Validating Loss of Support for Concrete Pavements

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ABSTRACT

Undersealing of concrete pavements is an important restoration mechanism. The success of its application is dependent on having a capability for locating the appropriate points of application. The future of the undersealing process will be dependent on focusing on the more general loss-of-support concept. This paper will outline the Epoxy/Core Test Method, which has proven to be an effective presence of voids evaluation method.

INTRODUCTION

Concrete pavements have been designed in the United States based on the assumption that they are uniformly supported. If this support does not exist then an increase in pavement fatigue can be expected. The result is reduced pavement life. Some degree of loss-of-support occurs throughout the day as the temperature gradient changes and the concrete pavement curls or warps. Curling and warping also occurs as the result of moisture gradients. Permanent loss-of-support occurs from densification or settlement of one of the supporting layers or from pumping caused by heavy vehicle traffic. In such a case, a void, which is an extreme case of loss-of-support, may develop.

Undersealing is the process of pumping a cement based grout or hot asphalt beneath the concrete pavement to restore uniform support. If undersealant is forced into areas where adequate support already exists, a pillar of undersealant will lift the pavement leaving other areas unsupported. The unsupported condition leads to high stresses and pavement fatigue. Rather than solving the loss-of-support problem, the misplacement of undersealant creates the condition that the undersealant was suppose to correct. The process of locating and delineating the degree of loss-of-support is a difficult technical problem.

A non-destructive means of detecting loss-of-support conditions is desirable. Non-destructive testing methods (NDT) that have been used to evaluate loss-of-support conditions include the Benkelman beam, Dynaflect, and Falling Weight Deflectometer (FWD). These devices involve loading the pavement and recording the resulting deflection. Loading is done with a static 18 kip axle load, vibratory load, or impact load, respectively. The deflections are measured at various points on slabs and used on a relative basis to evaluate slab support conditions. Another method identified as a Transient Dynamic Response (TDR) system (1) has shown some potential for evaluating loss-of-support. The TDR system consists of a series of 2 kg hammers with built-in force transducers that strike the pavement. Geophones located at fixed distances from the hammer point of impact with the pavement pick up transmitted waves. Analysis of these data provide information on pavement support conditions.

Until now, there has been no effective way to verify how well these NDT methods predict loss-of-support even for the case where a void may have developed. Volume of grout uptake, drop of a core into a core hole, and slab removal have been used to try to prove the validity of void detection methods. A new test method, the Epoxy/Core Test has been developed that addresses the basic question of whether a measurable void exists between the pavement and its foundation. Determining an answer to this basic question would be important in evaluating NDT methods. The test method involves drilling a hole through the slab and filling it with epoxy. The epoxy is fluid enough that it will penetrate a void if it exists. After the epoxy sets a core can be taken at the drill hole through the pavement and epoxy. In addition to filling the void, the epoxy will usually bond the base to the underside of the pavement. From the core, the void thickness can be measured and provides physical evidence that can be used to evaluate NDT methods.

Field tests were conducted to compare

the results of the Epoxy/Core Test to the results of NDT methods. It was found that voids may or may not exist at locations where NDT methods indicated a void. In addition, the more general concept of loss-of-support evolved. This concept recognizes that there can be reduced support without loss of contact or measurable voids.

This paper will discuss the mechanics of pumping and will outline the Epoxy/Core Test method. The findings will be presented of several case studies where the Epoxy/Core Test method was used to evaluate the results of traditional NDT methods.

MECHANICS OF PUMPING

There are three main factors associated with pavement pumping: 1) presence of an erodible subbase or subgrade, 2) free water and/or 3) high traffic volumes or heavy axle loads. The pumping process involves heavy loads deflecting the pavement causing high pressures in the free water beneath the pavement. Under pressure, the water flows towards the leave slab, i.e., the slab which is downstream from the joint relative to the direction of traffic movement. This water carries erodible subbase or subgrade

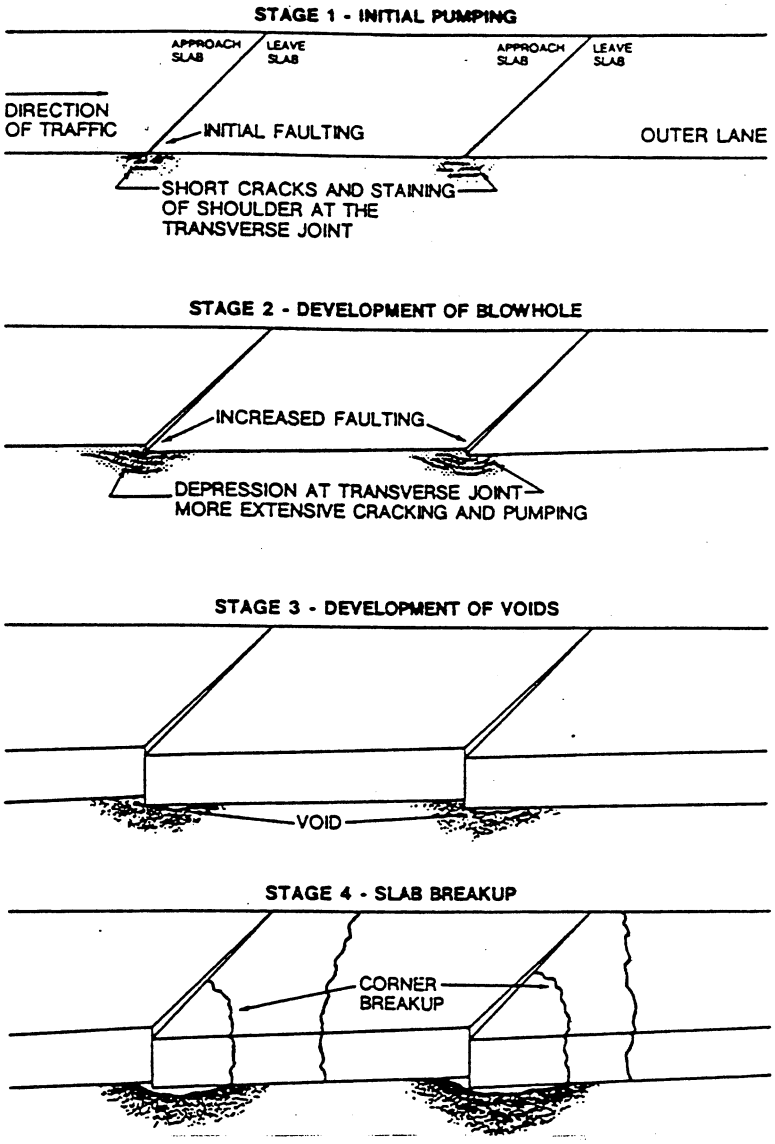


Figure 1. Typical states in the deterioration of a concrete pavement (5).

material with it. As the load hits the leave slab sudden, high pressure develops in the water under the pavement. At the same time a vacuum is created under the approach slab as the slab rebounds back into position. In this vacuum condition material is carried back and deposited under the approach slab. The classic location of a void/loss-of-support condition is at the down-traffic side of the joint. It is at this location where a void usually occurs. Figure 1 (2) gives the pictorial sequence of the pumping phenomenon.

