Void Detection and Rigid Pavement Undersealing in Indiana: A Comprehensive Approach

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The Indiana Department of Highways (IDOH) has been undersealing concrete pavements with bituminous materials since the late 1940s. Most early rigid pavements were constructed directly on soil subgrades and were subject to severe pumping. Thus early undersealing operations involved treating entire sections of roadway. As pavement designs improved, severe pumping became less prevalent and a method of identifying only those areas that required undersealing became necessary. The approach taken by IDOH personnel was global in nature. Because it was impractical to locate and treat specific voids, a method was developed to identify and treat the most severely distressed areas. The method of void detection presented herein uses Dynaflect deflections measured at regular (100-ft) intervals within each contract section. Decision criteria based on midslab deflections are established for each contract; Sensor 5 is the primary indicator variable. Because decision criteria are obtained independently for each contract section, the method is applicable to both jointed and continuously reinforced concrete sections and to previously overlaid sections. When the areas that require undersealing have been identified, all cracks and joints within each area are treated. The procedure involves carefully monitoring slab motion during material injection with a sensitive deflection gauge developed specifically for that purpose. Furthermore, injection time limits are observed to minimize material losses due to blowouts. Data are presented that demonstrate both the validity of the void detection method and the joint deflection improvements that can be expected from the undersealing procedure. The economic feasibility of the method is discussed in terms of the savings that have been realized since the implementation of the method.

The Indiana Department of Highways (IDOH) began undersealing concrete pavements with bituminous material in the late 1940s. Most of the early rigid pavements in Indiana were constructed directly on top of compacted soil subgrade and were subject to severe pumping under load. Thus the earliest undersealing operations involved treating entire sections of roadway. In some instances, as much as 4 gal of asphaltic materials were injected per square yard of pavement. The earliest specifications also included provisions for second treatments where, in the opinion of the engineer, the first treatment was insufficient or unsatisfactory. Reliable procedures for locating voids were not especially critical because pumping was visually apparent at nearly all joints and cracks.

As more information became available and design procedures improved, the state began constructing its concrete pavements over granular subbases. The presence of this select subbase material greatly reduced pavement pumping; however, problems associated with slab instability remained, and bituminous undersealing continued to be an important part of the overall rehabilitation-overlay procedure. In the years that followed, studies were conducted to determine the most effective and economical methods of injecting the undersealing materials. The method evolved from pumping through several holes at each joint or crack to injection at a higher pressure through a single hole placed at midlane, 3 feet from and on the leave side of each joint or crack. In the absence of a reliable void detection method, typical undersealing contracts called for undersealing every joint and crack; as much as 40 gal of material were pumped into each hole. The large quantity of material was attributed to the presence of large voids. However, evidence of pumping of the newer pavements was not sufficient to justify these quantities; furthermore, no large voids could actually be identified. In an attempt to reduce the overall cost of undersealing operations, studies were initiated in the 1970s to establish a method of locating voids or areas of poor support.

UNDERSEALING PROCEDURE

A comprehensive testing and undersealing procedure was developed by personnel of the Division of Research and Training of the IDOH and was implemented on a statewide basis in 1980. The method involves both Dynaflect deflection testing of each contract section to determine undersealing requirements and the detailed specification of undersealing procedures to be followed. The method is applicable, with minor alterations, to both jointed and continuously reinforced concrete (CRC) pavements. Because decision criteria are established for each contract section, the method is also valid for the evaluation of previously overlaid pavements. The steps of the Indiana method are outlined in the following subsections.

Step 1—Stationing

Each highway section scheduled for Dynaflect testing is "stationed" by the IDOH Construction Division. Large station markers visible from the test vehicle are requested.

Step 2—Equipment and Calibration

The state maintains a fleet of three Dynaflect testing machines. Operation is conducted in strict accordance with manufac-

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turer's recommendations to minimize measurement variations both within and between machines. Furthermore, periodic correlation studies are conducted at the division's test road in West Lafayette, Indiana, to determine intermachine variation. Although factory calibration establishes the 1,000-lb peak-to-peak force output, the 8-Hz operating frequency is calibrated at regular maintenance intervals. The operator calibrates the five geophone displacement transducers before testing each day.

