LONG TERM PERFORMANCE OF UNCONTROLLED LONGITUDINAL CRACKING AND FAILED LONGITUDINAL JOINTS IN CONTINUOUSLY REINFORCED CONCRETE PAVEMENTS

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INTRODUCTION

Background

Uncontrolled longitudinal cracking is a commonly observed distress in continuously reinforced concrete pavements (CRCP). In the late 1970s and early 1980s the Texas Highway Department, in cooperation with the University of Texas, Center for Transportation Research began a detailed investigation into the causes and possible remedies of uncontrolled longitudinal cracking in CRCPs in Houston, Texas. Presented here is an analysis of these repair procedures.

Two types of repair procedures were performed on over 100,000 linear feet of uncontrolled longitudinal cracks in CRCP in 1980. The first type of repair involved widening the crack and then filling it with polymer concrete. These repairs performed exceptionally well and in 1989-90, the pavement was rehabilitated using a 4-inch bonded concrete overlay. Prior to the overlay, a condition survey was made for subsequent analysis of the performance and effectiveness of this crack repair treatment.

The concrete overlay project also included the repair of several lengths of longitudinal joints where the steel tie bars had failed and large openings of 2 to 6 inches were observed along the longitudinal joint. The primary objective of this repair procedure was to reestablish load transfer across the joint and strengthen the joint enough to withstand the stresses imposed by thermal expansion and contraction. The repair technique consisted of a stitching process where three inch deep slots were cut transversely across the joint into the slabs on both sides of the joint. A steel bar was placed in the slot and the slot filled with epoxy. Measurements and discussions of the effectiveness of this treatment are included in this paper.

Figures 1 and 2 show typical examples of uncontrolled longitudinal cracking and failed longitudinal joints in continuously reinforced concrete pavement (CRCP). Numerous repair techniques for these distresses have been investigated over the past several years.

FIGURE 1 Typical uncontrolled longitudinal cracking.

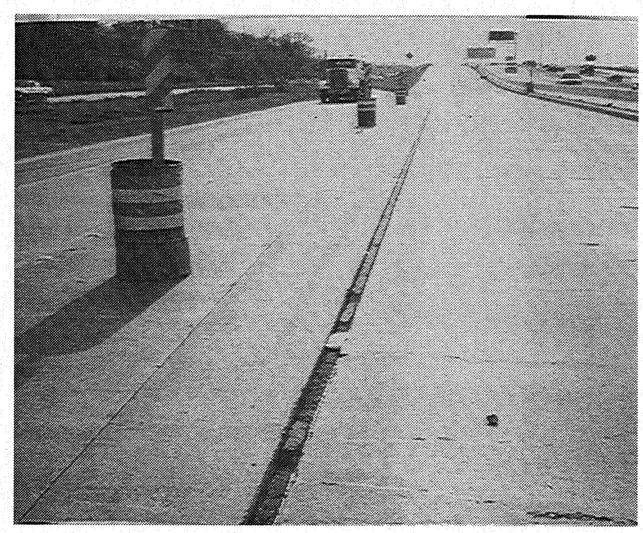

FIGURE 2 Typical failed longitudinal joint.

POLYMER CONCRETE CRACK REPAIR

Identify Distress

Extensive longitudinal cracking has occurred in many continuously reinforced concrete pavements in Houston. Although some of these cracks occurred along longitudinal construction joints, many occurred at other random locations including the wheel paths and along contraction joints. Much of the random longitudinal cracking can be attributed to excessive drying shrinkage which occurred shortly after placement of the concrete. This is especially true of the pavements placed in hot weather. Other uncontrolled longitudinal cracks have been attributed to reflective cracking and heavy axle loads. It was found on one particular project located in Houston, Texas, that 69 percent of the sawed longitudinal joints had cracked and the remaining 31 percent had cracked within a distance of one to two feet from the joint.

A mathematical model was developed to predict cracking along the longitudinal contraction joint. In using this model, the primary contributing factors were rate of heat of hydration and subsequent drying shrinkage of the pavement, inadequate saw-cut depth, pavement thickness in excess of design values, and concrete strength variability. One of the factors relative to concrete strength was the fact that the strength along the centerline was greater than that in adjacent areas due to the absence of a steel bar at the centerline and better consolidation.