EXPLANATION OF THE TERM "VOID"

A reevaluation of the assumptions on which the underseal industry has grown and a redefinition of the problem which the underseal process is trying to correct is needed. Loss-of-support can be the result of reduced support and/or voids. Reduced support is defined as the condition where the bottom of the concrete slab is in contact with the foundation or subbase but does not benefit from its full support. Two examples of this condition are given. The first is that curling or warping may reduce contact pressure with the foundation. A second example would be a case of a saturated subbase contaminated by subgrade soil. In this condition the foundation support value is low. In both cases large deflections can be measured without the existence of a void. At what point a measurable void develops is vague and arbitrary.

VOID VERIFICATION METHODS USED

In the underseal industry today the identification of appropriate underseal locations is determined by either visual inspection of the surface or mechanical testing but NOT by what is actually under the pavement. It is assumed that the result of such inspection or testing indicate the presence of voids. In fact, most research articles on the subject clearly state that the described NDT procedure identifies voids. However, without "looking" under the pavement there is no way of being sure.

Several unscientific procedures have been used to verify the presence of voids including coring, removing the slab or measuring the amount of grout or water that can be pumped into the holes. However, all of these procedures disturb the pavement/subbase interface.

To really verify the presence of a void, the subbase or subgrade/pavement interface must be seen in its undisturbed state. Unfortunately, people are too large to crawl down an open joint or crack and go spelunkering around looking for a void. The following procedure was devised to investigate this critical interface.

EPOXY/CORE TEST METHOD

The Epoxy/Core Test is used to verify the existence of voids. At the same time it can also be used to evaluate the effectiveness of mechanical testing procedures such as FWD, Dynaflect, Benkelman Beam, or the TDR. The premise of the procedure is that if a void lens can be filled with a low viscosity liquid medium which would subsequently solidify, then examination of a core of the pavement and supporting foundation would reveal any void that existed at the subbase/pavement interface.

The test should be done under temperature/sun conditions similar to those when the visual or mechanical survey was conducted or, ideally, at the same time. Generally, testing would be done in the early morning hours when the effects of thermal curl have not had a chance to mask the presence of voids. The test location for the epoxy access hole would generally be on the leave slab (down-traffic side), approximately 18" away from the intersection of the joint and edge of pavement. A rotohammer (not a core-drill) using a 1" to 2" dry bit is used to drill through the pavement and into the subbase to a depth of about 1". The sides of the access hole are scraped down using a long screw driver to make sure that any chips at the bottom of the hole are loose. Debris from the rotohammer operation is vacuumed out of the hole (Figure 2) leaving a small reservoir at the bottom. If water is present this reservoir will give a place for it to pond. Accumulated water can be vacuumed out of the hole and out of any void.

A two-part epoxy (i.e., mix part A with part B) is colored with dye (e.g. red food coloring) and poured into the hole (Figure 3). A viscosity of approximately 400 cps, which is the same consistency as pancake syrup, has been effective. In subsequent coring, it was found that this liquid would seek out and solidify in cracks which were only 1/32" thick.

Typically one pint of this epoxy would initially fill the access hole to the pavement surface. The epoxy percolates down, saturating the subbase/subgrade and fills any voids which might be present. After another pint, the percolation would generally cease as the epoxy could no longer flow through the interface under the pressure of a 9" to 10" pressure head.

One indication of a large void is the rapid intake of the epoxy. When this happens an equal part of Ottawa sand can be added to thicken the epoxy and reduce the amount of epoxy used in the test. This thickening process is continued until the access hole is filled. No attempt is being made to fill the entire void but only a localized area around the access hole. This is only a void detection test, not a

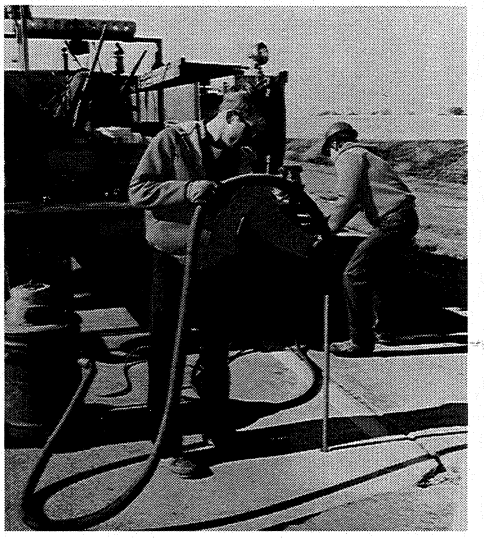


Figure 2. Vacuuming rotohammer debris from access hole.

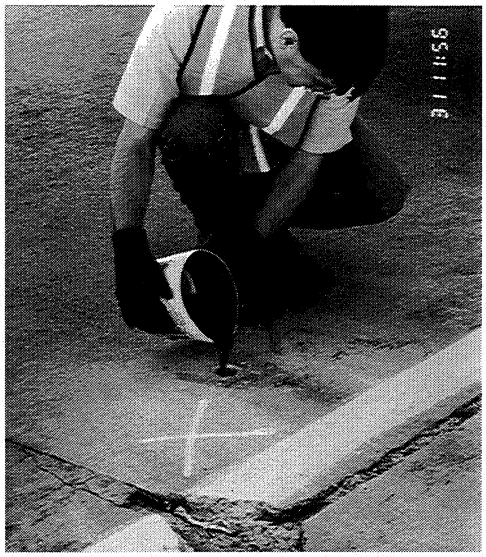


Figure 3. Pouring epoxy into access hole.

rehabilitation technique.

Generally after two hours depending on temperatures, the epoxy will solidify. A core is taken through the pavement, slicing the access hole and cross-sectioning the subbase/pavement interface. The subbase will generally be bonded to the bottom of the pavement with the void, once air but now a pink epoxy, trapped between the two. A picture of a typical extracted core is shown in Fig 4. This technique appears to give a true picture of what the voids look like under a concrete pavement.



Figure 4. Typical extracted core showing epoxied void lens (pictured upside down).

