Nondestructive Testing of Transverse Joints for Concrete Pavement Rehabilitation

THOMAS E. COUSINS, WILLIAM H. TEMPLE, AND MIKE P. MERONEY

A study was undertaken to develop an inexpensive, easy-to-use nondestructive test procedure for evaluating the structural condition of joints in concrete pavements. The test method consists of a load deflection measurement technique (18,000-lb single-axle load) in conjunction with a finite-element model of the jointed slab system, called JSLAB. Time-deflection measurements were recorded over a variety of concrete pavement thicknesses, ages, and conditions. A series of influence curves was developed to graphically relate slab support (*K*-value), load transfer, and measured slab deflection. Slab support was determined for new pavements and for old pavements suspected of having voids under the slab. Joint load transfer was determined for dowel bar systems and for a cantilevered load-transfer system. The magnitude of the remaining load transfer was compared with the severity of joint faulting. The process was determined to be very useful as an aid in making decisions to rehabilitate concrete joints. The procedure was successful in characterizing roadbed soil conditioned with lime and then treated with cement as containing greater stiffness than soil (on the same pavement) that was lime conditioned only. Deflection-based guidelines are provided for concrete pavement rehabilitation decisions for joint replacement and for grinding and undersealing of faulted joints.

The construction and performance of transverse joints in jointed portland cement concrete (PCC) pavements have been a source of problems for highway engineers since jointed pavements were first used in Louisiana in the 1920s. A transverse joint in a jointed PCC pavement creates a discontinuity in the pavement, causing a weaker zone adjacent to the joint. The most common problems that can affect jointed concrete pavements are load-transfer failure, joint faulting, pumping, sealant loss, and general joint failure as a result of concrete crushing.

Over 50 percent of the major highway systems in Louisiana has been constructed as jointed PCC pavement. Although the majority of these pavements are performing adequately, many pavements older than 20 years are in need of rehabilitation or reconstruction. Traffic demands on these pavements have been increasing significantly, whereas the procedures available to evaluate them are limited. In past years the Louisiana Department of Transportation and Development (LaDOTD) has not had a comprehensive joint evaluation and maintenance program. Where joint rehabilitation has been needed at a particular highway site, the choice of a repair procedure has usually been based upon visual observation of that site. Deflection testing to determine the need for joint rehabilitation has received limited use, but has not produced definitive results with existing equipment and techniques.

For some time, it has been believed that a structural evaluation procedure that utilizes a slow-moving heavy load might have advantages over lighter loads in evaluating the condition of PCC pavements. In particular, a test procedure was needed to assist in the decisions between various rehabilitation strategies and reconstruction. Also, guidelines were needed to decide between grinding and undersealing operations or full-joint replacement where joints were faulted and loss of land transfer was suspected.

Another factor that has contributed significantly to joint faulting on older concrete pavements (15 years or greater) is the use of a cantilever type of load transfer device called the starlug (instead of steel dowel bars). Pavements constructed with starlugs have been studied extensively in Louisiana (*1*) because this construction was used on many older concrete pavements both on and off the Interstate system.

Therefore, the objective of this research was to develop a fast, easy-to-use nondestructive test method for evaluating the condition of transverse joints in concrete pavements. This nondestructive test method included an in-place deflection measurement technique in conjunction with a finite-element model of the jointed slab system to evaluate joint conditions. Field measurements were made at 10 sites in Louisiana to illustrate the use of this test procedure and to test its validity. Starlug and dowel-type load-transfer devices were studied.

TESTING PROCEDURE

Corner deflections (vertical) and joint efficiencies have been extensively used to characterize the adequacy of a transverse joint (*2–4*). Therefore, an experimental testing procedure was developed to measure these factors in actual field conditions. Ten test projects that represent pavement and subbase conditions typical throughout Louisiana were evaluated to find corner deflections and joint efficiencies due to a known load. At each of the 10 test sites, measurements were taken at a minimum of 10 randomly selected joints. Table 1 contains the location and main pavement characteristics of each test site. Each site has varying age, slab length, subbase type, and load transfer device type that are representative of past and current construction practice in Louisiana and other parts of the country. All test sites have untied asphalt shoulders, which do not

T. E. Cousins, Louisiana State University, Baton Rouge, La. 70803. W. H. Temple, Louisiana Transportation Research Center, P.O. Box 94245, Baton Rouge, La. 70804-9245. M. P. Meroney, Howard, Needles, Tammen & Bergendoff, Suite J-200, 100 St. James, Baton Rouge, La. 70802.

provide load transfer to the shoulder. Core samples were taken over several load-transfer devices after deflection measurements were made on joints that exhibited poor load transfer.

