

cement and an accelerator or the proprietary product Roadpatch can be successfully used for patching PCC pavements.

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Void Detection for Jointed Concrete Pavements

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ABSTRACT

Procedures for the detection of voids or loss of support under jointed concrete pavements by using nondestructive deflection testing measurements are presented. A rapid field-applicable procedure is presented to quickly determine the presence of voids by analysis of the load and deflection response at slab-corners. A more detailed method is presented in which deflection measurements from center slab and corner locations are used to locate and determine the approximate size of any existing voids. The procedures were developed by using computer modeling of loadings with the ILLISLAB finite-element computer program. The procedures were field verified on several test projects. Basic guidelines for testing, locating joints or cracks requiring subsealing, and estimating grout quantities for jointed concrete pavements are presented.

The loss of support near transverse joints and working cracks because of the pumping of base or subgrade fines or both is one of several major causes of concrete pavement deterioration. Subsealing of locations with poor support by the injection of a grout mixture has become standard practice in many parts of the country. What has been lacking in this process is an established procedure to determine the locations along the pavement where loss of support exists. This deficiency has led many agencies to subseal on a blanket-coverage basis (e.g., all joints and working cracks), which has led to serious problems on several projects because it was not possible to determine (a) whether and where any voids existed in the first place, (b) an estimate of the grout quantity required to fill existing voids, and (c) the extent to which the voids were filled and support was restored.

Procedures were developed under NCHRP Project 1-21 at the University of Illinois for determining areas of loss of support (commonly called voids) by using nondestructive deflection testing (NDT) (1,2). Two different methods were developed:

1. A rapid and simple field method to give an indication of the existence of a void, and
2. A detailed approach to give an indication of the location and size of the void.

Both procedures were field tested at several different project sites.

BASIC APPROACH AND CONCEPTS

Computer modeling based on finite-element analysis was used to establish theoretical relations between

applied load and surface deflection for a wide variety of pavement conditions. These relations were then used as the basis for the formulation of the void detection procedures presented here.

Computer Modeling of Loadings

The computer program used to model the pavement's load-induced deflection response was the ILLISLAB finite-element program (3), which allows the user to input pavement material properties (layer thickness, elastic modulus, and Poisson ratio), loading conditions (magnitude, location, and area of load), and joint load transfer. The program then determines the theoretical surface deflections for specified nodal points on the slab.

A series of programs was run that varied slab thickness, slab modulus, subgrade support modulus, deflection load transfer, and void size to establish the effects of each of these parameters on pavement deflection. Deflection response was investigated at locations correlating to sensor locations commonly used on deflection testing equipment. To determine the effects of slab thickness on measured deflection, slab thicknesses of 8, 9, and 10 in. were examined. Subgrade stiffness values, modeled as spring constants acting at specified nodes (Winkler foundation k-value), were chosen to reflect the wide range of conditions that may be encountered in the field. Values ranging between 100 and 1,500 psi/in. were included.

Concrete slab modulus values were varied from 3,000,000 to 8,000,000 psi. Deflection load transfer across the transverse joint was varied to represent joint efficiencies of 0, 35, 65, and 100 percent. Voids were modeled as square areas located on one or both sides of the joint (equal area on both sides) by indicating a foundation support value of 0 psi/in. at all nodes inside the boundaries of these areas. Void sizes of 0, 4, 16, and 36 ft² were modeled on each side of the joint.

The effects of each of these variations were examined individually and in different combinations to determine whether any significance could be realized. Some of the findings of this computer modeling include the following:

1. Where full support exists, proportional variation of deflection due to available load transfer is independent (within testing accuracy limits) of slab thickness, slab modulus, and subgrade modulus;
2. Variations in deflection response due to void size are a function of both available load transfer and subgrade modulus when the void is located on only one side of the joint; and
3. Variations in deflection response due to void size are dependent only on subgrade moduli when equal-sized voids are located on either side of the joint.

Voids Under Slab

A void can be described as any unsupported area beneath the slab. The most common location for voids is along the outside edge of the driving lane at any transverse joint or working crack with poor load transfer. It is believed that these voids are created by a combination of excess moisture and independent large slab deflection in response to loading, which causes the erosion of subgrade or subbase fines or both.

Generally (but not always) this process begins under the leave side of the joint or working crack and expands in both the longitudinal and transverse

directions. As the void increases in size, corner loadings along the outer edge force the leave slab to act as a cantilever, which generally leads to serious faulting and a corner break or diagonal crack across the slab.

Because of the heterogeneous qualities of the pavement, subdrainage, and loading conditions, void progression develops in a random pattern. For this reason, testing of individual joints is necessary to determine the location and extent of void development along any given project.

NDT Equipment

The NDT equipment utilized for void detection must be capable of (a) applying a reasonably heavy range of loads, (b) measuring the deflection directly beneath the center of the load, (c) measuring the deflection basin up to 36 in. (and preferably 72 in.) from the center of the loading plate at 12-in. intervals, and (d) simultaneously measuring slab deflections across joints and cracks for load transfer.

Vibratory steady-state devices such as the road rater and impact load devices such as the falling weight deflectometer (FWD) have been used successfully. The procedures outlined here were developed for use with these types of devices.

Deflection Load Transfer

Deflection load transfer, also commonly referred to as joint efficiency, is measured at the extreme outer corner of the slab and is computed as follows:

$$\text{Load transfer (\%)} = \left(\frac{\text{deflection of the unloaded slab}}{\text{deflection of loaded slab}} \right) * 100$$

This load transfer can be the result of simple aggregate interlock, foundation stiffness, dowel bar shear transfer, or a combination of these mechanisms. Typical load transfer values measured along any given project may vary considerably and therefore each joint must be measured to determine the respective load transfer on each side of the joint.

