Restoration of Joint Load Transfer

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Load transfer at joints and cracks in concrete pavements greatly affects faulting, cracking, and spalling. The restoration of load transfer has been attempted recently by several highway agencies. The results of field performance studies of 369 restored joints and cracks located in 9 states are presented. Four retrofit load transfer devices were evaluated: round steel dowels, double-vee shear devices (without precompression or grooving), figure-eight devices, and minature I-beam devices. Extensive field and office data were collected and analyzed. Models were developed to predict the relative performance of the devices. Results indicate that the round steel dowel bar did the best job of reducing faulting, and it showed no device or matrix failure. Additional research is under way to provide improved performance data. A recommended retrofit dowel design for joints and cracks is provided.

Many jointed concrete pavements have been constructed with no mechanical load transfer devices across joints (e.g., no dowels), and significant faulting has occurred on some of these pavements. Many others have dowels, but they have become loose and faulting has developed. In addition, many transverse cracks have become working cracks and developed faulting and spalling due to poor load transfer.

In an effort to extend the life of in-service concrete pavements that exhibit poor load transfer, highway agencies have begun to use various devices to restore joint or crack load transfer to an acceptable level to prevent further faulting and spalling and reduce deflections and pumping. Even if asphalt concrete overlays are placed, poor load transfer leads to rapid deterioration of transverse joint reflection cracks.

This study deals with the field performance of four load transfer restoration devices. The effectiveness of these devices has been evaluated in terms of the amount of faulting associated with the rehabilitated joints and cracks, and failure of the device or bonding matrix.

The overall goal of this study is to improve the design and construction of load transfer restoration devices. Four load transfer devices are evaluated:

- Retrofit conventional round steel dowels placed in slots (*1, 2*);
- Double-vee shear devices marketed by Dayton Superior Corporation (*1, 2*);
- Figure-eight devices, used in a Georgia project, that were originally experimented with in France (*3*); and
- Miniature I-beam devices used in New York (*4*).

DATA BASE AND DATA COLLECTION

The load transfer restoration data base incorporates design, construction, and performance variables for 13 uniform sections. These variables are in addition to the original pavement design, traffic, and climatic variables summarized by Reiter et al. (*5*). Figure 1 shows these load transfer restoration variables. In addition to monitoring the performance of the device itself, some measure of joint and sealant distress was also recorded. Also, faulting measurements were taken at 369 restored joints or cracks, and device performance ratings were taken on 1,525 individual devices.

General Description of Project

Thirteen uniform sections were located in nine states: Colorado, Georgia, Illinois, Louisiana, New York, Ohio, Oklahoma, Pennsylvania, and Virginia. These uniform sections were broken into 20 sample units that were up to 1,000 ft (305 m) long, where possible (Figure 2).

Load Transfer Restoration Design Variation

Load transfer restoration devices were placed and evaluated at five different locations in the pavement:

- Regular contraction joints at 15- to 100-ft (4.6- to 30.5-m) joint spacings (predominant location),
- Full-depth repair approach joints,
- Full-depth repair leave joints,
- Pressure relief joints, and
- Transverse cracks.

The devices were mainly placed in the outer traffic lane; however, some were installed in the inner traffic lane as well. From one to eight devices were installed at any given joint or crack. The restoration projects had been in service from 1 to 9 years at the time of the survey.

Traffic and Climatic Variation

The devices have withstood from 0.3 million to 5.9 million 18-kip (80-kN) equivalent single axle loads (ESALs) while in service. Annual loadings ranged from 0.3 million to 2.0 million ESALs. The projects were located in several climatic regions as shown in Figure 3 (*6*).

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LOAD TRANSFER RESTORATION

DATABASE DESIGN VARIABLES

- Project Identification Number and Sample Unit.
- Load Transfer Device Type.
- Frequency of Installation.
- Lane Restored by Load Transfer.
- Number and Location of Devices along Joint/Crack.
- Diameter and Length of Retrofit Dowel Bars.
- Backfill Material and Bonding Agent for Slot or Core Hole.

DATABASE PERFORMANCE VARIABLES

Overall Distress

- Project Identification Number.
- Sample Unit Number, Length, and Present Serviceability Rating.
- Foundation of Sample Unit (cut,fill,at grade).
- Condition of Drainage Ditches and Subsurface Drainage.
- Joint/Crack Station.
- Transverse Joint Type or Crack.
- Load Transfer Device Type.
- Lane Restored by Load Transfer.
- Number of Devices along Joint/Crack.
- Device Performance:
    - no failure.
    - material failure.
    - device failure.
    - debonding on approach side.
    - debonding on leave side.
    - debonding on both sides.

Joint Distress

- Transverse Joint Spalling on Approach and/or Leave Side.
- Corner Spalling on Approach and/or Leave Side.
- Corner Breaks on Approach and/or Leave Side.
- Pumping.
- Joint/Crack Faulting.
- Joint/Crack Width.
- Durability Cracking.
- Reactive Aggregate.

Sealant Condition

- Sealant Absent.
- Cohesion Failure.
- Adhesion Failure.
- Sealant Extrusion.
- Sealant Oxidation.
- Incompressibles in Joint.

FIGURE 1 Load transfer restoration data base design variables.

Performance Variation

Faulting measurements ranged from flat to 0.36 in. (0.91 cm), and the majority of the joints had less than 0.07 in. (0.18 cm) of faulting at the time of the survey. All of the projects that involved load transfer restoration had been diamond ground the same year. At any joint, anywhere from zero to eight devices were in good condition (i.e., showed no visible signs of failure) at the time of the survey.

DATA COLLECTION

The data base is comprehensive; it contains as many projects as were available or could be included with available resources. This was done to provide a wide range of data to facilitate analysis of performance and development of performance models. The projects included in the data base are believed to be most of the highway pavements that have undergone load transfer restoration in the United States. These pavements were surveyed between June 1985 and July 1986.

There were five basic data sets that were deemed necessary for the development of life prediction models and for analysis to aid in the development and improvement of design and construction procedures:

- Field condition data;
- Original pavement structural design and construction and subgrade soil classification;
- Rehabilitation design factors;

FIGURE 2 Location of load transfer restoration sample units by state.

		PRECIPITATION		
		WET	WET -DRY	DRY
TEMPERATURE	FREEZE	5	0	1
	FREEZE -THAW	2	2	0
	NO FREEZE	3	0	0
	TOTAL	10	2	1

NOTE: A total of 13 uniform sections were evaluated through condition surveys.

FIGURE 3 Climatic zone factorial for load transfer restoration, uniform sections.

- Historical traffic volumes, classifications, and accumulated 18-kip (80-kN) ESALs; and
- Environmental data.