Other than representing a range of pavement and subbase conditions, the 10 projects were chosen for the following reasons:

1. Test Projects 1 and 2 provided a comparison of dowel bars and starlugs in older pavements of the same thickness, slab length, and subbase type. These pavements both contained distressed transverse joints or moderate to heavy faulting (½ to ¾ in.).
2. Test Projects 3 and 4 were new Interstate pavements selected to provide support and load-transfer characteristics of new pavements. Both projects contained a cement-treated roadbed soil except in several locations on Project 4 where lime treatment was substituted. This project was subdivided for testing to determine whether the procedure could detect any difference in support between the two types of soil treatment.
3. Test Projects 5 and 6 were selected to represent 9- and 8-in. concrete pavements that were relatively new and in good condition.
4. Test Project 7 was a 9-in. doweled pavement with a 4-in. bonded concrete overlay added in 1981 when the pavement was 20 years old. The project was selected because of its thickness.
5. Test Project 8 was a 15-year-old Interstate pavement that contained starlugs and an asphaltic concrete subbase that had experienced moisture damage (stripping). The project was selected because joint faulting had become noticeable (approximately ⅛ to ¼ in.).
6. Test Project 9 was an Interstate rehabilitation project containing starlugs where approximately one-half of the joints were faulted above ¼ in. and one-half below ¼ in. The project was selected to help define the relationship between joint faulting and remaining load transfer.
7. Test Project 10 was a 25-year-old doweled pavement that is to receive a bonded concrete overlay. The project was selected to evaluate the level of load transfer and slab support remaining.

Instrumentation

The instrumentation used to measure corner deflection and joint efficiencies consisted of two linear voltage differential transformers (LVDTs) connected to a data acquisition system as shown in Figure 1. The LVDTs were suspended over the joint from the untied asphalt shoulder.

The data acquisition system used was a Hewlett-Packard HP 9000 series 200 computer system with an HP98640 data acquisition card. A computer program was written in BASIC that enabled readings to be taken sequentially by each LVDT. Measurements were taken every 0.005 sec continuously for 15 sec in order to ensure that the maximum deflection was recorded. This test equipment proved to be especially fast and easy to use. Approximately 10 min was required at each joint to set up equipment and to record corner deflections.

To limit the effects of temperature change on deflection readings, readings were typically taken over a 2-hr period in

TABLE 1 PROJECT LOCATION AND PAVEMENT CHARACTERISTICS

TEST NO.	STATE ROUTE	LOCATION	THICKNESS (IN.)	LOAD TRANSFER DEVICE	SLAB LENGTH (FT.)	AGE (YRS.)	TYPE OF SUBBASE
1	I-10 West	West of LA 415 interchange (Port Allen)	10	dowels	58.5	17	soil-cement
2	I-12 East	Livingston-Tangipahoa parish line (near Hammond)	10	starlugs	58.5	20	soil-cement
3	I-49 North	north of LA 181 interchange (Cheneyville)	10	dowels	20	new	hot mix asphalt
4	I-49 North	north of LA 920 interchange (near natchitoches)	10	dowels	20	new	hot mix asphalt
5	LA-42 South	1.0 mile south of LA42-LA30 intersection (near Baton Rouge)	9	dowels	20	6	soil-cement
6	LA-408 East	just west of Comite River Bridge (near Baton Rouge)	8	dowels	20	6	soil-cement
7	US-61 South	3.2 miles north of I-10 - US-61 interchange (near Zachary)	13**	dowels	20	7	soil-cement
8	I-10 West	Lafayette-St. Martin parish line (near Breaux Bridge)	10	starlugs	20	15	hot mix asphalt
9	I-55 North	Independence - Amite	10	starlugs	58.5	19	soil-cement
10	US-90 East	Airport - Broussard	10	dowels	20	30	soil-cement

** - original 9" thick pavement with 4" thick overlay

the early morning and especially hot or cold days were avoided. Both of these precautions should limit the effects of pavement slab curling on the deflection readings.

Measurements

Because the ideal responses for pavement evaluation have been shown to be surface deflection under slow-moving loads (*3,5*), corner deflections were measured continuously at 6 in. on both sides of the joint and 6 in. from the shoulder (Figure 1) as a truck traveled at a creep over the joint. The truck was a standard LaDOTD dump truck (single axle with dual tires) loaded and weighed with a rear axle weight of 18,000 lb and a front axle weight of 5,000 lb. Deflections were taken from the time the truck's front axle moved onto the approach pavement until the truck's rear axle moved off the leave pavement.

The measurements recorded indicated deflection of the joint as a function of time. Figure 2 is a typical time-versus-deflection curve showing the deflection of both the approach and leave pavements. Each curve contains two peaks, a small one corresponding to the passing of the front wheel over the joint and a much larger one corresponding to the passing of the rear wheel over the joint. Referring to Figure 2, A is the maximum measured deflection of the approach pavement with the load on the approach pavement. B is the measured deflection of the leave pavement with the load on the leave pavement. A' and B' are the deflection of the unloaded adjacent pavements at A and B. The ratio of A'/A is the joint efficiency when the load is on the approach pavement slab and the ratio B'/B is the joint efficiency when the load is on the leave pavement slab.

Field Evaluation

In order to help evaluate the stage of pavement deterioration at the time the measurements were made, a summary of the pavement condition of all joints tested was recorded. Every joint measured for corner deflection was rated using the *Manual for Condition Rating of Rigid Pavements* (*6*).

