

**PRELIMINARY EVALUATION OF PROCEDURES FOR THE
ASSESSMENT OF LOAD TRANSFER ACROSS JOINTS AND CRACKS
IN RIGID PAVEMENTS USING THE FALLING WEIGHT
DEFLECTOMETER**

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Loss of load transfer across joints and cracks in rigid pavements is one of the major factors responsible for concrete pavement distress. This loss of load transfer has a significant influence on performance and thus on life cycle cost considerations of rigid pavements. It is therefore necessary to detect such defects in rigid pavements in their early stage so that the proper rehabilitation measures can be applied. For rigid pavement evaluation in order to determine the existence of such defects and the rehabilitation procedures necessary, the Texas SDHPT has recently purchased a number of Falling Weight Deflectometers (FWD) for use on the concrete pavements in the state. This study was primarily instituted to develop techniques for the analysis of FWD deflection data for the assessment of load transfer across joints and cracks of rigid pavements.

This paper describes the evaluation of procedures for the assessment of load transfer at transverse joints and cracks developed in previous studies, using FWD data collected on a controlled JRCPL laboratory test facility and a number of test sections on in-service pavements for their implementation in the field. These procedures are also applicable to the evaluation of longitudinal joints in rigid pavements, particularly rigid shoulder joints. The results of the analysis presented indicate that the FWD can be used effectively to assess load transfer across joints and cracks in rigid pavement. In some cases, however, more sensitive deflection sensors are necessary to detect the changes in load transfer at joints and cracks of concrete pavements in the field which, although of small magnitude, may be enough to result in significant distress at these discontinuities, with a consequent reduction in performance.

BACKGROUND

It has become increasingly necessary in recent years to develop methods for the efficient evaluation of in-service pavements using nondestructive equipment. Such evaluations are needed to assist pavement managers in the determination of the appropriate rehabilitation strategies for pavements required to maintain a high level of performance at the least cost and to evaluate the adequacy of the rehabilitation strategies that are applied to pavements.

For rigid pavements, such evaluations invariably require an evaluation of the joint systems which make up part of the pavement structure. In this instance, the term "joint systems" refers to the controlled transverse and longitudinal shoulder joints typical in rigid pavements, the transverse cracks which

develop in both jointed and continuously reinforced pavements, and the longitudinal joints between travel lanes. These joint systems or discontinuities represent the "weakest link" in rigid pavement structures and are the location of most of the distress that occur in such pavements. The ability of a joint system to efficiently transfer load across any such discontinuity will greatly influence the occurrence of distress. With inadequate load transfer the application of load on one side of the joint or crack leads to high slab deflections and the development of excessive stresses which invariably result in pavement distress, such as spalling, pumping, faulting, and corner cracking. Insufficient foundation support at the joint or crack will further compound the problem and contribute to still higher stresses and a higher rate of development of distress. Consequently, either by the action of installed load transfer devices or aggregate interlock, or both, good load transfer should be provided at the joints and cracks in rigid pavements to ensure a high level of performance. In most instances, this load transfer is achieved through a mechanism of shear transfer, as in the case of two-member dowel units and aggregate interlock, and to a lesser extent by moment transfer.

It is no surprise, therefore, that there is a considerable amount of on-going research to develop procedures for the assessment of load transfer across joint and cracks in rigid pavements. In most of such research, a comparison of the measured deflections on the slabs adjacent to a joint or crack when one slab is subjected to an application of a known magnitude of load has evolved as the measure most applicable in the field for the assessment of load transfer across joint systems. With the purchase of several Falling Weight Deflectometers (FWD) by the Texas State Department of Highways and Public Transportation (SDHPT), which can measure the deflections required for joint assessment, a study was initiated to develop procedures applicable in the field, for the assessment of load transfer across the joints and cracks of rigid pavements using the FWD. The three-fold objectives of the study are

1. the development of procedures for evaluating transverse joint efficiency in the field,
2. the development of a method to evaluate rigid pavement cracks for load transfer efficiency, and
3. the development of a method for the evaluation of longitudinal joints, especially shoulder joints, using the FWD.

To address these objectives, a considerable amount of data has been collected by the Center for Transportation Research

(CTR) at The University of Texas at Austin in a laboratory and field testing program supported by SDHPT. An instrumented jointed reinforced concrete (JRC) pavement research facility located at the Balcones Research Center (BRC) of The University of Texas was used for the laboratory part of the program, and field data has been collected from field test sections selected on a number of in-service rigid pavements in the state. This paper describes a preliminary evaluation of procedures initially identified for the assessment of load transfer across joints and cracks in the study.

DESCRIPTION OF LABORATORY TEST FACILITY

A plan view of the multipurpose instrumented JRC pavement research facility built for controlled testing is shown in Fig 1. The 10-inch-thick reinforced concrete pavement was placed on a 3-inch asphalt cement concrete base on a 6-inch-thick compacted crushed stone subbase over a 10-foot embankment of clayey gravelly sand compacted on an underlying natural rock layer. The pavement itself is comprised of a 39-foot 10-inch by 12-foot 6-inch large slab anchored in place, and an 18-foot 10-inch by 12-foot 6-inch movable small slab. The transverse joint between these two slabs is a specially constructed dowelled joint with two-member dowel units which make it possible for the small slab to be moved using a hydraulic ram system attached to one end of the small slab (Fig 1).

Load Transfer Studies

The dowel bar units are designed to provide variable load transfer at the transverse joint of the research pavement. The dowels are tapered to provide zero percent load transfer when the joint is fully opened and 100 percent load transfer when the joint is closed. The hydraulic ram system attached to the small slab is used to adjust the joint gap to allow variable load transfer at the joint. In all there are 13 dowel units spaced at one foot centers installed at the joint.

Void Studies

As indicated earlier, insufficient foundation support is detrimental to rigid pavements, especially at joints and cracks. To study the effect of a lack of support beneath pavement slabs on load transfer and provide an opportunity for the development of void detection techniques using the FWD, two 3-foot by 3-foot voids were created at the locations shown in Fig 1 to allow an examination of the effect of voids at the joint and edge of a pavement slab. The voids were formed by placing one-inch-thick foamed styrene layers into depressions formed in the asphalt concrete base prior to the placement of the portland concrete cement pavement. The foamed styrene layers were then subsequently dissolved to obtain the required voids which are approximately one-inch deep.