Step 3—Testing

Dynaflect testing is conducted at approximately 100-ft intervals in the outer wheelpath, about 3 ft from the shoulder edge of the pavement. Jointed pavement deflections are obtained by spotting the Dynaflect force wheels adjacent to and on the leave side of the joint or crack nearest each station (Figures 1 and 2). Typical jointed pavements were constructed with 40-ft joint spacing, but nearly all have cracked in two or three places so actual testing locations may occur as much as 15 ft on either side of the station markers. CRC pavements are tested at each station regardless of crack location.

Step 4—Decision Criteria

Although all five sensor readings are recorded, just two Dynaflect deflection values are used for the identification of the pavement areas that require undersealing. Numerous investigators have concluded that the displacement at the first sensor, commonly referred to as *DMD*, gives the best indication of pavement strength and most report using the difference between the fourth and fifth sensors *(BCI)* as an indication of support conditions. Majidzadeh *(1)* suggested using either the *BCI* or the Sensor 5 (W_5) value for this purpose. Experience in Indiana has shown the W_5-value, rather than the *BCI*, to be most sensitive to pavement support conditions. In reporting the results of tests in which voids were artificially created beneath a 9-in. pavement at both crack and center slab locations, Mutti *(2)* also concluded that W_5 is more sensitive to pavement support than is the *BCI*-value.

FIGURE 1 Dynaflect positioned at a typical crack in a jointed pavement.

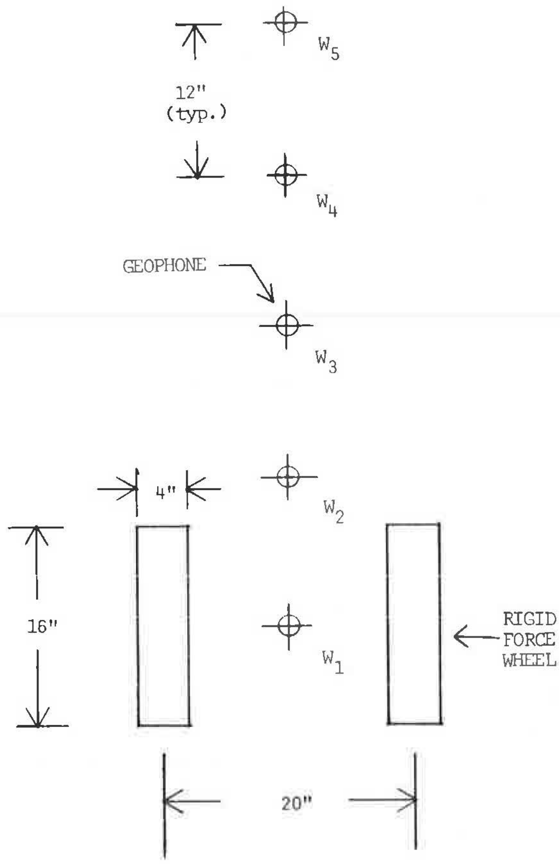

FIGURE 2 Dynaflect load and sensor arrangement.

Early in the development of the Indiana method, the magnitude of W_5 was the only decision criterion used. However, as more data were accumulated it appeared that undersealing areas where W_5 was marginal and *DMD* was low did not give satisfactory results. In cases in which borderline W_5-values were observed, pavement strength, as determined by *DMD* magnitude, showed little improvement if the initial *DMD*-value was less than approximately 0.60 mil.

Because of the inherent variability of in situ pavement properties, a value for the W_5 decision variable is established for each contract section. The determination of a suitable value is based on the premise that each slab must be fully supported at some point, and two possible locations that most often provide minimum deflection results have been experimentally identified. These are either along the outer wheelpath midway between joints or cracks, or both, (center-slab) or at the geometric middle of the slab (midslab). Continuously testing along the outer wheelpath is more convenient and center-slab results have been found to provide satisfactory W_5-values for most pavements.

Approximately 50 center or midslab readings are taken within each 5- to 8-mi contract section, and the average value of W_5 is used as the threshold limit for undersealing. Occasionally, relatively high W_5-values are obtained at some center or midslab test locations. These abnormal values are not included in calculating the average for the section, nor are the locations undersealed. Pumping has not been observed at these locations, and experience has shown that undersealing center or midslab areas almost always increases joint or crack deflections, or both.

