							Embeco 411A	Admixtures	
		A	B		C		D	E			
							B - C	A + C			
		Oven Dry Weight, lb	Required Absorption Water (+)		Actual Moisture Content (-)		Moisture Adjustment (+)	Wet Weight, lb	Cement, lb	Darex, ml	
			Percent	Weight, lb	Percent	Weight, lb					
									275		

Coarse Aggregate							Water				Priming Slurry, gm	
F	G		H		J	K	L	D	J	M		
					G - H	F + H				L + D + J		
Oven Dry Weight, lb	Required Absorption Water (+)		Actual Moisture Content (-)		Moisture Adjust-ment (+)	Wet Weight, lb	Required Mix Water, lb	F.A. Moisture Adjust-ment (+)	C.A. Moisture Adjust-ment (+)	Total Water Required lb	Cement Mortar Passing No. 8 Sieve	Water
	Percent	Weight, lb	Percent	Weight, lb								
							28.0				5,735	915

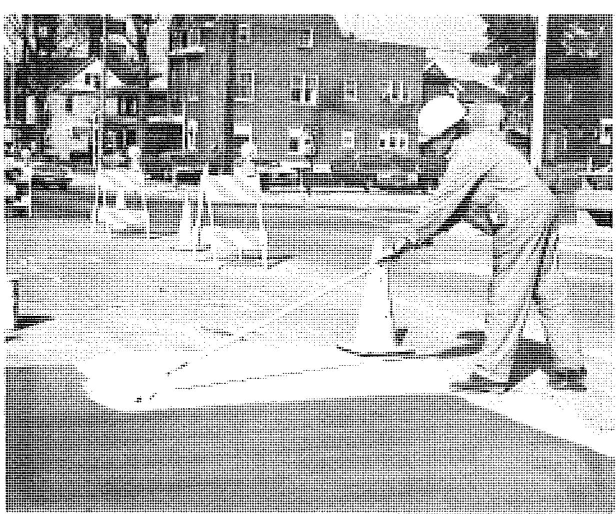


Reinforcement and substrate are sandblast cleaned.

Substrate is wetted with brooms.

When consolidating the low slump Embeco 411A mortar, the vibrator is pulled between rebar locations to free any air entrapped beneath the bars and completely surround the bars with concrete (note the initial priming mortar).

Surface is screeded, floated, and troweled. Crown curvature was cut into the screed board.



A white membrane curing compound was applied three hours after brooming.

Figure 9. Concrete placement and finishing operations.

