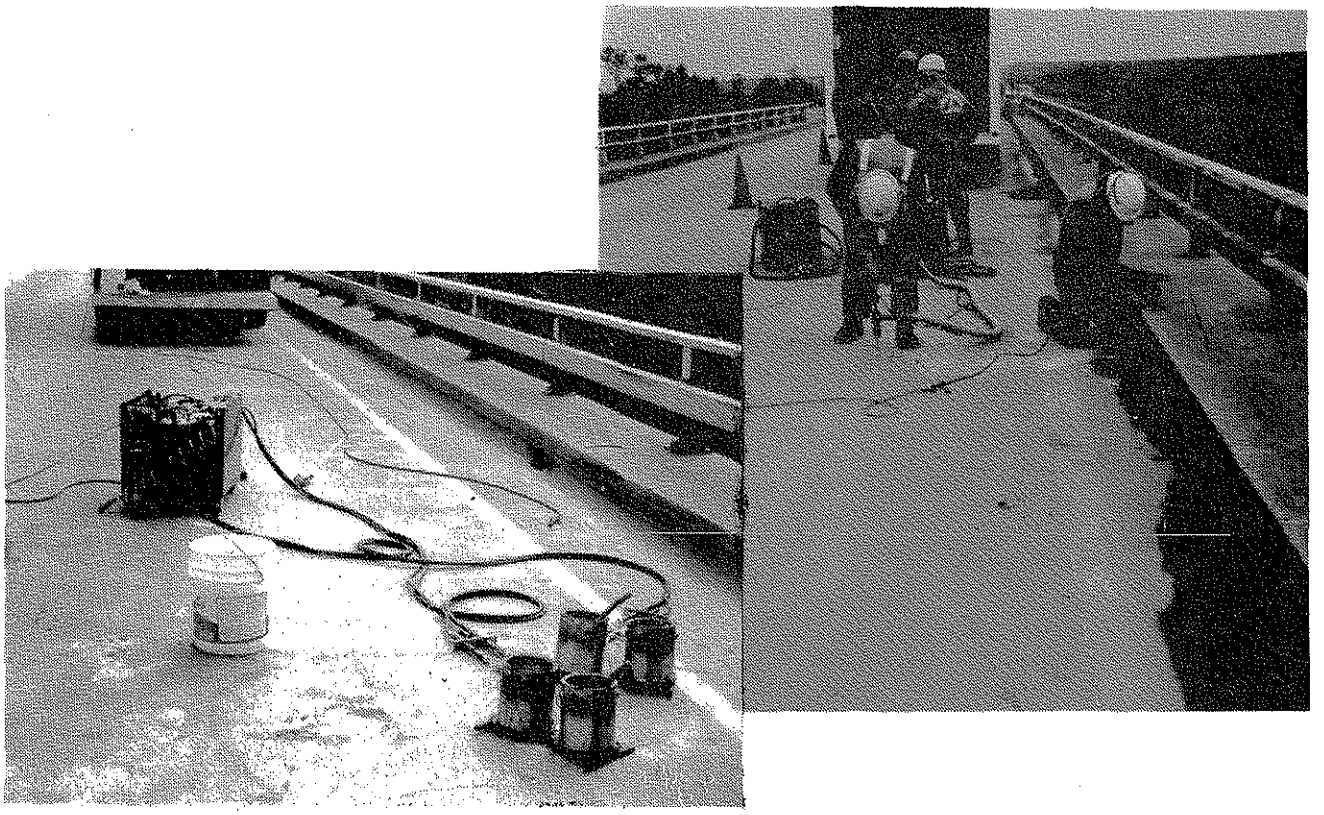
Bridge Deck Rehabilitation Rebonding a Delaminated PCC Overlay By Epoxy Injection



Final Report for Iowa DOT Project HR-1036 FHWA Project DTFH 71-83-51-1A-06

January 1989

Highway Division
Iowa Department of Transportation

FINAL REPORT

BRIDGE DECK REHABILITATION
REBONDING A DELAMINATED
P.C.C. OVERLAY BY EPOXY INJECTION

FHWA PROJECT
DTFA 71-83-51-1A-06

IOWA RESEARCH PROJECT
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ABSTRACT

Federal Highway Administration, Region 15, Demonstration Projects Team has performed a number of demonstration projects to promote the rehabilitation of bridge deck concrete by rebonding delaminations with injected epoxy thereby extending the service life.

