28. M.G. Spangler. Stresses in the Corner Region of Concrete Pavements. Bulletin 157. Engineering Experiment Station, Iowa State College, Ames, 1942.

# Establishing Load Transfer in Existing Jointed Concrete Pavements

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ABSTRACT

In this paper are described the results of a research project that had the objective of developing construction procedures for restoring load transfer in existing jointed concrete pavements and of evaluating the effectiveness of the restoration methods. A total of 28 test sections with various load transfer devices were placed. The devices include split pipe, figure eight, vee, double vee, and dowel bars. Patching materials used on the project included three types of fast-setting grouts, three brands of polymer concrete, and plain portland cement concrete. The number and spacing of the devices and dowel bars were also variables in the project. Dowel bars and double vee devices were used on the major portion of the project. Performance evaluations were based on deflection tests conducted with a 20,000-lb axle load. Horizontal joint movement measurements and visual observations were also made. The short-term performance data indicate good results with the dowel bar installations regardless of patching materials. The sections with split pipe, figure eight, and vee devices failed in bond during the first winter cycle. The results with the double vee sections indicate the importance of the patching material to the success or failure of the load transfer system: some sections are performing well and other sections are performing poorly with double vee devices. Horizontal joint movement measurements indicate that neither the dowel bars nor the double vee devices are restricting joint movement.

Many miles of Interstate pavement have been constructed using plain jointed concrete pavements of various thicknesses and joint spacings. The presence of a joint is a discontinuity that causes higher stresses and deflections in the pavement especially in the outside corner area. Many designs of jointed concrete pavement relied on aggregate interlock to provide for the transfer of the load across the joint, thereby reducing stress concentration and deflections under load. Laboratory studies conducted by the Portland Cement Association (PCA) found that the effectiveness of load transfer from aggregate interlock depended on load magnitude, number of repetitions, slab thickness, joint opening, subgrade value, and aggregate angularity (1). It was also found that the effectiveness decreased with cumulative load applications.

The variability of the amount of load transfer available from aggregate interlock created by changes in joint openings points out the need to provide for a more positive means of load transfer. In Georgia, and in many other states, dowel bars are placed in newly constructed pavements. Many older concrete pavements do not have the dowel bars and this absence of a positive means of load transfer is a factor that contributes to the deterioration of these pavement sections. Faulting measurements made in Georgia in 1972 on projects that contained both doweled and nondoweled joints indicated that the presence of dowels reduced the rate of faulting (2).

The distress found in plain jointed concrete pavements in Georgia generally has been caused by the presence of an erodible base or subgrade, infiltration of surface water into the pavement system,

and excessive movement of the slab at the joints. These conditions have led to faulted joints and cracked slabs. A large program to rehabilitate these deteriorated pavements in Georgia has been under way since 1976. These efforts have consisted of reducing slab deflections by filling any voids under the pavement with grout, replacing broken slabs, resealing joints and grinding the surface to restore rideability and skid resistance, or overlaying with asphaltic concrete.

The problem of providing a positive load transfer across the joint was not addressed in the rehabilitation efforts mainly because of the lack of a viable cost-effective method of providing load transfer and reducing corner deflection in existing pavements. It is likely that the life of a large percentage of the rehabilitated pavements could be extended if load transfer across the joint could be established by positive means.

Research into this area has been started during the last several years in France and the United States. A report published by FHWA in 1977 contained conceptual proposals for two load transfer devices that could be placed in existing concrete pavement joints (3).

In 1980 the Georgia Department of Transportation received a contract from the Federal Highway Administration to place and evaluate the performance of load transfer devices on in-service concrete pavements. The objective of the research project was to develop construction procedures for restoring load transfer in existing concrete pavements and to evaluate the effectiveness of the restoration methods.

The objectives of the study were to be accomplished through installation of various load transfer devices and monitoring the performance of these devices under actual Interstate traffic conditions.

## DESIGN AND PERFORMANCE OF TEST SITE

The location that was selected for the test site was on I-75 in the southbound lane approximately 40 mi south of Atlanta. The average daily traffic (ADT) on the test area is 15,000 to 17,000 vehicles per day with 19 percent heavy trucks.

The pavement in the test area is a 9-in. plain jointed concrete pavement with 30-ft joint spacing. The base course is a 3-in. bituminous stabilized soil aggregate on top of a 5-in. layer of granular subbase. The shoulder consists of a 6-in. cement-stabilized graded aggregate with a 1 1/2-in. asphaltic concrete topping. The pavement was opened to traffic about 1967.

This section was rehabilitated in 1976 by DOT maintenance forces because of the severe faulting and pumping that were taking place. The rehabilitation consisted of undersealing, spall repair, replacement of broken slabs, addition of edge drains, sealing of transverse joints, and grinding. Annual surveys conducted on this section have shown a significant increase in the faulting level in some areas since rehabilitation. There also has been an increase in the number of broken slabs and replaced slabs and visual signs of slab movement in the general area since the rehabilitation was completed in 1976.

## EXPERIMENTAL LAYOUT

The test sections were designed to examine variables such as patching materials, types of load transfer devices, and number of devices or dowel bars per joint. The patching materials used in the sections were polymer concrete, rapid set materials, and high early strength portland cement concrete. The load transfer devices consisted of split pipe, figure eight, vee, and dowel bars. The interactions of these variables as used in the research project are given in Table 1. In addition, 10 control sections ranging from 3 to 17 joints in size were placed throughout the project. The deflection data obtained on the control joints were used as a guide to determine whether the load transfer devices were effectively minimizing the differential deflection across a joint and reducing the total deflections of a slab.