EPOXY/CORE TEST PROJECTS

The Epoxy/Core Test Method has been used on six projects in an attempt to verify the existence of voids under concrete pavements. These projects consisted of two in Indiana, three in Ohio and one in Illinois. They are:

U.S. 52	Fowler, Indiana	June 22, 1989
U.S. 41	Boswell, Indiana	July 7, 1989
I-75	Cincinnati, Ohio	July 18, 1989
S.R. 35	Jackson, Ohio	July 30, 1990
S.R. 11	Youngstown, Ohio	Nov 4, 1990
Illinois Tollway	Oak Brook, IL	Nov 1, 1990

The following is a background statement on this study, an explanation of the method of data interpretation for the NDT methods of testing (FWD, Dynaflect, Benkelman Beam and the TDR) and a brief summary of the findings on each project. A more detailed research paper has been written for these projects and is available (3).

BACKGROUND

This study was initiated by a Strategic Highway Research Program (SHRP) contract, H-101. Part of this contract was to design an experiment to evaluate the effectiveness of various concrete pavement restoration techniques. One of the techniques to be studied was the undersealing of concrete pavements. In the process of developing the criteria for a distress survey, it became apparent that there was not a universally accepted measure of the need for undersealing. In the literature on undersealing there were numerous references

made to the need to locate and fill voids but there was little evidence to support the test data that voids were actually being found by these procedures. The Epoxy/Core Test method was developed under this SHRP project in an effort to provide a standard by which the NDT test methods could be compared. The first three projects listed above were tested under the SHRP contract. The next two projects were tested as part of an Ohio Board of Regents special study and the one project in Illinois was tested by the Illinois State Toll Highway Authority.

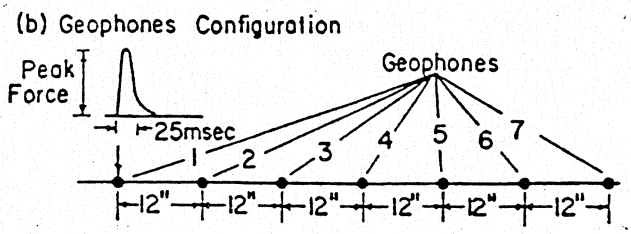


Figure 5. Schematic of Typical Spacing Diagram of Dynatest Model 8000 FWD Geophones (5).

METHODS OF NDT DATA INTERPRETATION

Falling Weight Deflectometer (FWD)

The FWD device produces a load impulse by dropping a mass from a height onto a pavement surface. Mass and drop height can be varied to produce different impact forces ranging from 1,500 to 27,000 pounds. For the Dynatest Model 8000 used in this study (4), the pavement deflections resulting from the pulse load are measured by seven velocity gages which are held in movable holders along a seven foot raise/lower arm (Figure 5). One velocity gage is located on the loading plate to measure the deflection at the point of loading. The other six gages are located on the pavement at various offset distances from the loading plate. Peak deflections sensed by the velocity gages are used to define a deflection basin. Analysis with one of several procedures can be used to match this "peak" deflection basin and evaluate pavement capacity and layer materials. However, testing and analysis for voids using the FWD involves different techniques.

One technique for void detection is the 3-Point Graph Method Figure 6 (5) which consists of making a series of three drops at a point on the pavement with the FWD.

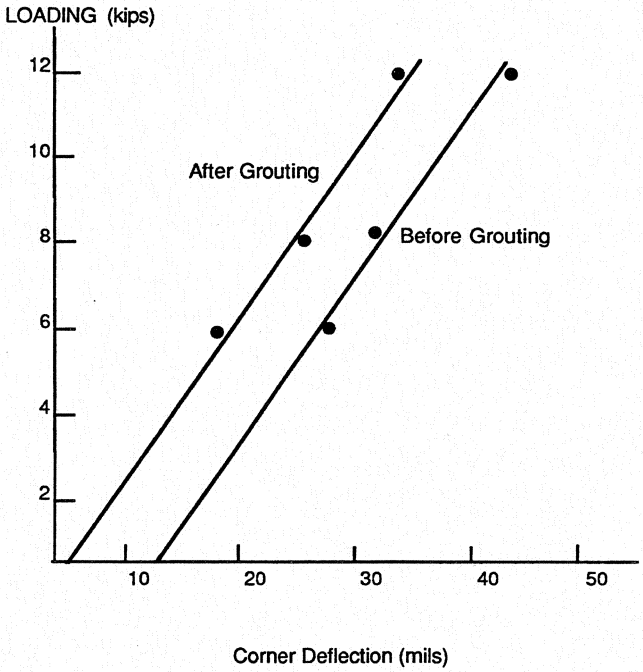


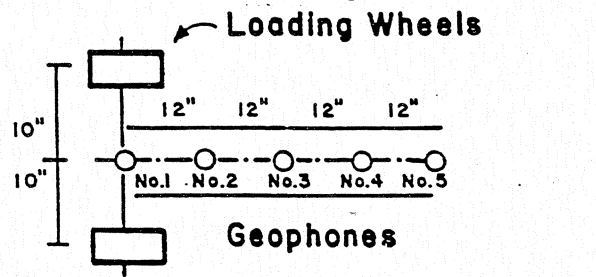
Figure 6. Typical graph of 3-point method for FWD (5).

This is done at a point where a visual inspection indicates the possible presence of a void. This typically occurs at either the leave or approach side of a joint. The magnitude of the impulse for these drops should cover a reasonable range, e.g., 6,000, 9,000 and 12,000 pounds. With this method only the sensor on the loading plate is recorded; all other sensors are ignored. A graph is made of maximum deflection versus the load applied, as shown in Figure 6. A best fit line is drawn between these three points and the x-intercept (deflection axis) is noted. If this x-intercept value is greater than .002 inches (45 microns), a loss-of-support is said to exist. After undersealing, the pavement can be retested using the same method and the fitted line should move to the left, hopefully into the acceptance region.

Dynaflect

The Dynaflect is a trailer-mounted testing device which induces a 1,000 lb. steady-state vibration into the pavement through two rigid wheels (6). The load is generated by two counter-rotating eccentric masses which resonate at a fixed frequency of 8Hz. Five geophones are used to measure the pavement deflection as shown in Figure 7. The peak deflection sensed by the geophones define the deflection basin. As with the FWD, the accepted methods of void detection do not utilize the data gathered from all of the sensors. The Ohio Department of Transportation (ODOT) and Indiana Department of Transportation (INDOT) methods of void detection were applied in this study.

ODOT uses a Joint Support Ratio (JSR). Only sensor No. 1 (W(1)) reading is used to determine this ratio. The W(1) sensor is located closest to the point of load application and, therefore, has the highest deflection. The JSR is the W(1) sensor reading when the load is applied on the approach side (uptraffic side) of a joint divided by the W(1) sensor reading taken when the load is applied on the leave side (downtraffic side) of the joint. This



(b) Configuration of Dynaflect Load Wheels and Geophones

Figure 7. Illustration of the Dynaflect loading wheels and geophones (6).

ratio compares support that is on one side of the joint relative to the other. It is reasoned that if the support capabilities of the pavement varies substantially then a void must be the cause. The range for JSR which can be interpreted as having full support is from 65% to 150%. A JSR which is lower than 65% indicates a void under the leave slab and one greater than 150% indicates one under the approach slab (7).