Back-Calculation of Effective Slab Modulus

The magnitude of deflection variation with respect to void development varies as a function of slab modulus. It is therefore desirable to determine the effective slab modulus along each project before the implementation of the comprehensive void detection procedures. These modulus values may be back-calculated from NDT data by analyzing the deflection basin produced during center slab testing. This back-calculation process compares the measured deflection basin area and maximum deflection with theoretical values obtained through computer modeling to yield the appropriate slab modulus and foundation k-value for each slab tested.

Zero Voids Band

A key assumption of the comprehensive void analysis is that a certain percentage of the joints along the pavement will not have voids present. NDT measurements taken at these joints provide a reference from which subsequent void size predictions are based. Computer modeling was used to first establish a relationship between corner deflection and load transfer for fully supported slabs. Proportionally, this relationship was found to be constant over all

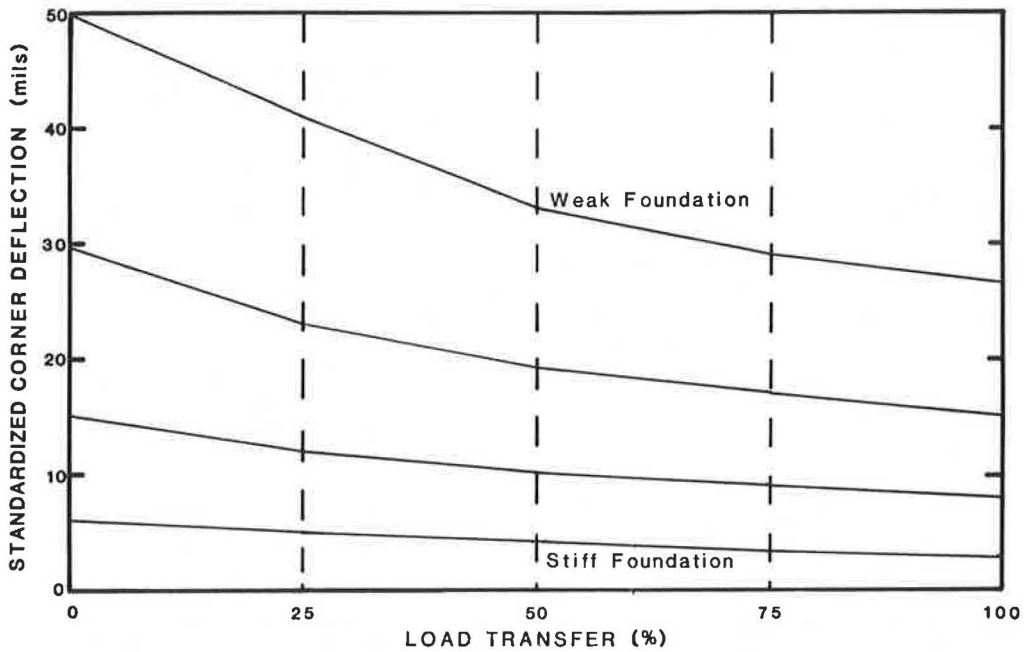


FIGURE 1 Corner deflection versus load transfer for fully supported slabs.

ranges of slab thicknesses and subgrade support values examined (8 to 10 in., 100 to 1,500 psi/in.), although the absolute magnitude of the corner deflections varies accordingly. Typical curves resulting from this analysis that represent deflection variation as a function of load transfer for fully supported slabs are shown in Figure 1.

The deflection responses shown in Figure 1 do not take into account any random variation that will be introduced into field deflection measurements because of the heterogeneous nature of both the portland cement concrete (PCC) slabs and foundation support along with load plate locating variations. The effects of field variables on corner deflections were examined by using data obtained with the road

rater and FWD on new and lightly loaded slabs for which no voids existed. With these data, it was determined that the coefficient of variation of deflection testing response ranged from 10 to 15 percent. Therefore, assuming normality, the inclusion of all points plus or minus two standard deviations away from the sample mean on any given corner deflection or load transfer plot should include roughly 90 to 95 percent of all deflection measurements taken at those joints for which no voids exist. Including the effects of load transfer in this concept results in an error band located along a given theoretical mean curve. This resulting error band is called the "zero voids band." Figure 2 shows the location of this band as applied to deflection