The Iowa project, subject of this report, is a 150' x 20' high truss bridge on Iowa route No. 210 over Indian Creek near Maxwell in Story County (Service level D, AADT-730, Inventory Rating HS-16.9, Operating Rating HS-25).

The objective of this study was to evaluate the effectiveness of repairing a delaminated bridge deck by epoxy injection, specifically a bridge deck with a delaminated portland cement concrete overlay.

Observations noted during this project lead to the following conclusions:

The delaminations rebonded with epoxy have remained solid through five years. The percentage of delamination has stayed essentially the same for both the epoxy injected and non-repaired areas.

Epoxy injection appears to be a practical, cost effective alternative to other forms of deck rehabilitation when undertaken at the proper time. Cost effectiveness would reduce dramatically if delayed until breakouts have occurred. On the other hand it would be a slow, labor intensive process if undertaken too early when delaminations are small.

REBONDING A DELAMINATED PC CONCRETE OVERLAY BY EPOXY INJECTION

INTRODUCTION

The test site selected was a two lane bridge located on Iowa Highway 210 over Indian Creek near Maxwell.

The used steel frame was taken from storage and re-erected at this location in 1954. The deck was resurfaced with AC concrete in 1966. A contract was let in 1972 for repair and placement of a dense portland cement concrete overlay on the concrete deck. Repair to the eastbound lane was completed in September 1972. Repair to the westbound lane was completed in May 1973.

Substantial areas of the deck overlay had become delaminated and at four separate locations the delaminated overlay had broken out. These breakouts had been filled with cold mix A.C. The remainder of the delaminated overlay exhibited considerable vertical cracking without displacement.

One half of the deck was repaired by Iowa Department of Transportation maintenance personnel. The FHWA Demonstration projects team provided equipment, material and guidance during the project. Testing was performed by personnel from the Iowa Department of Transportation Office of Materials and Testing.

The work plan called for repair of all delaminations using the epoxy injection procedure. This was not possible, however, without a substantial delay in the schedule due to an inadequate supply of epoxy. Work was terminated upon completion of one half of the bridge.

PRE-PROJECT TESTING:

Suitability of this bridge as a candidate for injection rebonding appeared to be marginal. Tests were conducted to better assess the feasibility of rebonding. Several test sites were proposed for trial injection by hand methods.

At each site two saw cuts were made to form a 60 degrees V shape with each leg three feet long. The saw cuts were intended to be of sufficient depth to intercept the delamination plane. A flexible resin epoxy was poured into these saw cuts in an effort to isolate the area within the V shape from the surrounding area. Three holes were then vacuum drilled into the isolated area to access the delamination plane. One hole was drilled near the apex of the saw cut angle and the other two at third points across the open side.

The intent was to hand inject epoxy into the apex hole until it could be observed at one or both of the other holes thus providing assurance that the delamination plane within the isolated area was filled. After allowing time for the epoxy to cure, a core would be cut from the isolated area for visual and laboratory examination.

Seven isolation test sites were developed. Cores were obtained at five sites. During the development of test sites a number of observations were made.

The overlay was designed for a nominal thickness of one inch. Partial depth removal of spalled areas followed by replacement, integral with the overlay, had produced a very irregular bond plane between old and new concrete in some areas. The depth of saw cut did not always reach the plane of delamination so isolation did not always occur.

The overlay was observed to be arched off the substrate. Separation was observed to be about one-eighth inch at one test site. The flexible epoxy, though more viscous than injection epoxy, flowed laterally within the delamination plane. In some cases, this rebonded the overlay at intended injection points. In other cases, the epoxy simply flowed away and failed to seal the saw cut.

One theory to explain the arching action of the overlay involves thermal action. The overlay was originally cast between curbs fixed to the deck. During daylight hours, in direct sunlight, the overlay temperature should be higher than the substrate and the overlay should expand more than the substrate. The expansion differential could produce the arching effect. No observations were made during night time hours to ascertain whether the overlay returned to bear on the substrate.