TABLE 1   Load Transfer Test Section Variables

| Type of Device | Patching Material | Devices per Joint | No. of Joints | Test Section No. |
|---|---|---|---|---|
| Split pipe | Bonded with epoxy | 4 | 6 | 1 |
| Figure eight | Bonded with epoxy | 4 | 20 | 2 and 3 |
| Vee | Polymer concrete | 4 | 10 | 4 |
| Double vee | Polymer concrete | 4 | 5 | 5 |
| | | 4 | 35 | 5, 30, 31 |
| | | 3 | 20 | 6 |
| | | 2 | 20 | 7 |
| | | 4 every other joint | 39 | 22 |
| | Set-45, Roadpatch, Horn 240 | 4 | 30 | 17,18 19 |
| | | 4 | 98 | 20,27 29 |
| | Portland cement concrete | 3 | 45 | 25 |
| | | 2 | 44 | 23 |
| Double bars | Set-45, Roadpatch, Horn 240 | 8 | 30 | 8,9,10 |
| | Polymer concrete | 8 | 10 | 12 |
| | | 8 | 20 | 11,14 |
| | | 5 | 5 | 15 |
| | Portland cement concrete | 5 | 10 | 34 |
| | | 4 | 5 | 16 |
| | | 3 | 10 | 33 |

## PATCHING MATERIALS AND LOAD TRANSFER DEVICES

A combination of five types of load transfer devices and seven patching materials was used in the test installations. All but two of the seven patching materials were used in short sections specifically placed to evaluate those materials.

The success or failure of a load transfer system depends on the performance of both the load transfer device and the patching materials. The following criteria must be met for a load transfer system to provide long-term performance:

1. The patching material and device must have sufficient strength to carry the required load;
2. Sufficient bond must be achieved between the device and the patching material to carry the required load;
3. Sufficient bond must be achieved between the patching material and the existing concrete to carry the required load;
4. The device must be able to accommodate movement caused by thermal movement of the concrete slabs;
5. The bond between the device and the patching material must be sufficient to withstand the forces due to thermal movement of the concrete slabs;
6. The patching materials must have little or no shrinkage during curing; shrinkage of the patching material can cause weakening or failure of the bond with the existing concrete; and

7. The patching material must develop strength rapidly so that traffic can be allowed on the slabs in a reasonable length of time (3 to 4 hr).

## Patching Materials

Three types of patching materials were used to secure the load transfer devices: special quick-setting materials, polymer concretes, and high early strength portland cement concrete. The special quick-setting materials consisted of two brands of magnesium phosphate-based materials (Set 45 and Horn 240) and one fiberglass-reinforced portland cement-based material (Road Patch). The polymer concretes consisted of three brands of methyl methacrylate-based material (Concresive, Silikal, and Crylcon). The portland cement concrete used Type III cement, calcium chloride, and aluminum powder to improve setting times and reduce shrinkage.

A thorough laboratory evaluation or trial installation should be made of any patching material that is to be used in a load transfer system. Working time, bond strength, rapid early strength gain, and shrinkage are prime factors that must be evaluated before a patching material is chosen.

## Load Transfer Devices

### Georgia Split Pipe Device

This device was developed by the Georgia DOT Office of Materials and Research personnel and is shown in Figure 1. To install these devices the two sides of the "split pipe" are epoxied to either side of the 4-in.-diameter core hole and the epoxy is allowed to set. The top and bottom plates rest on the top and bottom edges of the two split pipe pieces. The four bolts are tightened and the load transfer between the slabs is carried by the four bolts and the epoxy bond between the split pipe pieces and the concrete core hole surfaces. Thermal expansion movement is accommodated by the slippage of the top and bottom plates on the end of the split pipe pieces.
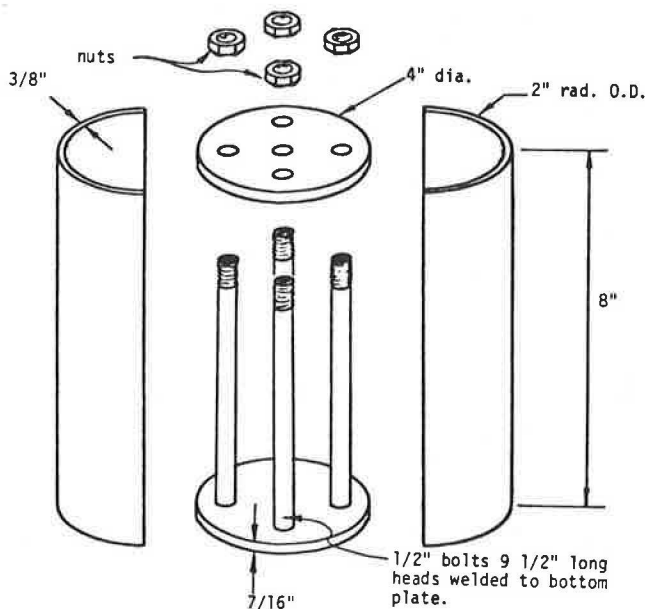