Environmental Data

Temperature and moisture variations in rigid pavements are known to result in slab movements commonly known as curling and warping. These movements are more pronounced at the joints, cracks, and edges of rigid pavements and have to be taken into account in the evaluation of load transfer at joints and cracks. The research pavement has thermocouples installed at depths of one inch from the top, one inch from the bottom and at middepth at each of the locations T_1 , T_2 , and T_3 in

Fig 1, which are used to monitor the temperature regime within the large slab. Moisture sensors are also installed under the test pavement at depths of 1, 4, and 8 feet from the surface and have been used to measure the moisture contents of the soil layers underneath the pavement. In addition a weather station and other facilities are available for monitoring environmental conditions, such as the ambient temperature, relative humidity, solar radiation, and wind speed.

LABORATORY TEST PROGRAM AND DATA COLLECTION

A wide range of tests were conducted on the research slab for the primary study. A Dynatest 8000 Falling Weight Deflectometer (FWD) was used for measuring deflections at the selected locations along the three defined test paths on the test pavement shown in Fig 2. Deflections at each location were measured with a 440-pound weight set-up dropped from four preset heights to give four peak loads ranging from about 4,500 to 20,000 pounds. The FWD sensor arrangement shown in Fig 3(a) was used for all the tests on the controlled test pavement. With an FWD load plate diameter of 11.81 inches (30 cm), the joint was approximately midway between sensors S1 and S2, and Sensors S3 and S1, respectively, for tests with the load upstream and downstream of the joint (Fig 4).

FWD testing on the controlled slab facility was comprised of tests for a 3-day period during which no major change in the weather condition was expected. Tests were conducted on one test path the first day, another the next day, and on the last the third day. As much as possible, tests on the test paths along the edges of the pavement were conducted on adjacent days. Two sets of tests were conducted on the test pavement. In the first set, tests on a path comprised of FWD tests at the upstream, downstream, and midspan locations shown in Fig 2 for an "opened-joint" condition which was followed by similar tests for a "closed-joint" condition. The whole sequence was then repeated at hourly intervals. The closed-joint condition was obtained by applying a 5,000 psi pressure to the joint via the hydraulic ram system, and this pressure was completely relieved for the opened-joint condition. The seven deflections for each of the four peak loads were obtained at each test location for these two joint conditions in a test. In the second kind of test, FWD measurements were conducted at similar test locations along the same test path in Fig 2 for joint openings varying in 1/8-inch increments from 0 to 1 inch. Environmental data comprised of ambient temperature, relative humidity, wind speed, and solar radiation were also collected at hourly intervals at the time of each test, and the temperatures within the slabs were obtained at hourly intervals via the thermocouples installed in the large slab, which were hooked up to an HP data acquisition system and microcomputer for automatic reading and recording.

To measure slab movements resulting mainly from curling due to temperature variations, tests have also been conducted in which linear variable displacement transducers (LVDTs), mounted on a wooden beam suspended across the width of the slab close to the transverse joint and also connected to the HP data acquisition system and microcomputer, have been used to record slab movements. The thermocouples are also hooked up to the HP system for the duration of this test to record the slab temperature.

FIELD TEST PROGRAM AND DATA COLLECTION

To permit an extension of the techniques developed in the laboratory study to the field, similar FWD tests have been conducted on nine selected JRC and CRC pavement test

sections on six representative in-service rigid pavements of the state's roadways. Four of these roadways are on the Interstate highway system and the remaining two are on U. S. highways. From the JRC pavements, data similar to that obtained from the laboratory program were collected for load transfer evaluation across transverse joints and cracks using the FWD sensor configuration shown in Fig 3(a). On the CRC pavements the same configuration was used to collect data at cracks for similar analysis.

These field test sections also provided the opportunity for the acquisition of data for the evaluation of longitudinal joints, namely shoulder joints and the joints between lanes. FWD measurements for longitudinal joint studies were made using the sensor configuration shown in Fig 3(b). These measurements were made with the longitudinal joints parallel to the direction of travel of the FWD and midway between sensors S5 and S1 or sensors S1 and S4, depending on whether the load plate was located on the shoulder or mainline, respectively.

As in the laboratory test program, at every test location the seven deflections for four peak loads were measured. The ambient temperature and solar radiation were also recorded at 30-minute intervals and the temperature within the pavement slab being tested was estimated from the temperatures measured from a portable slab with thermocouples installed at the top, middepth, and bottom, buried at the side of the roadway for the duration of the test. As in the test pavement the thermocouples were installed at depths of one inch from the top, middepth, and one inch from the bottom of the portable slab.

EFFECTIVE CHARACTERIZATION OF LOAD TRANSFER

As indicated earlier, efficient load transfer at a joint or crack is critical to the performance of rigid pavements. Consequently, effective procedures are necessary to characterize load transfer across joints and cracks, and the data collected for the main study are being used to achieve that purpose. As part of the study, therefore, a number of load transfer determination procedures were evaluated using the data collected on the research slab facility and the field test sections to determine the most appropriate measure for the effective characterization of load transfer at joints and cracks using FWD deflection measurements. Figure 4 illustrates the FWD load and sensor arrangement used for load transfer efficiency evaluation at transverse joints and cracks. The load and sensor arrangement used for load transfer efficiency evaluation at longitudinal joints is also shown in Fig 5.

Several load transfer efficiency determination procedures were evaluated. In a procedure developed in an earlier study (Ref 1) by the Center for Transportation Research (CTR), load transfer at a transverse joint and crack are characterized by a joint deflection ratio (JDR) and a crack deflection ratio (CDR), respectively. The joint deflection ratio or crack deflection ratio is the average of the upstream deflection ratio (UDR) and the downstream deflection ratio (DDR), which are the ratios of the deflections recorded by sensor 2 (S2) and sensor 3 (S3) for the upstream [Fig 4(a)] and downstream [Fig 4(b)] loading positions, respectively, with the largest deflection always as the denominator. For longitudinal shoulder joints, in order to characterize load transfer, a mainline deflection ratio (MDR) and shoulder deflection ratio (SDR) are calculated as the ratios of the sensor 4 (S4) to sensor 5 (S5) deflections (Fig 5), with the largest as the denominator, for the load located adjacent to the joint on the mainline and shoulder, respectively. Again a joint deflection ratio (JDR), calculated as the average of MDR and SDR, is used to characterize load transfer. This first procedure is referred to as Procedure A in this paper.