ANALYTICAL INVESTIGATION

Subgrade support and dowel-concrete interaction have been shown to be the primary subbase, slab, and joint properties affecting joint behavior under moving loads. Because of the significance of these pavement properties, a parametric study was conducted using the modulus of subgrade reaction (K), dowel-concrete interaction (G), corner deflection, and joint efficiency as the variables. For the purpose of this paper, K is modeled as a composite of subbase and subgrade support. A family of influence charts representing each pavement thickness studied (8, 9, 10, 13-in.) was developed, indicating the relationships between these parameters. Once these charts

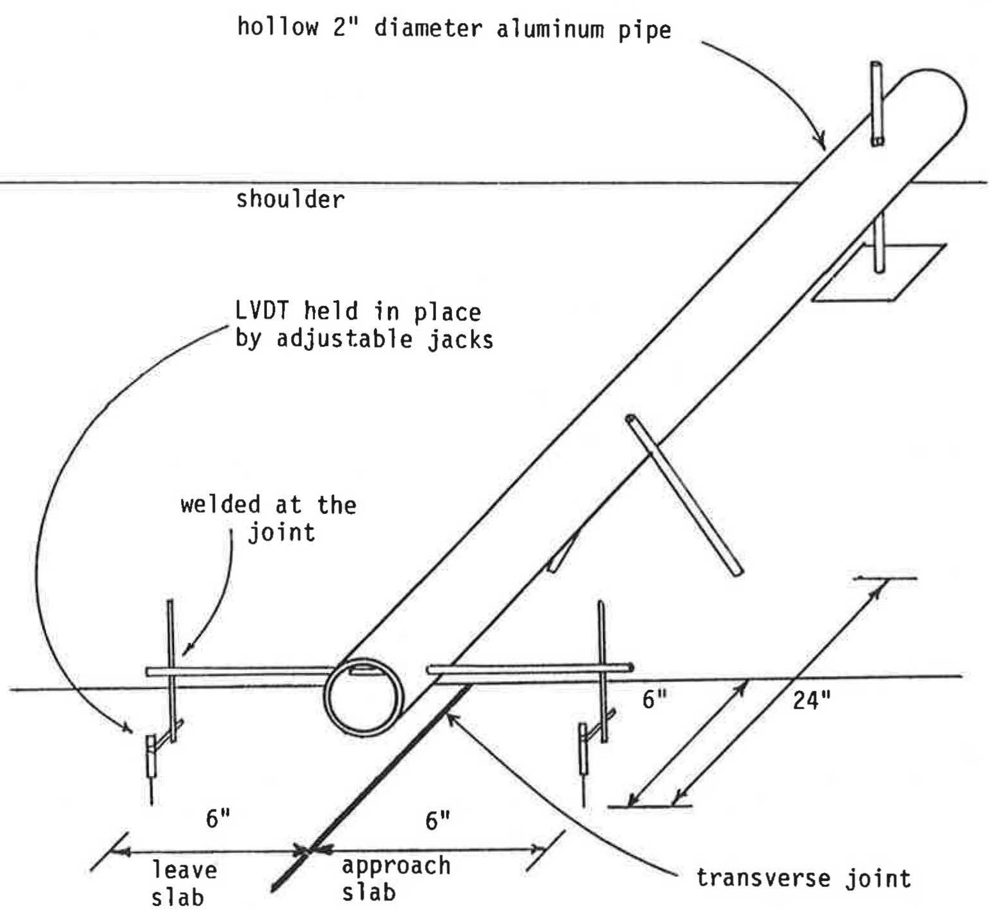


FIGURE 1 Schematic of instrumentation.

were produced, corner deflection and joint efficiency were measured for a specific joint in the field, and K and G were determined from the influence charts. Once K and G were known, the quality of subgrade support and load-transfer device system could then be determined.

Modulus of Subgrade Reaction (K)

Modulus of subgrade reaction (K) is a measure of the stiffness of the subgrade support expressed in terms of pressure in pounds per square inch of deflection, or simply pounds per cubic inch (pci) (*7*). In analysis, the use of a single value for K for the entire pavement slab implies elasticity for the subgrade (the support the subgrade supplies is directly proportional to the deflection). However, because joints cause nonuniform deflections, elastic-layer theory may be used only at the center of the pavement slab and not at or close to a joint or corner edge.

Westergaard (*8*) made one important simplification as compared with elasticity. He assumed that the subgrade cannot transfer shear stresses (that it is a Winkler foundation) (*9*). This means that the reaction of the subbase on the pavement slab, the vertical pressure, is a constant, K, times the deflection.

The numerical value of K depends not only on factors that affect soil behavior, such as soil texture, density, and moisture, but also on factors such as pavement slab rigidity and size of loaded area. If untreated or treated subbases are placed between the subgrade and the pavement slab, values of K can be increased substantially. K can range from about 50 pci for very poor subgrades up to 1,000 pci or more for extremely firm soils (*10*). Any value less than 200 pci is generally classified as a poor subgrade in need of rehabilitation.

Modulus of Dowel-Concrete Interaction (G)

The modulus of dowel-concrete interaction describes the bond between a load-transfer device and its surrounding concrete. It is a measure of the resisting pressure exerted from the concrete on the load-transfer device and is stated in terms of pounds per square inch of dowel deflection, or simply pci.

Typical values of G range from 25,000 to 5,000,000 pci (*10*). Looseness that develops in the load-transfer embedment under the action of repeated loads reduces this load transfer capability. Ozbeki et al. (*4*) found that corner deflection and joint efficiency change significantly for values of G less than 200,000 pci, and selected this value as a minimum limit for an acceptable G value. Modulus values less than 200,000 pci are considered to represent conditions when the load-transfer device has failed, and are an indication that joint rehabilitation is needed.