Results of the study showed that the previously used saw-cut depths were not providing the reduction in tensile strength required to ensure cracking at the joint. Therefore, the ratio of the tensile strength at the joint to that in adjacent areas had to be reduced. It was found that the depth ratio of the saw-cut should be reduced from approximately 75 percent to 56 percent so that 90 percent cracking occurs along the centerline (1).

In 1980 the Center for Transportation Research assisted the Houston District of the Texas Highway Department in developing a repair procedure for the extensive uncontrolled longitudinal cracking that was present on I-610 in Houston. An example of this type of cracking is presented in Figure 1. After examining numerous cores, it was observed that the cracks generally formed around longitudinal bars, apparently because of poor concrete consolidation below the reinforcing steel (see Figures 3 and 4). The objective of this repair procedure was to seal the cracks in order to prevent water intrusion and further corrosion of the reinforcing steel.

REPAIR TECHNIQUE

A polymer concrete (PC) was used for the repair of the portland cement concrete. The surface of the longitudinal cracks were grooved to allow for the placement of the PC. Several methods for enlarging the cracks were investigated. Conventional sawing was not feasible for following the irregular cracks. High pressure water jetting was not feasible since polymer concrete does not bond well to wet surfaces, and repair time was limited.

A single-piston pneumatic crack router (crack chaser) was selected as the best available piece of equipment to enlarge the cracks (Figure 8). The bit had a 0.75 inch diameter, and each crack was enlarged to a width of approximately 1 inch. The crack depth varied, but was usually 0.75 to 1 inch. The polymer was placed by filling the enlarged crack with clean, dry concrete sand and pouring methyl methacrylate (MMA) monomer system over the sand until it was completely saturated (Figures 6 and 7).

The monomer system consisted of 95 percent MMA and 5 percent trimethylol propane trimethacrylate (TMPTMA). Benzoyl peroxide (BzP) initiator, in dispersion form, was added at a level of about 1 percent (2.5 percent for 40 percent dispersion) and a promoter, dimethyl-para-toluidine (DMPT), was added at a level of 0.5 percent, both by weight of the MMA system. The levels of BzP and DMPT were dependent upon the ambient temperature.

The monomer had to be reapplied to keep the sand saturated since monomer is lost due to evaporation and leakage down through the crack. In some repairs silicone caulking was used to seal the crack below the PC to prevent monomer loss. In other repairs polymethyl methacrylate (PMMA) powder was mixed with the sand before it was placed in the crack. PMMA powder acts as a thickener and prevents leakage of the monomer. Most repairs, however, were made without the silicone sealant or PMMA powder. The objective was to have monomer penetrate into the crack and bond to the concrete.

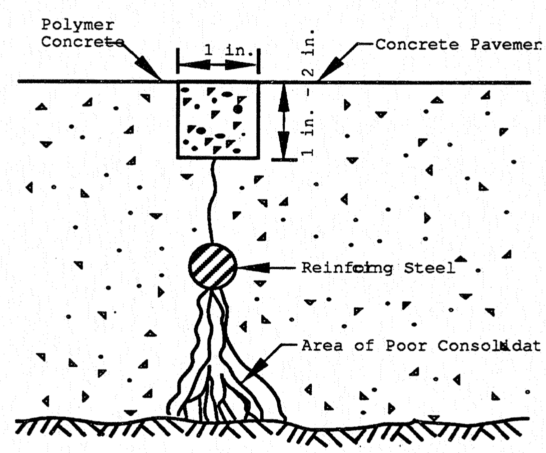

FIGURE 3 Distress Illustration.