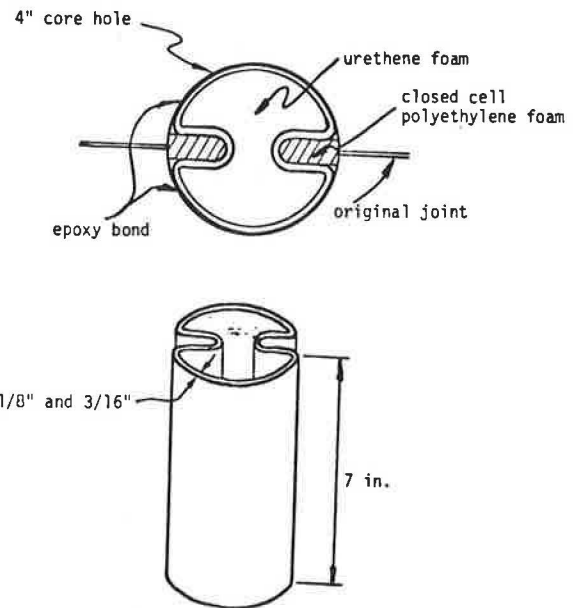FIGURE 1 Georgia split pipe device.



FIGURE 2 Figure eight device.

### Figure Eight Device

This device is a single piece cylindrical metal shell formed in the shape of the numeral eight as shown in Figure 2. The device is installed in a 4-in.-diameter core hole and epoxy is used to bond the device to the walls of the core hole. The center of the device and the indentations on the side are filled with foam to keep out debris. The device has previously been used experimentally in France (4).

### Vee Load Transfer Device

This type of load transfer device was first proposed in a report published by FHWA in 1977 (3) along with the figure eight device. The device consists of a 1/4-in.-thick steel plate bent into the shape of a V as shown in Figure 3. The device is not commercially available and was specially fabricated for this research project.

To be able to install the vee device, two 6-in.-diameter core holes have to be drilled and then filled with a patching material after installation. The vee portion was filled with urethane foam and a thin layer of polyethelyne foam was placed around the outside of the V to allow for expansion and contraction of the slab. An additional piece of foam was used to reestablish the joint.

### Double Vee Load Transfer Device

This device is essentially two vee devices placed back to back and downsized to accommodate installation in a 6-in. core hole. The device was designed and initially tested at the University of Illinois (5) and is now commercially available under the trade name of LTD Plus. Some minor additional design changes to the device shown in Figure 4 have taken place since its use in this research project. The center section of the device is filled with foam to keep out debris and a thin foam pad is placed around the outside of the vee portion to allow for expansion and contraction. The devices used in this project are epoxy coated to prevent rusting and current devices are manufactured from stainless steel.
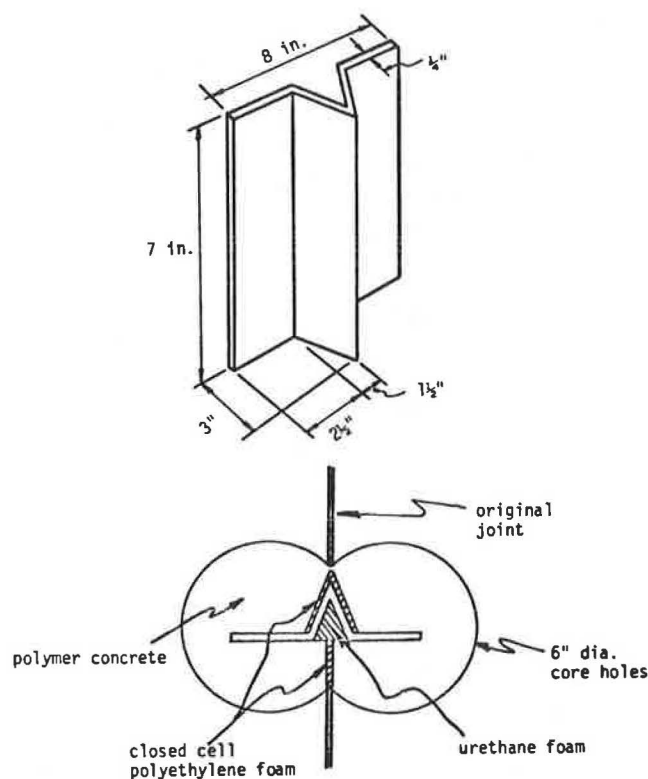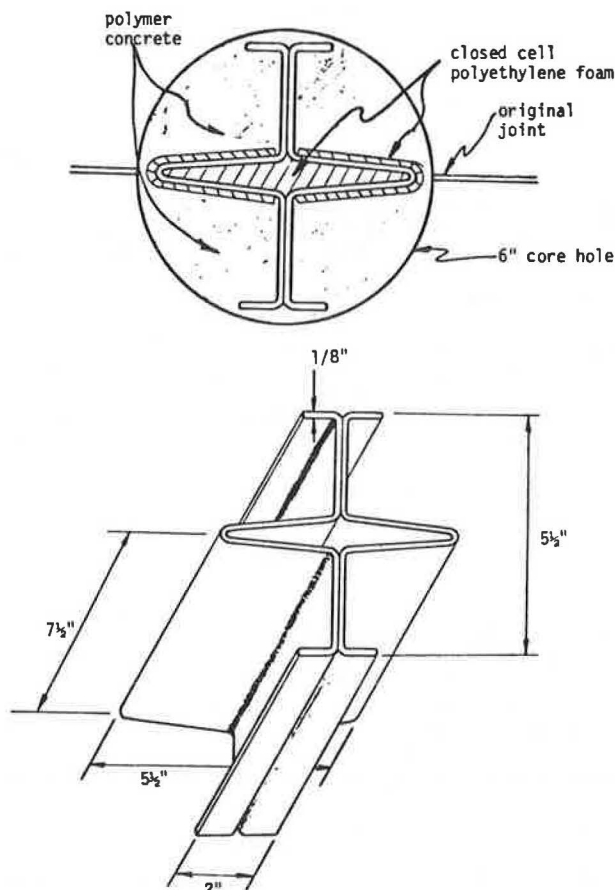
FIGURE 3  Vee device.



