

# Evaluation Methodology for Jointed Concrete Pavements

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## ABSTRACT

Many Interstate and other major highways that were constructed with jointed portland cement concrete pavements have reached their design life and consequently are deteriorating significantly. Few transportation agencies have an effective method for evaluating the structural adequacy of transverse joints. Most pavement rehabilitation programs now under way are based on subjective engineering judgment. A more objective evaluation procedure is presented. A newly developed finite element program, JSLAB, was used in a parametric study to determine which variables have the most significant effect on the performance of transverse joints. It was concluded that the variables that most significantly affect pavement deflections and stresses are the modulus of subgrade reaction and the modulus of dowel-concrete interaction. On the basis of this study, it was concluded that a rigid pavement system can be structurally evaluated if the modulus of subgrade reaction and the dowel-concrete modulus are known. Charts were developed to determine these moduli and subsequently to evaluate in-service pavements.

Many of the Interstate and other major highways in the United States were constructed with jointed portland cement concrete (PCC) pavements. Although these pavements have provided good serviceability, the design life of many of them has been exceeded and they have deteriorated significantly. In most cases the predominant distress associated with these pavements is the deterioration of the transverse joints rather than of the slab itself. Spalling, cracking, and faulting are the most serious types of distress found at the joints.

Many transportation agencies do not have an effective method for evaluating the structural adequacy of transverse joints. Most of the pavement rehabilitation programs now under way were undertaken on the basis of subjective engineering judgment. Typically an engineer will "walk" a project to determine the type of repairs or rehabilitation needed. The engineer will visually select the joints that should be removed and the joints that should remain in place. This type of evaluation can lead to the removal of sound joints or the acceptance of joints that are deteriorated. Without the proper evaluation of each joint it is difficult to select the appropriate rehabilitation procedure. Because repair and rehabilitation of major highways across the nation are important from an economic as well as an engineering point of view, a more objective scheme must be used to evaluate the condition of joints and their expected future performance.

The purpose of this paper is to discuss the development of a methodology for evaluating the structural behavior of jointed concrete with a nondestructive testing device (NDT). A newly developed finite element computer program, JSLAB, was used for the analysis of the rigid pavement joints.

## PCC EVALUATION REQUIREMENTS

There are several repair or rehabilitation schemes available for PCC pavements. They include resealing of joints, partial concrete removal and patching, joint removal and replacement, subsealing, overlays, and complete reconstruction. The selection of the wrong rehabilitation scheme will result in a loss of

both time and money because the repairs may not perform for the expected design period or because a repair scheme may be selected that is not needed. Deterioration of the transverse joints contributes most to the poor performance of PCC pavements; therefore, an effective evaluation methodology must address the condition of these joints.

Spalling and cracking at joints is of concern to engineers; however, faulting of the slabs is the largest contributor to the loss of serviceability of a PCC pavement. This faulting can be due to a loss of subgrade support (voids) or deterioration of the load transfer system, or both. An evaluation methodology should be able to distinguish the various causes of deterioration because the rehabilitation scheme is different for each type of distress. For example, subsealing is needed to correct a loss of subgrade support, whereas establishment of load transfer is required for a deteriorated load transfer system.

## FINITE ELEMENT MODEL

Most jointed PCC pavements are analyzed and designed by assuming continuous slabs that are infinite in length. Different types of joints with various load transfer systems will affect, in different ways, the structural response of jointed concrete pavements under the applied load. Therefore, any structural model used for design or analysis should consider the entire pavement structure with all its components, such as joints, load transfer systems, subbase support, and loading configuration. It should also consider loss of subgrade support, nonuniform slab thickness, and nonuniform subgrade modulus.

A number of finite element models have been developed for the analysis of concrete pavement systems. These may be divided into the following major classes: plane-strain models, three-dimensional models, and slab models. The most desirable model for concrete pavement analysis is probably the three-dimensional one in which the geometry of the entire system can be taken into consideration. There are computer programs that employ three-dimensional finite element models, such as the SAP program de-

veloped by Wilson (1), but the amount of input and the computational costs required to use these programs make them impractical.

The two-dimensional plane-strain representation of the concrete pavement system is rather simplistic. The pavement system is represented as a transverse slice of pavement with a unit thickness. These models, because of their simplifying assumptions, are not suited to the analysis of such concrete pavement features as joints, cracks, and load transfer devices.

The slab models are based on the classical theory of a medium-thick plate supported by a Winkler foundation. Slab models have been developed by Tabatabaie and Barenberg (2), Huang and Wang (3,4), and Bhatia (5). Although a number of structural models have been available for the analysis of concrete pavement systems, none of these contains all of the features that are essential to adequate representation of the pavement system.

The finite element model used in this study is called JSLAB. It was developed by Tayabji and Colley at the Construction Technology Laboratory, a division of the Portland Cement Association. The JSLAB program has many practical features and has the ability to allocate stiffness parameters to the load transfer device (LTD). Thus LTD stiffness allocation is not done at each set of nodes along a joint as is the case with programs such as ILLI-SLAB (1) and the program developed by Huang and Wang (3,4). This feature is useful for the analysis of jointed slabs with nonuniformly spaced LTDs at joints.