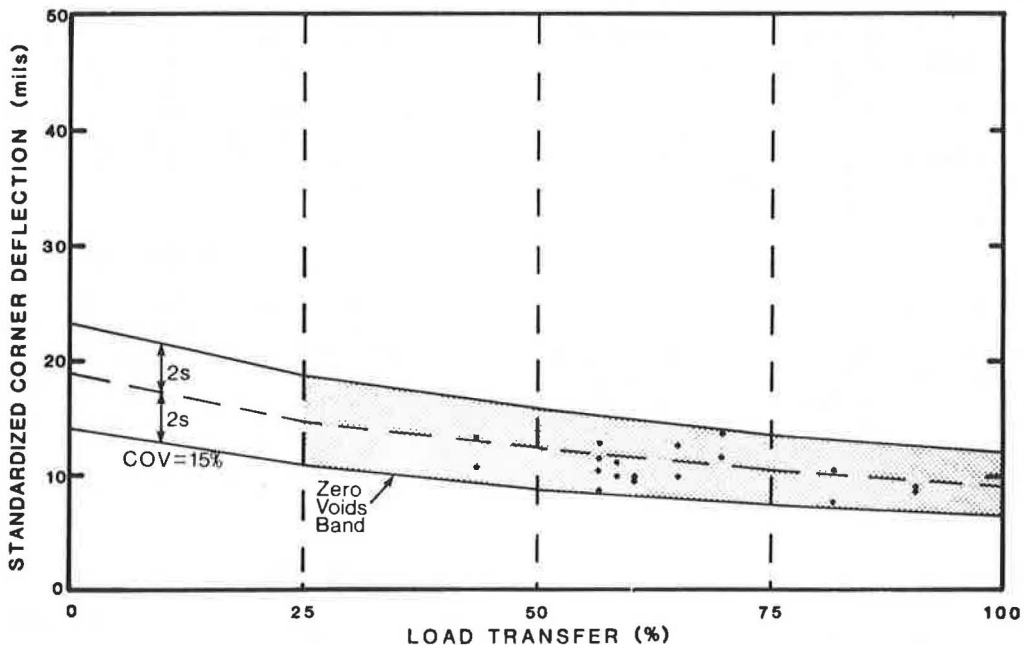


FIGURE 2 Zero voids band for newly constructed slabs on I-40, New Mexico.

measurements taken along a section of newly constructed slabs on I-40 in New Mexico.

Determining Corner Subgrade Support Value

In order to predict void size and locations at slab corners from deflection measurements, the effective subgrade support or *k*-value acting at the corner of a fully supported slab must be determined. With the ILLISLAB program it was found that for any given slab thickness, the effective corner subgrade support value is proportional to the deflection of a free corner (0 percent load transfer) in response to a corner load. Therefore, effective corner subgrade support can be determined rather easily.

Effects of Temperature

Temperature has two major effects on the slab, which affect measured deflections: slab curl and joint lockup. As the top of the slab warms from solar radiation, temperature differences between the top and bottom of the slab force it to curl downward. This may cause a reduction in deflection under load (and vice versa). The other effect occurs at the joints that lock up when the slab is warm and expands longitudinally. This produces a high load transfer at the joint and greatly reduces deflection. This joint lockup will also reduce the chance of finding voids that are located on only one side of the joint.

The combined effect of these two mechanisms can change slab corner deflections significantly. Temperature effects are considered in the procedures through restricting the measurement of deflections to a range of temperatures and testing primarily during early mornings or during ambient temperatures in the range of 50 to 80°F. Further testing and analysis are recommended to better quantify these effects so that they may be more fully incorporated into the void detection procedure.

Cracked Slabs

Cracks in slabs change the deflection patterns considerably, especially corner breaks or diagonal cracks near the joint. The void detection procedures presented here assume that the slabs are intact and that no cracks exist near the joints. If transverse cracks exist at 10 or more feet from the joint, they may be considered as joints and analyzed as such. However, slabs having a corner break or nearby diagonal cracks have had a loss of support, are difficult to stabilize, and should actually be considered for full-depth repairs.

VOID DETECTION PROCEDURES

The two methods of void detection developed will be presented by using actual data collected from various projects across the United States. The methods presented include (a) a rapid and simple method to indicate the existence of a void and (b) a comprehensive method to indicate the presence and approximate size of a void.

Rapid Void Detection Procedure

A rapid and fairly accurate procedure was developed to locate voids beneath slab corners. This method can be applied in the field and can give immediate

indication of the existence of a void or of loss of support. Because available load transfer is not taken into account, exact void size determination is not possible. This method involves three basic steps as follows:

Step 1: Measure Corner Deflections. Measure pavement deflections at slab corners while the temperature range is between 50 and 80°F with a device that can apply at least three different load levels. Loadings should be chosen to encompass 9,000 lb, such as 6,000, 9,000, and 12,000 lb.

Step 2: Plot Results. Plot the measured results directly on a graph of load versus deflection as shown in Figure 3. Draw the best-fit straight line through all three points and compare this line with the line formed by the simple connection of the three points. Marked differences between these lines indicate possible void locations.

Step 3: Locate Voids. If the best-fit line is satisfactory, extend the line to the horizontal (deflection) axis and note the intercept value. Locations where no voids exist generally have intercept values along the horizontal axis of <0.002 in. Joints with no voids have also been found to have intercept values less than zero. Joints with voids generally have intercept values in excess of 0.002 in. with values increasing as void size increases.

This simple procedure can be applied both before and after subsealing to provide information as to the number of joints requiring subsealing and the effectiveness of the subsealing operation. An example of this procedure can be seen in the load deflection plot from a selected joint on Ohio I-77 as shown in Figure 4. Note that the leave-side response shifted after subsealing, which indicates a satisfactory stabilization of the slab.

Comprehensive Procedure for Void Detection

This procedure indicates the existence of a void and estimates its horizontal area (in terms of loss of support). It is somewhat complex but can easily be mastered after a few applications. Step-by-step procedures will be presented to outline the entire process. The structural characteristics of the test pavement used to illustrate the procedure are as follows: a 9-in. PCC slab over 4 in. of cement-treated base over a 12-in. sand subbase that has been subjected to heavy truck traffic for many years. Deflections were recorded under a 5,000-lb peak-to-peak vibratory load.

Step 1: Measurement of Deflections

The pavement scheduled for testing must first be divided into uniform subsections, which should include portions of the pavement with similar structural characteristics (thickness, age, base type, subgrade type). Further breakdown of these subsections may be necessary if pavement temperature fluctuations during testing exceed 20°F. Deflection measurements should only be taken if the ambient air temperature is between 50 and 80°F to avoid excessive slab curling and joint lockup.