FIGURE 4  Double vee device.

Dowel Bars

Dowel bars are the most widely used load transfer device in new construction and were also used on this research project. The dowel bars were plastic-coated steel bars 18 in. long and 1 1/4 in. in diameter. The dowel bars were placed on chairs in the slots. Foam material was used to reestablish the joint over the bar when the patching material was placed.

CONSTRUCTION OF TEST SECTIONS

The first 22 test sections were constructed during the summer of 1981 and the remaining sections were placed during 1982. The 1982 test installation procedures were based on the most promising results from the 1981 installation.

The construction consisted of coring holes for all the devices or cutting slots for placement of the dowels. Four-in.-diameter holes were cut for the split pipe and figure eight devices. Six-in.-diameter holes were cut for the double vee devices, and two overlapping 6-in. holes were cut for the vee device. The slots were cut using a single bladed saw making four passes approximately 1 in. apart.

Placement of the devices and patching materials was done in accordance with the manufacturer's recommended procedures regarding cleaning the concrete, mixing time, use of primers, and so forth. The joint over each device was reestablished with a 1/2-in.-thick closed cell foam material during placement of the patching material.

Problems were encountered in 1981 with the placement of some of the polymer concrete. Some chemical components of the polymer concrete are sensitive to heat and had deteriorated. This chemical deterioration caused this polymer concrete to stay uncured. The low viscosity of the liquid component of the polymer concrete also posed a problem. This liquid component drained out of the polymer mix under the slab. This left a weak material near the top of the core hole. This problem became apparent after the 1981 installations when the material above the load transfer devices showed signs of raveling under traffic. This problem with the polymer concrete liquid component repeated itself in the Silikal test section in 1982. The liquid component "ran out" of the solid components, reducing to some degree the effectiveness of the material.

When the Crylcon test section was placed, precautions were taken to avoid the run out problem. Plaster was mixed and placed in the bottom of holes to seal any cracks and loose base material. When the Crylcon polymer concrete was placed in the holes run out did not occur and all material placed cured properly.

It was initially believed that a carbide-tipped cutting tool could be used successfully to cut slots for dowel bars in concrete at a reasonable rate of production.

A special mandrel was built by the CMI Corporation for a Rotomill PR-275-RT, which was owned by the Georgia Department of Transportation. The mandrel contained four rows of cutting teeth designed to cut slots 5 1/2 in. deep, 4 1/2 in. wide, and 15 in. apart center to center.

Before the Rotomill was placed on the Interstate test sections, a trial installation was attempted on US-41 near Macon, Georgia, in May 1981. One pass of four slots each was made in three joints before the trial was halted. Several problems were immediately apparent:

• The maximum depth of the slots that could be

cut was 3 1/2 to 4 in. due to physical restraints of the Rotomill.

• Excessive spalling occurred at the edges of the slots and at the joints themselves, which would make patching of the slots difficult.

• The machine endured excessive vibration during the cutting process, which could have damaged the equipment if cutting had been done on a long-term basis. The excessive vibration could possibly have been overcome by the use of a larger and heavier machine. The weight of the PR-275 was approximately 37,500 lb.

• An excessive amount of water and debris was left on the pavement. Cutting the slots with the Rotomill would make it necessary to place the dowels and patch the slots before opening the road to traffic because of the width of the slots. The threat of inclement weather would also hamper construction because workers would have to be sure that the slots could be patched before work was begun.

In light of these factors, it was concluded that cutting slots using carbide-tipped cutting equipment was not feasible.

Slots were cut in the concrete pavement on the actual test sections on I-75 using 30-in.-diameter diamond blade saws. The slots were cut 5 1/2 in. deep and approximately 3 1/2 in. wide, and were centered across the joints at the spacings indicated in Table 2. The length of the slots was such that the bottom of the slots was 20 to 24 in. long.

The slots were generally cut with a single blade saw. Four cuts were made per slot, leaving three "fins." After sawing, the slots are left open to traffic, with the fins in place, for several days while other slots are being sawed. These fins had a life expectancy of one week or less before they began to break out and the open slot became a hazard to traffic.

Both the sawing of the slots and the manual removal of the fins was a time-consuming process because no equipment was available to do this operation on a production basis.

DATA COLLECTION PROCEDURES

The performance of the test sections was monitored through deflection measurements and visual observa-

TABLE 2  Load Transfer Test Section Device Spacing

tions. Deflection measurements were made using a weight truck with a 20-kip load on a dual-tired single rear axle.

