Analysis of Three Concrete Restoration Techniques

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Three concrete pavement restoration techniques are described and the field performance of each is evaluated. Two of the three methods are used to restore the condition of continuously reinforced concrete pavements (CRCP) and the other was used to repair failed joints and broken slabs in an old plain jointed concrete pavement (JCP). Each of the techniques and the analysis results are described. A repair technique using polymer concrete to restore load transfer and seal surface cracks in several lane-miles of IH 610 in Houston, Texas, is described. This project, constructed in 1980, was surveyed in 1990. Results indicated that the majority of the repairs were intact after 10 years of heavy traffic. The area encompassing these polymer concrete repairs is currently being rehabilitated using a bonded overlay. One experimental section in the overlay project investigated the effectiveness of methyl methacrylate as a mop on pretreatment of the existing CRCP. Falling weight deflectometer (FWD) measurements taken before and after the treatment, as well as core analyses, indicated this technique to be only marginally effective in reducing deflection. A second technique used to repair longitudinal construction joints in CRCP before rehabilitation is described. Load transfer was reestablished by epoxying reinforcing steel in slots cut perpendicular to the joint. FWD measurements demonstrated this technique to be of significant benefit. Analyses indicated that the stress was reduced by as much as 40 percent through the use of this technique. The restoration of a two-lane JCP constructed in the 1930s was undertaken as part of an experimental test program to assess several rehabilitation options available for JCP. Deflection measurements were taken near transverse joints and longitudinal cracks before and after the repairs were made. Repairs were effected using precast joints and polymer concrete. Analyses indicated some reduction in deflection as the result of the restoration work.

Pavement repairs are often necessary to maintain a suitable riding quality. As traffic demands have increased substantially over the past several years and will continue to increase, it has become extremely important to implement effective pavement repairs. User costs escalate rapidly as delay increases. Therefore, the time required to implement a specific repair and the subsequent performance of the repair is of concern.

The University of Texas, Center for Transportation Research (CTR), and the Texas State Department of Highways and Public Transportation (SDHPT) have been working together to develop and implement effective repair procedures for PCC pavements. Several repair techniques have been investigated over the past years on distresses common in PCC pavements. Specific repair procedures implemented on continuously reinforced concrete pavements (CRCP) and jointed concrete pavements (JCP) are described and the effectiveness of each repair is evaluated.

The repair procedures discussed and evaluated in this article include the repair of uncontrolled longitudinal cracking on CRCP and JCP, the repair of failed longitudinal joints on CRCP, and the repair of transverse joints on JCP.

POLYMER CRACK REPAIRS OF CRCP

Uncontrolled longitudinal cracking was a commonly observed distress in CRCP in the Houston, Texas, area in the late 1970s. Uncontrolled longitudinal cracking may be defined as any longitudinal cracking not occurring at a construction joint or sawed joint. An investigation indicated that the primary contributing factors to this type of cracking included inadequate saw-cut depth, pavement thickness in excess of planned values, and concrete strength variability (*1*). An analysis of several cores indicated that the cracking typically occurred around steel bars, because of a plane of weakness created by the bar itself and by poor consolidation of the concrete beneath the bar as shown schematically in Figure 1. The deterioration associated with these cracks prompted an investigation into possible repair methods.

The University of Texas at Austin, CTR, and the SDHPT developed and implemented a repair procedure for the uncontrolled longitudinal cracking that was present on IH-610 in Houston (see map shown in Figure 2). An example of this type of cracking is shown in Figure 3. The objective of the repair procedure was to seal the cracks to prevent water intrusion and further corrosion of the reinforcing steel.

The repair procedure is described as follows. The cracks were enlarged to a depth and width of approximately 1 in. using a single-piston pneumatic crack router (see Figures 4 and 5). The crack was filled with dry concrete sand. A methyl methacrylate (MMA) monomer system was then poured over the sand until it was completely saturated (see Figure 6). This polymer concrete bonded to and sealed the crack.