The specific capabilities of JSLAB are

1. Stresses and deflections in concrete pavement sections of up to nine slabs with longitudinal and transverse joints can be determined;
2. A two-layer system, in which the layers may be bonded or unbonded, can be analyzed;
3. Load transfer can be modeled with dowels, aggregate interlock, or keys;
4. Concrete pavement slabs with full or partial subgrade contact can be analyzed, and the effect of thermal gradients on curling stresses can be analyzed, both independently and in combination with traffic loads; and
5. The effect of joints with nonuniformly spaced load transfer devices can be analyzed.

The JSLAB finite element model (6,7) is represented by an assemblage of subdivided or discrete bodies called finite elements. These elements are interconnected at specified locations that are called nodes or nodal points. Simple functions are chosen to approximate the distribution of displacements over each finite element. These assumed functions are called displacement functions or shape functions and are used to express continuous displacements in terms of discrete nodal displacements. Relationships are then established between nodal displacement ( $u$ ) and nodal forces ( $p$ ) applied at the nodes using the principle of virtual work or some other variational principle. These element force-displacement relationships are expressed in the form of an element stiffness matrix ( $k$ ), which incorporates the material and geometric properties of the element, namely,

$$[k] \{u\} = \{p\} \quad (1)$$

where  $\{u\}$  is element displacement and  $\{p\}$  is element applied force.

The overall or global structural stiffness matrix  $[K]$  for the entire system is formulated by superimposing the individual element stiffness matrices using element connectivity properties of the struc-

ture. The overall stiffness matrix is used to assemble a set of simultaneous equations of the form:

$$[K] \{U\} = \{P\} \quad (2)$$

where

$[K]$  = overall stiffness matrix,  
 $\{U\}$  = global displacement, and  
 $\{P\}$  = global applied forces.

The solution to Equation 2 results in nodal displacements for the entire system.

#### JSLAB COMPUTER PROGRAM

The JSLAB computer program was written in FORTRAN for a CDC computer. The program was modified for use on an IBM computer, to include graphic capabilities. The input to the program is

1. Geometry of the concrete slab, stabilized base or overlay, and load transfer system;
2. Elastic properties of the concrete slab, stabilized base or overlay, load transfer system, and subgrade; and
3. Loading configuration.

The output given by the program is

1. Dowel shear and moment at each node along the joint (for nondoweled joints this output is omitted);
2. Stresses in the concrete pavement, stabilized base, or overlay;
3. Deformations of the pavement system, which consist of vertical deflection and rotation; and
4. Applied loads, which consist of vertical components of applied load and moments about the x- and y-axis, respectively, at each node.

Because JSLAB is a relatively new program, a comparison was made of the results obtained from the program and those obtained from other solutions. Interior stresses and edge and corner deflections were calculated using JSLAB and Westergaard's equations (8) as follows:

$$\sigma = 0.275 (1 + \nu) (P/h^2) \{4[\log(l/b)] + 1.069\} \quad (3)$$

$$\Delta = (1/6^{1/2}) (1 + 0.4\nu) (P/k\ell^2) \quad (\text{edge deflection}) \quad (4)$$

$$\Delta = (P/k\ell^2) [1.1 - 0.88(a/\ell)] \quad (\text{corner deflection}) \quad (5)$$

where

$\sigma$  = maximum stress under the load;  
 $\Delta$  = maximum deflection under the load;  
 $P$  = applied load;  
 $a$  = radius of a circular loaded area;  
 $b = (1.6a^2 + H^2 - 0.675h)^{1/2}$ , for  $a < 1.724h$ ;  
 $b = a$ , for  $a > 1.724h$ ;  
 $k$  = modulus of subgrade support;  
 $\ell$  = radius of relative stiffness of the pavement with respect to subgrade given by  $\ell = 4[Eh^3/12(1 - \nu^2)K]$ ;  
 $h$  = thickness of the concrete slab;  
 $E$  = modulus of elasticity of the concrete slab; and  
 $\nu$  = Poisson's ratio of the concrete slab.

A comparison of the stresses and deflections obtained from the JSLAB program and Westergaard's equation is shown in Figure 1. The solid line in the figure represents Westergaard's exact solution,

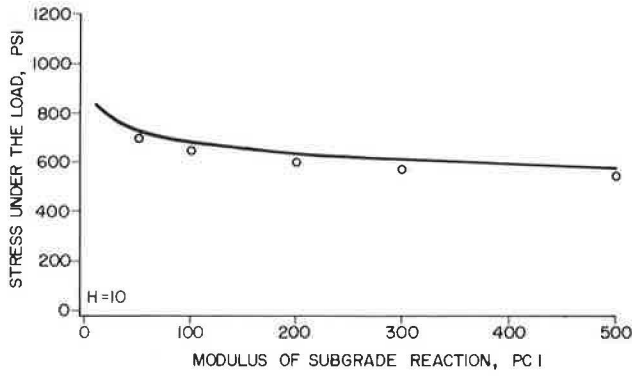


FIGURE 1 Comparison of finite element solutions and Westergaard's equation for interior loading.

loaded area for Westergaard's solution, therefore, was assumed to be a circle with a diameter of 15 in. (38.10 cm), and a 15-in. (38.10-cm) square was selected to represent the loading condition in the finite element analysis. A single load of 50 kips (222 kN) was used for the loading configurations. Figure 2 also shows the mesh of the finite element models used in this comparison. The modulus of elasticity and the Poisson's ratio of the concrete slab were assumed to be  $5 \times 10^6$  psi (34.5 GPa) and 0.15, respectively. The comparison was made for a slab thickness of 10 in. (25.4 cm) and five moduli of subgrade reaction: 50, 100, 200, 300, and 500 pci (13.6, 27.1, 54.3, 81.4, and 135.7 N/cm<sup>3</sup>).