Finite-Element Model

Numerous analytical models exist that can approximate a pavement-subgrade system. Recently, the finite-element technique has been used to model jointed concrete pavements. A finite-element model called JSLAB was recently developed by Tayabji and Colley (*11*) for FHWA by the Portland Cement Association. The program is based on the Winkler foundation theory (*9*), with the following assumptions:

1. Any plane section before bending remains plane after bending;
2. The pavement slab is homogeneous, isotropic, and elastic;

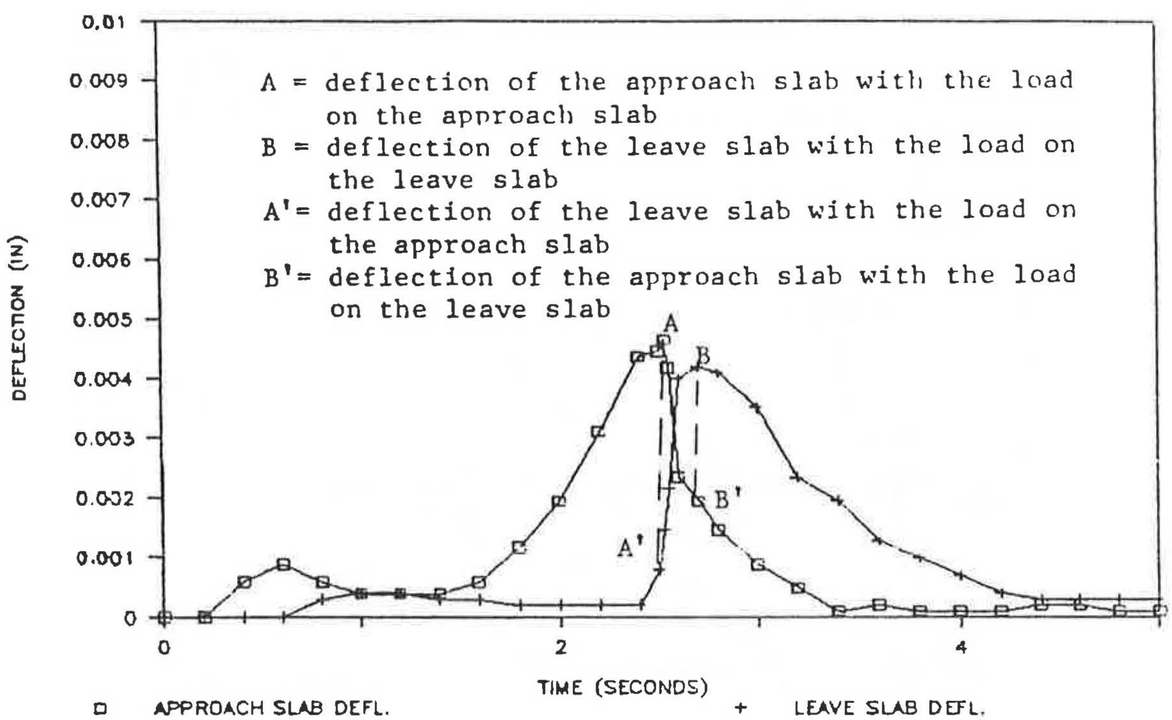


FIGURE 2 A typical time-deflection curve.

3. The subgrade cannot transfer horizontal shear stresses; and

4. The reaction of the subbase on the pavement slab (the vertical pressure) is a constant, *K*, times the deflection.

JSLAB can analyze concrete pavement sections consisting of up to nine slabs and can allow for the analysis of a two-layer system (a layer of concrete placed over either a stabilized layer or another concrete layer). In the case of this research the concrete slab was modeled as one layer and the subgrade or subbase, or both, was modeled as the other layer. The resulting *K*-value is a composite *K* for both subgrade and subbase. Load-transfer devices can be modeled as dowels or aggregate interlock and keyways. Dowel bars are modeled as short thick beams, whereas aggregate interlock and keyways are modeled as linear-elastic spring elements. Load input is in terms of wheel loads at any location on the pavement. The significant input variables are subgrade modulus (*K*), modulus of dowel-concrete interaction (*G*), dowel diameter and spacing, concrete modulus of elasticity (*E*), and Poisson's ratio of concrete. The accuracy of the model for the prediction of stresses and deflection has been verified both with closed-form solutions and results of experimental studies.

Development of Influence Charts

Pavement variables included concrete properties such as modulus of elasticity and Poisson's ratio, as well as dowel properties. For concrete, Poisson's ratio is not a constant, but varies as a function of a number of different factors such as temperature, moisture content, and stress conditions. Based on the result of many tests (*12*), it has been determined that the range to be expected for pavement slabs lies between 0.10 and 0.20. The average figure of 0.15 is usually adopted and was used in this study.

A summary of many tests (*7*) indicates that the modulus of elasticity for concrete (*E*) is roughly 1,000 times its compressive strength and ranges from 2 to 6 million psi. The modulus varies not only with strength but also with pavement age, moisture state, stress condition, and other factors. Because the American Concrete Institute (*13*) has stated that the compressive strength of concrete for the design of rigid pavement should not be less than 4,000 psi (28-day strength), 4 million psi is frequently used as an approximation for *E*. The compressive strength of concrete for pavements in this study was approximately 3,600 psi at 28 days. Therefore, 4 million psi is the value chosen to be used in this parametric study.