The Indiana DOT method is substantially different. It uses the W(5) sensor reading by itself as an indicator of the existence of a void. If the W(5) sensor reading is greater than 30 mils then a void is said to exist (8).

Benkelman Beam

The Benkelman Beam (Figure 8) has been used for many years in pavement deflection testing and void detection. Specifications for the procedure are outlined in AASHTO T256-77 (9).

Pavement rebound is measured using the Benkelman Beam as an 18-Kip Single Axle Load moves away from the beam tip contact point on the pavement. A commonly used criterion for the presence of a void is a rebound value of greater than .020 inches. Though the Benkelman Beam used in AASHTO T256 is a specific design, it often is replaced with a device unique to a particular state. It is important that these pseudo-Benkelman Beam devices are designed to measure the uplift of the pavement from a firm base outside the deflection basin.

Transient Dynamic Response

The Transient Dynamic Response (TDR) method (10) is used to test for the presence of voids under concrete pavements, as well as the integrity of the concrete. As shown in Figure 9, the basic TDR system consists of a series of hammers with built-in force transducers, geophones, a twin-channel Spectrum Analyzer, an HP-85 Computer and a plotter. The pavement surface is struck with the hammers (2kg) which are instrumented with load cells. Resulting waves transmitted through the pavement are picked up by the geophones which are placed at set distances from the point of impact. The force and velocity signals are recorded and then analyzed using a Fast Fourier Transformation (FFT) procedure. A plot is then made of the mechanical admittance (Velocity/Force) versus frequency as shown in Figure 10. From this plot a stiffness E' can be calculated by finding the inverse of the slope of graph form 0 to 100 Hz. This plot and its interpretation is the key to the TDR testing method.

Table 1 gives the general parameters which are used in the interpretation of the plots (10). The three most significant

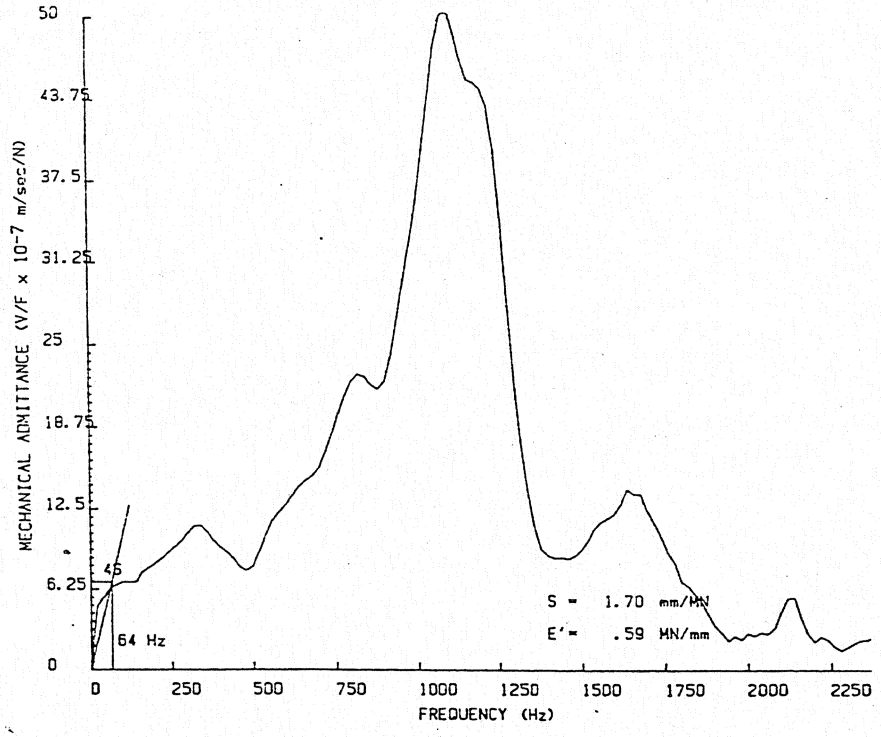


Figure 10. Frequency curve of TDR test on a sound slab.

A	-	GOOD SLAB
	-	Low average mechanical admittance ($15 - 40 \times 10^{-7}$ m/sec/N)
	-	Damped curves between 0 Hz and 1500 Hz
	-	Good stiffness (normally greater than 0.10 MN mm) E′
B	-	SLAB WITH CAVITY BENEATH
	-	High average mechanical admittance ($80 - 120 \times 10^{-7}$ m/sec/N)
	-	Very undamped curves between 0 Hz and 1500 Hz
	-	Very low stiffness (unmeasurable).
C	-	FAULTY CONCRETE IN SLAB (BROKEN, VOIDS OR HONEYCOMBING)
	-	Rising mechanical admittance with increasing frequency
	-	relatively low stiffness (<0-10 MN/mm).
D	-	POOR SUBGRADE CONDITIONS
	-	High mechanical admittance ($80 - 120 \times 10^{-2}$m/sec/N)
	-	undamped response
	-	very low stiffness (0.02 - 0.09 MN/mm).
E	-	DEBONDING BETWEEN UPPER LAYER (ASPHALT) AND LOWER LAYER (CONCRETE)
	-	Falling value of mechanical admittance from 0 - 1500 Hz
F	-	BROKEN SLAB (CORNER OR EDGE)
	-	Low stiffness
	-	undamped response from 0 Hz - 1500 Hz

Table 1. Typical results of Transient Dynamic Response (10).

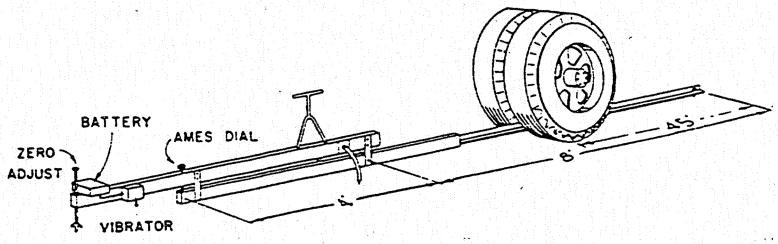
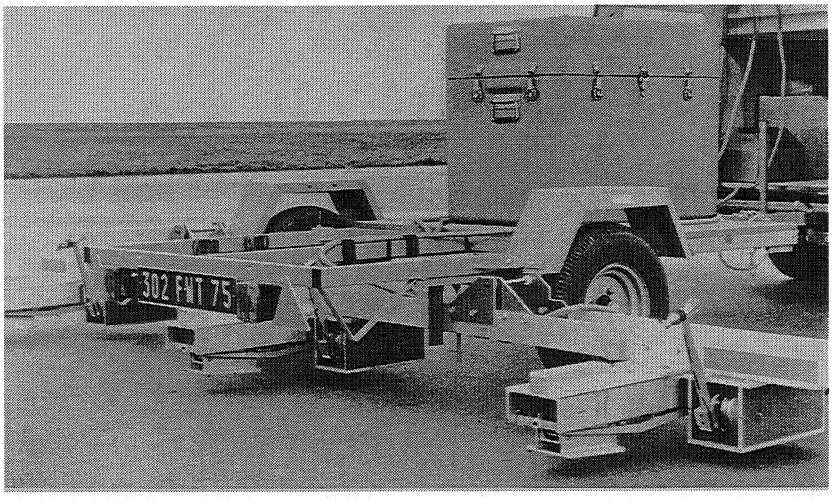


Figure 8. Illustration of the Benkelman Beam (9).