The agreement between the results obtained with JSLAB and those obtained with Westergaard's equation was quite good. In general the differences between the two solutions were small as shown in Figure 1 for an interior load. Corner and edge loading cases also have the same results.

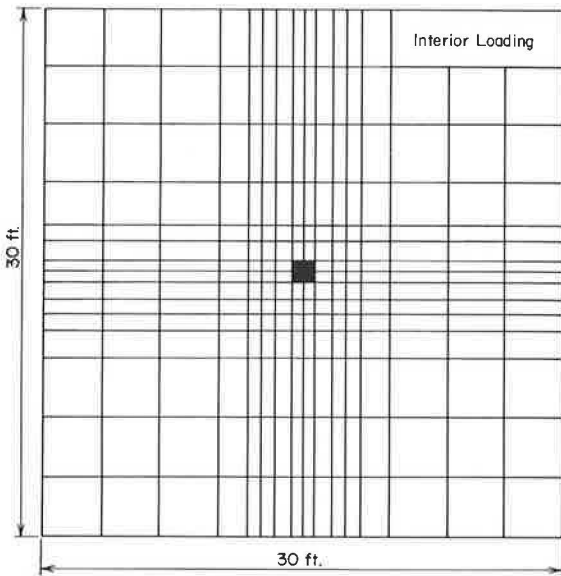


FIGURE 2 Slab used in finite element analysis.

PARAMETRIC STUDY OF PCC PAVEMENT PROPERTIES

A parametric study was conducted to determine the influence of selected design variables on the structural response of a typical jointed pavement as constructed in Pennsylvania. The responses, which were calculated using JSLAB, were the surface deflection of the loaded slab along the transverse joint, and the tensile bending stresses in the concrete under the tire along the longitudinal x-axis. The influence of the design variables on the efficiency of the transverse joint was also studied. Joint efficiency was defined as the vertical deflection of Point B divided by the vertical deflection of Point A (Figure 3).

The loading used in the parametric study consisted of an 18-kip single-axle truck. (This was the truck configuration used at the Pennsylvania Transportation Research Facility.) The contact area of the tire was converted to a uniformly loaded area with a tire pressure of 80 psi (9).

The following jointed pavement system, which is typical of pavements constructed in Pennsylvania in the 1960s, was used as a reference in the parametric study:

- Slab thickness = 10 in. (25.4 cm)
- Concrete modulus of elasticity = 4,500,000 psi (31.0 GPa)
- Modulus of subgrade reaction = 200 pci (54.2 N/cm<sup>3</sup>)
- Poisson's ratio of concrete = 0.20
- Twelve uniformly spaced dowels
- Dowel diameter = 1 1/4 in. (3.2 cm)
- Dowel spacing = 12 in. (30.5 cm)

while the small circles represent the finite element solutions. Because Westergaard's exact solutions are for an infinite slab, a large 30-ft (9.14-m) square slab (Figure 2) was used in the finite element analysis. Westergaard assumed that the load was distributed uniformly over the area of a small circle. The

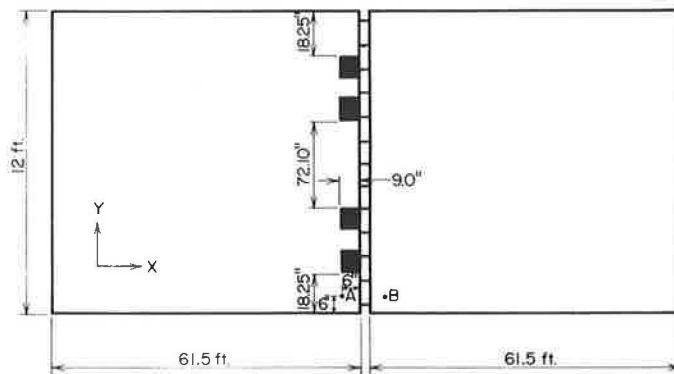


FIGURE 3 Loading configuration used in the parametric study.

Modulus of dowel-concrete interaction = 2 million pci (542.8 kN/cm<sup>3</sup>)  
 Dowel modulus of elasticity = 29 million psi (199.8 GPa)  
 Poisson's ratio of dowel material (steel) = 0.30  
 Joint opening = 0.25 in. (6.4 mm)  
 Slab length = 61.5 ft (18.7 m)

In considering the effect of a particular design variable, only one of the input values was changed while all other design variables were kept constant. The results are discussed in the following sections.