In 1980, a contract was let to repair approximately 100,000 linear feet of uncontrolled cracks using this technique. A visual examination of about 15 percent of the repaired cracks 1 year after the repairs were effected indicated that 56 percent were in good condition, 43 percent were in fair condition, and only 1 percent were in poor condition (*2*). Researchers reported that those areas rated fair or poor evidenced wear on the surface, apparently caused by evaporation of monomer from the surface or depletion of the monomer caused by leakage through the bottom of the crack (*2*). A second area

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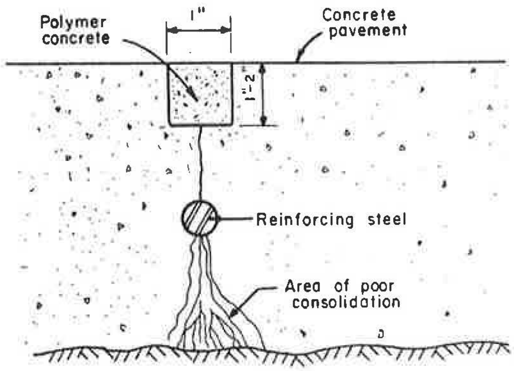

FIGURE 1 Cross section of distress and repair.

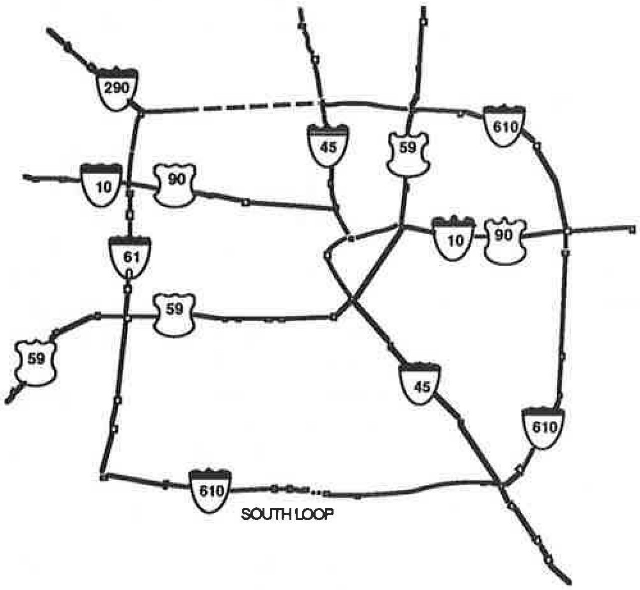

FIGURE 2 Map of Houston area showing location of repair sites.

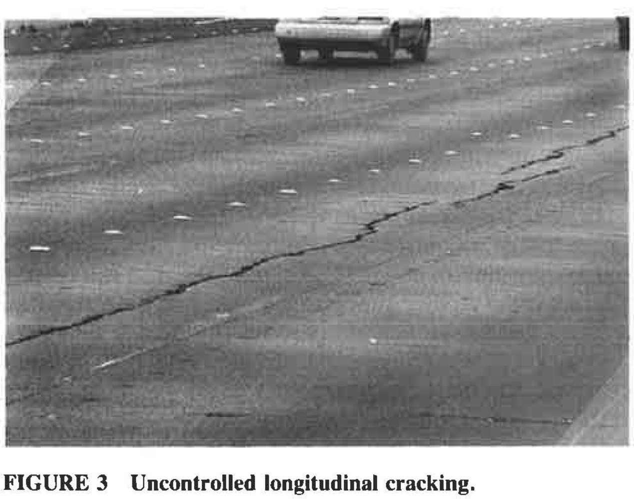

FIGURE 3 Uncontrolled longitudinal cracking.