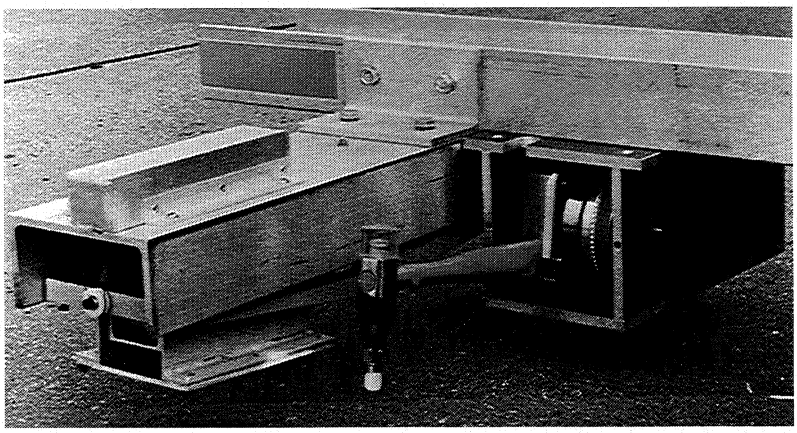


Figure 9. Illustration of Transient Dynamic Response (10).

aspects derived from these plots are the average mechanical admittance, the oscillation of the curve and the initial slope of the graph. Parameters which are used to locate voids are calculated automatically and a plan view of the voids is printed out, along with the stiffness of the pavement at the various points of testing. The plan views are immediately available from the on board computer and plotting system.

FINDINGS

U.S. 52; Fowler, Indiana

The pavement design at this site was 9" of wire mesh reinforced concrete pavement on top of 6" of dense granular subbase. Joints had dowel bar load transfer devices and were spaced at 60' intervals. All of these 60' slabs were cracked at the midpoint. For this testing, 30' slabs were

assumed. Thirty joints and thirty mid-slab cracks were tested in December of 1988 using two Dynaflects, a Falling Weight Deflectometer (FWD), a Benkelman Beam and the Transient Dynamic Response Apparatus (TDR).

Table 2 gives the results of all the slabs tested. A slab number of "x"a means that it is the first half of the broken slab and "x"b is simply the second half. Of these 60 possible slabs, 14 slabs which were most likely to have a void or loss-of-support condition as determined by each testing device were identified in the LOS (loss-of-support) column. With 14 being the maximum possible number of agreements, six slabs are selected by all four methods as needing undersealing. Interpretation of this table is subjective because there is no universally accepted definition of a void/loss-of-support. One way to interpret the meaning of this comparison is to let majority rule. Which method has the highest agreement rate with the other methods? Table 3 tabulates the incidence of agreement and gives an averaged score. The average score for the Dynaflect, Benkelman Beam and FWD were 8.3, 7.7, and 6.7 respectively, while the TDR agreed with the other methods an average of 9.0 times. On this basis it would appear that the TDR did the best job.

It was from the need of a test that would provide a truth scale that the Epoxy/Core Test method was developed. In June, seven of the thirty mid-slab cracks were selected for the application of the Epoxy/Core test. The mid-slab cracks were

	TESTING METHOD							
Slab No.	Dyna-flect	LOS	Benkelman Beam	LOS	FWD	LOS	TDR	LOS
1a	36	x	3		15		PS	
b	43	x	8		15		LV	x
2a	27		7		35		VPS	
b	40	x	25	x	120	x	LV	x
3a	29		10		45	x	PS	
b	29		10		102	x	LV	x
4a	30		3		0		PS	
b	24		7		-10		OK	
5a	27		11		25		PS	
b	25		19	x	100	x	PS	
6a	28		5		-20		PS	
b	27		2		-30		OK	
7a	30		4		15		PS	
b	24		14		0		PS	
8a	29		12		10		PS	
b	27		1		-10		OK	
9a	28		5		-10		OK	
b	40	x	28	x	40		LV	x
10a	29		2		15		OK	
b	28		10		-15		OK	
11a	31		17	x	-45		PS	
b	23		6		-30		OK	
12a	25		18	x	10		VPS	
b	22		3		-10		OK	
13a	23		4		-10		OK	
b	30		20	x	-80		VPS	
14a	23		4		-20		OK	
b	21		5		0		OK	
15a	24		5		20		PS	
b	27		17	x	30		LV	x

* Loss-of-Support Slab designated as most distressed by that treatment.

Table 2. Summary of most severe loss-of-support condition for each testing method; U.S. 52; Fowler, Indiana.

Slab No.	TESTING METHOD							
	Dyna-flect	LOS	Benkelman Beam	LOS	FWD	LOS	TDR	LOS
16a	25		7		20		VPS	
b	30		1		15		LV	x
17a	25		7		45	x	VPS	
b	35	x	27	x	110	x	LV	x
18a	24		3		20		PS	
b	19		6		25		OK	
19a	24		3		20		PS	
b	32	x	16	x	75	x	LV	x
20a	23		10		15		PS	
b	22		13		25		VPS	
21a	23		1		0		PS	
b	35	x	20	x	60	x	LV	x
22a	33	x	3		20		PS	
b	32	x	10		25		LV	x
23a	27		8		-5		OK	
b	25		6		-5		OK	
24a	24		4		-5		OK	
b	32	x	22	x	105	x	LV	x
25a	28		20	x	25		OK	
b	32	x	2		0		OK	
26a	30		7		55	x	PS	
b	27		7		10		PS	
27a	22		6		15		OK	
b	37	x	29	x	55	x	LV	x
28a	27		10		70	x	PS	
b	33	x	10		100	x	LV	x
29a	28		12		10		OK	
b	32	x	7		10		LV	x
30a	31		18	x	25		PS	
b	31		10		20		VPS	

* See Table 3 for comparison with Epoxy/Core Test.