Dowel Size

The dowel diameters considered were 3/4, 1, 1 1/4, and 1 1/2 in. (19, 25.4, 32, and 38 mm). As shown in Figures 4(a) and 4(c), dowel diameter has no major influence on corner deflection and joint efficiency. However, larger dowel sizes increase the tensile bending stresses along the x-axis (longitudinal) in the vicinity of the joint, as shown in Figure 4(b). However, it can be shown that larger dowel size de-

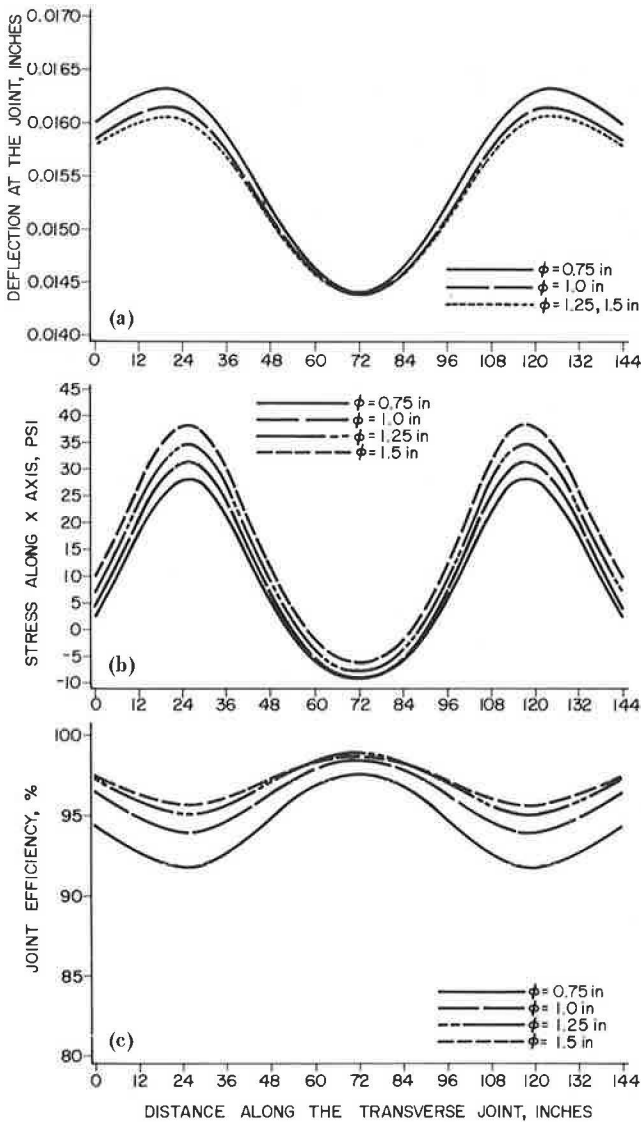


FIGURE 4 Effect of dowel diameter on pavement response: (a) deflection at the joint under the tires, (b) stresses along the x-axis under the tires, and (c) percentage joint efficiency.

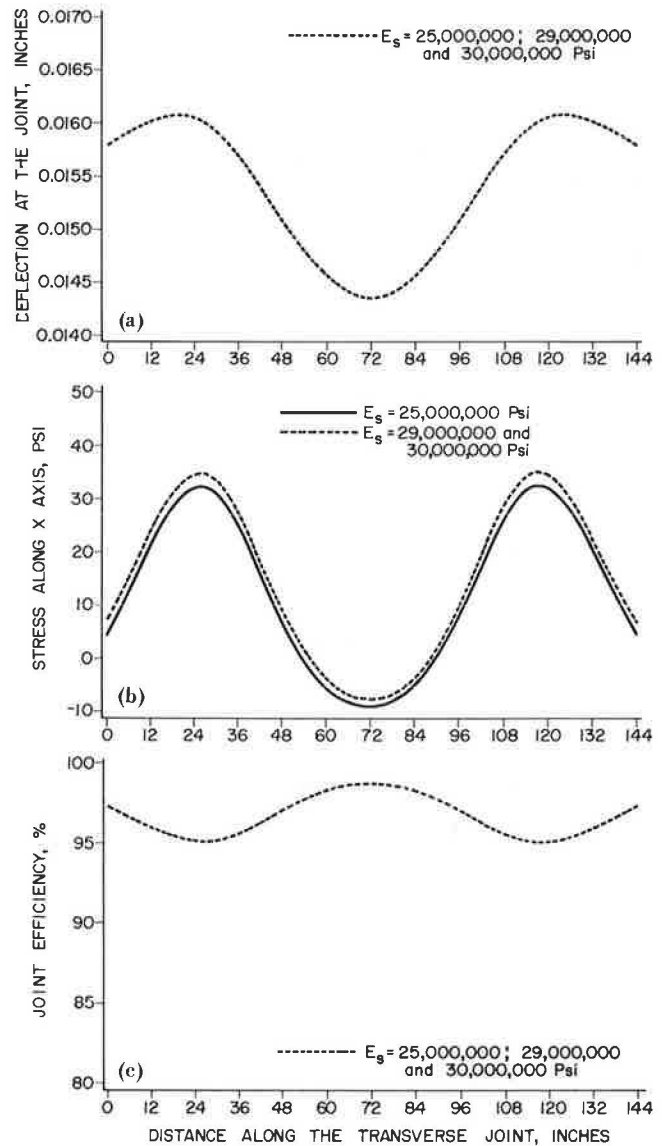


FIGURE 5 Effect of dowel modulus of elasticity on pavement response: (a) deflection at the joint under the tires, (b) stresses along the x-axis under the tires, and (c) percentage joint efficiency.

creases the stresses along the y-axis (transverse), which is the critical stress in this case.