Examination of the cores revealed that of the five cores from test sites, four had developed reasonable bound. Two of the four contained voids in the epoxy, perhaps because of the hand injection method. The fifth core revealed good bond of the epoxy to the upper face but the lower face was impregnated with fine granular dust. The surface of the substrate was covered with additional granular dust. It was obvious that an accumulation of this magnitude must be removed before rebonding can be accomplished.

Those cores which demonstrated successful rebonding were subjected to shear testing. Tests of bond interface shear were conducted as well as some in the substrate concrete. See Appendix A for core test results.

When developing test sites from which to obtain cores, perimeter saw cuts were made around the existing four breakout areas. These saw cuts were filled with flexible epoxy in the same manner as the test sites. Later, when cores were cut, it was noted that the overlay outside the perimeter saw cuts was fracturing. It was decided to repair the breakout areas immediately in an effort to stop the extension of failed areas.

The four breakout areas were repaired with low slump dense concrete using Iowa's standard procedures with the one exception that during removal, no attempt was made to extend the repair area to sound concrete at all edge boundaries. Figure 1 is a layout of the work completed prior to beginning the demonstration project.

The assessment of testing and evaluation to this point was that this bridge would be a suitable candidate and the Federal State Agreement was executed.

PRE-TREATMENT CONDITION SURVEY

Prior to the actual field work portion of the demonstration project a

pre-condition survey was conducted.

Field data were collected on June 13, 1983. A delamtect survey of the deck and electrical potentials were obtained. Copper-copper sulfate half cell readings were taken on a two foot by two foot grid. Figure 2 shows the contour plot from the electrical potential survey. Figure 3 shows the results of the delamtect survey.

The delamtect survey indicated that 693 sq. ft. were delaminated in the westbound lane and 192 sq. ft. in the eastbound lane. Half cell tests indicated that almost all of the eastbound lane was in the range of 0 to -0.20 volts as was about thirty five percent of the westbound lane. Nearly one-half of the westbound lane showed potentials at or higher than -0.35 volts, the generally accepted corrosion threshold level.

Samples were obtained from three cores representing substrate concrete at the top reinforcing level. These were tested for chloride content with the following results:

Sample Number	Chloride Content Lbs/Yd^3
1	1.37
2A	1.33
4	1.49

PROJECT NARRATIVE:

Friday, August 5, 1983.

FHWA Demonstration Team members James McCulloch and Gary Crawford arrived Friday P.M., August 5th. They were met at the bridge by John Whiting, Elvin Hebner, Roger Port and Bernard Bailey to review plans for beginning the project on Monday.

The Demo project team is equipped with a large van body truck equipped with air compressor, generator, portable tools, cleaning solvents, epoxy supplies, etc. to perform the anticipated work. There appeared to be no need for any state supplied equipment or material. The District One Bridge repair crew was asked to bring the state's vacuum drill as a backup. It was noted that Mr. Erl Pedersen from the Otto Pump Company planned to be present and bring a suitcase model pump unit. The Demo team had two Otto pumps on hand and Darrel Maret was in Casper to get a new Rocky Mountain pump. He was expected on Monday.

Monday, August 8, 1983.

The FHWA demonstration team and Iowa Department of Transportation participants arrived at the site approximately 8:00 A.M. It was expected that traffic control personnel and signing would be ready about 8:15 but they were somewhat later than planned and actual work started late.

Work began at the west end of the bridge in the westbound lane.

The lane was thoroughly sounded, manually, to determine boundaries of delaminated areas and to locate drill holes for injection of the epoxy. One-half inch diameter holes were then vacuum drilled to access the delamination plane.

The Rocky Mountain pump was set up for operation. Pumping rate was not controlled. The pump was set to maintain a discharge pressure of about 30 psi and pumping rate became a function of the resistance to flow. It was quite rapid, usually, at the start but as a large void space became nearly full, the pump speed would become almost imperceptible. In the mean time, of course, it became necessary to cork those holes from which the flowing epoxy tried to emerge. When no more epoxy could be pumped into a hole, the pump was stopped and the injection head moved to a new location. In this manner the operation progressed from the west end through a distance of 25 to 30 feet on Monday.

Tuesday, August 9, 1983.