The second procedure investigated, referred to as Procedure B, is a modification of the preceding procedure developed at CTR. The modification made is based on the common practice of determining load transfer as the ratio of the deflection of an unloaded slab to the deflection of an adjacent loaded slab. Consequently, for the upstream load position at a transverse joint or crack [Fig 4(a)] UDR is calculated as the ratio of the deflection at sensor 2 (S2) to the deflection at sensor 3 (S3). Similarly, at the downstream load position [Fig 4(b)] DDR is the ratio of the deflection at sensor 3 (S3) to the deflection at sensor 2 (S2). JDR or CDR the average of UDR and DDR for joints and cracks, respectively, are used to characterize load transfer. For longitudinal joints MDR is calculated as the ratio of the deflection at sensor 4 (S4) to the deflection at sensor 5 (S5) for the mainline load position, and SDR as the ratio of the deflection at sensor 5 (S5) to the deflection at sensor 4 (S4) for the shoulder load position.

A third procedure looked at is a method suggested by AASHTO and commonly used in recent practice (Refs 2, 3, and 4), and is referred to as Procedure C. This procedure is also based on a ratio of the deflection of an unloaded slab to the deflection of an adjacent loaded slab, with the additional requirement that the deflections be measured at equal distances from the joint separating the slabs. Using this procedure, for the upstream FWD load position [Fig 4(a)] UDR is the ratio of the deflection at sensor 2 (S2) to that at sensor 1 (S1), and for the downstream load position DDR is similarly the ratio of the deflection at sensor 3 (S3) to the deflection at sensor 1 (S1). For longitudinal joints MDR is the ratio of the S4 and S1 deflections [Fig 5(a)] and for the shoulder load position SDR is the ratio of the S5 and S1 deflections. JDR or CDR is calculated as the average of UDR and DDR for transverse joints and cracks, respectively, and JDR for longitudinal joints as the average of MDR and SDR.

These three procedures were used in a preliminary analysis of the data collected to determine the most appropriate measure of load transfer efficiency. Two other procedures also considered were dropped from consideration for different reasons. One is a procedure suggested by Westergaard (Ref 5), which defines the percentage load transfer, LT%, as follows:

$$LT\% = \left\{ 1 - \frac{d_{jl} - d_{ju}}{d_{zl} - d_{zu}} \right\} \times 100 \text{ percent} \quad (1)$$

where d_{jl} and d_{ju} are the deflections measured on the loaded and unloaded slab at the joint, and d_{zl} and d_{zu} are the corresponding deflections that would occur at the same locations if the joint had no capacity for load transfer. The difficulty in determining d_{zl} and d_{zu} , especially in the field, where there is always some load transfer even when no load transfer devices are used at joints, made this procedure inadequate.

A second procedure dropped from consideration was based on a method used by Sharpe et al (Ref 6) for transverse joint evaluation of rigid pavements from Road Rater deflections. In this procedure, the percentage load transfer, LT%, is defined as follows:

$$LT\% = \frac{(dL_m - dU_m)}{(dL_j - dU_j)} \times 100 \quad (2)$$

where dL_j and dU_j are, respectively, the deflections of the loaded and unloaded slab at equal distances from a joint or crack, and dL_m and dU_m are the corresponding deflections at a midslab load position measured by the same sensors used for dL_j and dU_j , respectively. Unreasonable load transfer efficiencies were obtained using this procedure. Most of the calculated values, even in instances where near perfect load transfer efficiencies were expected, were less than 50 percent.

ANALYSIS

The first three procedures described in the preceding section were used in the analysis of a selected set of data to determine the most appropriate measure(s) for load transfer evaluation. Within the load range of operation of the FWD in this study, it was found that the calculated load transfer ratios were independent of the peak loads, especially for the last three drop heights, with corresponding average peak load levels ranging from about 9,000 to 20,000 pounds. The results of repeatability tests reported in Ref 1 also indicate less variability in measured FWD deflections for peak load levels in the range of 9,000 to 24,000 pounds with the variability somewhat decreasing with increasing peak load level. As a result the load transfer ratios reported in this paper were all calculated from the FWD deflections for the highest drop height corresponding to the highest peak load for a test. Load transfer data are presented for FWD tests at the transverse joint of the test pavement for the closed-joint and opened-joint conditions; at a transverse crack and joint in a field test section of a JRC pavement; at the selected cracks and shoulder joint of a CRC pavement whose flexible shoulder was replaced with a rigid shoulder; and at the transverse joint of the test pavement for increasing joint gap to illustrate the results obtained in the analysis.

Load Transfer at Transverse Joints and Cracks

As indicated some of the tests on the test pavement slab have been conducted for a closed-joint and an opened-joint condition, which were obtained by applying a 5,000 psi pressure to the dowelled joint and completely relieving this pressure, respectively. These conditions were selected to, in essence, simulate conditions at cracks and joints in rigid pavements, with the closed-joint condition representing conditions at a crack and the opened-joint condition representing conditions at a good but ordinary transverse contraction joint in rigid pavements, for example. Using the load transfer determination procedures A, B, and C described previously, the deflection ratios at the transverse dowelled joint of the test pavement at the void edge, midslab, and no-void edge test paths (Fig 2) were determined for these two joint conditions.

Tables 1(a), 1(b), and 1(c) show the deflection ratios obtained for the void-edge, midslab, and no-void-edge test paths, respectively, determined from an FWD test on the test pavement in a 3-day period. The tables also show the corresponding temperature differential across the test pavement at the time of the test for each deflection ratio. The temperature differentials were calculated as the difference between the average of the three top slab temperatures and the three bottom temperatures recorded by the thermocouples installed in the research pavement. There is some evidence that, in general, along each test path the load transfer for the closed-joint condition or "crack" is slightly higher than the load transfer for the opened-joint condition, which represents the condition at an ordinary transverse joint. The differences are, however, very small and, in fact, for each joint condition, the data did not indicate any effect due to temperature differential variation contrary to what has been reported (Ref 7).