Dowel Modulus of Elasticity

The dowel modulus of elasticity values considered were  $25 \times 10^6$ ,  $29 \times 10^6$ , and  $30 \times 10^6$  psi (172.25, 199.8, and 206.7 GPa). As shown in Figure 5, responses are essentially the same in all cases.

Joint Width

The joint widths considered were 0.1, 0.2, 0.25, and 0.5 in. (2.5, 5.1, 6.4, and 12.3 mm). It was found that corner deflections, tensile bending stresses, and joint efficiencies are the same in all four cases.

Concrete Modulus of Elasticity

The concrete modulus of elasticity values considered were  $4 \times 10^6$ ,  $4.5 \times 10^6$ , and  $5 \times 10^6$  psi (27.6, 31.0,

and 41.4 GPa). The tensile stresses along the x-axis and the joint efficiency are relatively unaffected by these changes in modulus. As the modulus increases, the deflection decreases slightly. However, this decrease in deflection is not significant because the variation is less than 5 percent.

**Modulus of Subgrade Reaction**

The modulus of subgrade reaction values considered were 100, 200, 300, and 500 pci (27.2, 54.2, 81.6, and 135.5 N/cm<sup>3</sup>). As shown in Figure 6, as the modulus of subgrade reaction increases, the corner deflection of the pavement slabs decreases significantly. This increase in subgrade reaction does not significantly change the tensile bending stresses along the x-axis, as shown in Figure 6(b). Joint efficiencies do vary, however, as shown in Figure 6(c).

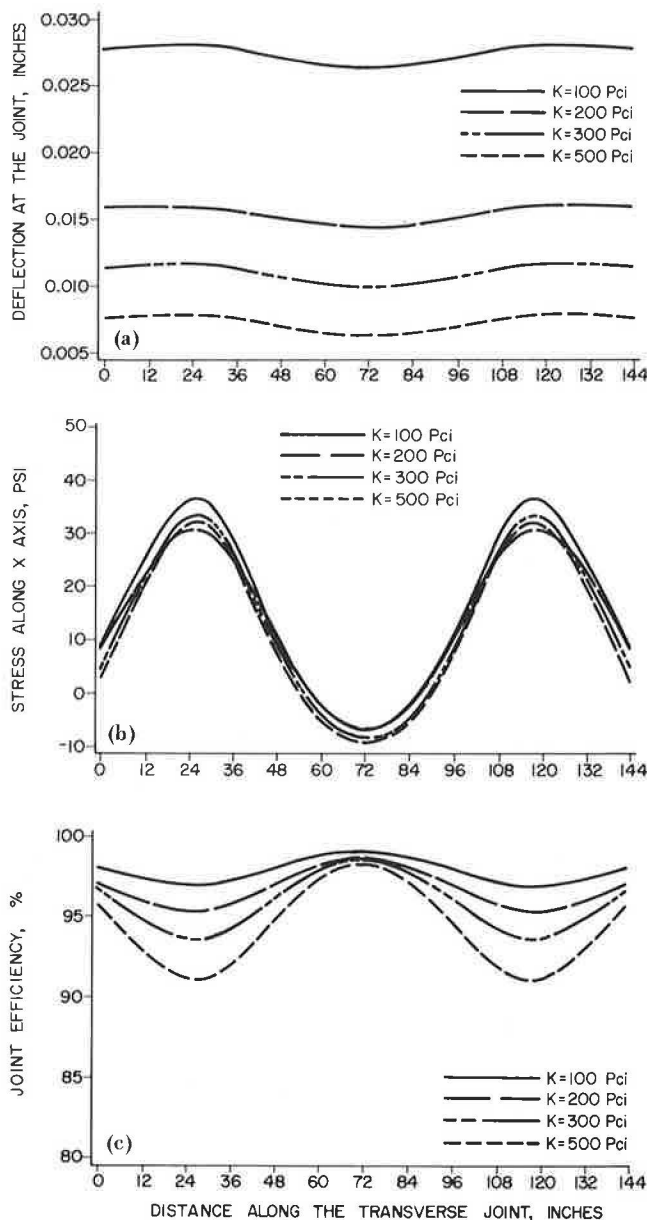


FIGURE 6 Effect of modulus of subgrade reaction on pavement response: (a) deflection at the joint under the tires, (b) stresses along the x-axis under the tires, and (c) percentage joint efficiency.