Work resumed on Tuesday, beginning quite a bit earlier than on Monday. Mr. Erl Pedersen, Otto Pump Company, and Mr. Richard Harmon, Chemical Division of Darling & Company, arrived with a new Model A-3-9 Otto Pump (suitcase model). The Rocky Mountain pump was put in operation at the point where injection terminated on Monday. The Otto pump was put in operation further along the lane on the near side of a site where a large repair had been made in the overlay concrete. It was thought that, in this manner, flow from the two pumps would meet to fill the intervening delamination voids.

During the pre-project testing it was observed that a fine dust prevented rebonding of one core sample. This core was taken from a site near one of the overlay breakout areas. It was assumed that the source of the material in the void space was by way of the breakout in the overlay. An attempt to remove this type of material was made when the work progressed near a breakout area. Compressed air was introduced into a drilled hole to force dust out of other nearby holes. This seemed to work quite well. A note of caution - too much pressure in the delamination plane of an overlay can lift the overlay. At one point, a small area of bonded overlay within a large debonded area was rebonded. This was observed both visually and audibly.

Later the Rocky Mountain pump was moved past the area being injected by the Otto pump and again put into operation. Finally the Otto pump was moved to the east end of the lane to complete the westbound lane.

About mid-day it was noted that the original sixty gallon supply of epoxy would likely be exhausted by day's end. It was also judged that the work in the west lane would about be completed when the material supply was exhausted. It was decided not to try for additional material after considering the known supply conditions as of Monday morning. Mr. Maret had brought with him all of the material available at the factory; the Dallas Company, Rocky Mountain distributor for this area had no material in stock; and the Minneapolis distributor had none in stock. Material manufactured on Monday or Tuesday might have been available but the probability of receiving it in time to make use of it by Thursday evening was doubtful.

By the end of the day Tuesday, it was judged that all of the westbound lane had been treated for rebonding. In addition, test sounding had indicated that epoxy had flowed from the west bound lane to some of the larger areas of delamination in the eastbound lane. At the completion of the treatment of the westbound lane, material supply was reduced to about 1.5 gallons of epoxy and it was decided to terminate the work.

POST-TREATMENT TESTING & EVALUATION

A post-treatment delamtect survey was conducted August 22, 1983. This survey indicated that 77 sq. ft. of delaminated PC overlay remained in the westbound lane and 143 sq. ft. remained in the eastbound lane. The original total delaminated area of 885 sq. ft. had been reduced to 220 sq. ft. This is a reduction from 29.2% to 7.2% or 22% of the total deck area. Delamination in the westbound lane where epoxy injection was preformed was reduced from 45.7% to 5.1% of the gross area of the lane. In the eastbound lane, a reduction from 12.7% to 9.4% occurred as carry over from treating the westbound lane.

The remaining areas of delamination in the eastbound lane are readily understood. The areas remaining in the westbound lane warrant additional analysis. A review of the post treatment delamtect plot, Figure 4, superimposed over the plot of pre-treatment test sites and overlay repair areas, Figure 1, shows a relationship between the pre-treatment activities and the remaining delamination (see Figure 5). The delamination near L2 is at the boundary between the end of first day treatment and the beginning of second day activity. With these factors taken into account it is estimated that, without pre-treatment interference, over half of the remaining delamination in the westbound lane would have been rebonded. It is presumed, also, that technique can be improved to reduce the failure to rebond at boundaries between days work areas such as at L_2.

1984 RESURVEY:

A delamination resurvey of the bridge deck was performed on April 16, 1984. Results of the resurvey indicated that the total delamination was 196 sq. ft. This is a 32 sq. ft. less than the area indicated by the post-injection survey in August 1983. The westbound lane indicated 81 sq. ft., an increase of 4 sq. ft. over the 1983 indication. The eastbound lane indicated 116 sq. ft., a reduction of 28 sq. ft. from the 1983 indication. The weather in April was cool and quite rainy. It was decided to rerun the survey later in the season during weather similar to the hot and dry conditions existing in August 1983.

The survey rerun was performed on September 19, 1984. Results of the strip chart interpretation indicated total delamination of 222 sq. ft., only 2 sq. ft. different from that indicated in August 1983. This time, however, the westbound lane indicated 98 sq. ft. of delamination and the eastbound lane indicated 124 sq. ft. Each of these indications varies from the August 1983 results by about 20 sq. ft. but in opposite directions to result in a total that represents virtually no change.