Table 2 continued.

selected in lieu of the dowelled joints because previous deflection testing indicated a greater severity of loss-of-support at these points. The results of this testing is shown in Table 4 and can be interpreted as follows:

* Column 1: Slab #. The slabs were numbered from 1 to 30 and subdivided into "a" and "b". The "a" portion was the first half of the slab (i.e. the traffic hits "a" slab first) and was separated from the "b" portion by a mid-slab crack. Because of the predominance of high deflections on the "b" portion it was the only side cored.
* Column 2: Core #. The first number indicates the slab from which it was taken and the second the core location relative to the slab edge. For example, the core next to the edge of pavement is x-1.
* Column 3: Epoxy (Pints). This is approximately the amount of epoxy poured into the respective holes.
* Column 4 & 5; x,y. The diagram at the bottom of the Table 4 gives the layout of the x and y axis with the origin located at the intersection of the pavement crack and the right edge of pavement.
* Column 6: Depth of Void (Inches). The thickness of the epoxy void lens as measured from the cores.
* Column 7: Void Detection Results. In the previous section covering Mechanical Testing, 14 of the most likely locations for each of these testing methods were selected. The yes/no under each of these devices indicates whether that joint location was selected by that device as having a void.

Analysis of Results

The single most valuable piece of information that can be gleaned from this table is that the maximum thickness of any

Testing Device	Methods Compared										
Dynaflect	x	x	x				x	x	x		x
Benkelman Beam	x			x	x		x	x		x	x
FWD		x		x		x	x		x	x	x
TDR			x		x	x		x	x	x	x
Agreement Between Methods	7	7	11	8	8	8	6	7	6	6	6

SUMMARY RATING FOR EACH METHOD

DYNAFLECT		FWD	
Benkelman	7	Dynaflect	7
FWD	7	Benkelman	8
TDR	11	TDR	8
	23/3=8.3		23/3=6.7
BENKELMAN BEAM		**TDR**	
Dynaflect	8	Dynaflect	11
FWD	8	Benkelman	8
TDR	8	FWD	8
	24/3=8.0		27/3=9.0

Table 3. Comparison of testing methods; U.S. 52; Fowler, Indiana.

of these voids was 1/8". Visual inspection of the cores themselves revealed that these voids were not well defined seams across the bottom of the slab, but rather resemble a miniature boulder field haphazardly spewed across the subbase/pavement interface. Analysis of actual cores is difficult in itself. To catch the small details in a photograph is even more difficult.

Analysis of Table 4 reveals a few qualified conclusions. Though the amount of epoxy poured into the hole is probably an indication of the presence of a void, it does not necessarily have a very good correlation to the thickness of the resultant void. For example, the 7 pints of epoxy used at Core #19-1 resulted in a void which was only 1/16' thick. This was the same thickness resulting at other locations which only took 1 pint of epoxy. If the readings of the mechanical deflection devices tested in December are compared against the void depth, then it appears that the Dynaflect and TDR did the best job, with Benkelman Beam next. The FWD appears to have found the fewest voids which was also the conclusion from Table 6.

U.S. 41; Boswell, Indiana

On July 7, 1989, Epoxy/Core Testing was done on U.S. 41, Boswell, Indiana beginning 1/2 mile north of S.R. 352 where undersealing was scheduled. The pavement consisted of 9" of Continuous Reinforced Concrete (CRC) supported by 6" of granular base material. The InDOT Dynaflect had been used to test the pavement at 100 foot intervals. InDOT plots longitudinal deflections to evaluate deflection trends exceeding the InDOT deflection criteria. Therefore the procedure is not used to locate specific voids. The Epoxy/Core Testing was done earlier on a day when the contractor was undersealing with hot asphalt. Cores were taken after the underseal operation which allowed for an analysis of the Epoxy/Core Testing as well as the effectiveness of the undersealing.

The only pretesting information which was available for this project was from the

Slab No.	Core No.	Epoxy Used*	Inches X	Inches Y	Void Depth	Dynaflect	BB	FWD	TDR
1B	1-1	2	8	30	0				
	1-2	1-1/2	4	48	1/16	Yes	Yes	Yes	Yes
	1-3	1	8	55	1/16				
2b	2-1	2	12	30	1/8	Yes	No	No	Yes
	2-2	1-1/2	24	30	0				
7b	7-1	1	72	30	0	No	No	No	No
	7-2	1	144	30	0				
9b	9-1	4	16	24	1/8	Yes	Yes	No	Yes
19b	19-1	7	10	10	1/16				
	19-2	3	18	15	1/8	Yes	Yes	Yes	Yes
	19-3	3	16	50	1/8				
24b	24-1	1-1/2	18	20	1/8	Yes	Yes	Yes	Yes
	24-2	1-1/2	15	60	1/16				
30b	30-1	1	-12	24	1/16	No	No	No	No
	30-2	1	18	24	1/16				

*Pints

Core Location Coordinates: Centerline

Traffic

Edge of Pavement

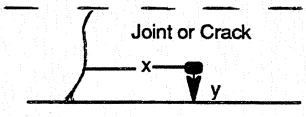


Table 4. Summary of Cores. U.S. 52; Fowler, Indiana.

Station Number	Core No.	Epoxy Used	Inches X	Inches Y	Void Depth	Dynaflect Reading * W1	Dynaflect Reading * W5
77+50	1-1	1/2	-80	24	?	65	40
	1-2	1	-18	24	?		
	1-3	2-1/2	12	24	0		
82+50	2-1	1/2	18	18	0	66	40
87+50	3-1	1/2	-12	18	1/16	70	36
	3-2	1/2	18	18	0		
88+00	4-1	1/2	-12	24	?	157	47
	4-2	1/2	12	24	0		
	4-3	1/2	12	72	?		
90+00	5-1	2	-12	24	?		
	5-2	1/2	12	24	?	65	38
	5-3	1/2	12	72	?		
91+00	6-1	1/2	12	24	?	121	49

* Epoxy/Core Testing was done at a suitable crack near this Dynaflect reading.

? No core taken.

Table 5. Summary of testing; U.S. 41; Boswell, Indiana.

Dynaflect readings initially taken in the evaluation of the job to determine the need for undersealing. From these records the highest deflections were identified in the 3,000 foot length of pavement ahead of the underseal operation.

Installation started at 9:30 a.m. and thirteen holes were filled with epoxy. However, because of traffic limitations only seven cores were attempted and only five were extracted successfully. Table 5 contains a brief summary of the results.

Analysis of Table 5 indicates that the Dynaflect readings were very high. The typical distinction between void or no void is at 32 mils on the W(5) sensor. As can be noted, deflections were substantially higher than this threshold value.

The epoxy access holes took only 1/2 pint of material. Once filled the epoxy level in the holes did not drop, as was the case at U.S. 52, Fowler. However, Station 77+50 which was at a construction joint (Core #1-3) took a large volume of epoxy. Subsequent core drilling was not possible because of metal which was encountered (a diamond bit was burnt). Initially, this location looked quite promising because of the large deflection readings and the faulting that had occurred.