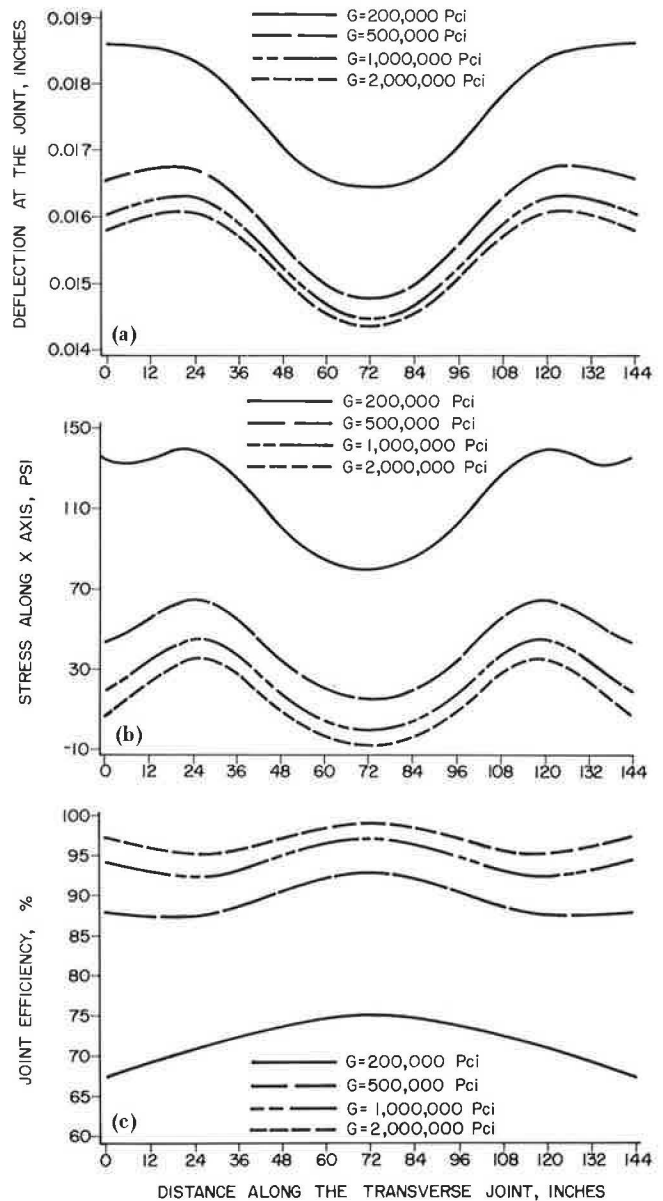


FIGURE 7 Effect of modulus of dowel-concrete interaction on pavement response: (a) deflection at the joint under the tires, (b) stresses along the x-axis under the tires, and (c) percentage joint efficiency.

**Modulus of Dowel-Concrete Interaction**

The modulus values of dowel-concrete interaction considered were  $2 \times 10^5$ ,  $5 \times 10^5$ ,  $10 \times 10^5$ , and  $20 \times 10^5$  pci (54.3, 135.7, 271.4, and 678.6 kN/cm<sup>3</sup>). As shown in Figure 7, the effect of these changes in modulus is significant for all of the structural responses. It should be noted that many researchers assume a value of  $1.5 \times 10^6$  pci (407.1 kN/cm<sup>3</sup>) for the modulus of dowel-concrete interaction. In this analysis the modulus values covered a wide range. The significance of the change in modulus will be discussed in detail later.

It was concluded that the variables that appreciably affect calculated pavement response are the modulus of subgrade reaction (k) and the modulus of dowel-concrete interaction (G). The influence of these parameters on pavement behavior was studied further.



### SENSITIVITY ANALYSIS FOR MODULUS OF SUBGRADE REACTION AND MODULUS OF DOWEL-CONCRETE INTERACTION

The parametric study showed that a loss in the modulus of subgrade reaction (low  $k$ ) or a loss in the modulus of dowel-concrete interaction (low  $G$ ) can increase pavement deflections and stresses enough to cause deterioration and eventual failure of the joint system. Therefore a sensitivity analysis was conducted to determine the effect of variations in  $k$  and  $G$  on the corner deflection of the pavement slab (the deflection at Point A shown in Figure 3) and joint efficiency (the deflection at Point B divided by the deflection at Point A). These responses were chosen because they are easily obtained with an NDT device such as the Road Rater, falling weight deflectometer, or Benkelman beam. Thus the theoretical analysis can be verified by field measurements.

For the pavement system analyzed, surface deflections and joint efficiencies were computed by varying one modulus ( $k$  or  $G$ ) while keeping the other constant. All other parameters and the loading configuration were kept the same as for the typical pavement section defined in the previous section.

Figures 8 and 9 show, respectively, the absolute deflection and the joint efficiency versus the modulus of dowel-concrete interaction ( $G$ ) for four different moduli of subgrade reaction ( $k$ ): 200, 300, 400, and 500 pci (54.4, 81.6, 108.8, and 135.5

N/cm<sup>3</sup>). As shown in these figures, for all practical cases in which the pavement support is in good condition, the change in pavement response becomes insignificant for values of  $G$  greater than approximately 200,000 pci (54.3 kN/cm<sup>3</sup>). A pavement is considered to have a good support condition when  $k$  is greater than 200 pci (10). However, the response of the pavement changes appreciably for values of  $G$  less than 200,000 pci (54.30 kN/cm<sup>3</sup>). Therefore the limiting criterion selected for the modulus of dowel-concrete interaction, for pavements with good support ( $k > 200$  pci), was 200,000 pci (54.30 kN/cm<sup>3</sup>).

It can also be seen in Figures 8 and 9 that the changes in pavement deflections and joint efficiencies become insignificant for values of  $k$  greater than 200 pci (54.4 N/cm<sup>3</sup>) as long as the load transfer is adequate ( $G > 200,000$  pci). Thus the limiting criterion selected for the modulus of subgrade reaction was 200 pci (54.4 N/cm<sup>3</sup>).