The total deck area is 3030.8 sq. ft., the total for one lane is 1515.4 sq. ft. All of the areas of indicated delamination mentioned above are in the range of 5% to 10% of the gross area either lane or total deck as

applicable. The variation in test results are within a range of about 1.5 percent of the gross area surveyed. It is concluded that results with a higher degree of accuracy probably cannot be obtained. It is also concluded that there is no essential change in the condition of the bridge deck since the epoxy injection was completed August 9, 1983.

Figure 6, attached, is a deck plot of the September 19, 1984 delamination survey.

FINAL SURVEY

A delamtect survey of the bridge deck was attempted in 1985. Results were inconsistent with those of previous surveys. This, together with other observations, led to the conclusion that our survey equipment was not sufficiently reliable at the time. Additionally, there was a desire to extend the survey period to enhance the probability that redelamination might begin and thus provide service life information.

A final survey of the bridge deck was performed on May 23, 1988. Visual observations indicated no change in the appearance of the deck surface from previous post-treatment observations. The delamtect survey provided results very similar to previous observations, nearly identical to the results obtained in April 1984. Figure 7 is a deck plot of the delamination survey conducted May 23, 1988.

Table 1 summarizes the results of delamination tests throughout the project period.

Table 1

Test Date	Area Delaminated, Sq. Ft.			Percent Delaminated		
	W.B. Lane	E.B. Lane	Total	W.B. Lane	E.B. Lane	Total
6-13-83 Pre-Injection	693	192	885	45.7	12.7	29.2
8-22-83 Post-Injection	77	143	220	5.1	9.4	7.3
4-16-84	81	115	196	5.3	7.6	6.5
9-19-84	98	124	222	6.5	8.2	7.3
5-23-88	84	113	197	5.5	7.5	6.5

CONCLUSIONS

Rebonding a PC concrete overlay with materials and procedures demonstrated in this project is a viable concept. The reduction of delaminated areas from 693 sq. ft. to 77 sq. ft. indicates excellent effectiveness. When the factors of pre-project activities are taken into account, it is estimated that the final area could well have been as low as 20 to 25 sq. ft. It should be remembered that the previous condition of the bridge was such that it was considered a marginal candidate for the project. The final survey observations indicate that the service life of the rebonded deck concrete is in excess of five years and may well approach or equal the service life of the deck overlay being repaired.

There are additional factors which make this rehabilitation procedure

attractive. Interference with traffic is minimal. A single lane closure is required during working hours only. The length of work zone needed is relatively short, about two hundred feet. The manpower and equipment necessary is minimal. Experience indicates that three workers are adequate and all equipment and materials can be accommodated in one vehicle.

This procedure is especially attractive for its application to delaminated PC concrete overlays. Delaminations in an original concrete deck will, typically, originate at the level of top reinforcing and slope upward to the surface. All surface openings, cracks, etc. must be sealed prior to injection to contain the injection epoxy. Such sealing is labor intensive and if extensive would detract from the cost effectiveness of the rebonding procedure. When an overlay delaminates from the substrate, however, the fracture tends to form on a plane parallel to the deck surface with very few, if any, openings to the surface.

In summary, epoxy injection of delaminations in PC concrete bridge decks is a viable procedure which offers an attractive alternative to be considered in rehabilitation.