The procedure for measuring the slab movement was to position dial gauges on both corners at the joint and zero the gauges. The dial gauges were mounted on a frame that sat on the shoulder. A loaded truck was then slowly moved forward onto the slab until the rear wheels were positioned within 3 in. of the transverse joint and close to the shoulder joint. The deflection on the loaded side and on the unloaded side of the joint was then recorded. The truck then moved ahead slightly to position the rear wheels just past the joint and the deflection at both corners was once again recorded.

Horizontal joint movement was measured at 100 joints in the test area to determine if any of the load transfer devices were restraining contraction and expansion movements. This horizontal movement was measured using pins set in the concrete across the joints.

Close-up visual examinations were made of each load transfer installation during each evaluation period to determine bond failures and spalling, cracking, or subsidence of the patching material. The condition of the concrete pavement slabs in the entire experimental area was also noted on strip charts during each performance evaluation.

## PERFORMANCE

### Load Transfer Capabilities

The main criterion for evaluating the performance of the load transfer devices is of course their effectiveness in lessening the effects of the discontinuity in concrete pavement that is caused by the presence of a joint. A standard method for determining this effectiveness is to compare the deflection of the loaded side of a joint to the deflection of the unloaded side of the joint under a static or dynamic load.

The amount of load transfer can be calculated by a method first used by Teller and Sutherland (6):

$$LT\% = [(2\,Du)/(Dl + Du)] \times 100 \qquad (1)$$

where

    LT = load transfer as a percentage,
    Du = deflection of unloaded slab, and
    Dl = deflection of loaded slab.

Joint efficiency is also used to describe the amount of discontinuity caused by a joint and is defined as follows:

$$JE\% = (Du/Dl) \times 100 \qquad (2)$$

Jointed concrete pavements in the field are constantly in vertical motion caused by changing temperature gradients in the concrete slab throughout a day. Slab corners are curled upward during morning hours and therefore lose contact with the subbase, and the reverse happens in the afternoon hours. The amount of load transfer that exists can change drastically throughout the day so that deflection measurements must be made several times during the day to determine load transfer values. If only one set of readings is to be obtained, the testing should be confined to the early morning hours when the highest deflections are likely to be encountered. Comparisons between test installations are only valid when the measurements are made at the time of maximum deflections and not when the slabs are curled down and

in maximum contact with the subbase. This is especially true for pavements that have been under traffic for some time and have developed small voids under the slab corners.

The location of the load at the joint for which the load transfer is to be determined is important because the slab at the approach side of the joint usually does not contain as large a void as could be the case under the leave side of the joint. In general, the deflections measured on the approach side of the joint are less than the deflections obtained on the leave side.

The manner in which the load transfer and joint efficiency ratios are calculated causes the results to be highly dependent on the magnitude of the deflections as shown in the hypothetical example that follows.

| Test Location | Deflection (mils) | | Joint Efficiency (%) | Load Transfer (%) |
|---|---|---|---|---|
| | Loaded Side | Unloaded Side | | |
| 1 | 6 | 1 | 17 | 29 |
| 2 | 10 | 5 | 50 | 87 |
| 3 | 35 | 30 | 86 | 92 |

The difference in deflections for all three joints in the preceding example is 5 mils, but the joint efficiency or load transfer becomes increasingly better with higher deflection levels.

From a performance standpoint, Test Location 1 in the example would be more desirable because it has low deflection levels yet fails to provide effective load transfer by the definitions given in Equations 1 and 2. The equations are meaningless for low deflection levels and a different approach must be used in analyzing the effectiveness of the various load transfer devices that were installed as part of this research project.

Because joint efficiency and load transfer percentages were not considered the best approach for analysis, another method was used. The deflection data obtained for this research project were analyzed in terms of maximum deflections and in terms of differential deflection between loaded and unloaded slab corners.

Deflections were obtained during three evaluation periods, January 1982, September 1982, and March 1983. Three sets of tests were made each time; one series was made early in the morning generally starting at 7:00 a.m., a second series of tests was run mid-morning starting at 10:00 a.m., and a third set was made in early afternoon starting at 1:00 p.m. The series of tests was done so as to be able to detect the changing deflection and load transfer conditions of the joints as they were affected by temperature changes and time of day.