For simplicity, starlugs were modeled as dowel bars on 12-in. spacings, even though the starlugs were spaced at 14-in. increments. The resulting load transfer characteristics therefore represent those that a dowel bar system would exhibit given the measured deflection characteristics of a joint containing starlugs. It was believed that this procedure would provide the best comparison between projects with different load transfer devices. Standard dowel properties utilized for the pavements tested were

1. Dowel modulus of elasticity = 29,000,000 psi,
2. Dowel spacing = 12 in.,
3. Poisson's ratio of dowel material = 0.29,
4. Joint opening = 0.1 in., and
5. Diameter of dowel = 1 in.

Loading Configuration

A total tire load equal to 18,000 lb was applied on four equivalent 7- by 8-in. rectangular areas corresponding to the four tire contact areas for the rear axle at the edge of the approach pavement slab. This loading is in agreement with the actual weight and type of truck used in the test procedure. Front-axle tires were neglected in the analysis because they have been shown in previous studies to have an insignificant effect on deflections caused by rear-axle loading (*4,10,14*). Results from this study were in agreement with this.

RESULTS

Using the loading configurations and pavement input variables discussed in the previous section, along with specific *K*- and *G*-values, JSLAB can determine a corner deflection and a joint efficiency. If *K* and *G* are varied, a unique pair of values for deflection and efficiency can be produced for each specific *K* and *G*. By varying *K* from 50 to 2,000 pci in increments of 50 and *G* from 50,000 and 5,000,000 pci in increments of 100,000, the results can be plotted as lines of *K* and *G* with corner deflection and joint efficiency as the independent and dependent variables, respectively. A graph of influence curves for a 10-in. concrete pavement is shown in Figure 3.

The measured corner deflection and joint efficiencies were plotted on the previously generated influence charts as shown in Figure 3 for a 10-in. concrete slab. Because the deflection and efficiency of a specific slab joint were known, an effective *K* and *G* for each joint could then be determined.

Pavements older than 15 years (Projects 1, 2, 8, 9, 10) had a significant scattering of *K*- and *G*-values. Because the deterioration process can vary from joint to joint depending on such factors as subbase or load transfer loss, one joint may perform adequately, whereas the adjacent joint may perform unacceptably. It should be noted, however, that the following sections use average values of *K* and *G* to draw several conclusions.

Comparison of Data with Project Characteristics

Table 2 contains average values of *K*, *G*, joint efficiency, and absolute deflection for each test site. The following observations can be made from this information:

1. Projects 1 and 2 represent a dowel bar and a starlug project at the end of their life and both projects contain *G*-values of approximately 200,000 psi. Cores obtained over doweled joints contained broken concrete above the bars, indicating a concrete bearing failure. The starlugs exhibited metal and concrete wear sufficient to allow faulting between ½ and ¾ in. *K*-values were relatively low for both projects (400 to 500 pci) when compared with similar values measured for new construction (1,000 to 2,000 pci). This indicates a loss of slab support that is possibly explained by voids under the slab near the joints.

2. Projects 3 and 4 represent new 10-in. jointed concrete pavement with dowel bars. *G*-values exceeded 5,000,000 psi and *K*-values exceeded 2,000 pci on Project 3 where the 2-in. asphaltic concrete subbase was constructed over a working table of soil cement. In fact, the average deflection under the 18,000-lb load was only 1.2 mils. Project 4 is identical except that the roadbed soil contained intermittent lime or cement treatment, depending on soil characteristics. *G*-values were also high; however, *K*-values in the cement-treated section exceeded 2,000 pci whereas *K*-values in the lime-treated section ranged between 600 and 1,000 pci. Average deflections were 0.2 and 2.9 mils, respectively.

3. Projects 5 and 6 represent recent concrete paving construction and contained *K*-values in excess of 1,000 psi.

4. Project 7, a 4-in. bonded PCC overlay over 9-in. plain doweled jointed concrete pavement, exhibited excellent load transfer and slab support after 7 years of service.

5. Project 8, a 15-year-old 10-in. plain jointed concrete pavement with starlugs on Interstate, has lost load transfer (G = 200,000 pci) and is experiencing faulting. The *K*-values are somewhat lower than on new pavements of this type and cores indicate some stripping of the asphaltic concrete base.

6. Project 9 indicates the reduction in load transfer due to faulting on an older Interstate project with starlugs. Joints faulted greater than ¼ in. (9b in Table 2) contained significantly less load transfer than joints faulted less than ¼ in. (9a).

7. Project 10 indicates the possibility of voids in the transverse joint area as evidenced by relatively low *K*-values (300 to 500 pci). The 30-year-old doweled jointed concrete pavement contained very little joint faulting. However, because the dowels resist faulting, the slabs tend to bridge over voids rather than fault as with starlug pavements, hence the low *K*-values. Because this project is a candidate for bonded concrete overlay, undersealing will be scheduled to restore slab support before overlay.