The data sources and procedures used in the collection of each are described elsewhere (*5*).

FIELD PERFORMANCE AND EVALUATION

Field Performance

The performance of individual load transfer restoration devices was evaluated only in terms of visual characteristics. As a result, none of the load transfer devices were rated as having a "device failure" because the devices themselves cannot be seen. Some of the devices may well have failed; however, these failures are probably manifested by the other failure modes. It is interesting to note that the retrofit dowel

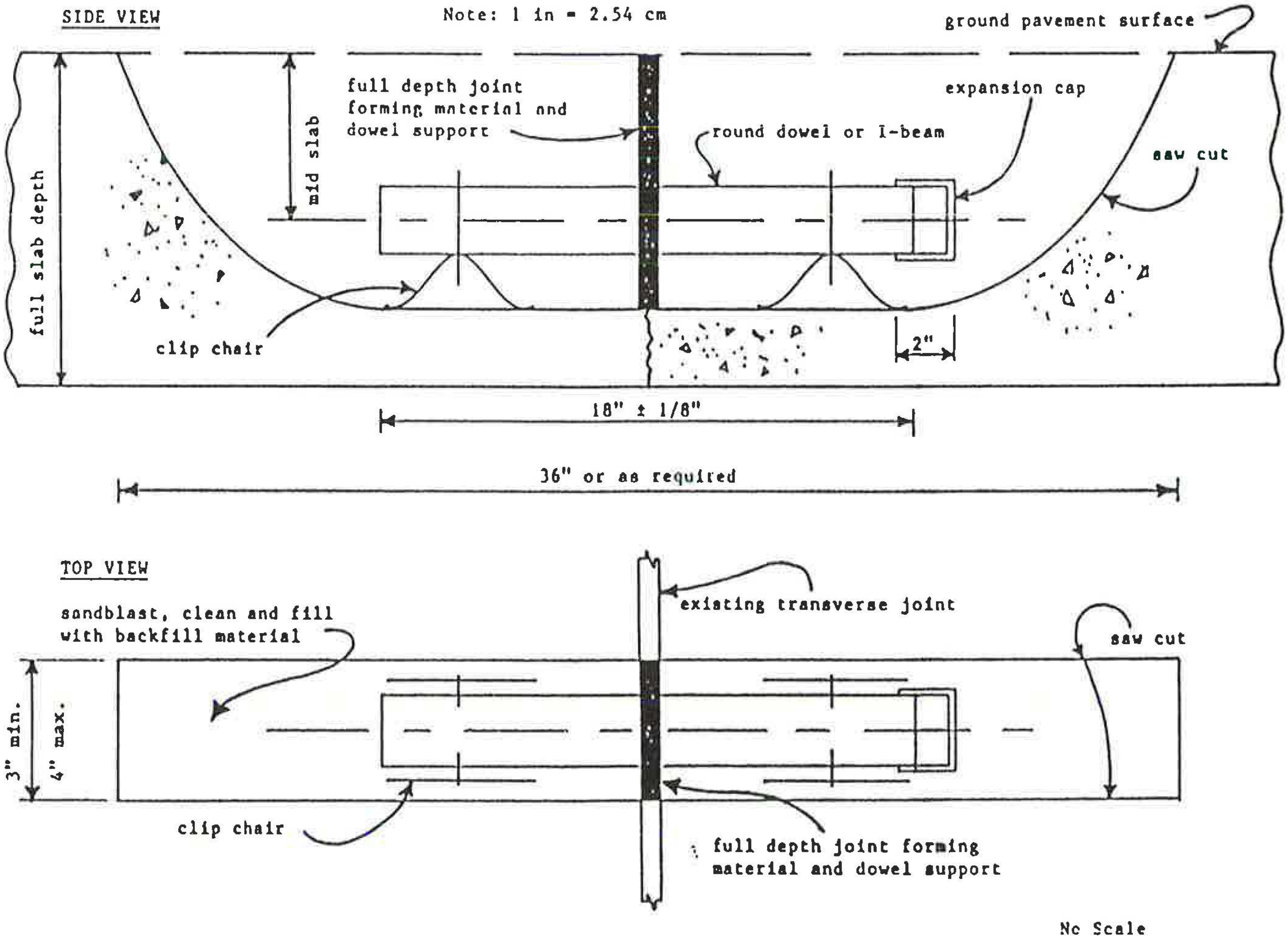


FIGURE 4 Diagram of retrofit dowel or I-beam device and installation.

bars and the miniature I-beam devices have similar performance characteristics. The same can be said of the double-vee shear and figure-eight devices. This is probably because both pairs of devices rely on similar mechanisms for load transfer restoration. It should be noted that some of these devices and their representative construction procedures have been modified and, it is hoped, improved since these installations. For example, the double-vee shear device construction procedure now recommends grooving the core walls and recompressing the load transfer device itself to improve performance; all of the shear devices in this study were uncompressed and ungrooved. The Florida Interstate 10 experimental study is evaluating the effectiveness of these construction modifications (*7*).

Retrofit Dowel Bar Performance

The performance of the retrofit round steel dowel bars, as shown in Figure 4, was measured in terms of two criteria:

- Faulting readings at 72 joints and
- Visual evaluations of 515 devices.

The mean faulting reading of the 72 joints restored with retrofit dowel bars was 0.04 in. (0.10 cm). This faulting occurred after an average of 2.62 million ESALs had loaded the pavements during an average 3.8 years of service. This mean faulting lies well below the failure criteria for faulting of 0.13 in. (0.33 cm), the point at which faulting affects rideability significantly (*8*).

Of the 515 retrofit dowel bar load transfer devices inspected, 507, or better than 98 percent, were in good condition (Figure 5). The most prominent mode of failure identified was material failure (1 percent or five devices) wherein the backfill matrix had been cracked or become loose and dislodged by traffic. Less than 1 percent of the joints were debonded on the approach, leave or approach, or leave side. None of the joints restored with retrofit dowel bars exhibited device failure or multiple modes of failure. Multiple modes of failure refers to the existence of two or more of the failure mechanisms given in Table 1 at any one device. The one exception to this is debonding at both the approach and leave sides of the same device. This was not recorded as a multiple mode of failure. Similarly, if a joint exhibited debonding on both the approach and leave sides of the same device, this was recorded in one category and not reflected under the individual failure modes of debonding approach side and debonding leave side so as to not record the failure twice.