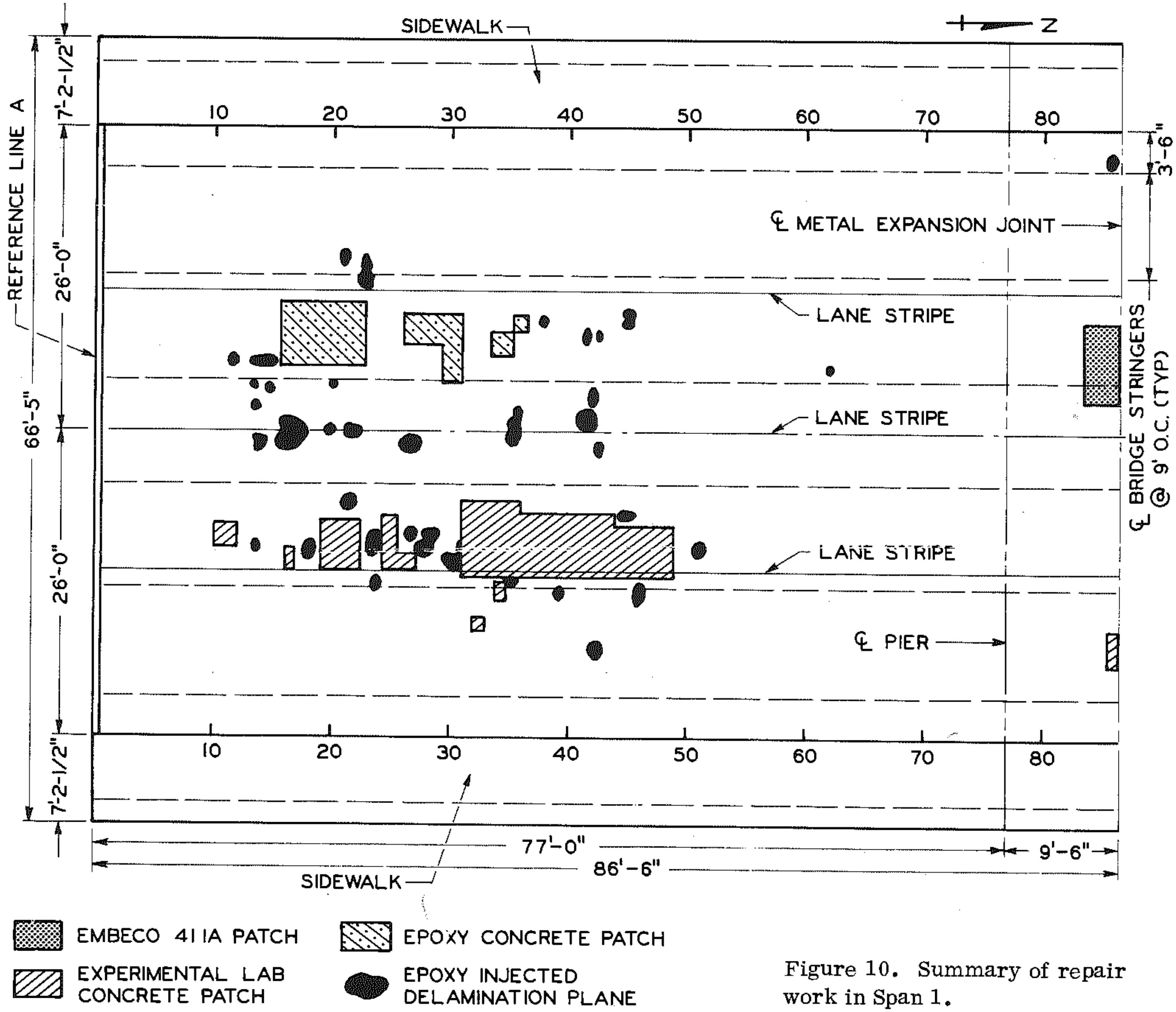


Figure 10. Summary of repair work in Span 1.

to "blow" more of these fissures and further impede complete penetration of the general area. In one area where there were two injection ports; after five minutes of little success at the first port, the injection nozzle was moved to the second. Air bubbles began coming out of the tee at the first port and epoxy began flowing out. A few seconds after the first tee had been stopped with a cork, the epoxy "blew" a fissure near the first port and came gushing out; never reaching either of the vent ports that were located slightly outside of the delaminated area. At another location, pressure was held on a tee for about five minutes and when the nozzle was removed, epoxy began flowing back out of the tee. This indicated that the vent ports did not intercept the delamination, and an air lock prevented good epoxy penetration.

The most interesting delamination was located 23 ft from Reference Line A and 13 ft from the east curbline (Fig. 10). Five minutes of injection at the first port produced nothing so the nozzle was switched over to the second port and it was pumped until epoxy showed up at one of the vent ports and began slowly flowing out of the first port. Then the nozzle was returned to the first port and a rapid flow came out of the second port that carried with it bits of rust. Epoxy also blew and started flowing from fissures near the first port. Apparently the pressure reversals had cleared a passageway through the rust build up over the bar and allowed a strong flow to occur between the two injection ports.

Repair Summary

Figures 10 and 11 are diagrams of the two spans of the bridge deck. They show the locations of all the successfully injected delamination areas plus all the areas patched with each of the three patching materials; Embeco 411A, epoxy concrete, and the experimental eight-sack patching concrete. To help in describing the location of a particular area, longitudinal distances in 10-ft intervals are shown along both curb lines. The numbering starts at Reference Line A and runs north the full length of the bridge. Hence any location on the deck is described by its longitudinal distance from Reference Line A and its lateral distance from either curb line.

EVALUATION TECHNIQUES

Epoxy Injected Delamination Planes

Core 75 CC-578, as previously described under the section entitled, Injection Technique Development, was cut through a transverse bar where epoxy was injected from either side. The core was retained in the Research