Effect of Faulting of Joint Performance

Faulting plays a significant role in joint performance. In order to evaluate the effect of faulting, results for joints were grouped together according to their severity level and compared. Table 3 shows the severity level of joint faulting as compared with average joint efficiencies and *K*- and *G*-values. Table 3 reveals the following:

1. When severe faulting (½ to ¾ in.) is present, average *G*-values are significantly below the minimum acceptable value

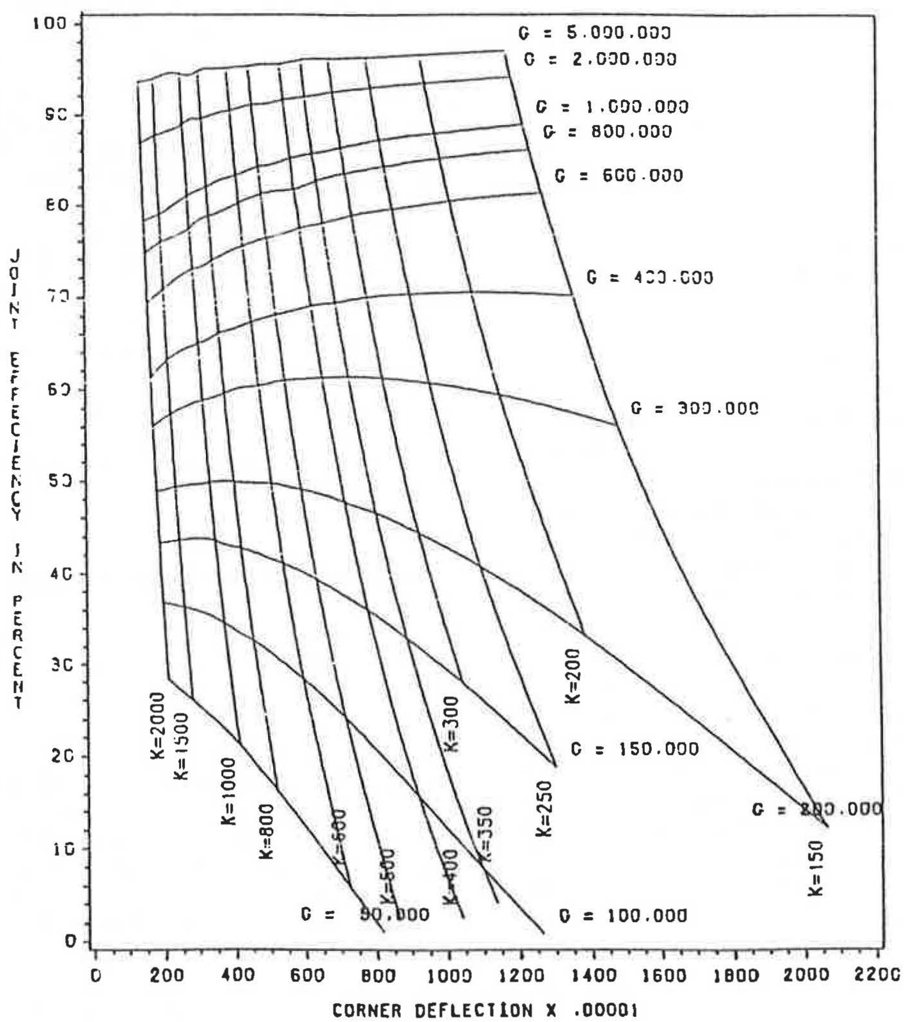


FIGURE 3 Influence curves of *K* and *G* for 10-in. jointed concrete pavement.

of 200,000 pci recommended by Ozebki et al. (*4*).

2. Regardless of severity level, average *K*-values are above the minimum recommended lower limit value of 200 pci.

3. A severe level of faulting corresponds to joint efficiencies below the acceptable limit of 50 percent recommended by many sources (*6,11*).

4. A moderate level of faulting (½ to ¼ in.) produces joint efficiencies that are near the 50 percent limit.

Evaluation of Joint Efficiencies

Corner deflections and joint efficiencies have previously been shown to be directly related to load transfer and subbase properties. Results presented in Tables 2 and 3 indicate that slabs with relatively no joint faulting produced lower joint efficiencies on the leave slabs than on the approach slabs. This is in agreement with others (*4,7,12*) because the amount of pumping and loss of subgrade support are greater under the leave pavement slab, causing lower joint efficiencies.

Nevertheless, the results show quite the opposite effect on pavements that contain higher levels of joint faulting and distress. The joint efficiency of the approach pavement slab is considerably lower than that of the leave pavement slab. As pavement age increases, pumping from underneath the leave slab causes water and subbase particles to be ejected from under the leave slab and deposited under the approach slab. As joint load transfer diminishes and faulting occurs, the leave slab "bottoms out," or is seated on subbase. This results in larger joint efficiency on the leave than on the approach slab.

Summary of Results

From the data and analyses presented in this section, it has been shown that low joint efficiencies and low values of the modulus of dowel-concrete interaction (*G*) are associated with the severity of joint faulting. Values of *G* tend to range near unacceptable levels (less than 300,000 pci) for severe or moderate faulting but increase substantially (to greater than 3,000,000 pci) when only slight or very slight faulting is present. Results indicate that high *G*-values are maintained at greater than 2,000,000 pci until they drop suddenly, indicating some form of brittle failure of the concrete surrounding the load-transfer device. This was supported by cores taken over load-transfer devices on joints that exhibited very low load-transfer efficiencies (less than 20 percent). Once this failure