Step 1a: Center Deflections

Center slab deflections should be taken for at least five sound slabs in each subsection. If this number of sound slabs does not exist, the minimum spacing

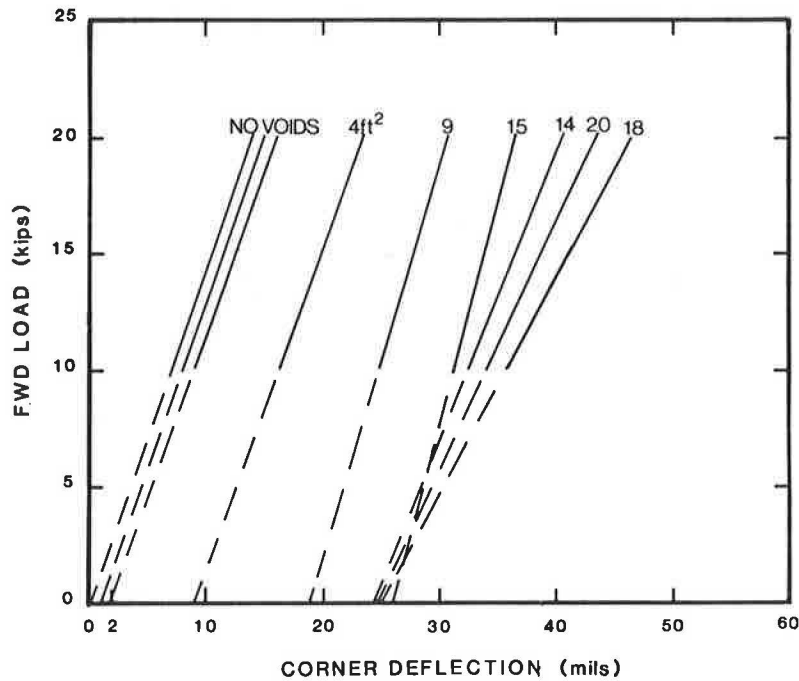


FIGURE 3 FWD load versus corner deflection (void sizes obtained from comprehensive method).

between the load cell and the nearest crack should be 6 ft as shown in Figure 5. The deflections for all four sensors along with the applied load should be recorded as shown in Table 1. Deflection measurements are recorded on Table 1 by using the notation W_{ij} , where W_{ij} corresponds to a measured deflection (W) at location i while the load is placed at location j . The six possible testing locations are shown in Figure 5. Additional values also listed in Table 1 will be explained later in this paper. When the

FWD is used for deflection measurements, it is advisable to record only those deflections measured with an approximate 9,000-lb load.

Step 1b: Corner Deflections

Deflection measurements should be taken with the loading plate in the extreme corner of the slab (see Figure 5) on both the approach and the leave sides

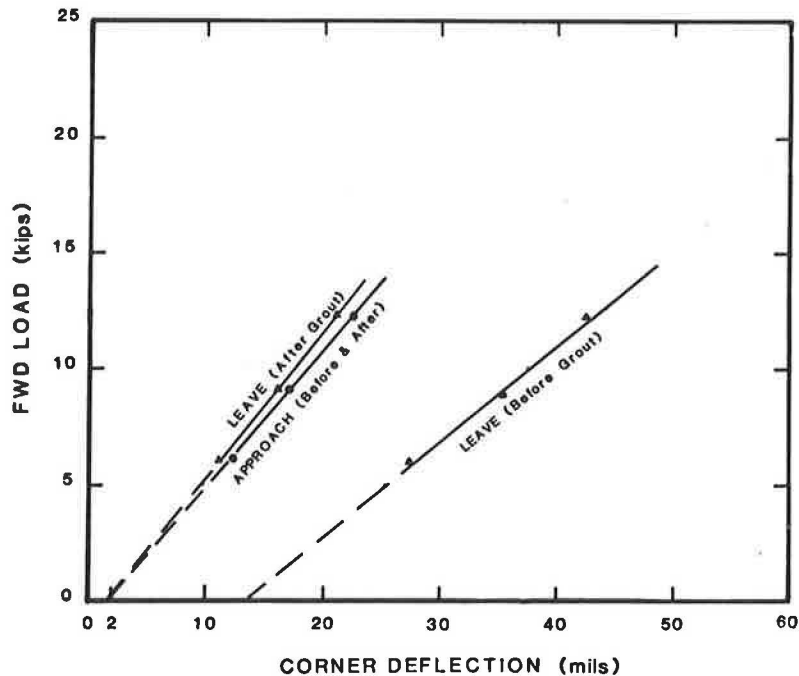


FIGURE 4 FWD load versus deflection before and after subsealing (I-77, Ohio).

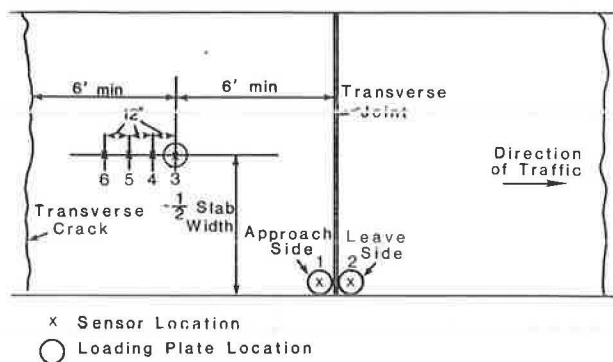


FIGURE 5 Load plate and sensor locations for center slab and corner deflection measurements.

of the joint. The second sensor should be located across the joint for at least one of these tests (and ideally for both) at each joint so that the existing load transfer at each joint can be determined. Deflections taken in the wheel path will not provide the accuracy required in void detection. Deflection measurements may be taken with any NDT equipment as long as the applied force to the slab is reasonably heavy (e.g., 5,000 lb or greater). Analysis of deflection data, however, suggests that the FWD provides the most accurate representation of a moving wheel load and is therefore recommended if a choice exists. Also, there is no significant pre-load weight for this equipment to bend the corner of the slab down before loading.