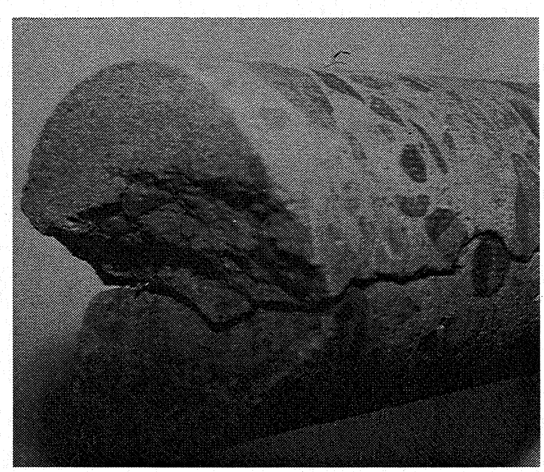

FIGURE 4 Core showing steel bar in crack.

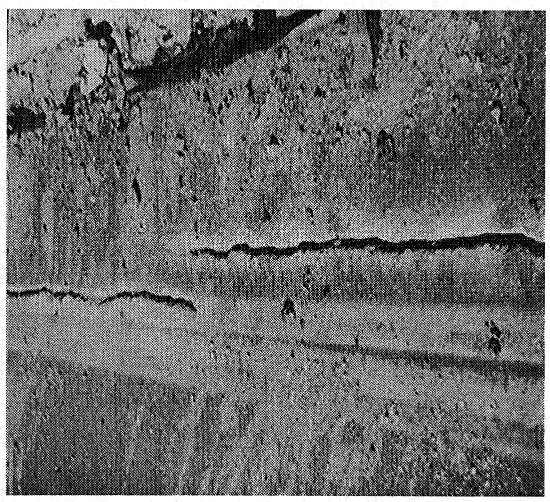

FIGURE 5 Routed crack.

FIGURE 6 Application of sand.

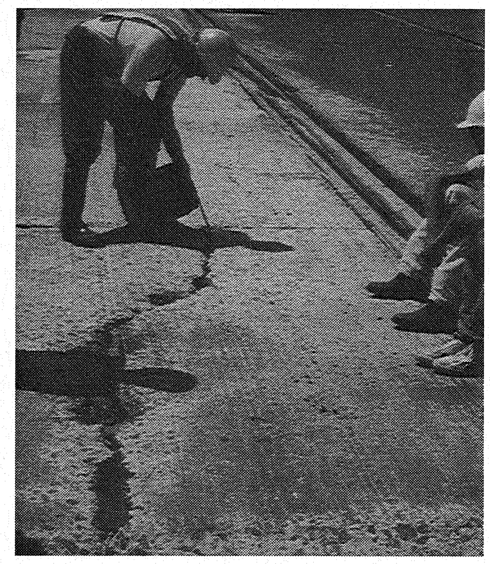

FIGURE 7 Application of monomer.

EVALUATION OF REPAIR

In 1981, approximately one year after the first crack repairs were made on the West Loop (I-610), a visual examination was made by district and CTR personnel. Of the 14,066 linear feet of repaired cracks, 55.8 percent were found to be in good condition, 43.2 percent in fair condition, and only one percent in poor condition.

The repairs rated fair or poor generally showed evidence of wear or erosion on the surface, apparently due to evaporation of monomer from the surface or depletion of the monomer caused by leakage through the bottom of the crack during the repair. When a portion of the West Loop was scarified in preparation for placement of bonded portland cement concrete overlays, many of the repaired cracks could easily be observed. In nearly every case, the repairs appeared to be sound with full bond between the PC and original concrete (Figure 8).

An inspection of repaired cracks on the South Loop in 1985 on repairs made approximately two years earlier indicated that 80 to 90 percent were in good condition. In a few cases, continued lateral movement of the pavement caused longitudinal cracks to reopen either in the repaired areas or adjacent to them. Some wear was observed in a few repaired cracks, again apparently due to lack of monomer (2).

On April 10, 1990, several of the original crack repairs made in 1980 on the South Loop of I-610 were inspected. The purpose of these inspections was to evaluate the long-term performance of the PC crack repair process. For orientation purposes, there are four lanes in each direction. Lane 1 is the inside lane while lane 4 is the outside.

FIGURE 8 Repair after milling.