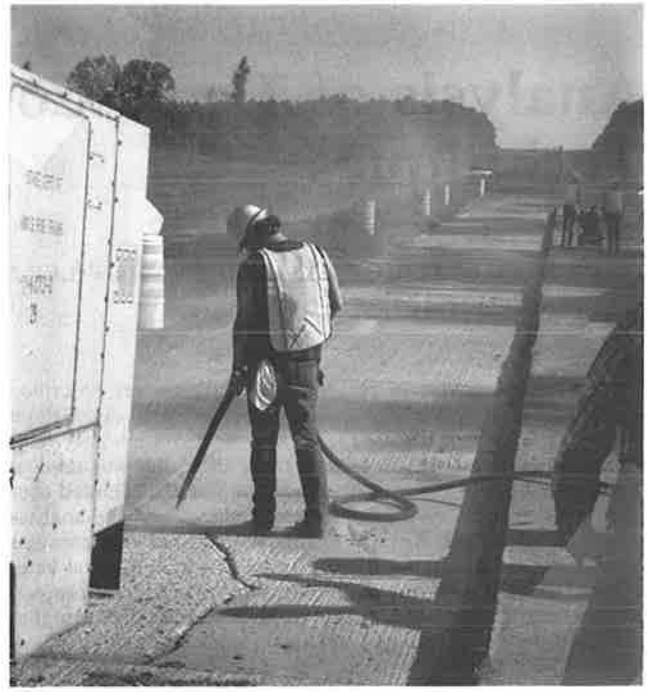

FIGURE 4 Crack router in operation.

FIGURE 5 Routed crack ready to receive polymer concrete filler.

FIGURE 6 Application of monomer.

was treated in 1985. An inspection of this area in 1987 indicated that 80 to 90 percent of the repairs 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 (*2*).

A followup survey was conducted in April 1990 to determine the long-term performance characteristics of the polymer concrete crack repairs. Five 200-ft sections were selected randomly. Three of these sections were located in the outside two lanes in the eastbound direction; the other two sections were located in the outside two lanes in the westbound direction. The repairs were again evaluated as being in good, fair, or poor condition. A rating of good required that the crack still be completely filled and sealed with the repair material. To be classified as fair, the majority of the repair material must be in place, but small infrequent cracks could be evident. A rating of poor required that all of the repair material had spalled out. Photos representing each rating condition are included in Figures 7–9. Rating quantities were based on linear feet of repair. The data obtained from the survey are presented in Table 1. Of the repaired longitudinal cracks surveyed, 85 percent were found to be in good condition, whereas only 10 and 5 percent were found to be in fair and poor condition, respectively.

An analysis of variance was performed on these data. The variance was checked between sections, between Lanes 3 and 4, and between ratings (good, fair, or poor). All two-way interactions were also checked for significance. The only parameter that indicated significance was that between ratings, as expected.

One of the westbound sections had transverse crack repairs as well as longitudinal crack repairs. The transverse crack repairs were evaluated in the same manner as the longitudinal crack repairs. However, the transverse crack repair data were not incorporated into the statistical analysis of the data. Within this section, 98 percent of the transverse crack repairs were in good condition, whereas the remaining 2 percent were in fair condition.

FIGURE 7 Repaired area typical of areas receiving a rating of good.

FIGURE 8 Repaired area typical of areas receiving a rating of fair.

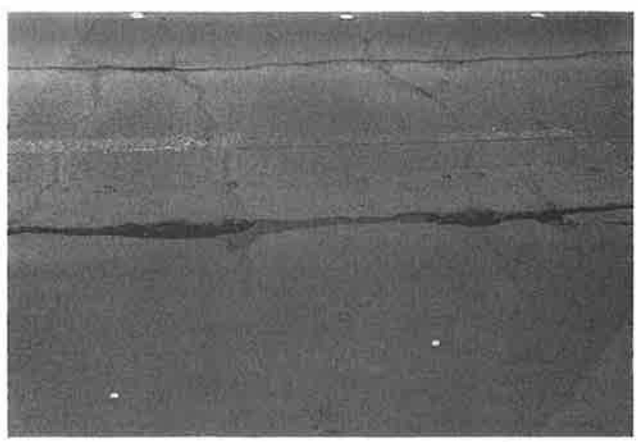

FIGURE 9 Repaired area typical of areas receiving a rating of poor.