Measured deflections should be tabulated in a manner similar to that shown in Table 2. Again, if the FWD is used for deflection measurements, only

TABLE 1 Sample Void Analysis, Center Slab Deflections, 9-in. Slab

Slab	Load (lb)	Measured Values (mils)				Calculated Values			
		W33	W43	W53	W63	Area (in.)	d33 (mils at 9 kips)	Eslab (psi)	Badj
1	5,000	1.82	1.63	1.58	1.42	31.85	3.28	7.00E+06	1.12
2	5,000	2.55	1.49	1.16	0.79	20.33	4.59		
3	5,000	2.67	1.65	1.51	1.31	23.15	4.81		
4	5,000	2.20	1.63	1.45	1.26	26.24	3.96	3.00E+06	1.35
5	5,000	1.82	1.53	1.43	1.23	29.57	3.28	5.60E+06	1.19
6	5,000	1.95	1.75	1.75	1.55	32.31	3.51	7.00E+06	1.11
7	5,000	2.90	1.58	1.58	1.30	21.77	5.22		
8	5,000	2.48	1.80	1.64	1.30	25.79	4.46		
9	5,000	1.82	1.49	1.54	1.20	29.93	3.28	6.10E+06	1.22
10	5,000	2.64	1.65	1.60	1.43	24.02	4.75		
11	5,000	1.85	1.65	1.48	1.40	30.84	3.33	7.00E+06	1.12
12	5,000	2.86	1.67	1.52	1.28	22.07	5.15		
13	5,000	1.60	1.40	1.30	1.16	30.60	2.88	7.00E+06	1.14
14	5,000	2.00	1.55	1.39	1.20	26.94	3.60	3.00E+06	1.33
15	5,000	2.66	1.80	1.62	1.37	24.52	4.79		
Average								5.71E+06	1.20
Ecorr									1.15

TABLE 2 Sample Void Analysis, Corner Deflections, 9-in. Slab

Joint	Load (lb)	Measured Values				Ecorr	Badj	Standardized Values			Void Size (ft ²) by Location	
		W11 (mils)	W22 (mils)	W12 (mils)	LT (%)			d11 (mils)	d22 (mils)	LT (%)	Approach Side	Leave Side
1	5,000	4.11	5.73	3.59	63	1.15	1.20	8.5	11.9	75	0	11
2	5,000	6.83	4.29	2.80	65	1.15	1.20	14.1	8.9	78	4	4
3	5,000	4.80	4.90	2.17	44	1.15	1.20	9.9	10.1	53	0	0
4	5,000	5.42	3.92	2.74	70	1.15	1.20	11.2	8.1	84	4	4
5	5,000	5.93	4.54	2.02	44	1.15	1.20	12.3	9.4	53	4	0
6	5,000	3.86	2.97	1.94	65	1.15	1.20	8.0	6.1	78	0	0
7	5,000	4.85	3.44	2.06	60	1.15	1.20	10.0	7.1	72	4	0
8	5,000	8.31	6.11	1.54	25	1.15	1.20	17.2	12.6	30	6	4
9	5,000	2.98	5.68	2.00	35	1.15	1.20	6.2	11.8	42	0	4
10	5,000	5.83	8.25	1.48	18	1.15	1.20	12.1	17.1	22	0	4
11	5,000	4.75	3.98	1.71	43	1.15	1.20	9.8	8.2	52	0	0
12	5,000	4.08	8.21	3.67	45	1.15	1.20	8.4	17.0	54	0	28
13	5,000	3.24	8.25	3.45	42	1.15	1.20	6.7	17.1	50	0	24
14	5,000	4.88	3.81	1.57	41	1.15	1.20	10.1	7.9	49	0	0
15	5,000	2.72	3.06	2.22	73	1.15	1.20	5.6	6.3	87	0	0
16	5,000	9.05	9.00	5.65	63	1.15	1.20	18.7	18.6	75	8	8
17	5,000	3.45	2.67	1.66	62	1.15	1.20	7.1	5.5	75	0	0
18	5,000	4.22	2.38	1.34	56	1.15	1.20	8.7	4.9	68	0	0
19	5,000	6.45	4.82	1.48	31	1.15	1.20	13.4	10.0	37	4	0
20	5,000	8.45	6.51	3.68	57	1.15	1.20	17.5	13.5	68	36	16
21	5,000	2.83	2.73	1.69	62	1.15	1.20	5.9	5.7	74	0	0
22	5,000	4.18	2.57	2.10	82	1.15	1.20	8.7	5.3	98	0	0
23	5,000	2.87	2.42	1.56	64	1.15	1.20	5.9	5.0	77	0	0
24	5,000	2.64	3.04	1.52	50	1.15	1.20	5.5	6.3	60	0	0
25	5,000	2.54	2.48	1.62	65	1.15	1.20	5.3	5.1	78	0	0
26	5,000	5.84	7.25	3.28	45	1.15	1.20	12.1	15.0	54	4	16
27	5,000	4.22	3.66	1.86	51	1.15	1.20	8.7	7.6	61	0	0

Note: LT = load transfer.

those deflections measured with an applied load near 9,000 lb should be recorded.