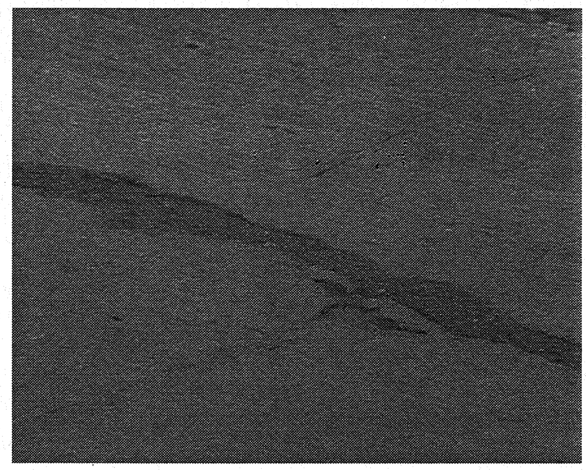

FIGURE 9 GOOD.

Five 200-ft sections were surveyed. Three of these sections were located in the outside two lanes (lanes 3 and 4) in the eastbound direction; the other two sections were located in the outside two lanes (lanes 3 and 4) in the westbound direction.

The repairs were evaluated as being in good, fair, or poor condition. A rating of "good" required that the crack be completely filled and sealed with the original repair material. A rating of "fair" required that the majority of the original repair material be in place; the crack could be slightly reopened, and small, infrequent cracks could be evident in the material. A rating of "poor" required that most of the repair material had spalled. Photos representing each rating condition are included in Figures 9,10, and 11.

Every effort was made in selecting the surveyed sections to insure that each adequately represented the crack repair conditions in that area. It was fairly difficult to find large areas for surveying due to several reasons:

(1) traffic control for the survey was limited,

(2) many areas were under construction, and

(3) many areas had been recently repaired.

When suitable areas were found, the section or sections to be surveyed were chosen near the center of the area or at least 100 ft from the end of structures or pavement transitions. In all of the sections, only lanes 3 and 4 were closed to traffic and surveyed. Lanes 1 and 2 were not surveyed.

The data obtained from the survey are given in Table 1.

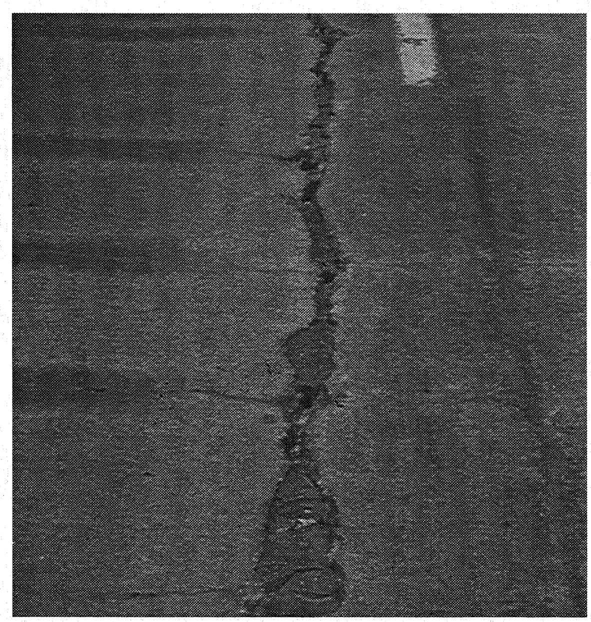

FIGURE 10 FAIR.

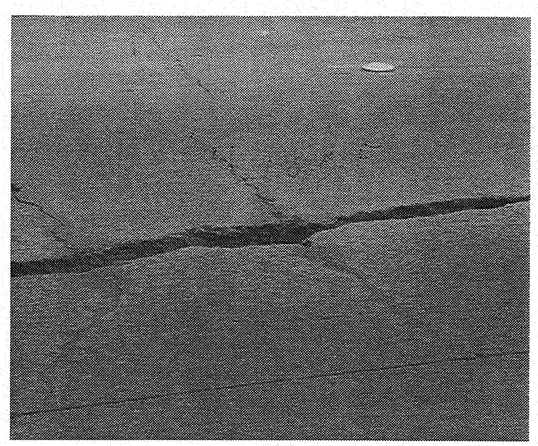

FIGURE 11 POOR.