### EVALUATION PROCEDURE

From the sensitivity analysis it was concluded that a rigid pavement system can deteriorate if it loses its subgrade support ( $k < 200$  pci) or if the dowel bar loses its interaction with the surrounding concrete. Therefore the condition of the joints in a rigid pavement can be established only if both the modulus of subgrade reaction and the modulus of dowel-concrete interaction are known. The ability to distinguish between the loss of subgrade support and the loss of dowel-concrete interaction is important in the selection of rehabilitation treatments. A loss of subgrade support can be repaired by subsealing, but a loss of dowel-concrete interaction requires the reestablishment of load transfer. The wrong repair scheme wastes money and will not extend the serviceability of the pavement.

Figures 10 and 11 were developed from the results of the sensitivity analysis for the purpose of determining these moduli and subsequently evaluating the condition of in-service joints. Although these figures can be combined, they have been separated for ease of explanation. For any given combination of joint efficiency and corner deflection there is a unique value of  $k$  and  $G$ . These values, computed with the JSLAB program, have been plotted in Figures 10 and 11 on isobars of  $k$  and  $G$ , respectively. Figure 10 shows the joint efficiency versus the surface deflection at Point A (shown in Figure 3) for seven different moduli of subgrade reaction ( $k$ ): 100, 200, 300, 400, 500, 600, and 700 pci (27.20, 54.4, 81.60, 108.80, 135.5, 163.2, and 190.4 N/cm<sup>3</sup>).

Similarly, Figure 11 shows the joint efficiency versus the corner deflection of the same Point A for eight different moduli of dowel-concrete interaction ( $G$ ):  $0.1 \times 10^6$ ,  $0.15 \times 10^6$ ,  $0.175 \times 10^6$ ,  $0.20 \times 10^6$ ,  $0.25 \times 10^6$ ,  $0.50 \times 10^6$ ,  $0.75 \times 10^6$ , and  $1.00 \times 10^6$  pci (27.14, 40.7, 47.5, 54.2, 67.85, 135.70, 203.55, and 407.10 kN/cm<sup>3</sup>). This figure, which is based on the same data shown in Figure 10, can be used to determine whether the load transfer system ( $G$ ) is adequate. Figures 10 and 11 can be used to estimate  $k$  and  $G$ , however, only if both the corner deflection and the efficiency of the joint have been measured. This evaluation technique differs from that used in most evaluation programs, in which only the relative deflection across the joint is measured. As a consequence, the two parameters, the modulus of subgrade reaction and the modulus of dowel-concrete interaction, can be estimated from these figures for a particular joint and then compared with the limiting values to determine whether the joint is structurally adequate.

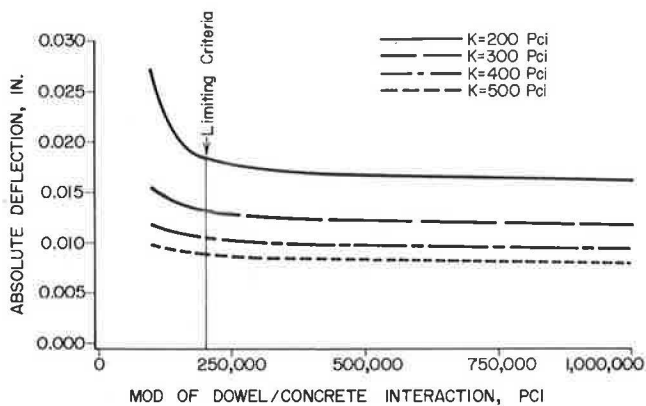


FIGURE 8 Variation of surface deflection at the joint 6 in. (15.24 cm) from the shoulder with the modulus of dowel-concrete interaction.

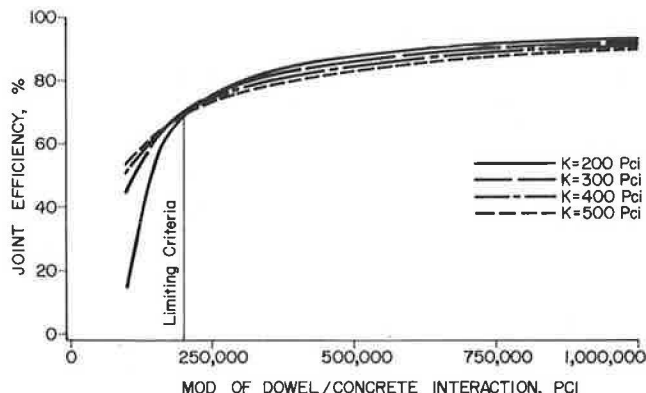


FIGURE 9 Variation of amount of load transfer across the joint for first dowel from the shoulder with modulus of dowel-concrete interaction.

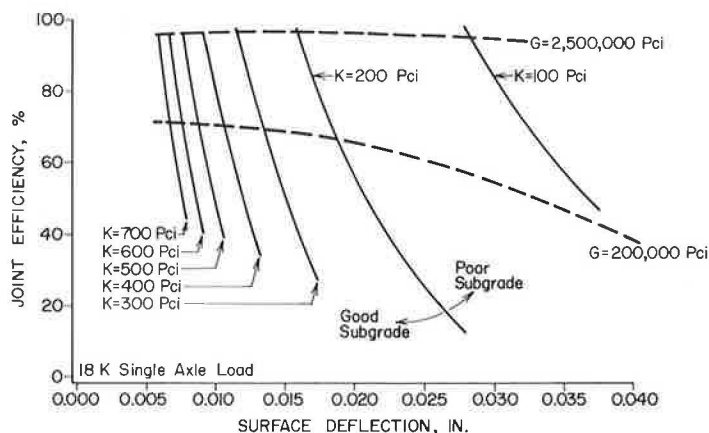


FIGURE 10 Joint efficiency versus surface deflection for various modulus values of subgrade reaction while modulus of dowel-concrete interaction is varied.