Step 2: Determination of Pavement Parameters from Center Deflections

The first task in this step is the calculation of the deflection basin area associated with each loading. This is accomplished by using the information obtained from center slab testing:

$$\text{Area} = (6/W33) * [W33 + (2 * W43) + (2 * W53) + W63].$$

The measured deflection W33 is then normalized to a 9,000-lb load by using the following formula:

$$D33 = W33 * (9,000 \text{ lb}) / (\text{applied load}),$$

where D33 is the normalized deflection in mils and W33 is the measured value in mils. The foregoing equation assumes a linear deflection response within the range of 5,000 to 15,000 lb. Deflections measured with loadings outside these limits may induce considerable error because of nonlinearity.

For each test location the calculated area and standardized deflection are used along with slab thickness to back-calculate the effective modulus of elasticity (E) of the slab. These E-values are then averaged to determine the average slab modulus for the subsection. Any values of E that are less than $3 * 10^6$ psi are suspect and should not be included in this average. Any values above $7 * 10^6$ psi should be considered to be $7 * 10^6$ psi for this analysis. See Table 1 for sample results.

The next task is a determination of the bending adjustment factor, Badj. This factor is computed for each test location as follows:

$$\text{Badj} = W33/W43,$$

where Badj is the bending adjustment factor and W33 and W43 are measured deflections at the center of the slab. Calculated values are averaged to obtain the representative bending adjustment factor for each subsection. The load transfer measured at each joint or crack is then multiplied by this average Badj to adjust for the slight bending of the slab between the first and second sensors, so that true load transfer across the joint is obtained (see Table 1 for sample results).

Step 3: Determination of Adjustment Factors to Standardize Corner Deflections

The measured deflections must be adjusted to a standard loading condition of 9,000 lb and a standard slab modulus of 4,000,000 psi. This is accomplished by graphically determining the elastic modulus correction factor, Ecorr. Once this value is known, the standardized deflections can be calculated by using the following equation:

$$d_{ij} = W_{ij} * E_{corr} * (9,000 \text{ lb}) / (\text{applied load}),$$

where

$$\begin{aligned} d_{ij} &= \text{standardized deflection,} \\ W_{ij} &= \text{measured deflection, and} \\ E_{corr} &= \text{elastic modulus correction factor.} \end{aligned}$$

(See Table 2 for sample results.)

Step 4: Determination of Adjusted Load Transfer

As mentioned previously, the measured load transfer (measured between sensors 1 and 2) must be adjusted

by the Badj factor to reflect conditions that exist at the interface of the joint walls. This is accomplished by using the following equation:

$$\begin{aligned} \text{Adjusted load transfer} &= \text{measured load transfer} \\ &* \text{Badj,} \end{aligned}$$

where measured load transfer is $(W21/W11) * 100$ or $(W12/W22) * 100$ (W21 is deflection at location 2 with load at location 1, W11 is deflection at location 1 with load at location 1, W12 is deflection at location 1 with load at location 2, and W22 is deflection at location 2 with load at location 2). (See Table 2 for sample results.)

Step 5: Construction of the Void Detection Plot

The standardized deflections and adjusted load transfers are now plotted on the graph of deflection versus load transfer known as the void detection plot. Figure 6 is a plot of typical deflection data taken at consecutive joints along a project at both approach and leave corners.

Step 6: Determination of Zero Voids Band

To determine those joints for which no void exists, a family of zero voids curves is superimposed over the void detection plot. This family of zero voids curves is a series of curves drawn at various intercept values to represent the wide range of possible locations that may result because of field variables (e.g., slab thickness and subgrade stiffness). With these as guides, a curve is established that envelops the bottom of all the plotted data points. (There will be times when some extreme values or outliers will fall below this bottom line because of random statistical variation or errors in measurement. When the lower envelope is established, the number of outliers should be kept below 5 percent of the values falling in the completed zero voids band.) Deflection intercept values are then measured directly from this curve for each of the five main load transfer divisions (0, 25, 50, 75, and 100 percent). These intercepts are then multiplied by 1.43 to establish the intercepts for the mean zero voids curve and then by 1.86 to establish the intercepts for the upper limit on the zero voids band.

Step 7: Construction of Void Size Lines

The mean zero voids intercept at 0 percent load transfer is then used to graphically determine the effective corner subgrade support k-value. Once the effective corner support value is known, adjustment factors for each void size and load transfer can be determined. These adjustment factors are then applied to the mean zero voids intercepts at each major load transfer division to determine the intercepts for each of the various void sizes. Connecting these points results in the final graph as shown in Figure 7 (assuming a 9-in. slab thickness).

During this construction, all curves may be approximated as piecewise linear between the main load transfer divisions without introduction of significant error into the analysis. This concept will be illustrated on all void size lines. Void size lines that represent single-sided voids are shown as solid lines and those that represent equal-sized voids across the joint are shown as dashed lines. Single-sided void lines are not extended past the 75 percent line transfer lines because these high levels of load transfer (75 to 100 percent) are not normally conducive to developing a single-sided type of void pattern.