TABLE 2 AVERAGE DEFLECTIONS AND PREDICTED *K*- AND *G*-VALUES FOR EACH TEST SITE

Test Site	A (in)	A'/A (%)	$K_{approach}$ (pci)	G (pci x 1000)	B (in)	B'/B (%)	K_{leave} (pci)
1	.0059	41	637	178	.0064	65	456
2	.0058	39	686	208	.0047	56	423
3	.0012	97	2,000	5,000	.0012	97	2,000
4(a)	.0002	97	2,000	5,000	.0002	97	2,000
(b)	.0029	97	800	5,000	.0027	97	800
5	.0030	88	1,120	3,250	.0030	82	1,186
6	.0022	89	1,350	2,830	.0022	83	1,445
7	.0007	95	2,860	4,420	.0011	81	3,300
8	.0033	47	1,120	220	.0027	68	1,047
9(a)	.0027	82	1,400	2,040	.0025	79	1,000
(b)	.0021	64	1,720	410	.0022	67	1,650
10	.0065	59	515	440	.0069	69	375

Note: 4(a) Subbase Type: 2-inch asphaltic concrete/6-in. cement treated soil
4(b) Subbase Type: 2-inch asphaltic concrete/6-in. lime treated soil

9(a) joint faulting < 1/4"
9(b) joint faulting > 1/4"

has taken place, the slab has the ability to move vertically, resulting in increased faulting and rapid deterioration of the entire pavement system.

Values for the modulus of subgrade reaction (K) indicated that all joints exhibited good subbase support, according to the criterion of Ozbeki et al. However, joints on pavements older than 15 years showed several signs of decreased subbase support. It is suggested here that the minimum value of K be raised to 500 pci when this test method is used, which is the average value of K for these older pavement slabs. Below this level it is believed that voids are probable and the pavement should be scheduled for coring and possibly for undersealing.

It should be noted that in approximately 10 percent of the joints evaluated, analytical results showed indications of poor load-transfer capability or subbase support, whereas visual observations showed no signs of pavement distresses. With only a visual observation, these joints would have been evaluated as satisfactory and would not have been selected for rehabilitation. This nondestructive test procedure can effectively determine the performance of a joint without reliance on visual observations only and would identify the poor joint that a visual inspection would not.

Recommended Joints for Repair

It has been shown that corner deflections and joint efficiencies, along with a visual observation of the site, can be used to predict the performance of a joint. Joints that are severely deteriorated from concrete breakage are usually scheduled for full-depth patching. Through this process load transfer is restored, pavement stresses are relieved, and a sealed joint is provided. However, in the case of a joint that is faulted but not otherwise deteriorated, the decision to grind and underseal (but not restore load transfer) or to replace the joint because of loss of load transfer is not always an obvious choice. It is in this situation that corner deflection and joint efficiency determination can provide the information needed to make these "fix it" or "replace it" types of decisions. The guidelines such as those shown in Figure 4 can be used for deciding how to rehabilitate faulted joints.

CONCLUSIONS

On the basis of the analysis of the experimental and analytical results, the following conclusions can be drawn:

1. The testing procedure is easy to use and highly adaptable.
2. The process evaluated has good potential as an aid in evaluating the remaining load transfer and slab support at joints in concrete pavements with relatively inexpensive equipment.
3. The process evaluated can be combined with visual evaluations of pavement distress, such as degree of joint faulting, to facilitate project-level rehabilitation needs. In this way the needs of each individual project can be assessed according to criteria pertinent to that particular project.
4. The modulus of dowel-concrete interaction has a direct relation to faulting at transverse joints and to concrete bearing stress failures around load transfer devices.
5. Older pavements that contained dowel bars (which resist joint faulting) exhibited K-values of about 500 pci. Cores indicate that these pavements contain voids immediately under the concrete slab in the transverse joint area. The new concrete pavements tested exhibited K-values greater than 1,500 pci. The magnitude of K-values resulting from the finite-

TABLE 3 SEVERITY OF JOINT FAULTING VERSUS AVERAGE VALUES OF K, G, AND JOINT EFFICIENCY

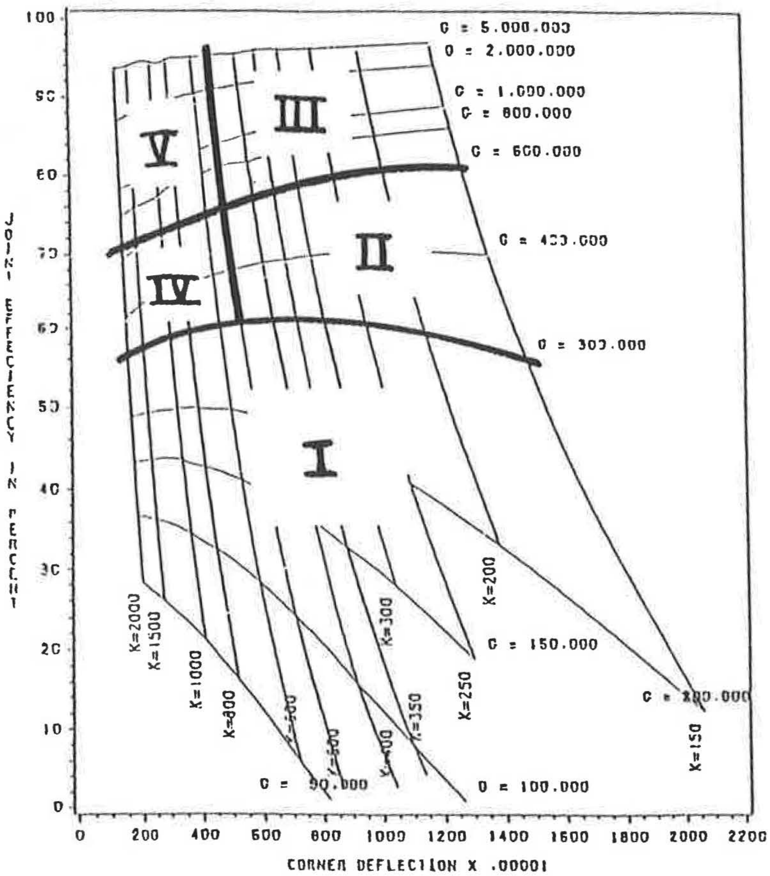
Severity of Joint Faulting	No. of Joints	Average Values: Joint Efficiency (%) Approach	Joint Efficiency (%) Leave	G (pci)	$K_{approach}$ (pci)	K_{leave} (pci)
Severe	15	32	60	120,000	710	500
Moderate	14	55	66	330,000	1,000	890
Slight	4	88	74	3,000,000	1,270	1,370
Very Slight	22	96	82	3,700,000	1,470	1,390