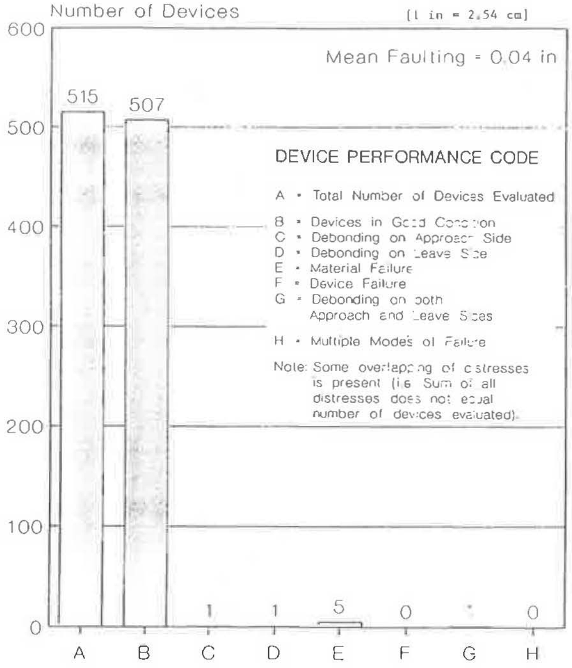


FIGURE 5 Distribution of retrofit dowel performance.

TABLE 1 PERFORMANCE SUMMARY FOR ALL DEVICES EVALUATED

	Dowel Bars	Double Vees	Figure Eights	I-Beams
Number of Devices	515	810	36	164
		Percentages		
Good Condition	98	72	75	99
Debonding Approach	<1	6	8	0
Debonding Leave	<1	4	6	0
Material Failure	1	9	8	1
Device Failure	0	0	0	0
Debonding Approach and Leave	<1	13	6	0
Multiple Modes of Failure	0	4	3	0
Average Faulting, ins.	0.04	0.07	0.08	0.13

Double-Vee Shear Device Performance

The performance of the double-vee shear devices (Figure 6) was measured in terms of two criteria:

- Faulting readings at 260 joints and cracks and
- Visual evaluations of 810 devices.

The mean faulting reading of the 260 joints restored with shear devices was 0.07 in. (0.18 cm). This faulting occurred after an average of 2.55 million ESALs had loaded the pavement during 2.5 years of service, on average. This mean faulting is approximately one-half of the failure criteria for faulting of 0.13 in. (0.33 cm), the point at which faulting affects ridability significantly (*8*).

Of the 810 uncompressed, ungrooved shear load transfer devices inspected, 583, or 72 percent, were in good condition (Figure 7). The most prominent mode of failure identified was debonding on both the approach and leave sides of the same device, which was found on 108, or 13 percent, of the devices. As was stated previously, this failure mode was recorded separately from the individual modes of debonding failure. Again, the Florida study is evaluating the use of device precompression and core wall grooving as remedies to this debonding mode of failure. None of the joints restored with

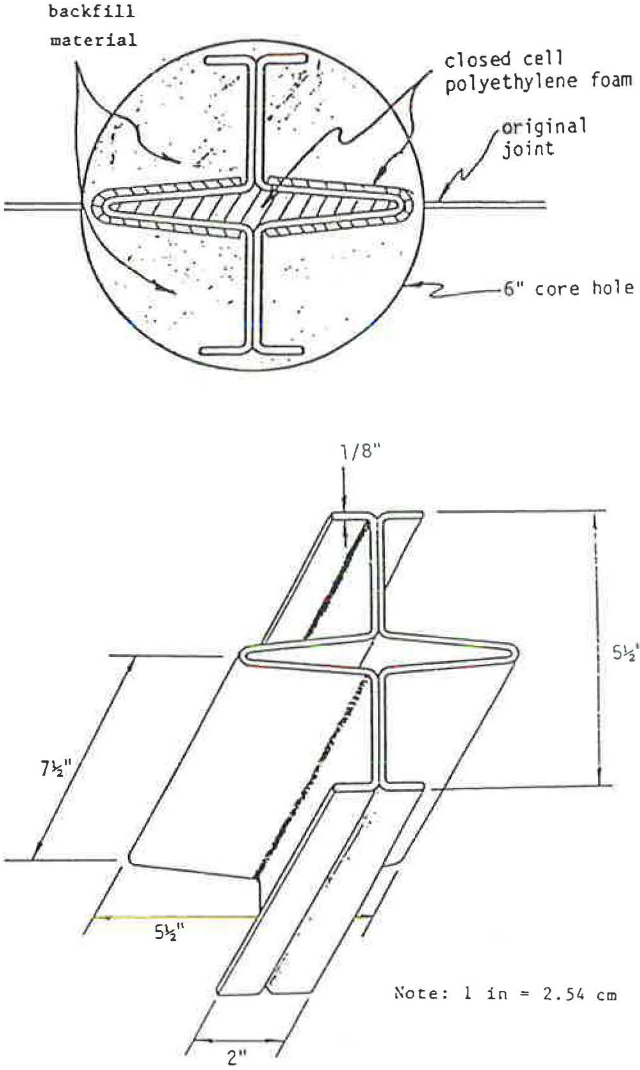


FIGURE 6 Diagram of double-vee shear device and installation.

shear devices exhibited device failure. Multiple modes of failure were identified at 4 percent of the devices.

Miniature I-Beam Device Performance

The performance of the miniature I-beam devices, as shown in Figure 4, was measured in terms of two criteria:

- Faulting readings at 23 joints and
- Visual evaluations of 164 devices.

The mean faulting reading of the 23 joints restored with miniature I-beams was 0.13 in. (0.33 cm). This faulting occurred after an average of 4.01 million ESALs had loaded the pavement during 2.0 years of service, on average. This mean faulting is equal to the failure criteria for faulting of 0.13 in. (0.33 cm), the point at which faulting affects rideability significantly (*8*).

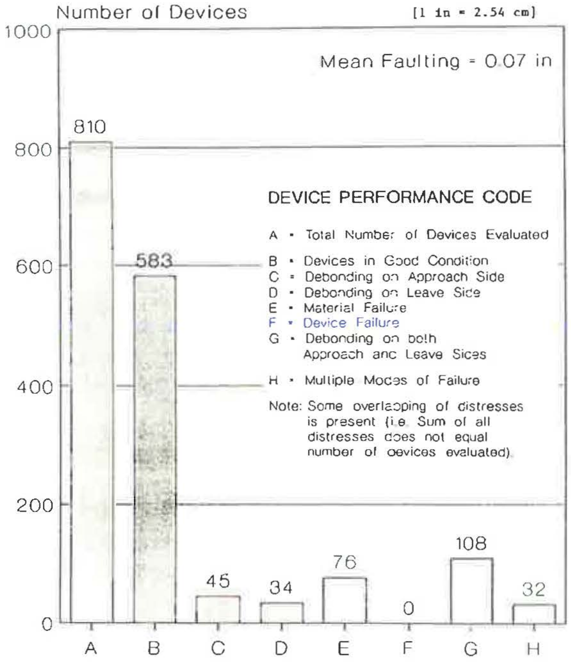


FIGURE 7 Distribution of double-vee shear device performance.