TABLE 1 NUMBER OF LINEAR FEET OF REPAIRED CRACK IN EACH CATEGORY AS OF APRIL 1990

Section ID	Lane Number	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

The repairs have performed well overall and, based on performance, this technique is an effective means of repairing CRCP. However, the repair process is labor-intensive. Repairs on IH-610 were performed by several contractors. Investigators reported the cost for repairs ranged from $6/ft to $8/ft. The crack routing was performed at the rate of 25 ft/hr and bits had to be sharpened or replaced every 175 ft. The sand and monomer were placed manually and the sand was rewetted with monomer several times to maintain a saturated condition (*2*). If this technique is to considered viable, alternate procedures and techniques should be investigated to make the repair be more economical.

REESTABLISHING LOAD TRANSFER IN CRCP LONGITUDINAL JOINTS

Major repairs of CRCP longitudinal joints are increasingly becoming a necessary, though onerous, task for many highway agencies. When repair of longitudinal joints or cracks is required on major freeways, lane closures constitute a significant inconvenience to users. Fifty percent of the capacity of a four-lane facility may be lost if repair of the center longitudinal construction joint is required. Obviously, any effective method that expedites the procedure will result in a substantial savings to the public.

The preparation of an existing CRCP for rehabilitation using a bonded concrete overlay also requires repairs. In addition to the prerequisite surface cleaning using shot-blasting or cold milling, repairs are normally required to restore the structural integrity of the existing pavement. These repairs range from longitudinal joint routing and sealing to full-depth replacement of highly distressed areas. The discussion that follows is directed to the repair of longitudinal joints and cracks before the placement of a bonded concrete overlay. Similar techniques could be used on a CRC pavement that was not planned for immediate rehabilitation.

A common problem found in multilane facilities is the separation of lanes, particularly at the longitudinal construction joint shown in Figure 10. The parting of the adjacent lanes is particularly severe on horizontal curves where separation of 6 in. have been found. Uncontrolled longitudinal cracking may also be present on CRCP being considered for a bonded overlay. Although these cracks are narrow initially, with time they propagate and spall, resulting in a reduction in load transfer efficiency. The widths of these uncontrolled cracks are generally less than 1 in.

FIGURE 10 Separation of longitudinal construction joint.

These gaps, whether between lanes or midlane, represent a structural deficiency of the pavement. Transverse steel at these locations is deteriorated or nonexistent, thus eliminating load transfer. The opening allows the infiltration of water and incompressible fines, further aggravating the problem. Faulting and the associated traffic safety hazard eventually result if this problem is left untreated. Restoration of the structural integrity of the underlying slab is necessary before the placement of a bonded overlay.

Several types of repairs were performed on an existing CRCP in Houston, Texas, before the placement of the 4-in. bonded overlay. One form of repair attempts to reestablish load transfer across failed longitudinal joints and cracks by stitching the two sides of the crack together. In this context, stitching refers to cutting 1-in.-wide slots at 12-in. centers perpendicular to the joint. These slots are cut to a depth of 3 in. and an overall length of about 54 in., centered on the joint. After the slot is cleaned, a No. 5 tiebar is epoxied in the groove. Normal surface preparation follows after the specified curing time. A schematic of the repair is shown in Figure 11.