The primary decision variable used for CRC pavement screening is the W_5-value. Threshold values are obtained by testing areas known to be performing "satisfactorily" at 1- or 2-ft intervals or from center or midslab deflection measurements taken on uncracked slabs at least 8 ft in length. Satisfactory performance is determined both visually and by reference to measured deflections. Although *DMD*-values may be used in identifying "satisfactory" control sections, this variable is, in general, not used to determine CRC undersealing requirements.

Step 5—Material Quantity Estimates

An average crack and joint frequency is determined for estimating purposes during Dynaflect testing of jointed pavements; typical frequencies range from five to eight joints and cracks per station. Bituminous material quantities are estimated on the basis of the single hole treatment at the rate of 15 gal per hole. CRC pavements that require undersealing are treated along the lane centerline at 8-ft intervals with 10 gal per hole.

Step 6—Undersealing

Undersealing is performed at considerable pressure (60 to 90 psi) to ensure uniform material distribution beneath the slab, and, as a result, the pavement starts to rise as soon as pumping begins. Slab motion is monitored with a sensitive deflection gauge developed at the Research and Training Center specifically for this purpose; use of the gauge is shown in Figure 3. Maximum slab uplift values of 1/4 in. for jointed and 1/8 in. for CRC pavements are specified in each undersealing contract. The difference in allowable motion for the two pavements is because jointed sections tend to settle somewhat when pumping stops whereas CRC pavements tend to rise slightly when pumping begins in the next hole. In either case, total injection time is limited regardless of pavement rise to minimize material loss due to blowouts through joints or cracks or at the shoulder. The time limits are 15 sec for jointed and 12 sec for CRC pavements *(3)*.

The effectiveness of the current single-hole injection method has been verified at numerous locations. Uniform distribution of the undersealing material can be observed whenever subsequent joint or crack repairs require slab removal. A uniform seam of the bituminous material has also been observed where edge drains have been installed along previously undersealed pavements *(4)*. Such a seam of material is visible in the photograph in Figure 4.

Step 7—Safety

Dynaflect testing is a slow-moving and potentially dangerous operation, particularly on high-volume roads. Thus appropriate safety precautions and traffic control measures are required to protect both the traveling public and testing personnel. A typical testing crew consists of the Dynaflect operator and two additional employees who follow in vehicles equipped with arrow boards and signs for traffic control. Daily production rates for the crew average about 8 lane-miles.

The undersealing operation is also potentially hazardous, so contractors who perform the work are required to comply with all state signage and traffic control specifications. Additional safety precautions are recommended because of the potential

FIGURE 3 Deflection gauge in use during undersealing of a section of CRC pavement.

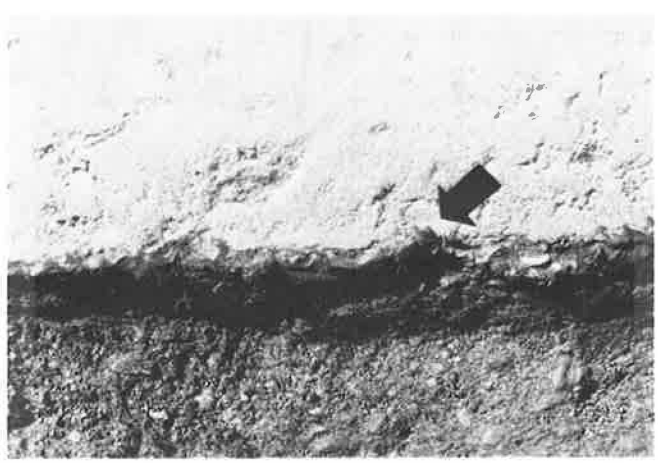

FIGURE 4 Seam of bituminous underseal exposed during installation of edge drain.