Of the 164 I-beam load transfer devices inspected, 162, or better than 98 percent, were in good condition (Figure 8). The most prominent mode of failure identified was material failure (about 1 percent or two devices) wherein the backfill matrix had been cracked or become loose and dislodged by traffic. None of the devices were debonded on the approach, leave, or both approach and leave sides. Also, none of the joints restored with I-beams exhibited device failure or multiple modes of failure.

Figure-Eight Device Performance

The performance of the figure-eight devices (Figure 9) was measured in terms of two criteria:

- Faulting readings at 8 joints and
- Visual evaluations of 36 devices.

The mean faulting reading of the 8 joints restored with figure-eight devices was 0.08 in. (0.20 cm). This faulting occurred after an average of 5.45 million ESALs had loaded the pavement during 9.0 years of service, on average. This mean faulting is approximately two-thirds of the failure criteria for

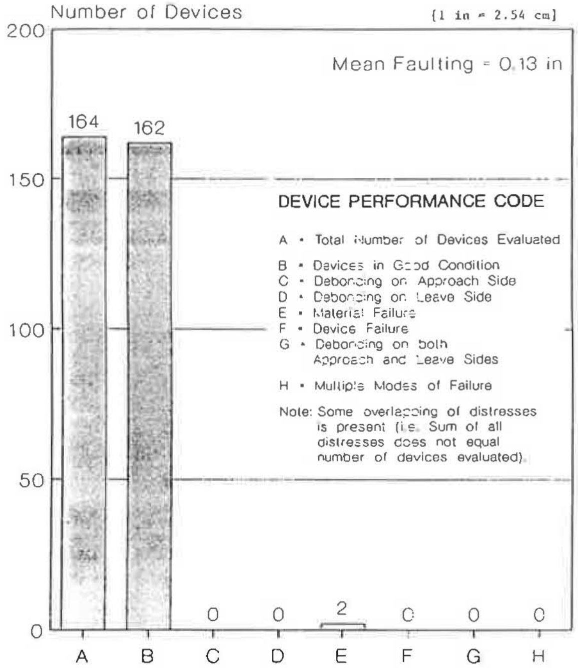


FIGURE 8 **Distribution of I-beam device performance.**

faulting of 0.13 in. (0.33 cm), the point at which faulting affects rideability significantly (*8*).

Of the 36 figure-eight load transfer devices inspected, 27, or 75 percent, were in good condition (Figure 10). The most prominent failure modes identified were debonding on the approach side and material failure. Both of these failure modes occurred at 8 percent of the devices. None of the joints restored with figure-eight devices exhibited device failure. Multiple modes of failure were identified at approximately 3 percent of the devices.

Performance Summary

Table 1 gives the four load transfer devices evaluated in this study along with their respective modes of failure. If a device had more than one failure mode, each failure mode was recorded separately. This resulted in a cumulative percentage greater than 100 percent. The entry entitled "multiple modes of failure" was established to help determine if any of the devices had deteriorated drastically and to provide a possible indication of the extent of device failure present (the devices themselves cannot be seen).

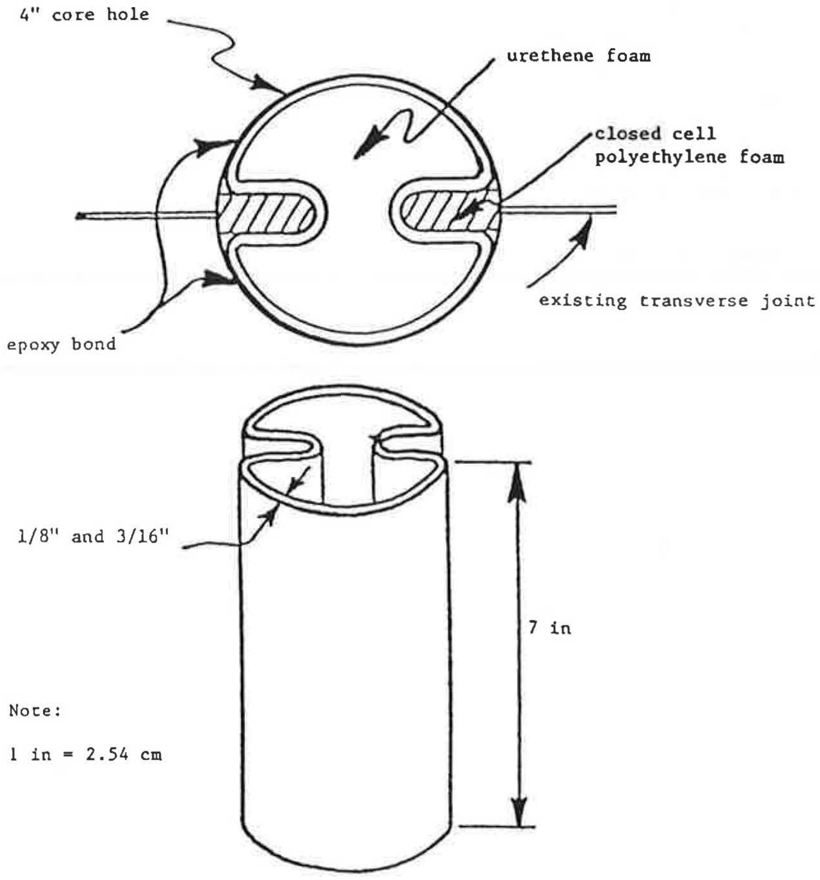


FIGURE 9 **Diagram of figure-eight device and installation.**

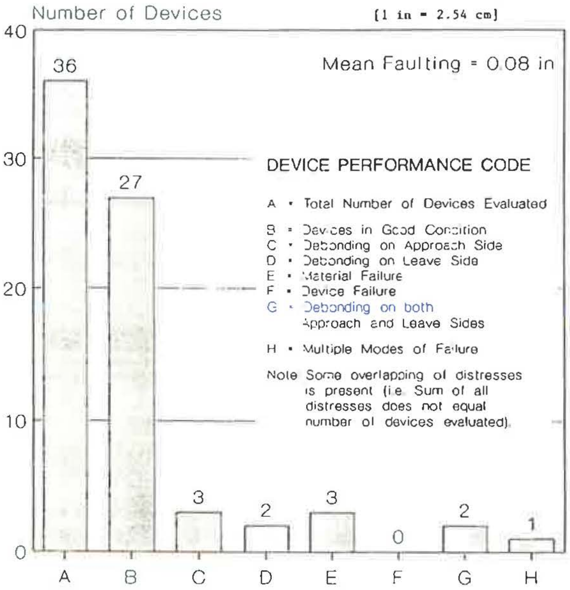


FIGURE 10 Distribution of figure-eight device performance.