The majority of the stitching was done on longitudinal construction joint at the center of the four driving lanes in each direction. Some repairs of this type were necessary between Lanes 1 and 2, or Lanes 3 and 4, on the sawn longitudinal

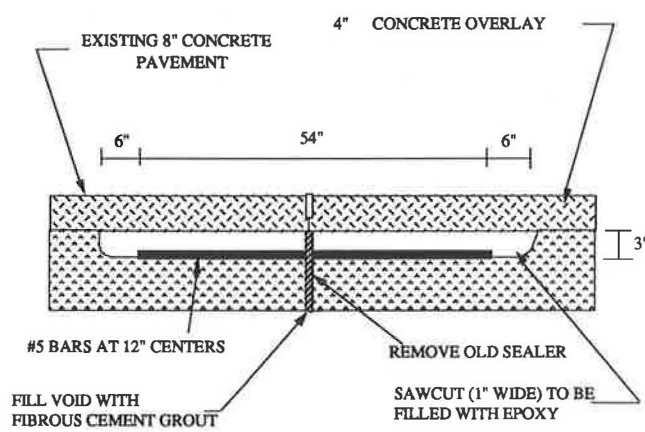

FIGURE 11 Schematic of longitudinal construction joint repair technique.

joint. The center construction joint could not be accessed because of the concrete median barriers used for traffic control during construction. Therefore two joints, each approximately 75 ft in length at the longitudinal sawn joint between Lanes 1 and 2, were selected for investigation.

Falling weight deflectometer (FWD) measurements were taken in each of these sections after the area had been closed to traffic. Before repair, FWD measurements were taken in February 1989 and, after repair, data were collected in June 1989. The general layout of the data collection at each site is shown in Figure 12. A summary of the influence of the repairs on the measured deflection is presented in Table 2. These results indicate that there has been a substantial decrease in the deflection as a result of the stitching repairs. However, because these measurements were taken at different times of the year under different environmental conditions, it is possible that some of the reduction in deflection could be attributed to seasonal effects rather than the repairs themselves.

Deflection measurements were taken at several (94) sites in February and June that were not repaired. These nonrepaired sites allow the influence of season and environment to be factored out of the repair site measurements. Thus, the true effect of the repair may be determined. Table 3 presents a summary of this work. Obviously a substantial decrease in deflection has occurred in the repair areas that may be attributed solely to the stitching. The deflection parameters most representative of the condition of the surface layer, namely the surface curvature index (SCI), basin slope (BS), and Sensor 1 deflection, have all decreased approximately 40 percent

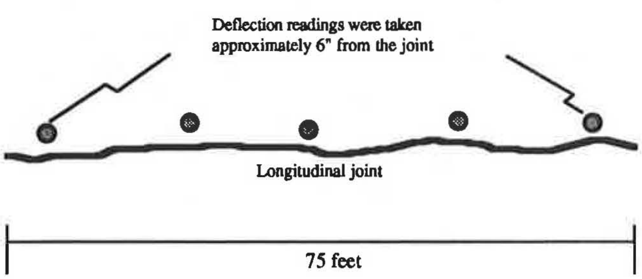

FIGURE 12 Plan view of deflection measurement locations.

TABLE 2 AVERAGE PERCENT CHANGE FOR ALL DROP HEIGHTS IN VARIOUS DEFLECTION PARAMETERS AFTER REPAIR

Site	Location	Load	DF1	SCI	BCI	BS
1	1	-8	-46	-72	-27	-55
	2	-10	-44	-69	-28	-54
	3	-12	-40	-23	-28	-48
	4	-12	-44	-42	-49	-51
	5	-11	-48	-76	-40	-59
2	6	-10	-45	-50	-28	-52
	7	-12	-36	-44	-29	-40
	8	-24	-34	-36	-45	-40
	9	-18	-42	-51	-31	-47
	10	-11	-39	-13	-30	-46

Notes: DF1= deflection sensor #1
SCI = Surface curvature index (sensor #1 - sensor #2)
BCI = Base curvature index (sensor #6 - sensor #7)
BS = Basin slope (sensor #1 - sensor #7)

TABLE 3 INFLUENCE OF SEASON (JUNE TO FEBRUARY) ON AVERAGE PERCENT DIFFERENCE OF VARIOUS DEFLECTION PARAMETERS

	Load	DF1	SCI	BCI	BS
Repaired	-13	-42	-56	-32	-49
Non-Repaired	-14	-8	-8	1	-5

as a result of the repairs. Although this is indicative of the effectiveness of the method, it does not establish fully the benefit received through the use of this repair technique.