Core #1-1 was located completely away from any transverse crack and it took as much epoxy as those located in the classic void areas, i.e., near the cracks. One conclusion might be that any area which took 1/2 pint did not have any voids.

Only one core, #3-1, had any evidence of a void. The epoxy had bound some of the subbase to the bottom of the core. In that interface area there was evidence of some epoxy which had filled an existing air void. No other core showed any evidence of a void.

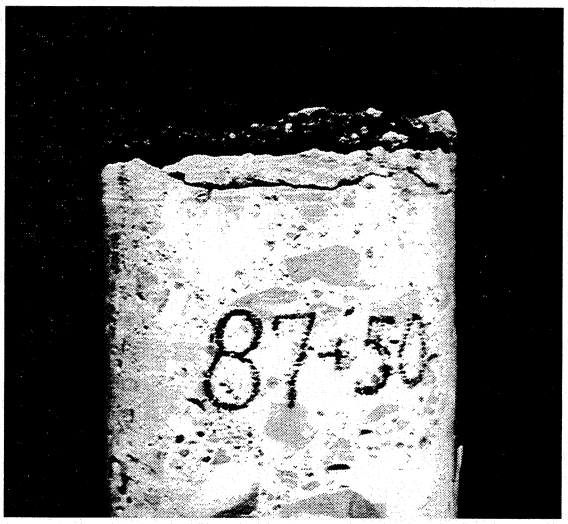


Figure 11. Asphalt adhered to the bottom of core, Boswell, Indiana.

Several of the cores showed a 1/8" layer of asphalt undersealant material adhered to the bottom of the pavement. The photograph in Figure 11 shows such a layer adhered to the bottom of the core #3-2. If a "void" of 1/8" had really existed, the epoxy would have penetrated and solidified in it prior to undersealing.

There are two possible conclusions to be drawn from this site. 1) Although the pavement exhibited high deflections, substantial voids did not exist under the pavement. Such a conclusion is supported by the fact that epoxy lenses were not found with the subsequent cores and that the access holes took very little epoxy. 2) Because there were no voids, the hot asphalt undersealant which was pumped under the slab simply raised the slab. This was evidenced by the thin layer of asphalt directly under the cores which were taken.

What is the significance of such findings? The underseal industry concentrates on voids. This pavement exhibited high deflections but did not have voids. If undersealing is only effective in a condition where voids are present, then undersealing on this pavement may not have had any value. If the purpose of undersealing is to decrease deflections regardless of the cause then it was probably effective. InDOT has previously carried out pretesting and post-testing of undersealed pavements. These tests show that the deflections have decreased as a result of undersealing. However, there is no conclusive evidence that this decrease resulting from undersealing is cost-effective.

I-75; Cincinnati, Ohio

On July 18th, the Epoxy/Core Test was applied on the outside lane of southbound I-75 in Cincinnati, Ohio, two miles north of the Ohio River. The pavement consists of 10" of reinforced concrete on 6" of gravel subbase with joints spaced at 60'. The concrete surface had ruts (>3/4") worn into the wheelpaths. The slabs were generally sound with one or two transverse hairline cracks located randomly across the 60' length. The joints were unsealed and were generally greater than an inch wide but were not significantly faulted. Many of the joints had corner breaks both at the edge of the pavement and the longitudinal construction joint.

Deteriorated joints were being repaired and various sections were being undersealed in preparation for overlay. The site had been tested with a Dynaflect. Traffic control had been setup for general rehabilitation work on about 1/2 mile of the outside lanes. A visual survey identified the site as a good prospect for the presence of voids. Deflection tests began at 8:00 am using the FWD, Dynaflect and TDR testing systems. ODOT provided the

FWD and Dynaflect for testing. Testconsult, Inc. staff used a hand-held version of the TDR. Purdue staff did the Epoxy/Core Test at locations suggested by ODOT personnel. The order of testing was Dynaflect, FWD, TDR and Epoxy/Core Testing. Testing was completed by 9:00 am. Seven additional slabs were tested around 10:30 a.m. but because of slab lock-up, thermal curl or the lack of voids, no areas suitable for further testing were found.

Table 6 summarizes the test results from the various systems used and provides evidence of a trend.

* Column 1; Joint Number. The joints were numbered and tested on both the approach and leave side of the joint.
* Column 2; W(1) Approach (mils). The Dynaflect was positioned such that only the W(1) sensor was placed on the approach slab and all others on the leave slab.
* Column 3; W(1) Leave (mils). The Dynaflect is positioned entirely on the leave slab with the W(1) sensor next to the joint.
* Column 4; Joint Support Ratio (%). This is the ratio of W(1) leave/ W(1) approach.
* Column 5; Void ?. Indicates the presence of a void according to ODOT's guidelines.
* Column 6; W(5) leave (mils). This reading is taken while the Dynaflect is positioned totally on the leave slab.
* Column 7; Void ?. The presence of a void is indicated by using the InDOT deflection criteria (W(5) sensor).
* Column 8; Void Thickness, (inches). There were ten cores taken on six joints and one at a mid-slab. Of the ten cores taken at the joints, eight showed some evidence of an epoxy lens.
* Column 9; Epoxy/Core Test. All six cored joint areas indicated a thin void.
* Column 10; Epoxy (pints). Epoxy in each of the access holes percolated down to some extent and took more epoxy. This column lists the epoxy consumed.
* Column 11; FWD, Void? The FWD test results did not indicate the presence of voids.
* Column 12; TDR results. TDR testing primarily indicated Poor Support (PS) and two areas of Small Voids (SV).

The voids which were filled with epoxy were in some cases paper thin. The InDOT procedure identified five of six voids but core testing was not done at all areas identified by the InDOT as having voids. Therefore no definitive conclusion can be drawn about its application. The following discussion of results is somewhat more subjective.