PERFORMANCE MODELS

Model Development

A predictive model for faulting, after load transfer restoration, was needed to determine the effectiveness of the devices and for estimating future faulting. Regression analysis of the load transfer restoration data base was accomplished using the SHAZAM and SPSS (Statistics Package for the Social Sciences) statistical packages (*9, 10*). The initial analysis included all variables in the data base that were potentially meaningful for the performance of restored joints and cracks. The analysis resulted in the development of a performance model for joint and crack faulting.

Faulting Model

The model for the prediction of future joint or crack faulting from the time of load transfer restoration is given hereafter. It should be stressed that this model was derived from a data base in which all of the projects had diamond grinding performed at the joints or over the entire project length in the same year as load transfer was restored. To develop the model, all of the projects in the grinding data base and the load transfer data base were used.

Joint Faulting

$$FAULT = -5.62\,(ESAL + AGE)^{0.540}\,[5.85\,(DRAIN + SUB + 1)^{0.0529} - 3.8 \times 10^{-9}\,(FI/100)^{6.29} + 0.48\,(THICK + PCCSH)^{0.335} + 0.1554\,BASE - 7.163\,JSPAGE^{0.0137} + 0.136\,DOWEL + 0.003\,SHEAR - 0.027\,FIG8 - 0.316\,IBEAM]/100$$

where

$FAULT$ = mean faulting of the restored, ground joints or cracks (inches);
$ESAL$ = equivalent 18-kip (80-kN) single axle loads accumulated on the restored, ground joints or cracks (millions);
AGE = age of the restored, ground joints or cracks (years);
$DRAIN$ = 0 if subdrainage is present currently (whether installed initially or incorporated in the rehabilitation) and 1 if no subdrainage is present;
SUB = 0 if subgrade is a fine-grained soil and 1 if subgrade is a coarse-grained soil;
FI = mean freezing index (degree days below freezing);
$THICK$ = thickness of the in-place concrete slab (inches);
$PCCSH$ = 0 if concrete shoulders are not present and 1 if concrete shoulders are present;
$BASE$ = 0 if granular base type and 1 if stabilized base type (asphalt, cement);
$JSPAGE$ = contraction joint spacing (feet);
$DOWEL$ = 0 if retrofit dowels are not used to restore load transfer and 1 if retrofit dowels are used to restore load transfer;
$SHEAR$ = 0 if double-vee shear devices (uncompressed, ungrooved) are not used to restore load transfer and 1 if double-vee shear devices (uncompressed, ungrooved) are used to restore load transfer;
$FIG8$ = 0 if figure-eight devices are not used to restore load transfer and 1 if figure-eight devices are used to restore load transfer; and
$IBEAM$ = 0 if I-beam devices are not used to restore load transfer and 1 if I-beam devices are used to restore load transfer.

R^2 = 0.30
SEE = 0.04 in. (0.10 cm)
n = 114 ground sections without load transfer restoration plus 368 load transfer joints

Range of Applicability of Equation

- *ESAL*: The accumulated ESALs ranged from a minimum of 0.225 million in Minnesota to a maximum of 7.812 million in South Carolina; most projects had accumulated fewer than 3.0 million ESALs.

- *AGE*: The range of project ages varied from a low of 1 year in Arizona, Illinois, Iowa, Louisiana, Pennsylvania, South Carolina, and Virginia to a high of 9 years in Georgia and South Carolina; most projects were less than 5 years old.
- *FI*: The freezing index ranged from a minimum of 0 in 9 southern states to a maximum of 1750 in Minnesota; a majority of the projects were exposed to a freezing index between 0 and 250 freezing degree days.
- *THICK*: The range in pavement thickness varied from a low of 7 in. (17.8 cm) in Minnesota to a high of 12 in. (30.5 cm) in Arizona; most projects had a 9- or 10-in. (22.9- or 25.4-cm) thick pavement.
- *JSPAGE*: The contraction joint spacing ranged from 15 ft (4.6 m) in Arizona, Arkansas, California, Minnesota, and Oklahoma to 100 ft (30.5 m) in Illinois; most projects were built with a joint spacing between 15 and 30 ft (4.6 to 9.1 m).

Note that all of the pavements incorporated into the regression analysis of load transfer restoration had also undergone diamond grinding of the entire pavement surface or localized grinding at the restored transverse joints.

A sensitivity plot is shown in Figure 11 for jointed reinforced concrete pavement (JRCP). The inputs for the pavement design variables were selected from a list of standard inputs considered representative of current trends in design parameters (*7*).

Faulting of both the jointed plain and jointed reinforced pavements increased rapidly initially and then leveled off as the pavements accumulated more loadings. This type of curve has been found for all types of new and restored pavements as well as full-depth repairs (*11*). The figure contains five curves for

- Retrofit dowels,
- Double-vee shear devices,
- Figure-eight devices,
- Miniature I-beam devices, and
- No devices (diamond grinding alone).

The plot shows that the retrofit dowel bars reduce faulting significantly from that obtained with grinding alone. The double-vee shear devices and figure-eight devices have practically no effect, and the I-beam devices appear to increase faulting. This increase, however, must not be taken literally because there is no physical reason for this result. It should only be concluded that the device has no effect on faulting according to the available data. These results are in response to the coefficients that were derived from the regression analysis. Similar results are shown in Figure 12 for JPCP, but without the I-beams because these devices were used only on JRCP. If 0.13 in. (0.33 cm) and 0.26 in. (0.66 cm) are used as faulting criteria for JPCP and JRCP, respectively, the following allowable loadings result from this model:

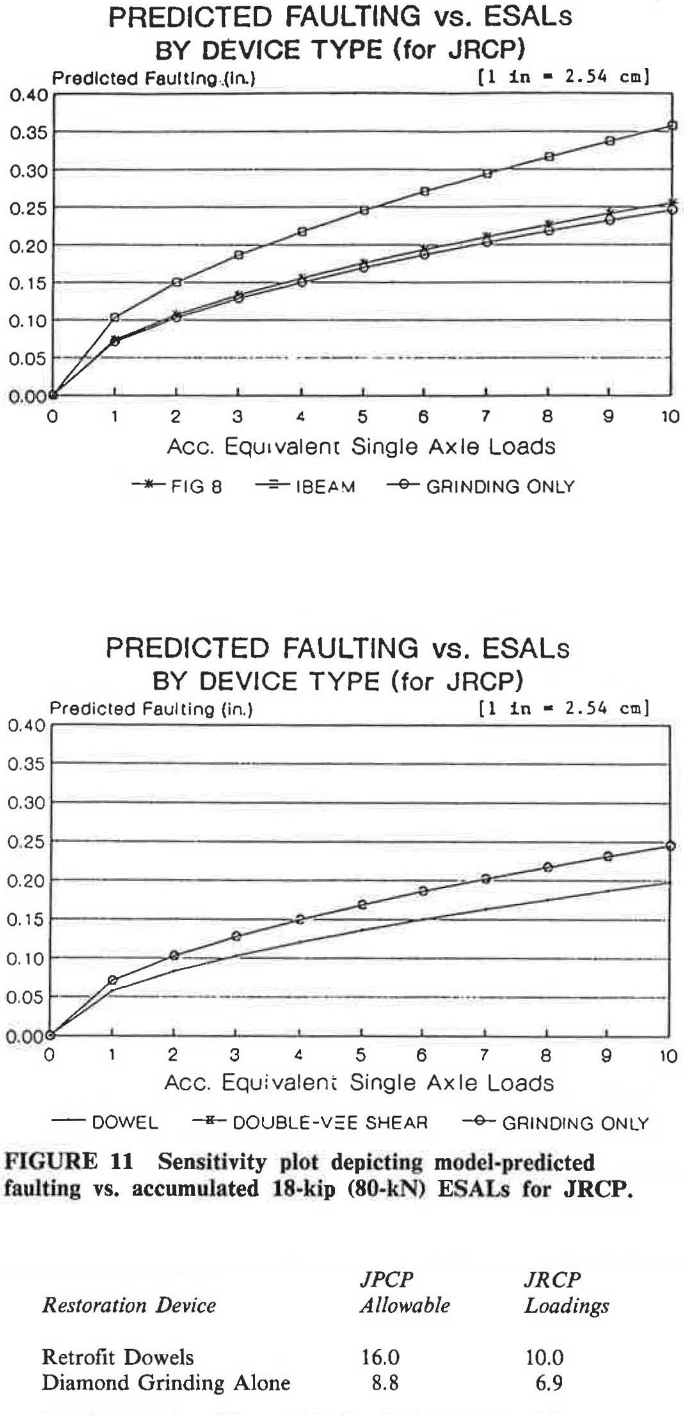


FIGURE 11 Sensitivity plot depicting model-predicted faulting vs. accumulated 18-kip (80-kN) ESALs for JRCP.

Restoration Device	*JPCP Allowable*	*JRCP Loadings*
Retrofit Dowels	16.0	10.0
Diamond Grinding Alone	8.8	6.9

Loadings are in millions of 18-kip (80-kN) ESALs (*8*)

The extension of life obtained with retrofit dowels is significant (almost double). Diamond grinding addresses only the symptoms of pavement deterioration (excessive faulting) without addressing the source of the deterioration, which may require load transfer restoration, subdrainage, and the like. If diamond grinding is used as a temporary repair strategy, it has been shown that faulting will develop at a rate greater than that of initial new pavement faulting (*7*). Load transfer restoration appears to be an effective means of extending the life of a restoration project.

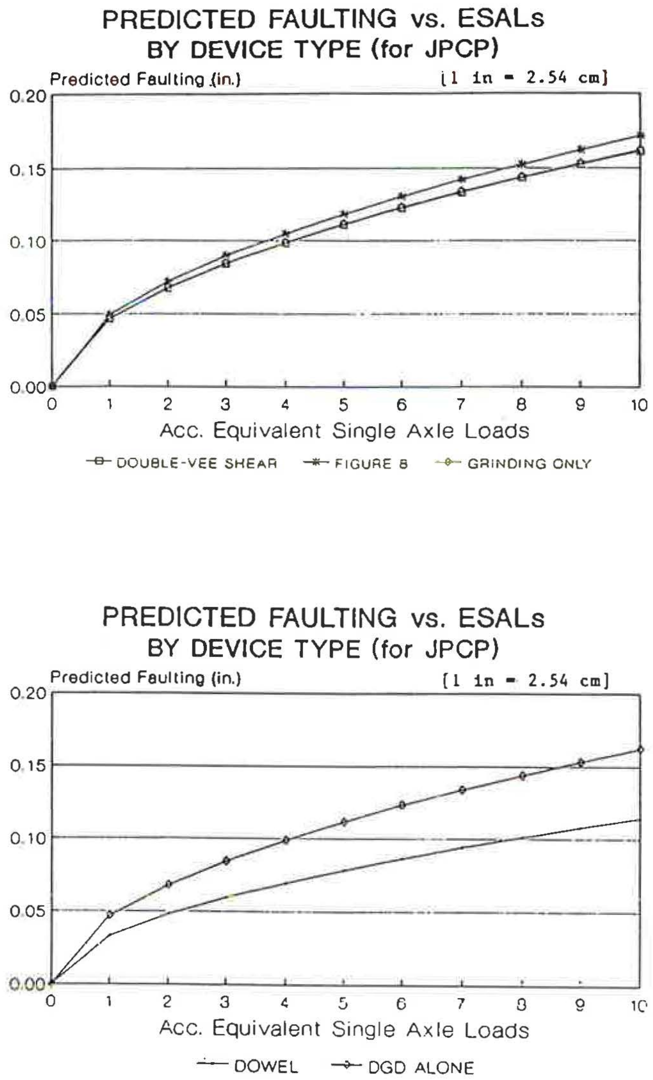


FIGURE 12 Sensitivity plot depicting model-predicted faulting vs. accumulated 18-kip (80-kN) ESALs for JPCP.

It is important to note that the projects in which double-vee devices were used did not include grooving of the core walls or precompression of the devices. These two modifications may or may not have a significant effect on performance of these devices and are currently under study at a Florida experimental section on I-10 near Tallahassee.

DESIGN AND CONSTRUCTION GUIDELINES

Guidelines were originally prepared under NCHRP Project 1-21 and published in NCHRP Report 281 (*2*). Further updates resulted from the research conducted under this study and are published elsewhere (*7*).

Restoration of load transfer across a transverse joint or crack can be used to retard further deterioration. Poor load transfer leads to joint or crack deterioration, including pumping, faulting, corner breaks, and spalling. Overlays placed over joints or cracks that have poor load transfer will soon develop reflective cracks that will spall and deteriorate into potholes.