By comparing deflection ratios with approximately equal temperature differentials, it can also be determined whether there are distinctions between the load transfer in the different test paths for similar joint conditions. Thus, for example, for a similar temperature differential range, load transfer at the void-edge from Table 1(a) can be compared to load transfer at the no-void-edge from Table 1(c) for the same joint condition, to determine the effect of voids on load transfer. Such

comparison indicated, contrary to expectations, that load transfer at the no-void-edge and void-edge of the test pavement is about the same for both the closed-joint (crack) and opened-joint (ordinary joint) conditions. The load transfer at midslab, however, is appreciably better for both joint conditions, as shown in Table 1(b).

All the three procedures for load transfer determination showed similar trends for the comparisons described. The load transfer values obtained using Procedure C are, however, slightly less than the values from the other procedures for the same test paths and joint conditions.

COMPARISON WITH FIELD DATA

To permit comparison with field data, similar results are presented in Tables 2(a) and 2(b) for FWD load transfer tests on one of the field test sections with characteristics similar to those of the test slab facility. This field test section on US 90 near Beaumont in Texas, is on the 12 foot 6-inch-wide outer-lane of the two eastbound lanes of a JRC pavement, with a sawed longitudinal joint separating the lanes. The pavement is comprised of a 10-inch slab on 4 inches of cement stabilized flexible base, all over a 6-inch lime stabilized subbase. FWD load transfer tests were conducted in the outer wheelpath and at midslab of the test section for three groups of a crack and an adjacent transverse dowelled joint. These tests in the outer wheelpath and at midslab are comparable to the FWD tests on the instrumented test pavement at the void-edge or non-void-edge and at midslab, respectively. The data in Tables 2(a) and 2(b) are for one of the groups of a crack and an adjacent joint and show the calculated deflection ratios at the crack and joint, and the temperature differential values determined as the difference between the top and bottom temperatures of portable slab buried at the side of the test section during the tests.

Comparison of the deflection ratios for the tests in both the outer wheelpath and at midslab in Tables 2(a) and (b), respectively, show that the load transfer at the crack and joint were not appreciably different for Procedures A and B. The load transfer is, however, shown to be higher at the crack in comparison to the load transfer at the transverse joint for the C procedure, especially for FWD measurement at midslab, which is in agreement with the results obtained from the test pavement. Cross comparisons of the deflection ratios within the same temperature differential range also indicate, as in the case of the tests on the test pavement, that at a joint or crack the load transfer at midslab is not any higher than the load transfer within the more traveled outer wheelpath. In general, especially at the joint, in both the outer wheelpath and at midslab the load transfer ratios calculated using procedure C were again lower than the load transfer ratios determined from the other procedures.

Load Transfer at Cracks in CRC Pavements

As part of the study, load transfer measurements were conducted on some CRC pavements to determine how the FWD could be used to evaluate transverse cracks in such pavements. A field test section on a CRC pavement used for this kind of evaluation was a section on the southbound lanes of U.S. Highway 59 east of Victoria, Texas, whose flexible shoulder was replaced with a 10-foot wide rigid concrete shoulder. The pavement comprises of an 8-inch-thick slab on a 6-inch cement stabilized subbase, all over a subgrade of untreated clay. The two 12-foot southbound lanes were separated by a sawed longitudinal joint at the centerline.

Among the various tests conducted on this section were FWD load transfer measurements conducted at nine selected cracks in the outer wheelpath of the outer lane for the three

shoulder conditions of the pavement with a flexible shoulder, without a shoulder, and with a rigid concrete shoulder. The deflection ratios determined for the nine cracks using the three load transfer determination procedures are shown in Table 3 for the three shoulder conditions. The temperature differentials estimated from a portable slab buried at the roadside during the tests are also given. From the table it is evident that the load transfer in the wheelpath was virtually unchanged for the three shoulder conditions. A check of the maximum deflections measured under the FWD load plate indicated that, in fact, the maximum FWD deflection measured under the load plate did not change much for the three shoulder conditions. The stiff cement stabilized subbase is believed to have played a major role. In this instance also, temperature change in the pavement did not have any appreciable effect on the load transfer across the selected cracks.

Load Transfer at Longitudinal Joints

FWD deflection measurements were also made at longitudinal joints of rigid pavements to evaluate them, using the load and sensor configuration shown in Fig 5. For the CRC pavement described in the preceding section, FWD deflection measurements were made at the shoulder joint at selected locations after curing of the rigid shoulder, with the load located on the mainline pavement and then on the shoulder as in Fig 5. Similar measurements had been taken at the same locations before the flexible shoulder was removed but with loading on only the mainline pavement. A comparison of the maximum FWD deflections under the load indicated that the deflections at the edge decreased considerably, as expected, with the replacement of the flexible shoulder. Deflection ratios calculated from the FWD tests with the rigid shoulder in place are presented in Table 4 for two pavement temperature differential ranges estimated from a buried portable slab. It is evident that the FWD can be used to obtain load transfer data similar to that for transverse joints and cracks for longitudinal joint evaluation. However, these data also indicate as before that the load transfer at the joint is not affected by temperature differential variation.

Effectiveness of FWD for Load Transfer Characterization

So far results have been presented for FWD load transfer tests for a variety of cases representative of the joints and cracks under evaluation in this study. It is apparent that except for a few instances the data presented are not in line with what has been observed in the field through a manifestation of certain pavement distress associated with a loss in load transfer at joints and cracks and a loss of foundation support. For example, pavement movements as high as 80 mils, representing the difference between the extreme vertical positions attained, have been recorded at both edges of the test pavement. Since curling movements are mostly recoverable, and this was found to be the case from the data collected, the movements can be attributed to curling due to temperature differential variations in the pavement. However, this recorded curling of the test pavement and, therefore, the temperature differential variations did not affect load transfer at the joint as indicated by the data presented.