The modulus values for a three-layer pavement structure were calculated using a backcalculation program for the before and after repair conditions. Average deflections for each of the four FWD drop heights were used as input to the program. The average modulus values for the three layers specified are presented in Table 4.

Using these modulus values and the equations of Westergaard, stresses in the concrete layer before and after repair can be calculated. The before-repair case was assumed to be best represented by the edge condition described by Westergaard caused by the large crack width and relative lack of load transfer. The after-repair condition was represented by an interior 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. Table 5 presents the stresses calculated for each of the conditions.

Using the fatigue equation presented by Taute et al. and an assumed concrete strength of 650 psi, the expected life of the before-repair pavement was 880,000 18-kip ESALs, while the after-repair pavement should survive 3,900,000 ESALs repetitions without failure. These projections of fatigue life are provided for comparison purposes only.

From these analyses, it appears that a substantial reduction in deflection has occurred in those areas where the stitching repair technique was used. Although the exact benefit in terms of added life can not be determined, it is logical to assume that any reduction in pavement deflection on the order of 40 percent will substantially increase the life of the pavement. This reduction in deflection is of particular benefit when placing a thin, bonded concrete overlay.

JOINT AND CRACK REPAIR ON US-59

In 1989, repairs were made on a selected area on US-59 in District 11. This project served as a pilot study to determine the effectiveness of various types of concrete repairs. Repair techniques judged effective will be included in test sections to be constructed in 1991. These test sections are part of a research project undertaken by the Texas SDPHT to develop a long-range plan for the rehabilitation of 140 mi of US-59 in east Texas.

Approximately one-half of the total centerline mileage is rigid pavement and all of the rigid pavement has been overlaid with asphalt concrete. Reflective cracking and rutting are the most common distress manifestations throughout these overlaid sections. In the particular area selected for the pilot

TABLE 4 MODULUS VALUES BACKCALCULATED FROM FWD MEASUREMENTS

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

TABLE 5 CALCULATED STRESSES BEFORE AND AFTER REPAIR

	Composite k	Radius of relative stiffness	Stress (psi)
Before repair	1000	20.7	243
After repair	1500	20.8	148

FIGURE 13 Repair site before construction.

study, the rigid pavement was constructed in the 1930s. The overlaid 9-7-9 thickened-edge jointed pavement was thought to be representative of the rigid pavements in the project.

The pilot study consisted of removing the existing asphalt concrete, effecting the repairs, and replacing the overlay. The effectiveness of the repairs would be judged by comparing the before- and after-repair FWD measurements and time for reflective cracks to develop repaired and non-repaired areas.

Figure 13 shows the repair site before milling. Approximately 7 in. of asphalt concrete was removed. After milling was completed, three joints were selected for replacement using the precast drop-in unit (see Figure 14). Sawing and subsequent removal required approximately 4.5 hr. The precast joint was placed on a graded bed of cement-stabilized sand. Set 45 was used as the filler material, or zipper, for two of the slabs and polymer concrete for the other.

FIGURE 14 Placement of precast joint section.

Another joint was milled to a depth of about 3.5 in. and a width of 4 ft using the milling machine. On the following day, this joint received a prefabricated dowel basket assembly and Type III concrete. The milling operation required approximately 30 min (see Figure 15). Because both joint repair preparation techniques (sawing and milling) use water to lubricate the cutting heads, there was considerable water standing on the slab following joint preparation. Several hours were spent removing the water and cleaning the slab for monomer placement the following day.

Drying of the cracks and joints using propane burners and additional cleaning of these areas were required before implementing the crack repair procedure. Air-blasting of the cracks was followed by sand blasting in preparation for the monomer treatment. Most of the cracks were repaired using a monomer treatment. Others were treated with epoxy mortar. The monomer material was the same type as that used for the previously discussed repairs in Houston.