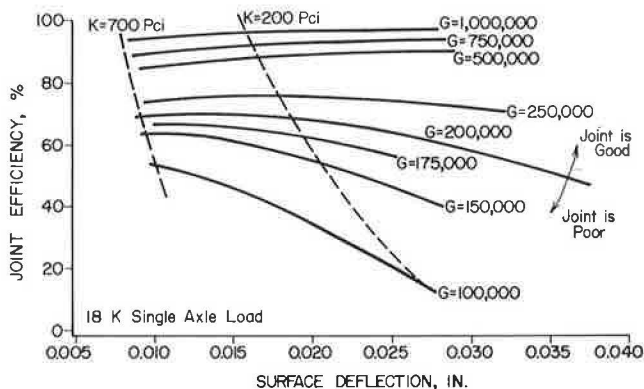


FIGURE 11 Joint efficiency versus surface deflection for various modulus values of dowel-concrete interaction while modulus of subgrade reaction is varied.

#### SUMMARY AND CONCLUSIONS

The methodology outlined here can be used to evaluate the condition of the subgrade support and the load transfer devices in a jointed concrete pavement. The methodology makes use of deflection measurements taken at the slab corners under an 18-kip (80-kN) single axle load. The absolute deflection and the relative deflection at the joint are required in order to predict the modulus of subgrade reaction ( $k$ ) and the modulus of dowel-concrete interaction ( $G$ ). A value of  $k$  less than 200 pci indicates a poor subgrade, and a value of  $G$  less than 200,000 pci indicates a poor joint system. Separating the evaluation of subgrade support and joint efficiency will help determine whether subsealing or joint replacement, or both, are required for the rehabilitation scheme.

The following conclusions have been drawn:

1. The JSLAB finite element program is a practical model of a jointed concrete pavement system. It can be used to calculate the stresses and deflections in a pavement system under realistic loading conditions. The model can be used to analyze joints that are doweled, keyed, or have an aggregate interlock.

2. The parametric study showed that the variations in the modulus of subgrade reaction and the modulus of dowel-concrete interaction have the most

significant effect on changes in stresses and deflections in a jointed pavement system.

3. When the modulus of dowel-concrete interaction is 200,000 pci (54.3 kN/cm<sup>3</sup>) or less, the deflections of the pavement increase significantly and therefore the stresses in the pavement increase significantly.

4. The modulus of subgrade reaction and the modulus of dowel-concrete interaction can be predicted from deflection measurements at the corners of the pavement slab. Two measurements are required: the absolute deflection of the loaded slab and the relative deflection on either side of the joint.

#### ACKNOWLEDGMENT

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## Controlling Longitudinal Cracking in Concrete Pavements

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### ABSTRACT

The objective of the study reported in this paper was to investigate the development of longitudinal cracks in wide concrete pavements (two or more lanes in one direction) and to develop a model to estimate the depth of saw cut needed to control these cracks within the groove. The model developed uses the concepts of variability in the material properties of the concrete (tensile strength), pavement thickness (as constructed in the field), and depth of saw-cut groove. It was observed that estimates of longitudinal cracking have a reasonable match with field observations. It was observed that the longitudinal cracking of concrete pavements (two or more lanes in one direction) was dependent on the type of aggregate used in the concrete mix. Two types of aggregates were investigated. Uniformity of concrete mix strength (tensile) represented by standard deviation (tensile strength) affected the development of longitudinal cracks. A lower value of standard deviation obtained for concrete mix using lime rock aggregate in the mix was responsible for confining more cracks within the saw cut compared with the mix using river gravel aggregate. A sensitivity analysis of the model indicated that substantial reduction in saw-cut depth can be achieved if the variability of concrete strength during construction can be reduced.

Wide concrete pavements (two or more lanes in one direction) will develop longitudinal cracks due to shrinkage of concrete soon after it is poured. The repair of these cracks is difficult and expensive, especially when they are spalled. The presence of these cracks in pavement is unsightly. Therefore longitudinal joints at reasonable spacing (12 ft or one lane wide) are provided to encourage development of controlled cracks along these joints.

Longitudinal joints are generally formed by cutting a groove in the green concrete with a power saw. Adequate depth of saw cut must be provided to ensure that the longitudinal cracks will be confined within the groove. This provides an aesthetically acceptable regular longitudinal joint in the pavement at a low maintenance cost.

The performance of any saw-cut joint depends on its depth. An inadequate depth of saw cut may result in the development of longitudinal cracks away from the groove. These cracks eventually will spall and require expensive repair and maintenance.

The objective of this study was to investigate the development of longitudinal cracks in concrete pavements and to develop a model to estimate the depth of saw cut needed to control these cracks within the groove.

### DEVELOPMENT OF LONGITUDINAL CRACKS ALONG THE SAW-CUT GROOVE

Let us assume that a wide concrete pavement is constructed with a saw cut, as shown in Figure 1. Fur-