The results of FWD load transfer tests on the test slab where the joint gap is varied in 1/8-inch increments from 0 to 1 inch, which by the nature of the design of the dowelled joint results in a load transfer of 100 percent when the joint is closed and zero percent (due to dowel action for the loads tested) when the joint is opened to about 3/8 inch, shed some light on such concerns. The variation of the load transfer with

increasing joint gap for such a test is illustrated in Figs 6(a) and 6(b) for various temperature differential ranges in the slab. Figure 6(a) shows the variation of the joint deflection ratio determined using procedures A and B, which turned out to be almost identical, and Fig 6(b) is a corresponding graph for ratios determined using procedure C all at the midslab of the slab. These two graphs illustrate that there were indeed distinct changes in load transfer at the dowelled joint with increasing joint gap and that the temperature differential in the slab had a definite effect on the measured deflections. Again as in other tests, the load transfer determined using procedure C, which is based on the ratio of the deflection on an unloaded slab to the deflection measured under the FWD load, is in most cases slightly lower in magnitude. However, a comparison of the graphs in Figs 6(a) and 6(b) show the trends in load transfer at the joint of the slab for the varying joint opening are nearly identical for all the three procedures for determining load transfer.

DISCUSSION

From the results of FWD tests on the test slab for an increasing joint gap, it is clearly shown that the device is capable of detecting changes in load transfer at a joint system. It is also apparent that, to a large extent, any of the procedures for determining the joint deflection ratios can be used in the assessment of load transfer at a joint or crack and they show similar trends. It is only a matter of establishing the load transfer ranges corresponding to the required performance levels for the different procedures. However, from the data presented for FWD load transfer tests on the test slab for the opened-joint and closed-joint conditions, and on the field test sections for cracks and joints in both JRC and CRC pavements, factors which are known to be of consequence in the assessment of load transfer could not be detected. In general, relatively high load transfer deflection ratios were obtained which did not change much with factors such as a temperature differential in the pavements. On the other hand, the effect of very similar temperature differential variation was clearly discernible in tests carried out on the test slab for increasing loss of load transfer. This points to the fact that the magnitude of change in load transfer at a joint or crack under different conditions has some bearing on the effectiveness of using deflection measurements from the FWD for the assessment of load transfer. It appears that, for thick, very stiff pavement sections, the deflection sensors on the FWD used for the tests were not sensitive enough to permit the detection of changes in load transfer due to environmental effects at most of the joints and cracks. Consequently, attempts are being made to find more sensitive sensors which will provide the opportunity to detect the not so drastic changes in load transfer at joints and cracks in the field, which all the same may lead to distress. With the availability of such sensors the techniques for interpretation of FWD data developed can be applied to the evaluation of load transfer across joints and cracks to determine whether treatment is needed before rehabilitation decisions are made.

CONCLUSIONS

From the data and analyses presented in this paper, it is concluded that FWD deflection measurement at cracks and joints and deflection based parameters can be used to assess the transfer of load across these discontinuities. In many instances, however, the change in load transfer at the joints or cracks in the field are of such small magnitude that the effectiveness of the assessment procedures may be dependent on the sensitivity of the sensors used for the tests. Based on the analyses of the

data obtained in this study, Procedure C (AASHTO) is recommended for joint and crack evaluation as the procedure provides the more conservative results.

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Table 1(a). Comparison of joint deflection ratios, percent, at void edge of test pavement for closed and opened joint conditions.

Temperature Differential (DT), °F	Joint Deflection Ratio, Percent, for Closed Joint Condition			Joint Deflection Ratio, Percent, for Opened Joint Condition		
	A ¹	B ²	C ³	A	B	C
-5.4	91	100	82	81	81	66
-0.6	89	89	72	78	78	63
5.8	92	92	74	80	80	64
11.8	86	93	75	83	83	66
17.3	80	80	67	71	71	53
21.0	82	83	65	72	72	54
22.9	86	86	71	73	73	59
23.2	88	88	73	81	81	58

¹ Joint deflection ratio using Procedure A

² Joint deflection ratio using Procedure B

³ Joint deflection ratio using Procedure C

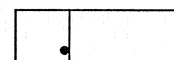


Table 1(b). Comparison of joint deflection ratios, percent, at midslab of test pavement for closed and opened joint conditions.

Temperature Differential (DT), °F	Joint Deflection Ratio, Percent, for Closed Joint Condition			Joint Deflection Ratio, Percent, for Opened Joint Condition		
	A ¹	B ²	C ³	A	B	C
-5.4	87	115	93	94	94	76
-1.9	93	108	84	95	96	75
3.9	97	97	76	95	95	74
10.0	95	98	78	92	92	68
14.9	97	97	78	95	95	73
18.8	95	97	81	94	94	74
20.9	97	98	80	96	96	78
20.1	97	97	79	95	95	74
*	99	100	82	97	97	75

¹ Joint deflection ratio using Procedure A

² Joint deflection ratio using Procedure B

³ Joint deflection ratio using Procedure C

Missing data

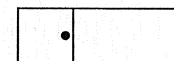


Table 1(c). Comparison of joint deflection ratios, percent, at no-void edge of test pavement for closed and opened joint conditions.

Temperature Differential (DT), °F	Joint Deflection Ratio, Percent, for Closed Joint Condition			Joint Deflection Ratio, Percent, for Opened Joint Condition		
	A ¹	B ²	C ³	A	B	C
-1.6	82	82	66	74	81	66
5.4	84	84	62	77	80	62
11.7	84	84	68	77	80	63
17.4	89	89	70	78	85	67
21.4	90	90	72	*	*	*
21.9	89	89	73	77	77	61
22.5	92	93	76	79	79	62
21.6	88	88	73	76	76	59

¹ Joint deflection ratio using Procedure A² Joint deflection ratio using Procedure B³ Joint deflection ratio using Procedure C

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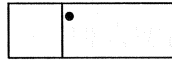


Table 2(a). Comparison of deflection ratios, percent, in outer wheelpath of JRCP field test section at adjacent transverse crack and joint.