FWD measurements were taken on the concrete pavement before and after repairs. Analysis of the measurements in the entire repair section showed a 20 percent overall reduction in deflection because of the repairs. The precast slab showed a 22 percent reduction in deflection, on the basis of measure-

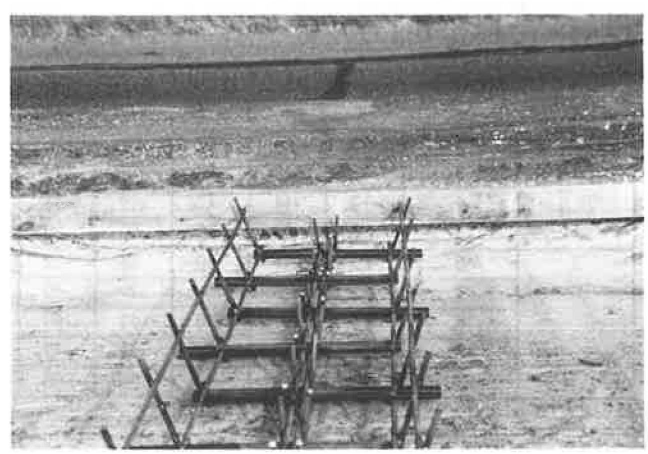

FIGURE 15 Milled joint and dowel basket assembly.

ments taken at the joint and adjacent to the slab on both sides of the joint. This reduction represents improved load transfer across the joint, which causes lower stress and subsequently increases pavement life. This reduction also reduces the probability that faulting will occur at the joint and subsequently reduces the severity of reflective cracking.

For the monomer crack repair, a 30 percent reduction in deflection was realized. Deflections were not measured on the dowel basket assembly joint replacement because the concrete needed time to cure. Deflections were compared before and after repairs at a location where no repairs occurred to realize differences in deflection caused by temperature. The change in deflection was insignificant and was, in fact, a slight increase.

A visual inspection of the pilot repair site was conducted in December 1989. No significant cracks had developed in the asphalt concrete. This short period, however, cannot be used to determine the performance of the repairs. The site should be monitored for several years to properly assess the effectiveness of the repairs. These repair techniques will also be implemented and subsequently monitored in a 1,000-ft test section on US-59 to be constructed this year.

On the basis of the FWD measurements taken, both the joint and crack repairs have proven effective. With regard to short-term performance, these repairs have performed well under traffic. However, both joint and crack repair techniques are labor-intensive. For the joint repair techniques to become more cost-effective, a better procedure for removing the concrete is needed. For the crack repairs, better procedures for routing and filling the cracks are needed. The estimated material costs for each repair procedure are as follows: (a) precast joint—$620 per joint lane, (b) milled joint—$150 per joint per lane, and (c) polymer concrete crack repair—$0.20 per linear foot.

CONCLUSIONS AND RECOMMENDATIONS

All of the repair procedures discussed have proven effective. The polymer concrete crack repairs in Houston have performed extremely well for 10 years under heavy traffic. The longitudinal joint repairs in Houston have been effective, as they have resulted in a 40 percent reduction in deflection. The polymer concrete crack and joint repairs in east Texas have resulted in a significant reduction in deflection and have performed well under traffic for several months.

However, further investigation is recommended for these repair procedures, as they have also proved to be labor-intensive. Alternative techniques should be investigated to make each repair procedure more economical. For the polymer concrete crack repair, a more rapid procedure for enlarging the cracks and a less labor-intensive method for filling the cracks are needed. For both the longitudinal and transverse joint repair, a more rapid method for removing the concrete is needed. It is anticipated that using larger bars at a larger spacing will result in a more cost-effective process.

The University of Texas at Austin, CTR, and SDHPT will continue to investigate the implementation and performance of these and other repair procedures for PCC pavements. It is expected that these repair procedures will be improved and that new techniques will be developed.

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