The effects of seasonal changes on the load transfer conditions were evident from the three series of tests that were conducted at different times of the year and clearly showed that the higher deflections were obtained in September 1982 and always occurred in the early morning test series for all three evaluation periods. The deflections obtained with the load on the leave side of the joint also were generally larger than the deflection obtained on the approach side when loaded. The deflection data also show that the vertical movement measured in the early afternoon is generally negligible regardless of the magnitude of the movement measured in the early morning (Figure 5). Performance comparisons of the various load transfer systems were therefore based on deflections measured during the early morning hours when significant slab movements are likely to take place.
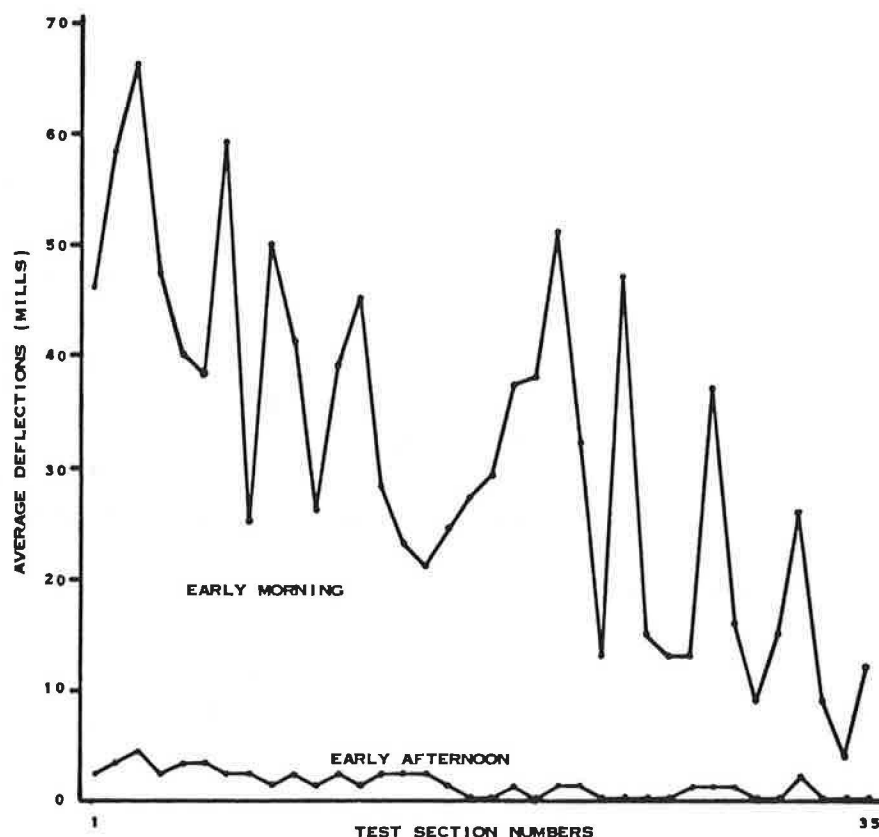
FIGURE 5   Deflection levels of leave slab corners, September 1982.

A low differential deflection value could indicate one of two conditions:

1. The loaded slab is in contact with the base and has a low total deflection value and transfer of load by means of a device is not necessary.
2. The load is being transferred across the joint to a large extent even though the maximum deflection of the slab may be large.

The field data also showed that, when there is a significant amount of interlock between adjoining slabs through mechanical or other means, the differential deflections are small and do not change much throughout the day regardless of the magnitude of the actual deflection.

The critical data for analysis are the deflections obtained during the early morning testing with the load placed on the leave side of the joint. The average differential deflection values for each test section are shown in Figure 6 for the March 1983 test period with the load placed on the leave slab. The bar charts in Figure 6 clearly show that all the sections with the dowel bars were performing well along with 10 of the 14 sections containing double vee devices. Section 4, containing the vee device, shows good performance on the bar chart; however, the data are suspect for this section for March 1983 because the deflection difference obtained in September 1982 was 35 mils. The March 1983 readings were generally much less than those obtained in September 1982 for sections showing poor performance. For the sections with good performance there generally was not much difference between the September 1982 and March 1983 differential deflection values. This is an indication of the seasonal influence on sections with little or no mechanical interlock. When adequate mechanical interlock is present, the

seasonal influences are minimized in a manner similar to that noted previously for daily temperature cycle changes.

The discussion so far has been confined to average deflection values for each test section. An average value, however, can be artificially inflated by a few poor-performing joints within a test section when only a small number of joints make up the section. The percentage of joints with a differential deflection value of 10 mils or less for each test section is given in Table 3 for the case with the load on the leave slab and early morning test results. The values for September 1982 for Sections 23 and higher, excluding control sections, represent initial values because they were obtained soon after construction.

The sections containing dowel bars are all performing well compared to the control sections regardless of the number of dowels per joint. Little difference can be noted between the sections with the split pipe, figure eight, and vee device and the control sections, which are all performing poorly.

The performance of the sections with the double vee devices varies: half of the sections show good performance and half of the sections show marginal to poor performance.

Horizontal Joint Movement Restrictions

Horizontal joint movement measurements were made to determine if any of the load transfer devices would prevent the joint from functioning in a normal manner with respect to daily and seasonal temperature changes. Joint movement data are similar to deflection data in that they can vary from joint to joint and from day to day for a joint over the same temperature range.
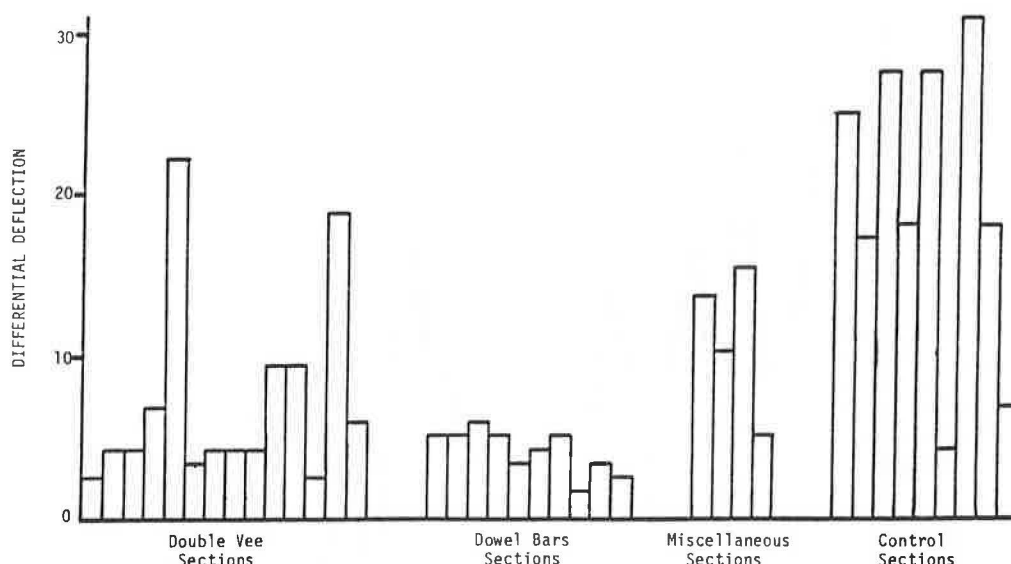
FIGURE 6   Differential deflection values in early morning on leave slab, March 1983.