Temperature Differential (DT), °F	Deflection Ratio, Percent, at Crack			Deflection Ratio, Percent, at Joint		
	A ¹	B ²	C ³	A	B	C
-5	98	102	94	83	83	68
4	97	103	95	98	98	81
10	97	103	96	100	100	82
12	97	103	96	97	103	84
20	98	102	94	97	97	79
21	100	100	94	97	97	80
20	99	99	93	96	96	82
15	99	100	89	99	99	83

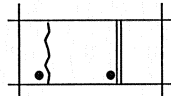
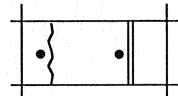
¹ Deflection ratio using Procedure A² Deflection ratio using Procedure B³ Deflection ratio using Procedure C

Table 2(b). Comparison of deflection ratios, percent, at midslab of JRCP field test section at adjacent transverse crack and joint.

Temperature Differential (DT), °F	Deflection Ratio, Percent, at Crack			Deflection Ratio, Percent, at Joint		
	A ¹	B ²	C ³	A	B	C
-5	99	101	96	97	97	68
4	99	99	95	98	98	69
10	97	97	91	98	98	63
12	99	99	90	97	99	73
20	99	99	93	94	101	60
21	100	100	93	95	100	61
20	100	100	97	91	97	62
15	100	100	94	97	103	66

¹ Deflection ratio using Procedure A² Deflection ratio using Procedure B³ Deflection ratio using Procedure C

SESSION 6: JOINTS, BASES AND DRAINAGE

Table 3. Deflection ratios, percent at selected cracks on a CRCP field test section in the outer wheelpath for three shoulder conditions.

Shoulder Condition	DT ¹	Deflection Ratio, %	Selected Crack								
			1	2	3	4	5	6	7	8	9
Pavement with a Flexible Shoulder	6.0-11.50	A ²									
		B ³	86	93	99	97	99	94	94	97	96
		C ⁴	106	108	101	103	101	106	106	99	105
	19.25-22.50	A	73	90	93	94	92	93	91	90	92
		B	98	93	98	95	98	95	93	95	97
		C	96	108	102	105	101	105	108	99	103
Pavement with Shoulder Removed	4.25-5.50	A	88	96	94	94	92	93	93	92	92
		B	86	93	97	94	100	96	96	96	96
		C	118	108	100	106	100	104	100	99	105
	3.00-2.50	A	85	91	92	90	89	89	86	91	90
		B	86	93	98	97	98	97	99	95	98
		C	117	93	98	103	100	103	99	99	102
Pavement with a Rigid Shoulder	3.25-11.25	A	89	83	92	98	90	88	87	91	91
		B	85	96	99	94	99	97	93	96	98
		C	107	102	99	101	101	99	108	101	100
	15.75-13.75	A	84	89	92	88	91	87	91	91	90
		B	92	98	96	96	90	98	*	93	93
		C	105	100	104	101	103	101	*	100	103

¹ DT = temperature differential range, °F² Deflection ratio using Procedure A³ Deflection ratio using Procedure B⁴ Deflection ratio using Procedure C

* Missing data

Table 4. Deflection ratios, percent, at selected stations along longitudinal shoulder joint of a CRCP field test section with a newly constructed rigid shoulder.

Station	Deflection Ratio, Percent					
	DT ¹ = 1.5 to 4.5 °F			DT = 4.5 to 13.0 °F		
	A ²	B ³	C ⁴	A	B	C
1	90	90	73	95	95	77
2	91	92	78	94	95	84
3	97	97	82	97	102	92
4	84	84	68	97	97	78
5	71	71	54	96	96	79
6	81	81	64	84	84	67
7	93	95	76	94	100	86
8	92	92	76	92	98	80
9	83	83	65	92	92	78
10	92	97	77	96	102	82
11	94	97	73	93	98	76
12	80	80	63	96	96	77
13	88	88	70	84	84	73
14	95	97	78	98	99	79
15	95	95	77	96	96	80
16	88	90	67	91	96	77
17	95	95	70	83	83	75
18	84	84	68	91	91	74
19	97	99	79	97	99	92
20	97	97	78	98	99	84
21	90	90	75	95	97	81

¹ DT = Temperature differential range² Joint deflection ratio using Procedure A³ Joint deflection ratio using Procedure B⁴ Joint deflection ratio using Procedure C

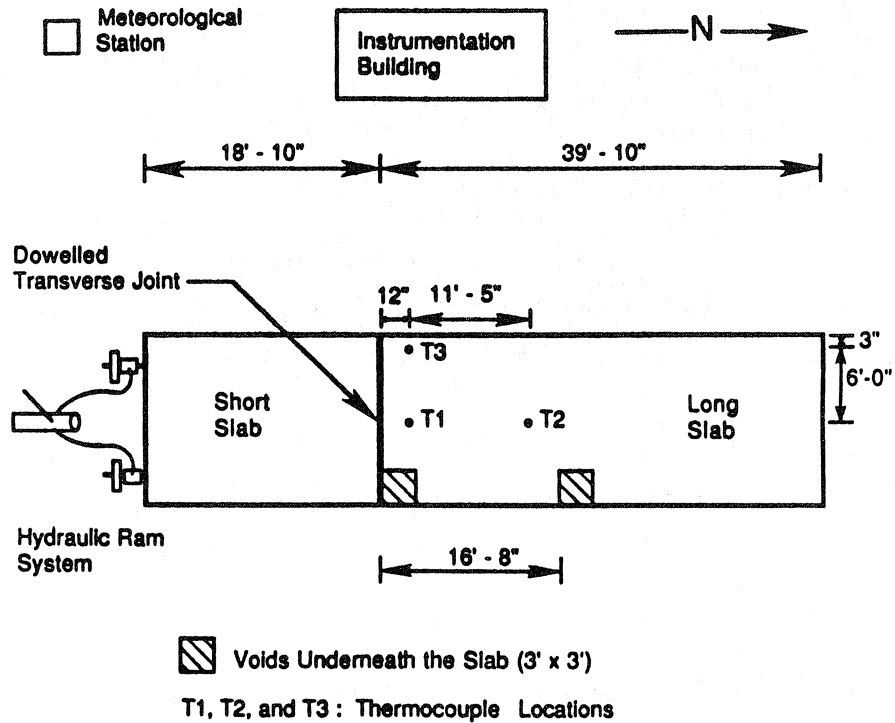
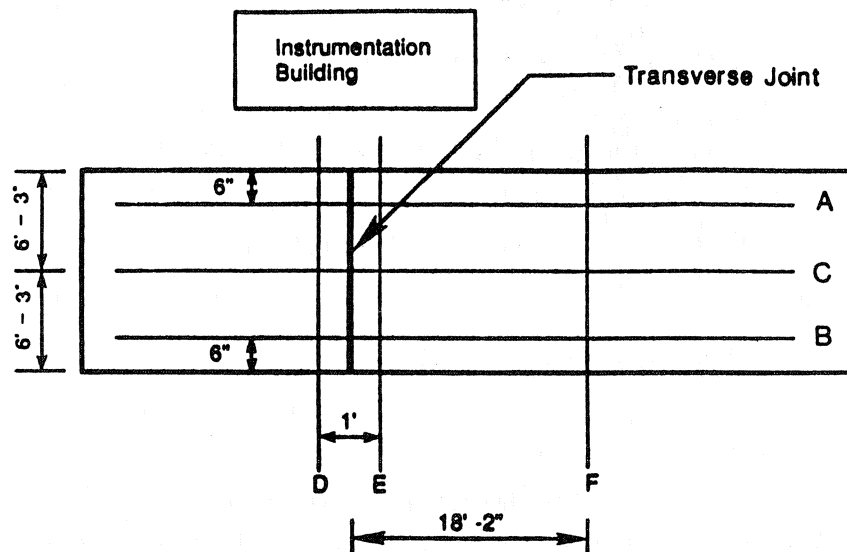