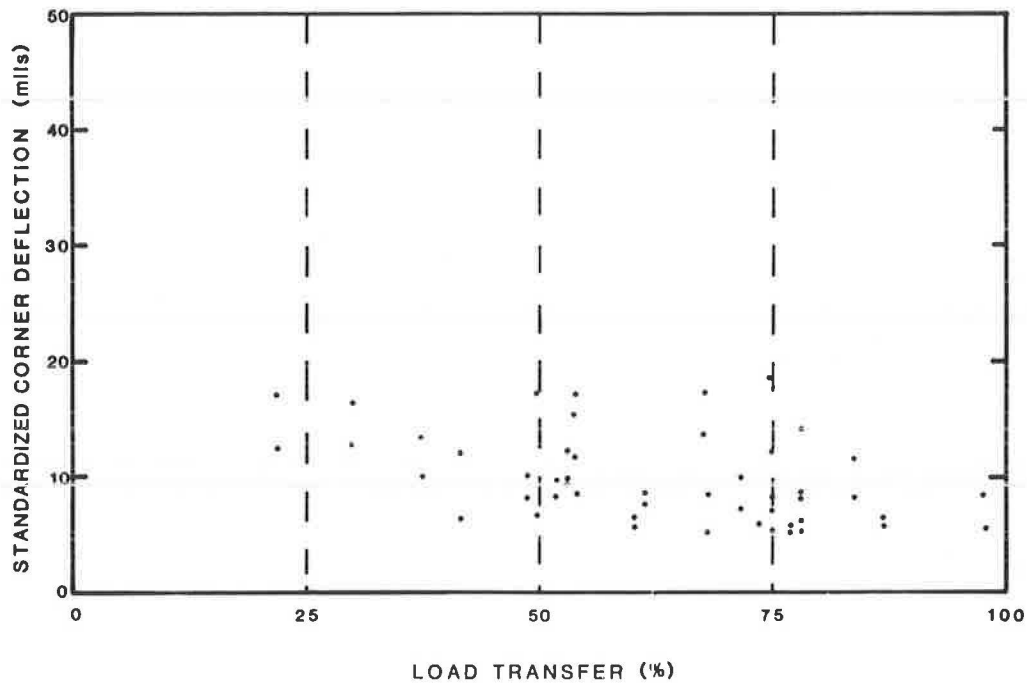


FIGURE 6 Typical plot of corner deflection versus load transfer.

Step 8: Determination of Void Sizes at Individual Joints

Approximate void sizes existing at each joint are found by using the following guidelines:

1. Points falling within or below the zero voids band are recorded as having no void.
2. Points falling above the zero voids band represent joints with voids developed. To size these voids, one must first determine whether a void exists on one or both sides of the joint. This is done

by assuming that equal-sized voids exist across the joint if the deflections recorded at a joint (approach and leave sides) differ by no more than 15 percent.

One-Sided Voids

1. Any points falling between the upper limit of the zero voids band and the solid 4-ft² line are recorded as having a void of 4 ft².
2. Points falling between the 4- and 36-ft² void lines are interpolated as closely as possible.

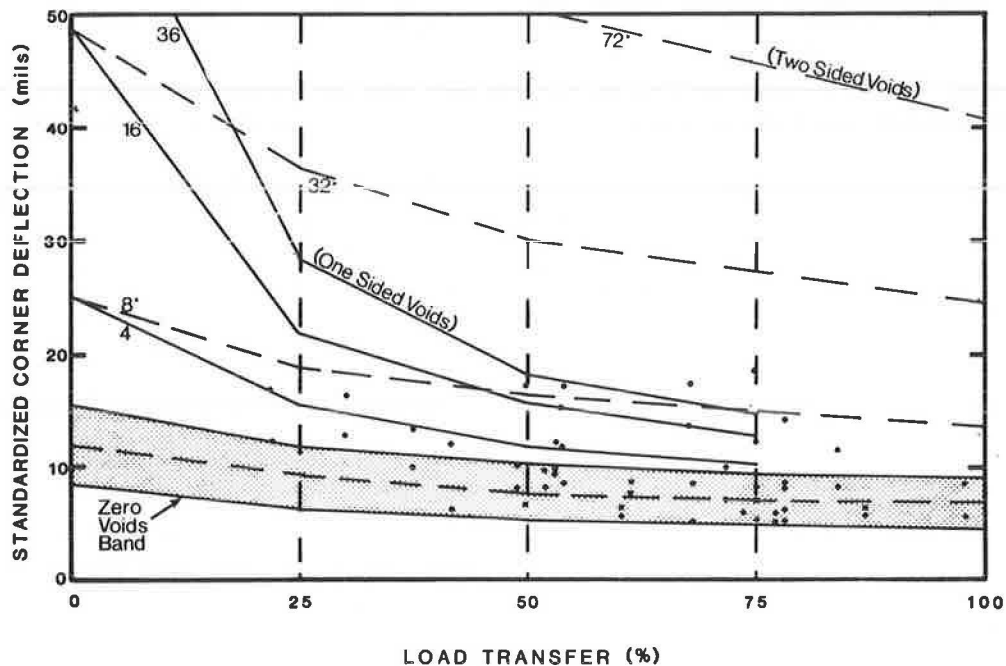


FIGURE 7 Completed void detection plot using typical deflection data.

3. Points above the 36-ft² line are recorded as 36 ft².

[Note: It is possible to have single-sided voids on both sides of a joint. This situation indicates voids of much different sizes (one large and one small).]

Double-Sided Voids

1. For points believed to have equal-sized voids, void predictions are based on only the larger measured deflection.

2. Points falling between the upper limit of the zero voids band and the 8-ft² line are recorded as 8 ft² (4 ft² on either side).

3. Points between 8 and 72 ft² are interpolated as closely as possible.

4. Points above the 72-ft² line are recorded as 72 ft² (a situation that rarely occurs).

Void sizes obtained by using Figure 7 have been entered in Table 2. This completes the void detection evaluation. The next step is to estimate the grout quantities required to fill these voids.

Step 9: Estimation of Grout Quantities

The amount of grout that is required to restore support for a given project logically should depend on the extent of voids that have developed beneath the slab or base. Experience has shown that this is true in general. However, the quantities of grout that are being pumped on projects today depend on several additional factors, including the amount of slab lift allowed during grouting (very important), the base type and condition, the subgrade soil type and extent of holes or discontinuities, shoulder type, and available channels for flow.