TABLE 1 Repair Performance Data.

SECTION	LANE	RATING* GOOD	FAIR	POOR
1	3	77	0	0
	4	143	0	0
2	3	58	15	36
	4	119	29	9
3	3	14	0	0
	4	140	0	0
4	3	31	7	0
	4	39	0	0
5	3	78	29	0
	4	0	0	0

*VALUES GIVEN REPRESENT LINEAR FEET OF REPAIR

Of the repaired longitudinal cracks surveyed, 85 percent were found to be in good condition while only 10 percent and 5 percent were found to be in fair and poor condition, respectively.

CONCLUSIONS / RECOMMENDATIONS

Overall, the longitudinal crack repairs have performed quite well. It is recommended that this type of repair continue to be used for the repair of CRCP. However, the repair process is labor intensive. Alternative procedures and techniques should be investigated so that the repair is more economical. The repairs on I-610 were performed by several contractors. The cost for repair ranged from $6 to $8 per linear foot. The crack routing was performed at a rate of 25 ft per hour. The bits had to be sharpened or replaced every 175 ft. The sand and monomer were placed manually. It was necessary to rewel the sand several times to maintain a saturated condition. To make the repair procedure more economical, the following improvements are needed: (1) a more rapid procedure for enlarging the cracks, and (2) a less labor-intensive method for filling the crack with the PC.

LONGITUDINAL JOINT REPAIR

Identify the Distress

The second repair technique that this paper addresses is on failed longitudinal joints. An example of this type of distress was given in Figure 2. The objective of the repair is to reestablish load transfer across failed longitudinal joints and cracks and to prevent further widening.

Repair Technique

In 1989, the Houston District of the Texas Department of Transportation repaired 3,000 linear feet of longitudinal joints on I-610 in Houston. The objective of this repair is to reestablish load transfer by "stitching" the two sides of the crack together. In this context, stitching refers to cutting 1-inch wide slots at 12-inch centers perpendicular to the joint. These slots were cut to a depth of 3 inches and an overall length of 54 inches, centered on the joint or crack. After the slot was cleaned, a #5 tiebar was epoxied in the slot. A drawing of the repair is shown in Figure 12. Normal surface preparation preceded all repairs. Photos of the repair process are shown in Figures 13 and 14.

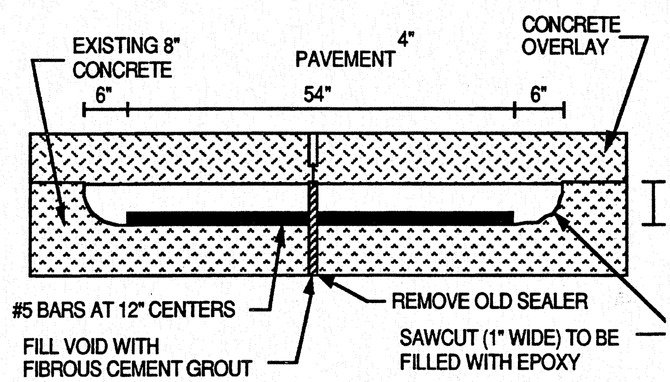

FIGURE 12 Cross section of stitching repair.

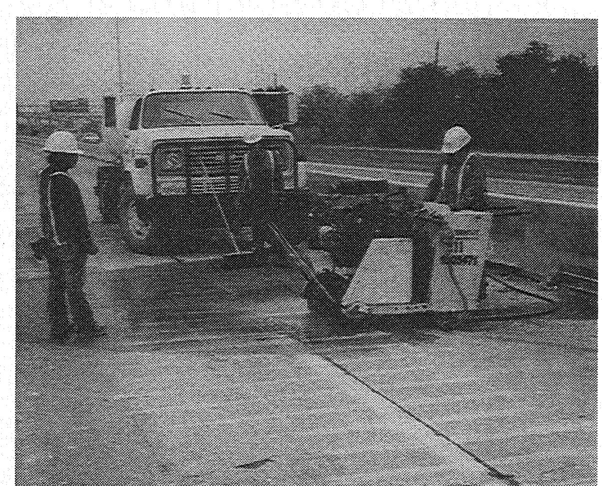

FIGURE 13 Stitching repair process - cutting slots.