TABLE 3   Percentage of Joints with Differential Deflections of 10 Mils or Less—Load on Leave Slab

| Test Section | Dl–Du | |
| | September 1982 | March 1983 |
| --- | --- | --- |
| Double vee | | |
| 5 | 85 | 95 |
| 6 | 70 | 65 |
| 7 | 20 | 30 |
| 17 | 70 | 70 |
| 18 | 50 | 40 |
| 19 | 90 | 100 |
| 20 | 90 | 90 |
| 22 | 71 | 76 |
| 23 | 95 | 75 |
| 25 | 98 | 98 |
| 27 | 95 | 93 |
| 29 | 100 | 91 |
| 30 | 90 | 90 |
| 31 | 90 | 90 |
| Dowel bars | | |
| 8 | 90 | 100 |
| 9 | 60 | 90 |
| 10 | 80 | 90 |
| 11 | 100 | 90 |
| 12 | 80 | 100 |
| 14 | 100 | 100 |
| 15 | 100 | 100 |
| 16 | 80 | 100 |
| 33 | 90 | 100 |
| 34 | 100 | 90 |
| Miscellaneous | | |
| 1 | 0 | 50 |
| 2 | 17 | 42 |
| 3 | 0 | 50 |
| 4 | 20 | 100 |
| Control | | |
| 10A | 33 | 33 |
| 13 | 0 | 20 |
| 18A | 17 | 17 |
| 21 | 0 | 33 |
| 24 | 0 | 10 |
| 26 | 90 | 80 |
| 28 | 0 | 10 |
| 32 | 0 | 38 |
| 35 | 50 | 80 |

Note: Dl = deflection of loaded slab and Du = deflection of unloaded slab.

The resistance to opening or closing of a joint by the various load transfer devices is of concern because slab cracking can occur if the expansion and contraction movements cannot be accommodated at the joints. It is also important because excessive stress can cause a bond failure of the patching material thereby rendering the load transfer device useless.

The general indication from the joint movement data is that double vee devices and dowel bars do not excessively restrict horizontal joint movement. Bond failure had already taken place for the split pipe, figure eight, and vee devices when the first tests were made in January 1982. The bond failure could have been caused by excessive restraint of the joint movement, failure of the patching materials, installation problems, or other causes.

No detailed analysis of horizontal movement trends and variations will be made in this paper because the only reason for obtaining the data was to determine excessive restraint of horizontal joint movement imparted by the load transfer devices.

## Visual Observations of Load Transfer Device Installations

Each of the load transfer installations was visually evaluated during each testing period. The items of concern are visible separations between the patching material and the devices or the pavement, loss of patching material, and cracking of the patching material.

Visual observations of the test sections have shown problems with disbonding between the patching material and the pavement on many of the double vee installations and on some of the dowel bar slots. The double vee installations with Horn 240 patching material have experienced cracking located over the fins of the device. Some transverse cracking at the end of the bars has been noted in the dowel installation with plain portland cement concrete as the patching material. To date, the best performing materials with the double vee are two polymers and plain portland cement concrete.

## Reduction in Deflection Levels

One of the objectives of the research project was to determine if corner deflections of concrete slabs

would be reduced by placing load transfer devices in the joint.

Determination of the amount of reduction that can be expected when load transfer systems are installed was a difficult proposition because the magnitude of joint deflection changes from day to day and from location to location even within short distances.

An estimate was made by comparing the deflection levels of "failing" joints to "good" joints within a section and by comparing the average deflection levels of joints that were performing well to control sections in the immediate vicinity. For comparison purposes a joint was considered to have failed to provide adequate load transfer when the differential deflection was more than 10 mils. The analysis was based on deflections obtained during the early morning testing conducted in March 1983 and only those joints where the load transfer systems are performing well were included in the analysis.

The short-term performance data indicate that a definite reduction in deflection levels can be obtained using mechanical load transfer. A reduction ranging from 50 to 75 percent was obtained in the dowel sections, and similar reductions were measured in the double vee sections, which were still performing well. To enhance the long-term performance of the joint, it is advisable to stabilize excessively moving slabs through undersealing before load transfer devices or dowel bars are installed. In Georgia a deflection value of more than 0.030 in. is considered excessive on the basis of past experience with undersealing of concrete pavements.