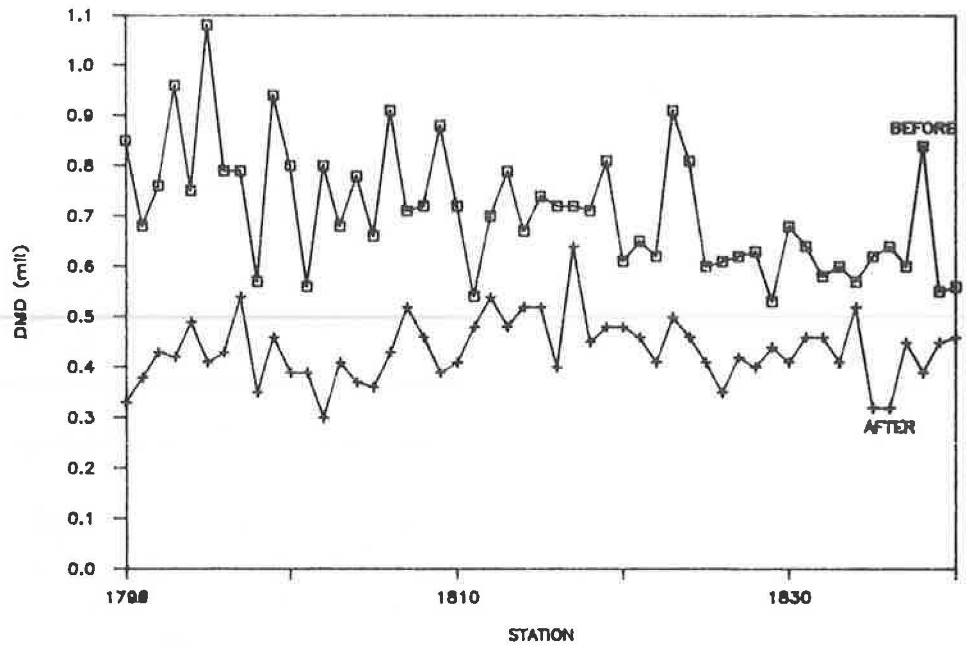

FIGURE 5 1983 IDOH void detection survey results: maximum Dynaflect deflections versus station before and after undersealing on US-30 between IN-23 and Queen Road (undersealing contract R-13899A).

hazard associated with handling the hot asphaltic material under high pressure.

RESULTS OF 1983 UNDERSEALING EFFORTS

Twelve jointed concrete pavement sections that had been undersealed during the 1983 construction season were retested with the Dynaflect to determine the extent of deflection improvement *(5)*. Graphic comparisons of the *DMD* data obtained before and after the undersealing of subsections in four of the twelve contracts are shown in Figures 5–8. Figures 2–7 show data representative of areas that showed substantial improvement after undersealing, and Figure 8 is a reminder of the statistical nature of the problem: the section from Station 200 to Station 246 showed little improvement after underseal-

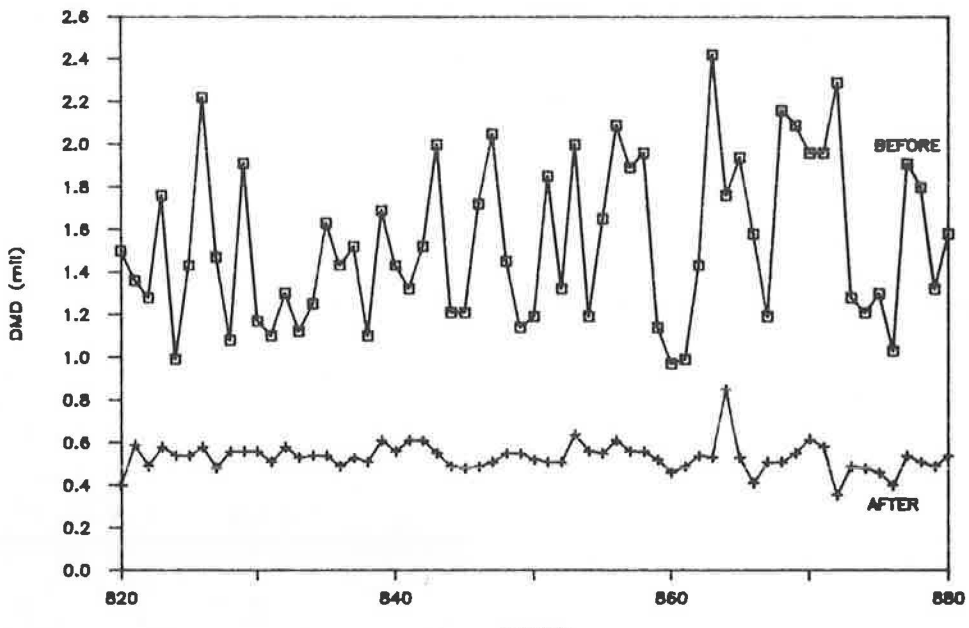

FIGURE 6 1983 IDOH void detection survey results: maximum Dynaflect deflections versus station before and after undersealing on I-69 from 2.3 mi east of IN-238 to 1.38 mi northeast of IN-38 (undersealing contract R-13947).