FIGURE 14 Stitching repair process - bar placement.

The majority of the stitching on the South Loop was performed on the longitudinal construction joint (between lanes 2 and 3). However, some repairs were made on the sawn longitudinal joint between lanes 1 and 2 and between lanes 3 and 4.

LOAD TRANSFER EVALUATION OF "STITCHING" REPAIR OF LONGITUDINAL JOINTS

Two of the repaired areas, each approximately 75 feet in length, were selected for investigation. Falling Weight Deflectometer (FWD) measurements were taken in each of these sections after the area had been closed to traffic. FWD measurements were taken before and after the repair (February 1989 and June 1989, respectively).

Selected deflection parameters were calculated for each of the four FWD drop heights. The percent change in deflection was then calculated for each deflection site before and after the repairs were made. These results are shown in Table 2. The deflection parameters calculated include the following:

(1) Surface Curvature Index (SCI) = sensor #1 - sensor #2

(2) Base Curvature Index (BCI) = sensor #6 - sensor #7

(3) Basin Slope (BS) = sensor #1 - sensor #7

These data indicate a substantial increase in load transfer as a result of the stitching repairs. However, because these measurements were taken at times of the year and under different environmental conditions, it is possible that some of the reduction in deflection may be attributed to seasonal effects rather than the repairs themselves. Therefore, control deflection measurements were also taken at several sites (94) in February and June that were not repaired. These "non-repaired" control sites allowed the influence of season and environment to be factored out of the repair site measurements. Thus, the true effect of the repair could be determined. Table 3 shows these results.

These data indicate that the stitching repair did indeed provided a substantial increase in load transfer. The deflection parameters most representative of the surface condition, namely the SCI, BS, and sensor #1 deflection, have all decreased approximately 40 percent as a result of the repairs. The practical significance of this reduction in deflection is increased pavement life. A series of calculations was made to estimate the magnitude of the percent increase in fatigue life.

The modulus values for a three-layer pavement structure were back calculated using RPEDD1 for the before and after repair conditions. Average deflections for each of the four FWD drop heights were used as inputs to the back calculation program. The average modulus values for the three layers specified are shown below.

	Modulus Values in psi	
Pavement Layer	Before Repair	After Repair
CRC	4,300,000	6,500,000
Cement Treated Base	300,000	930,000
Roadbed Material	14,400	17,800

Stresses in the concrete layer before and after repair were calculated using these modulus values and Westergaard's equations. The "before repair" case was assumed to be best represented by the edge loading condition described by Westergaard due to the large crack width and relative lack of load transfer. The after repair condition was represented by an interior loading condition. The modulus of subgrade reaction required for the Westergaard analysis was obtained using the procedure described in the AASHTO Design Guide for determining a composite k-value. The results are shown below.

	Composite k	Radius of Relative Stiffness	Stress (psi)
Before Repair	1000	20.7	243
After Repair	1500	20.8	148

Using the fatigue equation presented by Taute and an assumed concrete strength of 650 psi, the expected life of the pavement before the repair was calculated to be 880,000 18-kip ESAL's, while the expected life after the repair was calculated to be 3,900,000 18-kip ESAL's. It should be emphasized that these values should not be used as accurate predictions of remaining life. The purpose of performing these calculations is to show a substantial increase in relative pavement fatigue life directly related to increased load transfer.

CONCLUSIONS AND RECOMMENDATIONS

An evaluation of the data indicates that the stitching repairs were effective at restoring load transfer. However, this process is also labor intensive and for the procedure to be more economical, the most significant improvement would be to develop a more effective method for grooving the pavement and removing the concrete. It may also be possible to obtain the same effect by using larger bars at larger spacings. A graph of bar size versus bar spacing for different percentages of steel is shown in Figure 15. It has been proposed that these alternatives and others be investigated in future repair projects so that a more cost-effective procedure can be developed.