Mechanical testing produced high deflections. When compared to that of Indiana, the Ohio Dynaflect method of data interpretation seems to be more conservative having indicated only three voids to the 13 identified by the Indiana

	Ohio Dynaflect				Indiana Dynaflect						
Joint Number	W (1) Approach (mils)	W (1) Leave (mils)	Joint Support Ratio %	Void ?	W (5) Leave (mils)	Void ?	Void Thickness (inches)	Epoxy/Core Test	Epoxy Used Pints	FWD Void ?	TDR Results
2	1.55	1.77	114		.76	Yes	1/32	x	1	No	PS
3	1.39	1.46	105		.72	Yes				No	PS
4	1.85	1.58	85		.67	Yes				No	PS
5	1.73	1.00	173	Yes	.38	Yes				No	PS
6	2.03	1.44	71		.53	Yes				No	PS
7	2.38	1.44	60	Yes	.50	Yes	1/8	x	4	No	SV
8	.93	.77	83		.23					No	PS
9	.66	.64	97		.25		1/16			No	PS
10	1.18	1.42	120		.55	Yes	1/16	x	1	No	SV
11	1.39	1.79	129		.84	Yes	1/32	x	1- 1/2	No	PS
12	.85	1.30	153	Yes	.53	Yes	1/32	x	1	No	PS
13	1.03	1.23	119		.51	Yes		x	3/4	No	PS
14	.83	.88	106		.34	Yes				No	PS
15	.76	.63	83		.21					No	PS
16	.59	.62	105		.20					No	PS
17	.67	.65	97		.21					No	PS
18	.94	.66	142		.33	Yes				No	PS
19	.72	.70	97		.23					No	PS
20	1.36	1.27	93		.44	Yes				No	PS

Table 6. Summary of testing; I-75; Cincinnati, Ohio.

method. It is significant that Joint #7 took most of the epoxy and had the thickest void. Both criteria indicated the presence of this void. The TDR indicated Poor Support (PS) throughout the test site and showed the presence of two small voids (SV) at joints #7 and #10.

FWD deflections were significantly high but all other efforts to interpret the data were meaningless. The Joint Support Ratio as used in the Dynaflect testing in Column 4 did not yield any discrepancies greater than the needed 50%. The 3-Point Graph Method as described previously was not satisfactory. Rather than showing a high positive number, the resulting abscissa deflection reading was generally negative. As in the U.S. 52, Fowler project, the interpretation of the FWD data did not provide beneficial information.

S.R. 35; Jackson, Ohio

ODOT conducted Dynaflect testing on the day of the Epoxy/Core test. The purpose of the test was to find large voids. Only those locations that had the greatest promise of the having the existence of a void were evaluated with the Epoxy/Core test. As can be seen in Table 7, most of the locations that showed the greatest promise of having a large void as indicated by the Dynaflect readings only took a minimal amount of epoxy. The one location which showed only a small promise of having a void took the most epoxy and resulted in a void which was 3/8" thick. This was the biggest void found at any site evaluated to date. Once again there did not appear to a good correlation between the indicators resulting from the NDT systems and what was actually found with the epoxy.

S.R. 11; Youngstown, Ohio

In consultation with ODOT pavement research engineers, this project was suggested because of its potential for having large voids. The main reason that ODOT felt that it would be a good candidate for finding large voids was because of the inordinate amount of underseal material that had already been pumped under the pavement as part of a contract on the southbound lane. The contract quantity and all allowable extras were consumed in doing just half of the project.

The Dynaflect readings were acquired from ODOT and the epoxy core tests were performed at locations with the highest deflections. These deflection readings were not any worse than readings from previous jobs. However, the resulting cores and epoxy consumption were by far the largest for the jobs performed to date (Table 8). One core revealed as much as 0.8" void. This was found at a location which had only moderate deflection.

Station	W(1)A	W(1)L	JSR	Pints	Thickness
647+08	0.90	1.62	1.80	.7	0"
645+02	0.85	0.77	0.91	.6	0"
633+60	0.81	1.69	2.09	.6	0"
632+96	0.71	0.69	0.97	.6	0"
627+39	0.85	1.76	2.07	.6	0"
626+00	0.98	2.22	2.27	2.7	1/4"
614+42	1.22	2.14	1.75	.6	3/8"
575+98	1.48	2.35	1.59	6.0	0"

W(1)A	W(1) sensor reading on Approach Slab
W(1)L	W(1) sensor reading on Leave Slab
JSR	Joint Support Ratio; W(1)L/W(1)A
Pints	Pints of Epoxy poured into hole
Thickness	Thickness of Epoxy Void

Table 7. Dynaflect and Epoxy/Core Test results; Jackson, Ohio.

Station	W(1)A	W(1)L	JSR %	Core #	Pints	Thickness
571+93	1.67	2.59	155	1	7	.8"
				2	5	0"
				3	9	.7"
572+53	1.42	2.19	154	4	4	.1"
				5	6	.6"
575+54	1.41	2.47	175	6	7	.3"
				7	4	.2"
576+13	1.38	2.00	145	8	8	.3"
				9	7	.3"
				10	7	.5"

Table 8. Dynaflect and Epoxy/Core Test; Youngstown, Ohio.

Illinois Toll Highway

The Illinois State Toll Highway Authority evaluated their East/West Extension with an FWD. Results of these tests indicated that there were few if any voids. Subsequently, the Epoxy/Core Test was used for verification. No measurable voids were detected. It would seem that the Epoxy/Core Test confirms the validity of the FWD results. This is not the case because the FWD was the least reliable of the test devices whenever a comparison could be made on other test sites evaluated in this study. At this site it would appear to be reasonable to accept the Epoxy/Core Test results alone as an indicator of no voids.

Summary

The findings of this study are not and were not meant to be conclusive. The findings were meant to raise questions about the current practices of selecting locations for the application of the underseal restoration technique. These are some general findings:

1) No clear evidence exists as to whether a void must be present in order for the undersealing process to be successful.

2) If the success of the undersealing process is dependant on the presence of a void, then the conventionally used NDT methods are not making the distinction between voids and poor support.

3) Little correlation exists between the magnitude of the deflections found by the NDT methods and the size of the void. A certain deflection on one pavement may reflect a very small void whereas the same deflection on another pavement may reflect a large void.

4) The Falling Weight Deflectometer (FWD) which is the most widely used NDT method for void detection does not appear to be superior to other methods. This study indicates the opposite.

CONCLUSIONS

Further study must be done on how important it is that a void actually exist before undersealing can be successfully applied. The importance of void existence may be unique to a particular pavement structure and location. The only way that this can be done is to first measure the voids. It is the authors recommendation that this void verification be done using the Epoxy/Core Test.

The purpose of the Epoxy/Core Test is not to replace the conventional test methods. It is being offered as a method by which pavement research engineers can better understand a particular pavement by giving them an opportunity to "look" under the pavement. By correlating the deflection results with the findings of the Epoxy/Core Test method it is hoped that transportation departments will be able to more effectively manage their scarce rehabilitation dollars.

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Tables

1. Table 1. Typical results of Transient Dynamic Response (10).

2. Table 2. Summary of most severe loss-of-support condition for each testing method; U.S. 52; Fowler, Indiana.

3. Table 3. Comparison of testing methods; U.S. 52; Fowler, Indiana.

4. Table 4. Summary of Cores. U.S. 52; Fowler, Indiana.

5. Table 5. Summary of testing; U.S. 41; Boswell, Indiana.

6. Table 6. Summary of testing; I-75; Cincinnati, Ohio.

7. Table 7. Dynaflect and Epoxy/Core Test results; Jackson, Ohio.

8. Table 8. Dynaflect and Epoxy/Core Test; Youngstown, Ohio.