Fig 1. Layout of test pavement research facility.



Test paths: A: No-void-edge test path
 B: Void-edge test path
 C: Midslab test path

Locations: D: Upstream of Transverse Joint
 E: Downstream of Transverse Joint
 F: Midspan

Fig 2. Test paths and test locations on test pavement.

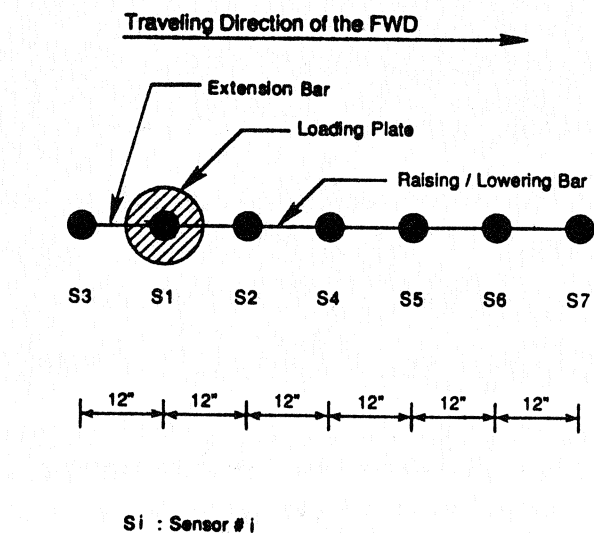
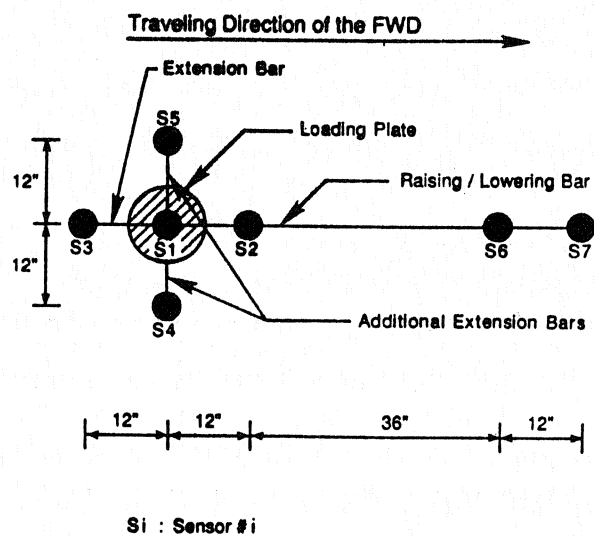
**(a) Transverse joint and crack tests.****(b) Longitudinal joint tests.**

Fig 3. Arrangement of FWD load and sensors for load transfer tests.

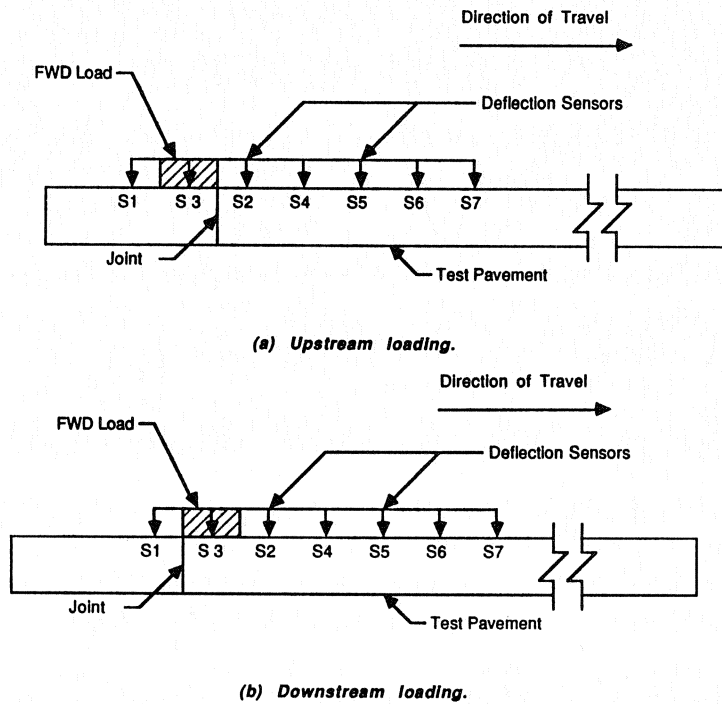


Fig 4. Location of FWD load and sensors at transverse joint or crack for load transfer evaluation.