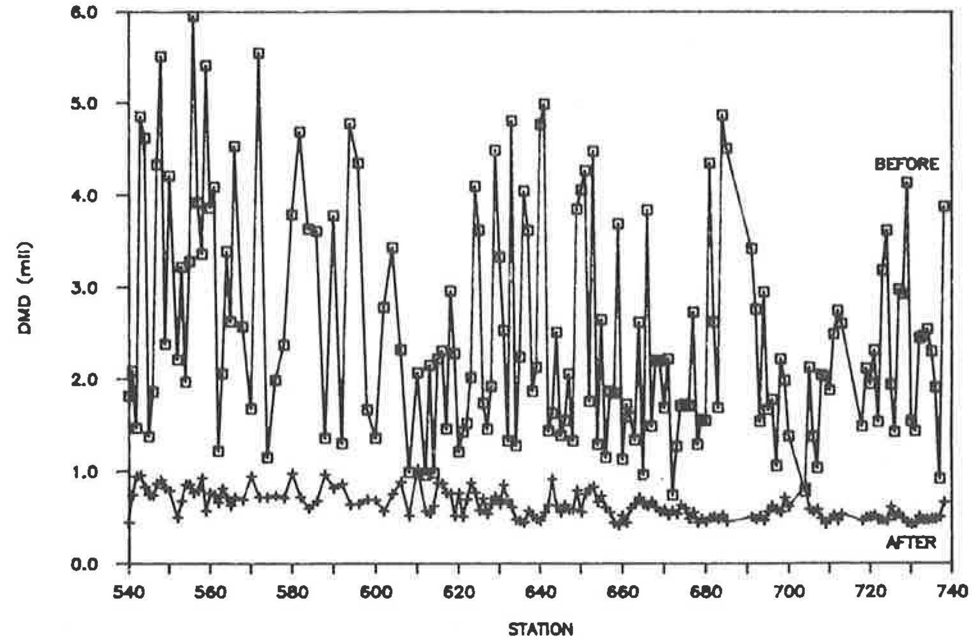

FIGURE 7 1983 IDOH void detection survey results: maximum Dynaflect deflections versus station before and after undersealing on I-69 from IN-18 to IN-124 (undersealing contract R-13773).

ing. In general, the most obvious features exhibited in these figures are the reduction in magnitude and variability of *DMD* deflections and the evidence of greater improvement in areas of higher initial *DMD*-values. A summary of mean *DMD* and standard deviation values determined for each of the twelve data sets is given in Table 1.

Figure 9, a comparison of the percentage improvement in *DMD* deflections versus initial *DMD* magnitudes, was prepared from the data obtained from all 12 sections. The percentage improvement was defined as

$$\text{Percentage improvement} = 100 * (DMD_i - DMD_a)/DMD_i$$

where DMD_i is the magnitude before undersealing and DMD_a is the magnitude after undersealing. It is evident from an inspection of Figure 9 that, in the majority of cases, an