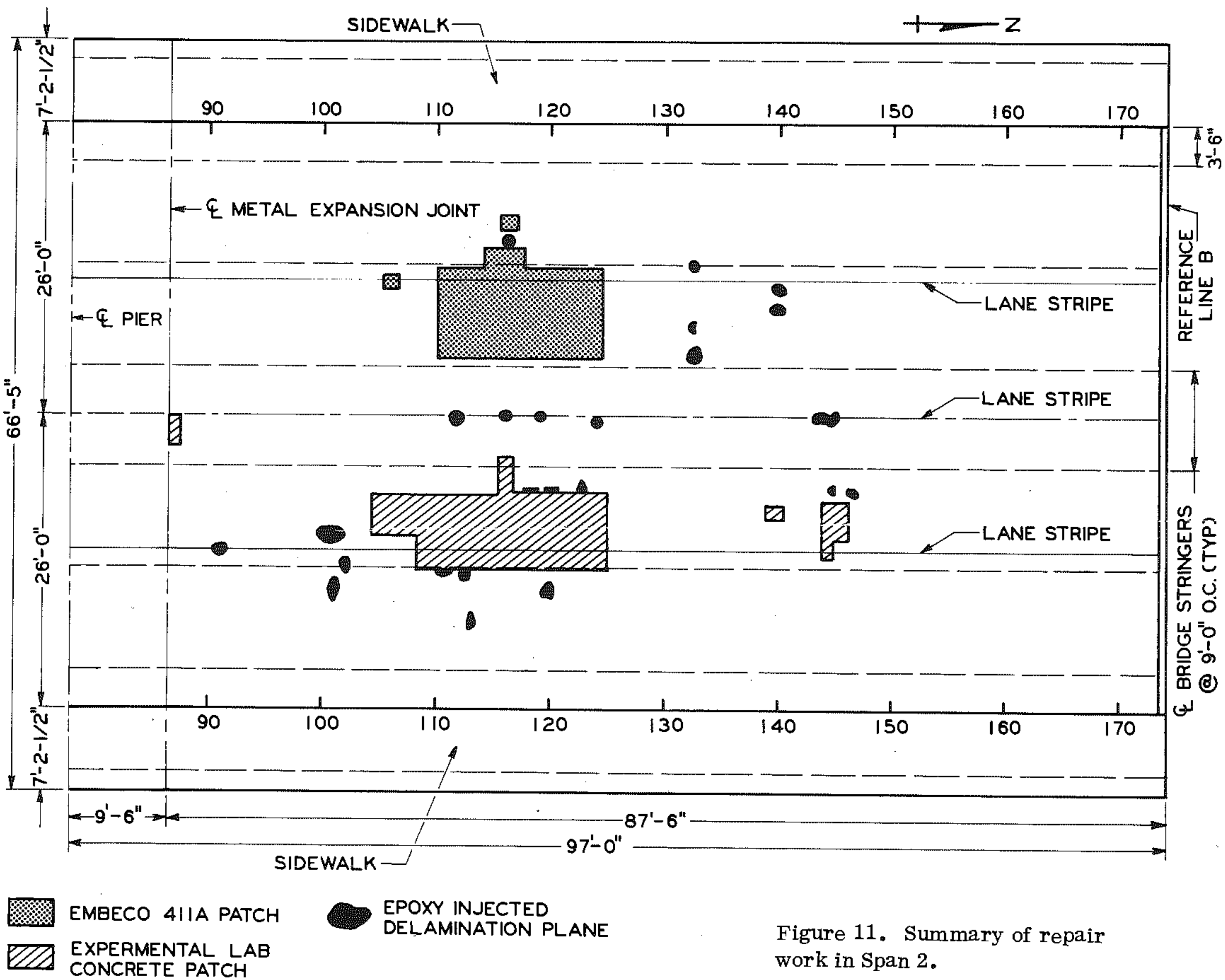


Figure 11. Summary of repair work in Span 2.

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1. Evaluation of Four Organic Resin Binder Systems. Michigan Department of State Highways and Transportation, Research Report No. R-1005.

2. Stratton, F. W., and McCollom, B. F., "Repair of Hollow or Softened Areas in Bridge Decks by Rebonding with Injected Epoxy Resin or Other Polymers." State Highway Commission of Kansas, Report No. K-F-72-5, 1974.

3. Experimental Patching Concrete Field Application on Test Bridge S01 of 33035A (Westbound M 36 Over US 127). Michigan Department of State Highways and Transportation, Research Report No. R-871, July 1973.

4. Evaluation of Five Commercial Fast-Setting Hydraulic Patching Mortars. Michigan Department of State Highways and Transportation, Research Report No. R-715, October 1969.

5. "Methods of Sampling and Testing Expansive Grouts." U. S. Corps of Engineers, Standard CRD-C 589-70.

Laboratory until one day in December, it was discovered that a crack had developed that closely paralleled the epoxy filled delamination plane. This crack appeared on only one-half of the core and ran around the core perimeter from the bar on one side to the bar on the other side. It was measured and found to be about 0.003 in. wide. It was realized that the water that was observed seeping from the underside of the bar in Core 75 CC-576 was a condition that was typical of all corroded bars and that this rust would expand and refracture the epoxy bonded delamination plane. What was more discouraging, was the fact that it would be very difficult, if not impossible to completely dry out the moisture at that depth. This fact was not mentioned in the Kansas report. Possibly the hot dry summer weather in Kansas is capable of thoroughly drying out the concrete. The successfully injected delamination planes on our bridge deck will be closely monitored during the summer of 1976 to see if they will recrack. Recently built delamination detectors will be used to assist in this evaluation.

Experimental Laboratory Patching Concrete

This shrinkage compensating concrete was placed on the east half of the bridge and will be directly compared in performance with the proven product Embeco 411A which occupies the patch areas on the northwest quadrant of the bridge. The evaluation technique will consist of annual inspections to check for the following deterioration features: surface scaling; edge shrinkage around the patch perimeter; shrinkage, as evidenced by craze cracks; shrinkage, as evidenced by loss of substrate bond; and shrinkage, which produces stress concentration, delamination development, and ultimate spalling in the original concrete near the patch corners and the longitudinal edges. Should the annual inspections leave unresolved questions concerning the quality of the patch, cores will be taken at strategic locations to yield further detailed information.

Epoxy Concrete Patches

These patches are located in the southwest quadrant of the bridge deck; they will also be compared in performance with the control material Embeco 411A. The evaluation techniques will be much the same as for the Experimental Laboratory Patching Concrete except much emphasis will be given to checking for loss of substrate bond due to differential thermal contraction, and stress concentrations in adjacent concrete due to shrinkage and compressive modulus incompatibilities.