NOTE: Severe faulting: 1/2 to 3/4 inch
Moderate: 1/4 to 1/2 inch
Slight: 1/8 to 1/4 inch
Very Slight 1/8 inch

element program seem high compared with currently used design values in Louisiana. For this reason, values of K less than 500 pci determined by this process may indicate a significant reduction in slab support on older concrete pavements with treated bases. In these cases, the need for undersealing should be explored by taking cores or by other methods.

6. The process evaluated was successful in indicating higher K-values for cement-treated areas of a roadbed soil than for lime-treated areas where both were used on the same construction project.

7. Guidelines for concrete pavement rehabilitation decisions were developed to aid in the determination of whether to replace faulted joints because of loss of load transfer or whether to grind and underseal on the basis of the modulus of dowel-concrete interaction. Joint replacement is recommended when G is less than 300,000 pci.



	CONDITION		REHABILITATION ACTION RECOMMENDED	
	LOAD TRANSFER	VOIDS	JOINT FAULTING (OTHERWISE OK)	JOINTS BROKEN (SPALLS, CRUSHING)
I.	UNACCEPTABLE	POSSIBLE	F.D.P. (1)	F.D.P.
II.	MARGINAL	PROBABLE	F.D.P. OR GRIND & UNDERSEAL	F.D.P.
III.	GOOD	PROBABLE	GRIND & UNDERSEAL	F.D.P.
IV.	MARGINAL	DOUBTFUL	F.D.P. OR GRIND	F.D.P.
V.	GOOD	DOUBTFUL	N.A.	F.D.P.

(1) FULL DEPTH PATCH

FIGURE 4 Guidelines for rehabilitation of jointed concrete.

REFERENCES

1. Z. Bolourchi, W. H. Temple, and S. C. Shah. *Evaluation of Load Transfer Devices*. Louisiana Highway Research, Louisiana Department of Highways Research and Development Section, Nov. 1975.
2. J. M. Armaghani, T. J. Larsen, and L. L. Smith. Design Related Distress in Concrete Pavement. *Concrete International—Design and Construction*, Vol. 10, No. 8, Aug. 1988.
3. I. Minkarah, J. P. Cook, and S. Jagahoory. Vertical Movement of Jointed Concrete Pavements. In *Transportation Research Record 990*, TRB, National Research Council, Washington, D.C., 1983.
4. M. A. Ozbeki, W. P. Kilareski, and D. A. Anderson. *Computer Simulation and Field Evaluation of Transverse Joints in Rigid Pavements*. Pennsylvania State University, 1985.
5. M. S. Hoffman and M. R. Thompson. Comparative Study of Selected Nondestructive Testing Devices. In *Transportation Research Record 852*, TRB, National Research Council, Washington, D.C., 1982.
6. G. J. Chong, W. A. Phang, and G. A. Wrong. *Manual for Condition Rating of Rigid Pavements*, 2nd ed. Ontario Ministry of Transportation and Communications, Research and Development Branch, Downsview, Ontario, April 1982.
7. E. J. Yoder and M. W. Witczak. *Principles of Pavement Design*, 2nd Ed. John Wiley and Sons. New York, 1975.
8. H. H. S. Westergaard. Stresses in Concrete Pavements Compu by Theoretical Analysis. In *HRB Proc.*, Part One, Washington D.C., 1925.
9. E. Winkler. *Die Lehre von der Elasticität und Festigkeit*. Dominous, Prage, 1967.
10. J. L. Figueroa. Determining Composite Modulus of Subgrade Reaction by the Use of the Finite Element Technique. In *Transportation Research Record 930*, TRB, National Research Council, Washington, D.C., 1983.
11. S. D. Tayabji and B. Colley. *Analysis of Jointed Concrete Pavements*. FHWA, U.S. Department of Transportation, Feb. 1984.
12. H. Clarkson, J. Oglesby, and R. G. Hicks. *Highway Engineering*, 4th ed. John Wiley and Sons, New York, 1982.
13. ACI Committee 316. *Recommended Practice for Construction of Concrete Pavements and Concrete Bases*. ACI 316.74. American Concrete Institute, Detroit, Mich., 1974.
14. K. M. Marshek, H. Chen, R. Connel, and C. Saraf. Effect of Truck Tire Inflation Pressure and Axle Load on Flexible and Rigid Pavement Performance. In *Transportation Research Record 1070*, TRB, National Research Council, Washington, D.C., 1984.

Publication of this paper sponsored by Committee on Pavement Rehabilitation.