Thus, it is difficult to provide a reliable procedure for estimating the required grout quantities for a given project. During the demonstration projects for NCHRP Project 1-21, approximate grout quantities pumped during subsealing operations were obtained for joints with various predicted void sizes. Joints that indicated no voids (the deflection and load transfer point fell within the zero voids band) took an average of 1.8 ft³ of grout per joint. The deflections remained essentially the same after grouting as before grouting and thus no increase in support was achieved. In fact, sometimes an increase in deflection occurred at these joints. This grout may be going into the subgrade, under the shoulder, lifting the slab, and so on. For example, one joint that indicated no void took 6 ft³ of grout. If this amount of grout were actually filling a void of 36 ft², the depth would be 2 in. Thus, it is concluded that joints for which no loss of support or void development is indicated should not be subsealed because no structural benefits are obtained.

Joints for which the existence of voids are indicated from 4 to 36 ft² in horizontal size averaged between 2 and 3 ft³ of grout injected per joint. However, even here a substantial proportion of this grout must be going elsewhere than into the thin void beneath the slab or base. For example, a large void 36 ft² and 0.2 in. deep would require only 0.6 ft³ of grout to fill.

Even though it is believed that much of the grout being pumped is going somewhere other than into the actual void cavity, an average of 2 to 3 ft³ of grout per joint should be planned for joints where voids exist to ensure adequate dispersion and coverage of all existing cavities. Therefore, this quan-

tity should be multiplied by the estimated number of joints and cracks with voids to estimate the overall grout quantity for the project. Joints for which no voids are indicated should not be subsealed.

For grout quantity estimation, a continuous sample of joints should be selected to represent the project under consideration (e.g., 25 consecutive joints per mile). These joints should be analyzed for voids by using the methods presented. The proportion of joints for which voids are indicated can then be determined. The sample project showed that voids existed at 14 out of 27 joints, or 52 percent. If this sample was chosen to represent a project 3 mi long with a joint spacing of 20 ft, the total grout quantity would be estimated as follows:

$$\text{Total joints} = (5,280/20) * 3 \text{ mi} = 792,$$

$$\begin{aligned} \text{Estimated number of joints requiring grout} &= 792 \\ &* 0.52 = 412, \end{aligned}$$

$$\begin{aligned} \text{Estimated grout quantity} &= 412 \text{ joints} * 2.5 \text{ ft}^3/ \\ \text{joint} &= 1,030 \text{ ft}^3. \end{aligned}$$

SUMMARY AND CONCLUSIONS

The void detection procedures developed under NCHRP Project 1-21 are the result of a detailed 3-year study of both computer analysis and collected field data. During the study, emphasis was placed on simplicity and reliability of the resulting procedure. It is the authors' belief that if the procedures outlined here are followed, substantial savings, both in immediate rehabilitative costs and future maintenance costs, can be realized. The selective subsealing of only those joints and cracks that have loss of support is the most cost-effective way to restore support to jointed concrete pavements. Deflection testing provides assurance of restored support. If deflection measurements and void analysis are not performed before and after subsealing, there is no way to determine the benefit of the work. In addition, continued deflection monitoring of the pavement can show whether support is being maintained and grouting can be programmed if support is reduced.

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data. The contents do not necessarily reflect the official views or policies of the Transportation Research Board, the National Academy of Sciences, FHWA, the American Association of State Highway and Transportation Officials, or the individual states participating in NCHRP.

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Experimental Project on Grout Subsealing in Illinois: A 20-Month Evaluation

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ABSTRACT

Several experimental features were included in an undersealing project conducted by the Illinois Department of Transportation during the fall of 1983. This experimental project evaluated the performance of limestone-cement slurries versus that of pozzolan-cement slurries, the effects of admixtures (water reducer and superplasticizer) on these slurries, and the effects of various pumping pressures (10, 20, and 30 psi) on the undersealing operation. Initial studies indicated that the fly-ash grouts were generally superior to limestone grouts on the basis of the higher strengths exhibited by the fly-ash grouts regardless of admixtures, the greater improvements in deflections produced by the fly-ash mixes, the possible damaging effects produced by the limestone mixes when grouting is done in areas that display low initial deflections, and, finally, the greater flowability of the fly-ash mixes. Four slabs that were removed after undersealing verified this superior ability of the fly-ash grouts to flow into voids. Fly-ash grouts either with no admixture or with superplasticizer produced the greatest decrease in the pavement deflection at cracks and joints, whereas limestone grouts with admixtures produced the least decreases in deflections. It was also observed that, for a given pavement, a limiting deflection value exists below which deflections will not be reduced. In addition, if the initial deflection is low, it appears better not to grout the pavement, because deflections may increase. Pumping pressures investigated had a negligible effect on undersealing operations. Pavement deflections measured 7 and 20 months after undersealing supported the initial evaluations of undersealing materials.

Rehabilitation and restoration of portland cement concrete (PCC) pavements in Illinois have traditionally included the patching of failed areas followed by the placement of a bituminous overlay. Although overlaying the pavements will improve the ride quality, it does not correct the problems caused by the development of voids beneath the concrete slab. The purpose of undersealing or subsealing is to restore support to a pavement structure by filling these voids with grout under pressure without intentionally raising the pavement. The inclusion of pavement subsealing in conjunction with patching and

resurfacing, therefore, appears to be a more effective rehabilitation technique.

Because of the projected increase in the use of this technique in the state, the Illinois Department of Transportation (IDOT) studied the design and proper application of grout slurries in undersealing. Specifically, this experimental project evaluated the performance of limestone-cement slurries versus that of pozzolan-cement slurries, the effects of admixtures on these slurries, and the effects of various pumping pressures on the undersealing operation.