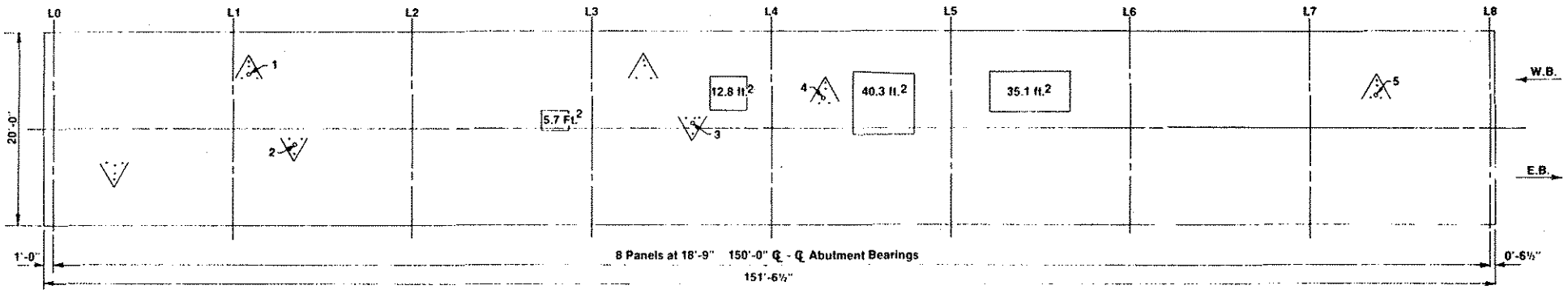


FIGURE 1
PRE-PROJECT LAYOUT

LEGEND:

Test Core - Injection Test Site

- Overlay Repair Site

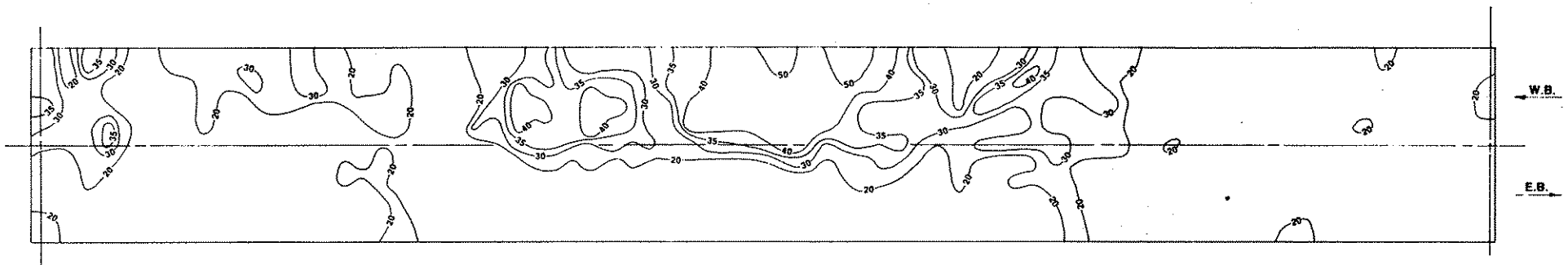


FIGURE 2
BEFORE CONDITION SURVEY
HALF CELL ELECTRICAL POTENTIAL

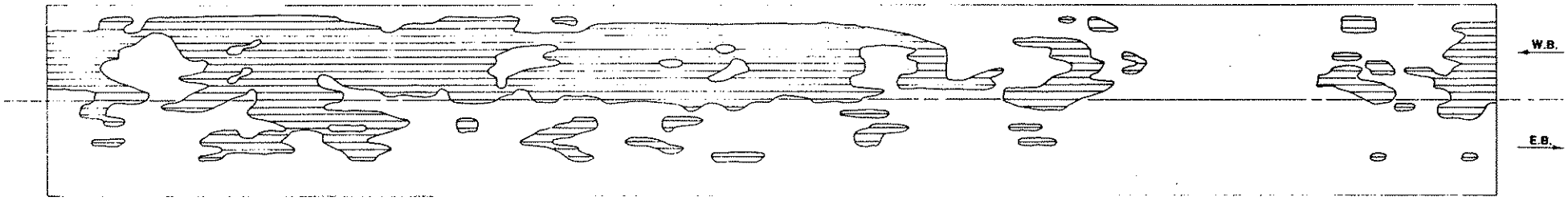


FIGURE 3
BEFORE CONDITION SURVEY
DELAMTEC

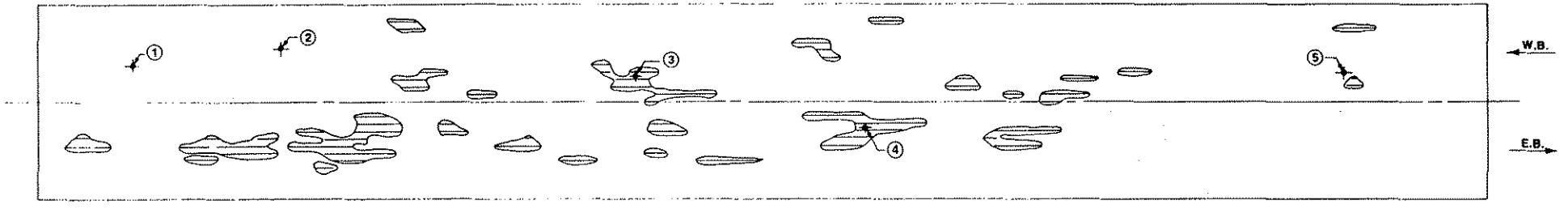


FIGURE 4
AFTER CONDITION SURVEY
DELAMTEC CORES

LEGEND:

- After Treatment Core
- Delamination

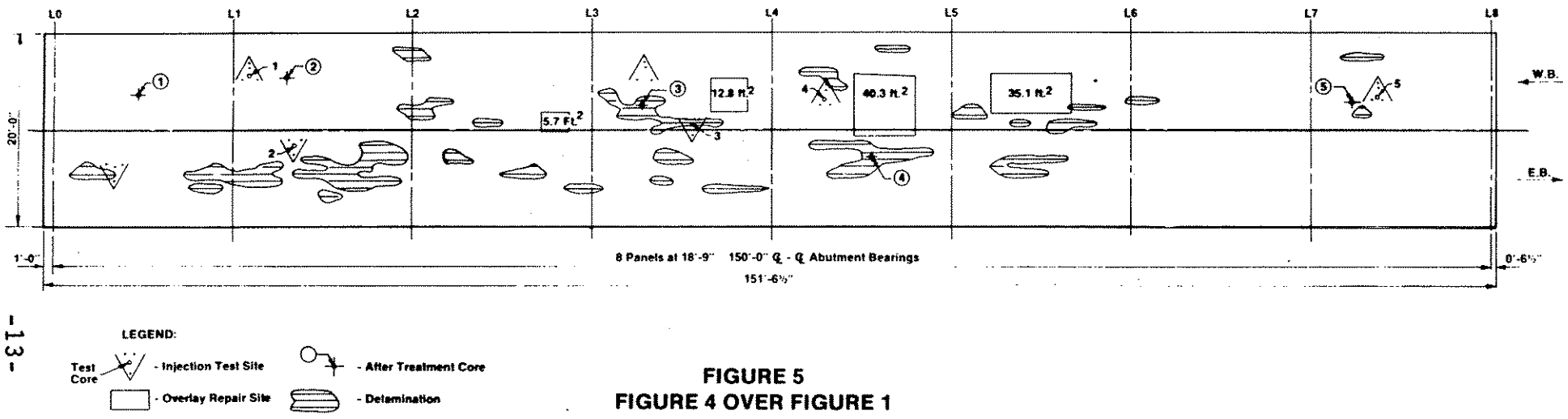
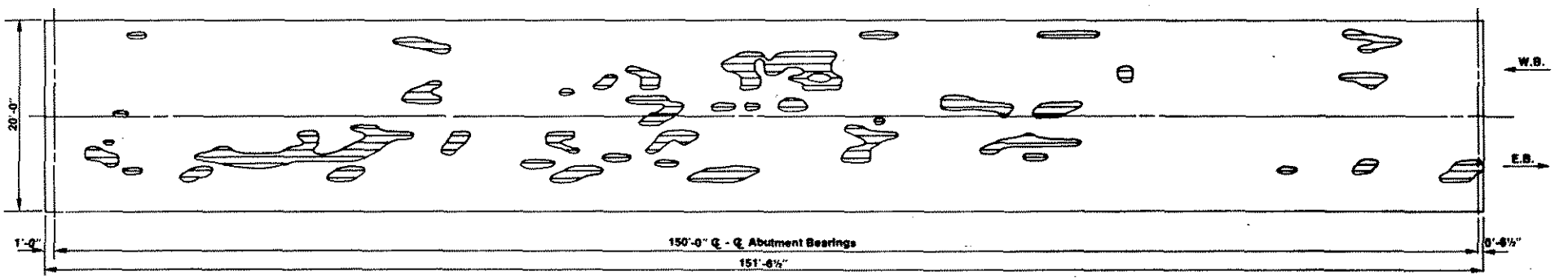