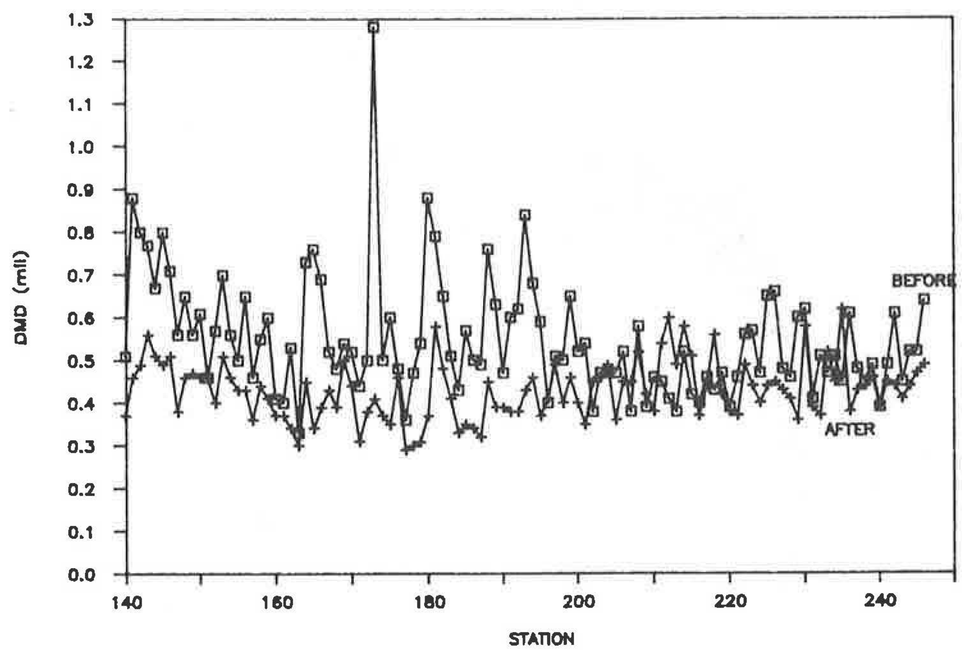

FIGURE 8 1983 IDOH void detection survey results: maximum Dynaflect deflections versus station before and after undersealing on I-69 from the West Fork of the White River to IN-332 (undersealing contract R-13903).

TABLE 1 SUMMARY OF 1983 DYNAFLECT DEFLECTION RESULTS

	Before Undersealing			After Undersealing		
Contract	Mean *DMD* (mil)	Standard Deviation (mil)	Coefficient of Variation (%)	Mean *DMD* (mil)	Standard Deviation (mil)	Coefficient of Variation (%)
R-13724	1.05	0.56	53	0.44	0.10	23
R-13724A	1.06	0.31	29	0.57	0.07	12
R-13773	2.51	1.21	48	0.64	0.15	23
R-13860	0.70	0.27	39	0.43	0.11	26
R-13899	0.62	0.11	18	0.49	0.07	14
R-13899A	0.71	0.12	17	0.43	0.07	16
R-13902	0.64	0.17	27	0.40	0.11	28
R-13903	0.55	0.14	25	0.43	0.07	16
R-13944	0.74	0.17	23	0.45	0.08	18
R-13947	1.54	0.38	25	0.54	0.06	11
R-13947A	1.17	0.31	26	0.52	0.06	12
R-13948	1.03	0.20	19	0.49	0.09	18

improvement of from 25 to 65 percent may be expected after undersealing. It is also evident that the effect of undersealing areas with DMD_i-values below about 0.50 or 0.60 mil is greatly reduced.

ECONOMIC BENEFITS

Use of the comprehensive Indiana testing and undersealing method has resulted in substantial savings by assuring more efficient allocation of the state's pavement rehabilitation resources. The result has been that, since implementation of the method, many additional miles of pavement are undersealed annually for the same or fewer relative dollars. These savings accrue from a reduction of both the number of joints and cracks treated and the volume of material injected at each location. Depending on the test results, undersealing requirements may vary from 30 to 100 percent of the joints and cracks in a contract section.

A summary of material savings realized on the 28 contract sections tested and undersealed during the 1985 construction season is given in Table 2. Based on a material cost of $300 per ton, the reduced material requirements represent a savings of approximately $12.2 million.

SUMMARY

The Indiana method, which is based on a Dynaflect deflection survey and a controlled undersealing procedure, has been