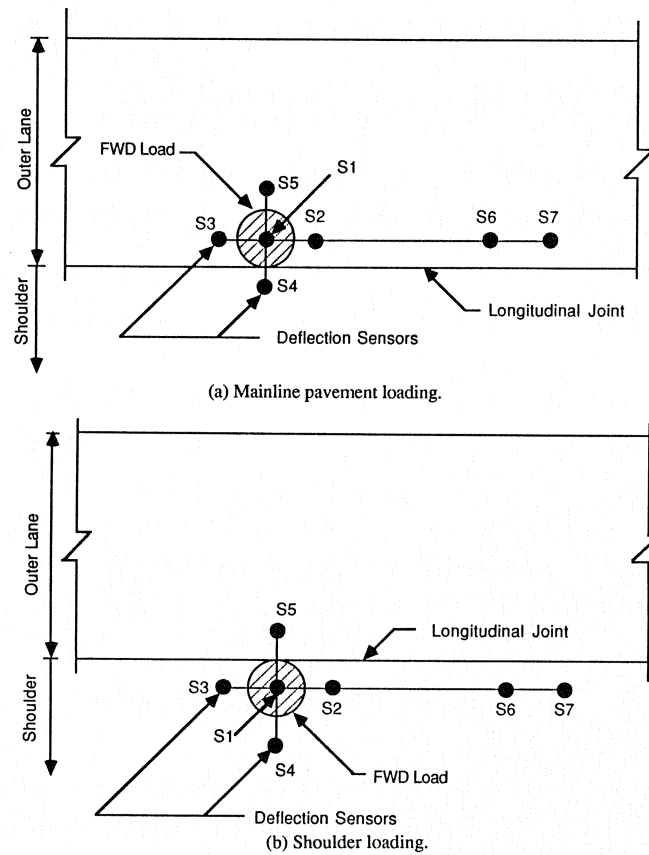
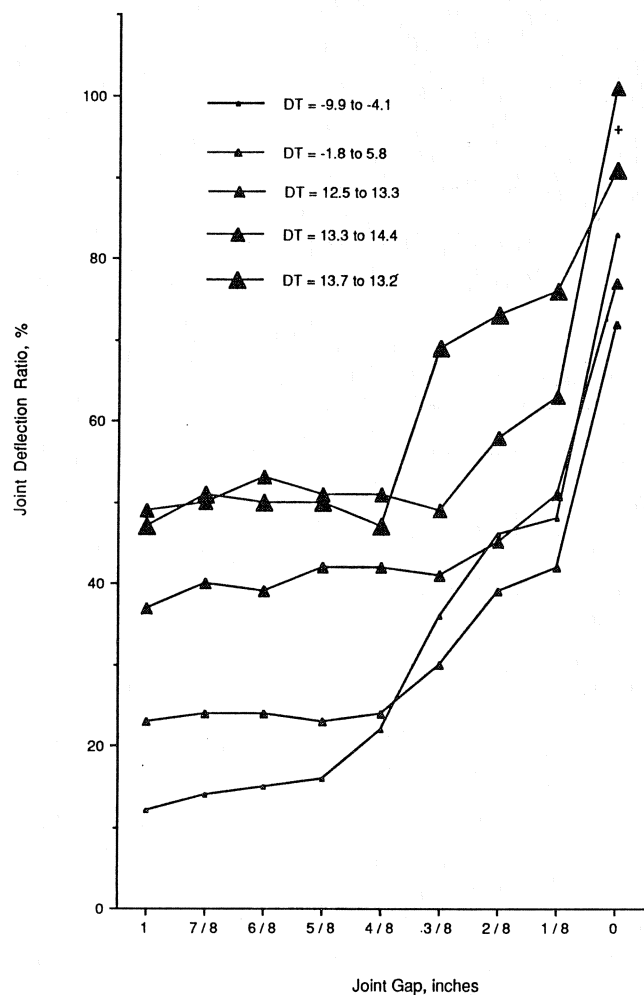
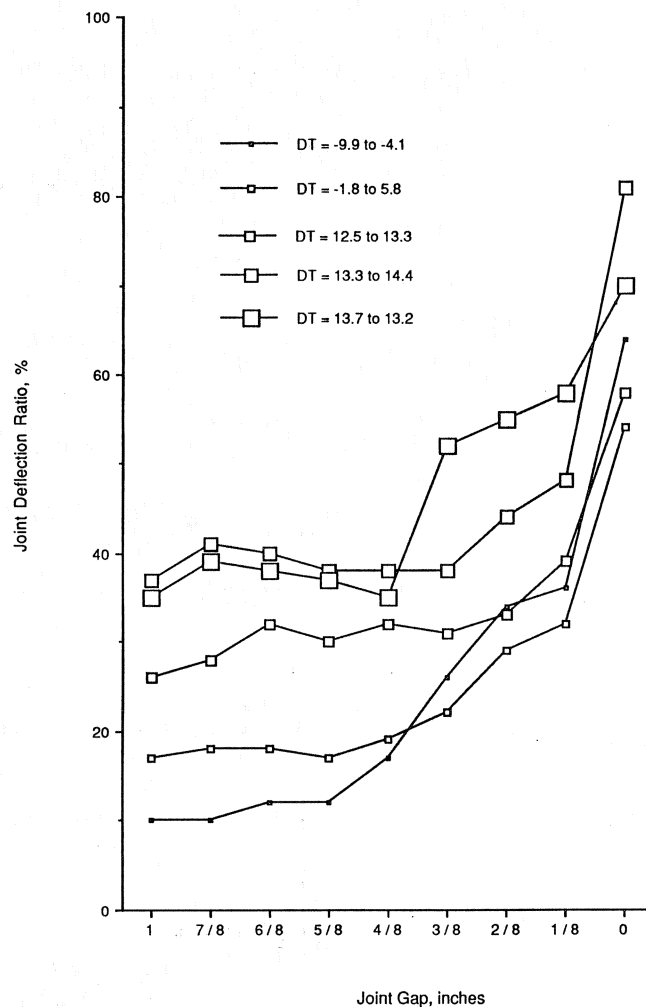


Fig 5. Location of FWD load and sensors at longitudinal joint for load transfer evaluation.



(a) Load transfer using procedures A and B.



(b) Load transfer using procedure C.

Fig 6. Variation of load transfer at test pavement joint with increasing joint gap.