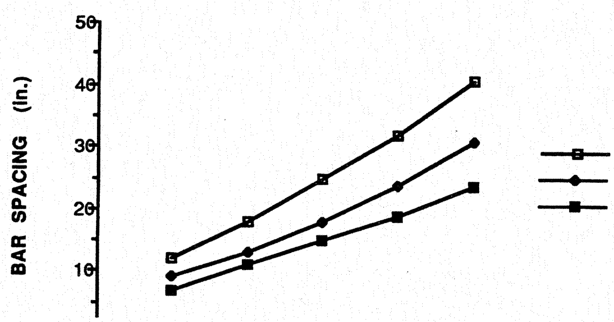

FIGURE 15 Spacing vs. bar size.

SUMMARY

Both repair procedures discussed in this report have proven effective. The polymer concrete crack repairs have been effective and have performed extremely well for several years. The longitudinal joint repairs have been very effective as they have resulted in a significant increase in load transfer. It is recommended that both of these repair procedures continue to be used for the repair of continuously reinforced concrete pavements.

However, further investigation is recommended for both repair procedures. Since both repair processes are labor intensive, alternate techniques should be investigated to make the repair processes more economical. For the polymer concrete crack repair, the following improvements are needed: (1) a more rapid procedure for enlarging the cracks, and (2) a less labor-intensive method for filling the crack with the polymer concrete. For the longitudinal joint repair, the most significant improvement would be to develop a more effective method for removing the concrete. It is anticipated that using larger bars at a larger spacing will result in a more cost-effective process.

The Center for Transportation Research continues to investigate the performance of these and other repair techniques for continuously reinforced concrete pavement. It is expected that existing repair techniques will continue to be improved and new techniques will be developed.

REFERENCES

1. McCullough, B. Frank, James R. Lundy, and Brock E. Hoskins, "Repair Techniques for Uncontrolled Longitudinal Cracking and Failed Longitudinal Joints in Continously Reinforced Concrete Pavements," Center for Transportation Research, The University of Texas at Austin, January 1991.

2. McCullough, B. Frank, "Longitudinal Cracking of CRCP in Houston Area," Technical Memorandum 388-2, Center for Transportation Research, The University of Texas at Austin, December 23, 1983.

3. Mangum, Wayne D., Alejandro J. Bermudez-Goldman, David Whitney, David Fowler, and Alvin H. Meyer, "Repairing Cracks in Portland Cement Concrete Using Polymers," Research Report 385-2F, Center for Transportation Research, The University of Texas at Austin, November 1986.

TABLE 2 Percent change in various deflection parameters after repair.