Load transfer restoration is recommended for all transverse faulted joints or cracks that exhibit poor deflection load transfer of approximately 0 to 50 percent when measured early in the morning or in cool weather. Heavy load deflection devices that resemble regular traffic loads should be used for measurement. These recommendations are for jointed concrete pavements with or without asphalt overlays (*2*).

If deflection measurements are impossible, an indicator of poor load transfer is faulting of the joint or crack. Any joint with 0.10 in. (0.25 cm) of faulting or more will likely have poor load transfer.

Gulden and Brown (*1*) conclude that the following criteria must be met for a load transfer restoration system to provide long-term performance:

- The patching material and device must have sufficient strength to carry the required load.
- Sufficient bond must be achieved between the device and the patching material to carry the required load.
- Sufficient bond must be achieved between the patching material and the existing concrete to carry the required load.
- The device must be able to accommodate movement due to thermal movement of the concrete slabs.
- The bond between the device and the patching material must be sufficient to withstand the forces due to thermal expansion of the concrete slabs.
- 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.
- 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).

Results of tests conducted in Georgia, Florida, and other states show that the retrofit dowel bars can meet these requirements. Dowels, when properly constructed, were found to greatly improve existing load transfer (and reduce deflection) and to permit horizontal movement (or opening and closing) of joints (*1, 2*).

The number, diameter, and spacing of dowel devices must be determined. An analysis was conducted by Tayabji and Colley that determined that stresses and deflections for six dowels spaced nonuniformly in a joint (three in each wheelpath) were similar to stresses and deflections obtained for a joint with 12 uniformly spaced dowels (*12*). Placing retrofit dowels in the wheelpaths should provide similar performance and be more cost-effective.

The number, spacing, and diameter of the dowels will determine the amount of future faulting of the transverse joints. Several different retrofit dowel load transfer restoration designs were evaluated during this study. Table 2 gives these design variations and pertinent pavement factors.

Results from NCHRP Project 1-19 showed the significant impact dowel diameter has on faulting. Larger-diameter dowels slow down the development of faulting in new pavements.

TABLE 2 DESIGN VARIATIONS AND PERTINENT FACTORS

Devices in Wheelpath		Dowel Spacing (in.)	Mean Fault (in.)	Dowel Diameter (in.)	Accumulated ESALs (millions)	Joint Spacing (ft)
Outer	Inner					
4	4	15	0.04	1.25	5.45	30.0
3	3	12	0.09	1.25	1.49	15.0
3	2	18	0.03	1.25	5.45	30.0
4	0	18	0.01	1.25	5.45	30.0

NOTE: Faulting values pertain to the outer lane only, measured 1 ft in from the lane edge. 1 in. = 2.54 cm; 1 ft = 0.3048 m.

The larger dowels also showed less loss of load transfer in the Illinois I-70 full-depth repair study (*7*). Figures 13 and 14 compare joint faulting of new JPC and JRC pavements built with dowels of various diameters with joint faulting of similar rehabilitated pavements (either diamond griding alone or diamond grinding along with retrofit dowel load transfer restoration). These figures indicate that retrofit dowels reduce faulting; however, they do not do so to the same level as they do in newly constructed pavements. This probably occurs because the aggregate interlock is much less for an older pavement than for new construction.

The development of a mechanistic, empirical retrofit dowel design procedure is currently under investigation using the results from the Florida test site in addition to data from other states. The best recommendations that can be provided at this time follow:

1. Use dowel bars with diameters of at least 1.25 in. (3.2 cm) and preferably 1.50 in. (3.8 cm). For more heavily trafficked pavements that sustain 0.5 million ESALs per year in the outer lane, the 1.50-in. (3.8-cm) diameter bars should be used. The length of the bars should be 18 in. (46 cm).
2. Use three or four dowels placed in each wheelpath at 12-in. (30.5-cm) spacings.
3. The outermost dowel in the outer wheelpath should be located 12 in. (30.5 cm) from the outer lane edge.
4. Care must be taken to avoid any existing dowels in the pavement.

A recommended layout is shown in Figure 15 for retrofit dowel design.

Patch material used with load transfer devices is a critical factor in performance, particularly with shear devices. Sufficient bond must be established between the device and the patching material as well as between the existing concrete and the patching material to carry the applied loads and movement from thermal changes. Patching material must also develop strength rapidly to accommodate traffic and thermal stresses soon after placement.

Polymer concretes and high early strength portland cement concrete have been used in most installations to date. Polymer concrete material properties, fine aggregate gradation, and mix designs should be specified by the agency. A high early strength concrete mixture in conjunction with an epoxy applied to the existing slab was used successfully in Georgia (*1*). Aggregate gradation should meet the fine aggregate requirements of ASTM C33, Standard Specification for Concrete Aggregates. This allows the polymer concrete to easily

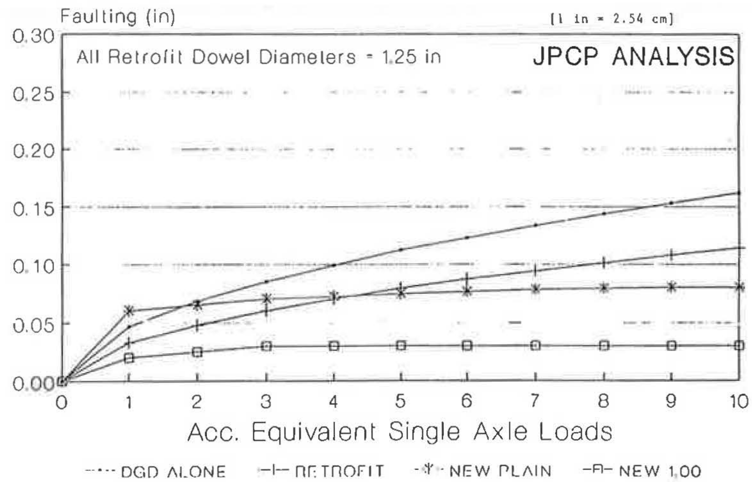


FIGURE 13 Comparison of JPCP joint faulting: new pavement vs. rehabilitated pavement.