### Overall Performance

A rating of the performance of the various installations is given in Table 4. These ratings are based on the authors' interpretation of the percentage of joints having differential deflection values of 10 mils or less, the average differential deflection values, and the visual appearance of the installation obtained during the last comprehensive evaluation conducted in March 1983. The split pipe, figure eight, and vee devices all failed within the first winter and their performance rating is not included in Table 4.

A visual condition survey conducted in June 1984 indicated additional bond failures in the various test sections. The visual ratings indicate overall performance of the test sections and do not mean that each individual joint has failed in a "marginal" or "poor" performing section.

The ratings do indicate that the dowel sections are generally performing better than the sections with other load transfer devices. All the ratings are based on only 3 years of traffic, and long-term performance of any of the installations now rated as "good" is still in question.

### CONCLUSIONS

1. The success or failure of a load transfer system depends on both the device and the patching material. The patching material must develop sufficient strength and bond to allow the device to open and close and to withstand the vertical stresses imparted by the loads. The load transfer device must be able to accommodate horizontal joint movements without disbonding the patching material.

2. Commonly used formulas for calculating load transfer and joint efficiency are inadequate for conveying the true effect of a load transfer system. These formulas cause the load transfer value to be highly dependent on the magnitude of the deflection levels. The difference in deflection between the loaded and unloaded slab is a better indicator of the performance of the joint.

3. Analysis of the effectiveness of any load transfer at a joint should be based only on the deflection levels that are present during the early morning hours when significant slab movements are likely to take place.

4. The sections with the split pipe device, the vee device, and the figure eight device and some of the sections with the double vee have failed to provide adequate load transfer by the criteria used in this study.

5. The sections with the dowel bars, regardless of the number of bars per joint, are performing better than the other sections after 2 and 3 years of traffic although some failures are occurring. Horizontal joint movement measurements indicate that

**TABLE 4  Performance Ratings of Test Sections**

| Patching Material | Type of Device | Test Section No. | Devices per Joint | March 1983 Performance Rating | June 1984 Visual Rating |
|---|---|---|---|---|---|
| Set 45 | Double vee | 17 | 4 | Marginal | Marginal |
| | Dowels | 8 | 8 | Good | Good |
| Road Patch | Double vee | 18 | 4 | Poor | Poor |
| | Dowels | 9 | 8 | Good | Good |
| Horn 240 | Double vee | 19 | 4 | Good | Poor |
| | Dowels | 10 | 8 | Good | Marginal |
| Concresive | Double vee | 5 | 4 | Good | Poor |
| | | 6 | 3 | Marginal | Poor |
| | | 7 | 2 | Poor | Poor |
| | | 22 | 4 | Marginal | Poor |
| | Dowels | 12 | 8 | Good | Good |
| Crylcon | Double vee | 30 | 4 | Good | Good |
| Silikal | Double vee | 31 | 4 | Good | Marginal |
| Portland cement | Double vee | 20 | 4 | Good | Good |
| | | 23 | 2 | Marginal | Marginal |
| | | 25 | 3 | Good | Marginal |
| | | 27 | 4 | Good | Marginal |
| | | 29 | 4 | Good | Marginal |
| | Dowels | 11 | 8 | Good | Marginal |
| | | 14 | 8 | Good | Good |
| | | 15 | 5 | Good | Good |
| | | 16 | 4 | Good | Good |
| | | 33 | 3 | Good | Marginal |
| | | 34 | 5 | Good | Good |

the dowel bars and the double vee devices do not excessively restrict horizontal joint movement. Bond failures had already taken place for the split pipe, figure eight, and vee devices when the first horizontal movement measurements were made during the first winter cycle.

6. The short-term performance data indicate that a definite reduction in deflection levels can be obtained using dowel bars or double vee devices. The amount of reduction on the research sections ranged from 50 to 75 percent when the deflection levels of the good performing test sections were compared to control sections in the immediate vicinity. These data are based on short-term performance only.

RECOMMENDATIONS

1. The type of patching material to be used with a load transfer device must be given careful consideration and laboratory tests should be conducted on new materials to determine ultimate bond strength, rate of strength gain, working time, and other factors before any material is used on a construction project.

2. It is recommended that the core hole walls or slot walls be grooved or a rough wall be provided in load transfer installations to reduce the dependency on the bond between the patching material and the existing concrete to carry the load.

3. The core hole or slot must be thoroughly sealed on the bottom and along the side when polymer concrete is used as the patching material to prevent drainage of the liquid component in the polymer concrete mix.

4. Retrofitted load transfer installations should not be installed to reduce excessive deflections in slabs but should be placed to prevent high deflections from reoccurring when slabs have been stabilized.

It is desirable that vertical slab movement in excess of 0.030 in. measured during early morning hours be reduced through undersealing before the installation of any load transfer devices.

5. It is recommended that for dowel installations three dowels be placed in the outside wheelpath and two dowels be placed in the inside wheelpath with a dowel spacing similar to Test Section 34. When long-term performance data have been obtained it may be possible to eliminate the load transfer devices in the inside wheelpath. Four double vee devices per joint should be used on future installations.

6. Any future installations should be placed on an experimental basis until long-term performance data can be obtained on the current test sections. New installations are encouraged to provide additional performance data under a variety of traffic, weather, and design conditions.

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