			Percent Change (June - February Readings)									
	Station	PSI	DF1	DF2	DF3	DF4	DF5	DF6	DF7	SCI	BCI	BS
SITE #1	934+00	-9	-52	-49	-45	-39	-33	-30	-31	-73	-22	-62
		-12	-49	-45	-42	-38	-35	-32	-30	-73	-42	-58
		-5	-43	-38	-35	-31	-27	-24	-24	-73	-25	-52
		-6	-38	-33	-31	-27	-22	-19	-20	-69	-19	-47
	934+20	-17	-51	-46	-43	-39	-38	-36	-36	-75	-41	-62
		-12	-48	-43	-40	-37	-36	-34	-34	-75	-39	-57
		-4	-40	-36	-32	-28	-27	-23	-23	-65	-22	-51
		-6	-37	-34	-31	-27	-27	-24	-26	-59	-9	-45
	934+35	-18	-44	-48	-45	-37	-36	-32	-35	-400	30	-50
		-13	-43	-44	-41	-35	-33	-29	-28	-16	-37	-53
		-8	-39	-39	-36	-30	-27	-23	-21	-27	-33	-49
		-7	-32	-32	-30	-25	-21	-18	-18	-26	-15	-41
	934+53	-19	-49	-51	-52	-51	-48	-46	-44	-125	-56	-53
		-12	-48	-48	-48	-45	-41	-37	-34	-47	-52	-58
		-5	-42	-41	-42	-39	-35	-33	-31	-52	-46	-50
		-12	-37	-37	-39	-35	-33	-30	-28	-26	-40	-43
	934+65	-19	-51	-49	-44	-40	-39	-34	-33	-75	-42	-63
		-13	-51	-46	-41	-38	-36	-38	-32	-82	-62	-62
		-6	-48	-43	-39	-35	-34	-28	-28	-77	-26	-58
		-7	-42	-37	-32	-28	-26	-22	-21	-71	-29	-52
SITE #2	935+30	-14	-52	-54	-52	-50	-48	-47	-48	25	-35	-55
		-12	-48	-47	-44	-41	-38	-33	-34	-55	-30	-56
		-6	-43	-42	-39	-36	-33	-28	-28	-46	-29	-52
		-6	-37	-37	-34	-31	-29	-25	-26	-49	-19	-45
	935+44	-22	-42	-42	-41	-35	-36	-36	-30	-49	-62	-49
		-15	-39	-39	-37	-33	-33	-34	-36	-42	-23	-41
		-5	-32	-31	-29	-24	-22	-21	-22	-47	-17	-38
		-8	-29	-28	-26	-22	-21	-22	-24	-38	-14	-32
	935+61	-35	-40	-42	-40	-39	-39	-36	-33	-22	-50	-45
		-29	-37	-36	-35	-33	-33	-28	-24	-44	-45	-43
		-20	-33	-31	-32	-31	-32	-29	-24	-48	-50	-38
		-12	-28	-28	-27	-27	-28	-24	-21	-32	-36	-32
	935+78	-28	-46	-46	-43	-38	-39	-33	-31	-49	-46	-55
		-22	-44	-43	-42	-41	-39	-38	-38	-58	-37	-49
		-12	-40	-38	-37	-35	-34	-33	-34	-53	-20	-43
		-10	-37	-36	-35	-33	-32	-32	-32	-44	-30	-40
	935+96	-14	-45	-47	-46	-41	-41	-32	-33	5	-28	-54
		-13	-44	-45	-44	-40	-38	-35	-36	-28	-28	-50
		-8	-36	-37	-35	-31	-30	-29	-28	-7	-35	-42
		-8	-32	-34	-33	-30	-28	-25	-24	9	-27	-38

TABLE 3 Influence of season (June to February) on the average percent difference of various deflection parameters.

		Drop Height								Overall Average	
		1		2		3		4			
Deflection Parameter	Statistic	Non-Repair	Repair	Non-Repair	Repair	Non-Repair	Repair	Non-Repair	Repair		
Load	Average	-23	-20	-15	-15	-8	-8	-10	-8	-14	-13
	St. Dev.	5	6	5	5	5	4	3	2	7	7
DF1	Average	-18	-47	-13	-45	-4	-39	3	-35	-8	-42
	St. Dev.	23	4	23	4	25	4	27	4	26	6
DF2	Average	-20	-47	-13	-44	-3	-38	2	-34	-8	-41
	St. Dev.	21	4	22	3	24	4	25	3	25	6
DF3	Average	-20	-45	-12	-41	-3	-36	3	-32	-8	-38
	St. Dev.	19	4	20	4	22	4	23	3	23	6
DF4	Average	-19	-41	-12	-38	-2	-32	4	-29	-7	-35
	St. Dev.	17	5	18	4	20	4	20	4	21	6
DF5	Average	-20	-40	-12	-36	-2	-30	4	-27	-8	-33
	St. Dev.	15	4	15	3	17	4	17	4	18	7
DF6	Average	-20	-36	-12	-34	-2	-27	4	-24	-7	-30
	St. Dev.	15	5	12	3	14	4	15	4	17	7
DF7	Average	-21	-36	-12	-33	-3	-26	3	-24	-8	-30
	St. Dev.	12	6	11	4	12	4	12	4	15	7
SCI	Average	-48	-84	-1	-52	0	-49	16	-40	-8	-56
	St. Dev.	136	119	103	20	113	20	77	23	112	62
BCI	Average	-13	-35	-4	-39	6	-30	15	-24	1	-32
	St. Dev.	57	26	39	11	38	10	42	10	46	16
BS	Average	-13	-55	-12	-53	-2	-47	5	-42	-5	-49
	St. Dev.	43	5	38	6	41	6	45	6	42	8