FIGURE 5
FIGURE 4 OVER FIGURE 1



LEGEND:

- Delamination

FIGURE 6
1984 DELAMINATION SURVEY

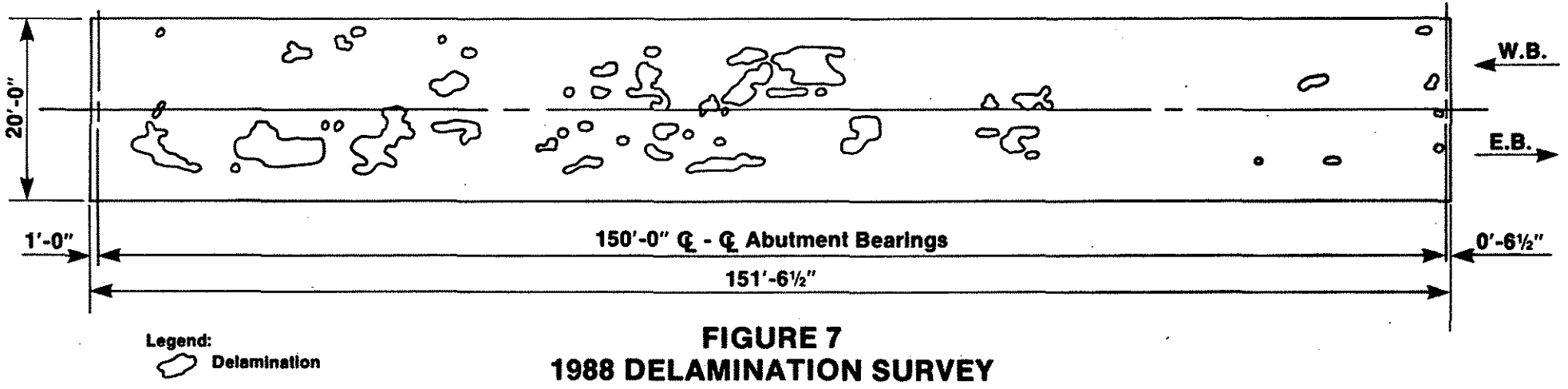


FIGURE 7
1988 DELAMINATION SURVEY

APPENDIX A

Evaluation of Pre-project Cores

Five four inch diameter cores were cut from injection test sites May 10, 1983. These are shown in Figure 1. Visual-examination indicated good rebonding of the fracture plane in cores 1, 2 and 5. Core number 4 was partially rebonded; the remainder of the interface appeared to be coated but not filled with epoxy.

The overlay was not bonded to the substrate in Core 3. The layer of epoxy was bonded to the overlay. The face of the substrate exhibited a layer of powdery contaminant. Part of the contaminant adhered to the epoxy and the remainder, a thin layer, prevented bond of the epoxy to the solid substrate. This core was obtained from a test site near an overlay repair area (L3-L4).

Core 2 was retained. Cores 1, 4 and 5 were tested in shear at the bond plane with the following results. Cores 1 and 5 were also tested in shear in the substrate.

Core Number	Bond Shear	Substrate Shear
1	464 psi	1110 psi
4	286 psi	--
5	493 psi	875 psi

APPENDIX B

Evaluation of After Treatment Cores

Five four inch diameter cores were cut from selected locations on August 31, 1983. The locations from which these cores were obtained is shown in Figure 4. Cores were located to avoid top reinforcing, cut to a partial depth to contact bottom layer reinforcing, then broken out by wedging. Cores 3 and 4 were deliberately selected where delamination was indicated in an attempt to evaluate failure to rebond. In both cases, the top portion of the core had rotated to destroy conditions at the delamination interface. No evidence of epoxy indicates failure to inject at these points. No evaluation could be made to confirm the presence of a contaminant such as observed in pretest core Number 3, see Appendix A.

Cores 1, 2 and 5, by visual examination, indicated successful rebonding. Core 1 broke too close to the bond plane to be shear tested. Cores 2 and 5 were tested in shear at the bond plane and in substrate. Core 5 contained a sufficient depth of overlay concrete to permit a test in this zone also.

Core Number	Bond Shear	Overlay Shear	Substrate Shear
2	1201 psi	- -	990 psi
5	1105 psi	1118 psi	1225 psi