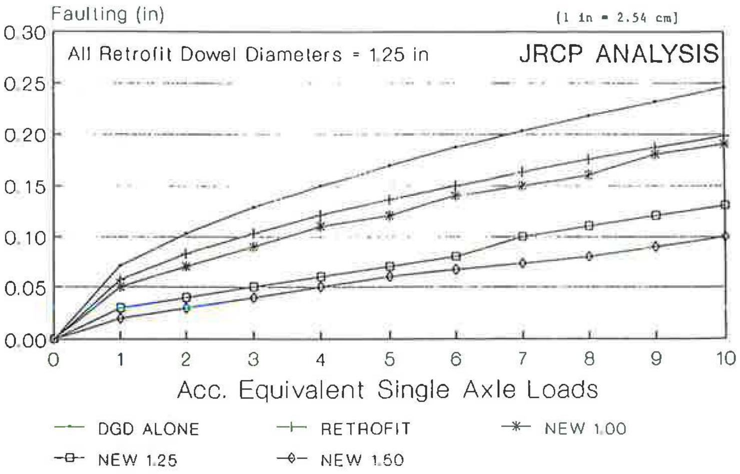


FIGURE 14 Comparison of JRCP joint faulting: new pavement vs. rehabilitated pavement.

fill the space. The mix design should allow the fine aggregate to be easily and completely coated.

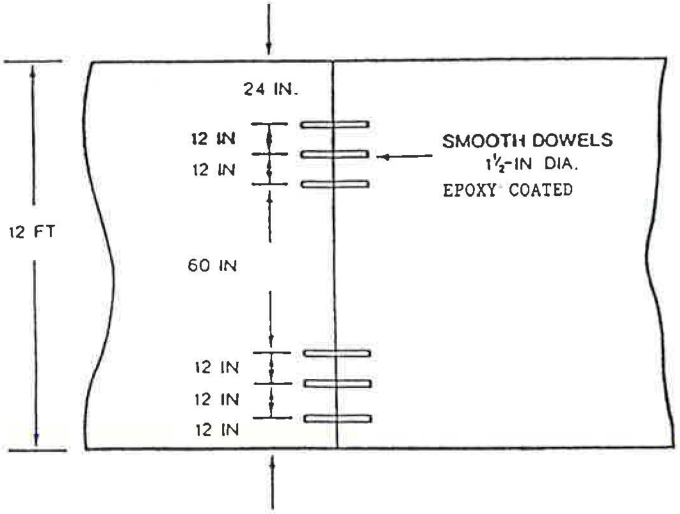
On the Florida test section a heavy-duty patch material (Trade name HD-50, manufactured by Dayton Superior Corporation) was successfully used for both the retrofit dowels and the double-vee shear devices. In addition, a ⅜-in (0.95-cm) top sized pea gravel extender was used for the dowels.

When dowels installed in slots are used, expansion caps should be specified. Coated dowels should be 18 in. (35.6 to 45.7 cm) long and of sufficient diameter to reduce faulting to an acceptable level, described in the section on design.

Slots for dowels should first be cut with multiple-blade saws (a ganged sawing assembly will allow for a more uniform and efficient sawing operation). The "fins" have a life expectancy of about 1 week, depending on width, before they break down and the open slot becomes a hazard to traffic (*13*).

Lightweight pneumatic hammers are then used to remove the concrete with minimal damage to the surrounding concrete. Sandblasting of the slots followed by airblasting to provide final cleaning should be performed.

Slots should be cut so that the dowels are allowed to rest



Note: For very heavy traffic, 4 dowels may be necessary in each wheelpath.

1 in = 2.54 cm
1 ft = 0.3048 m

FIGURE 15 Recommended retrofit dowel design for heavy traffic.

horizontally and perpendicular to the joint or crack at middepth of the slab. Each dowel should be placed on a support chair to allow the patch material to surround the dowel.

Dowels must be provided with filler board or styrofoam material at midlength to prevent the intrusion of patch material into the existing joint or crack and to form the joint in the kerf. To fill varying joint or crack widths over the project, multiple thin sheets of filler can be used. To keep joints or cracks free of material it is important to have a tight-fitting filler that matches the existing contraction joint width. Details of dowel placement are shown in Figure 4.

CONCLUSIONS AND RECOMMENDATIONS

1. This research study revealed that retrofit dowel bars did the best job of reducing faulting. The double-vee shear device (without precompression or grooving of the core walls), the figure-eight shear device, and the retrofit miniature I-beam device did not reduce faulting to any greater degree than did diamond grinding alone. All of the projects considered here had diamond grinding conducted as part of their rehabilitation strategies. The initial faulting, therefore, was zero in all cases, and direct comparison of the devices could be made. Device faulting performance is summarized in Table 3. The results of this analysis reflect a wide range of both project and rehabilitation design, in-service life, traffic loading, and climatic variables.

2. Faulting analysis of load transfer–restored and control joints clearly showed the benefit of some types of load transfer restoration as a rehabilitation technique for restricting the development of joint or crack faulting. As expected, load transfer efficiency at the Florida test site was greatly increased and deflections reduced through the use of load transfer restoration devices.

3. The most promising method of restoring load transfer to existing transverse joints and cracks is retrofit dowels. Results from test sites in Georgia and Florida, as well as from field tests, show that retrofit dowels can reliably reduce faulting. These dowels, when properly installed, were found to greatly improve the existing load transfer (and reduce deflections) and to permit horizontal joint movement (or opening and closing).

4. The retrofit dowels were more effective and reliable than the other load transfer devices. However, the contractor in Florida indicated that, as expected, the dowels were more difficult to install properly than were the double-vee shear devices (even when the shear devices required core wall grooving and precompression). Equipment manufacturers are currently developing more efficient means of cutting the slots and removing the concrete "fins."

5. The device performance evaluation indicated that the critical factor for any of the devices was the performance of the backfill material. Backfill material failure was either the most prominent or second most prominent failure mode for all of the four load transfer devices evaluated. This was evident even on the retrofit dowel bars and miniature I-beams, less than 2 percent of which exhibited any failure mode.

TABLE 3 DEVICE FAULTING PERFORMANCE

Device Type	Mean Fault in.	cm	Mean ESALs (millions)	Mean Age (years)
Retrofit dowels	0.04	0.10	2.6	3.8
Double-vee	0.07	0.18	2.6	2.5
Figure-eight	0.08	0.20	5.5	9.0
I-beam	0.13	0.33	4.0	2.0

6. The successful performance of load transfer restoration is controlled, as are so many other rehabilitation techniques, by the ability to identify and address the source of the deterioration. These distress mechanisms must be addressed and any deficiencies corrected before load transfer restoration. Typical rehabilitation work associated with load transfer restoration can require (a) localized subsealing to provide uniform slab support to compensate for a pumped subbase, (b) retrofit subdrainage to provide a positive way for infiltrated free water to more rapidly leave the pavement structure, (c) diamond grinding of the restored joints or the entire pavement to reestablish a smooth riding surface, and (d) joint resealing. Diamond grinding and joint resealing are done after the load transfer devices have been installed.

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