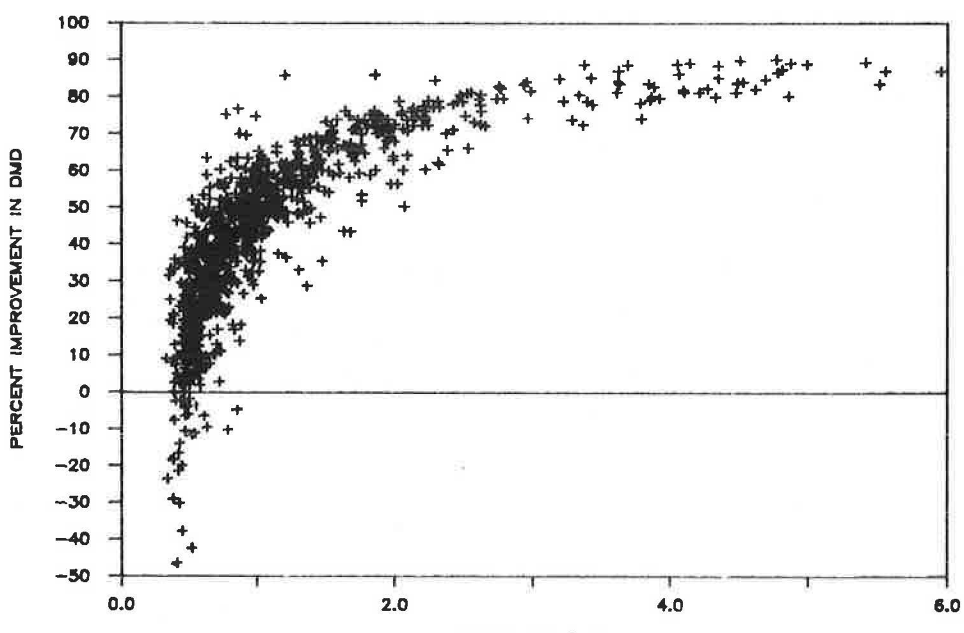

FIGURE 9 1983 IDOH void detection survey results: percentage improvement in *DMD* as a function of initial *DMD*.

TABLE 2 COMPARISON OF 1985 UNDERSEALING MATERIAL REQUIREMENTS WITH ESTIMATED REQUIREMENTS OF THE PRE-1980 UNDERSEALING METHOD, ADAPTED FROM LOVE *(4)*

Highway	Contract	Location	Comprehensive Method (tons)	Pre-1980 Method (tons)	Savings (tons)
US-31	R-15366	3.6 mi E of US-31 to IN-19	398.3	1,393.2	994.9
I-465	R-15414	I-565 to Fall Creek Pkway	754	6,907.6	6,153.6
US-41	–[a]	Margaret Ave. to Maple Ave.	150	703.7	553.7
US-30	–[a]	4.1 mi E of US-24 to OH line	141	1,632.7	1,491.7
US-31	–[a]	1 mi S of IN-25 to IN-110	0	2,199.1	2,199.1
IN-49	–[a]	Toll road to 3.9 mi N	293.7	837.2	543.5
US-24	–[a]	US-31 to IN-13	255	1,046.8	791.8
I-70	–[a]	Emerson to Shadeland	0	450.8	450.8
IN-3	R-15309	3.05 mi S of IN-244 to US-52	325.2	961.3	636.1
IN-9	R-15157	IN-14 to IN-205	0	527.8	527.8
I-65	R-15423	Greenwood to I-465	0	1,231.5	1,231.5
US-40	–[a]	Centerville to 0.73 mi W of US-27	38.7	726.4	688.6
IN-9	–[a]	12.23 mi S of US-24 to 6 mi S of US-24	194	1,029.6	835.6
I-65	–[a]	IN-56 to US-50	648.4	3,430.3	2,781.9
I-65	–[a]	Ohio River to IN-160	89	3,195.4	3,106.4
US-31	–[a]	Mills to Southern	48.7	129.9	81.2
US-52	R-14721	US-52 to Stockwell Rd.	929	2,059.2	1,130.2
US-30	R-15500	IN-109 to I-69	515	2,885.5	2,370.5
IN-67	R-15502	0.5 mi N of IN-239 to IN-144	252	2,532.3	2,280.3
I-70	R-15320	I-465 to Harding St.	237	1,561.9	1,324.9
I-69	R-15245	I-465 to Sand Creek	96.5	1,955.5	1,859
US-24	R-15141	US-24 bypass Fort Wayne	212	1,166.2	954.2
I-65	R-15544	College Ave. to North Western	138	1,539.4	1,401.4
IN-64	R-15313	US-231 to IN-145	230.5	1,276.2	1,045.7
US-35	R-15314	2.01 mi S of IN-18 to IN-18	45	169.9	124.9
I-465	R-15527	1.88 mi W of US-231 to 1.22 mi W of US-431	16.2	218.8	202.6
IN-3	–[a]	I-69 to Decalb Co. Line	256.4	1,935.2	1,678.8
I-465	–[a]	56th St. to I-65 S	121.5	3,443.6	3,322.1
Total			6,384.2	47,147.0	40,762.8

[a]Contract numbers not available at time of recording.

shown to be both practical and economical. The method is applicable to both virgin and overlaid jointed and CRC pavements with only minor procedural modifications and has been used successfully throughout the state to reduce the cost of undersealing unstable concrete pavements.

REFERENCES

1. K. Majidzadeh. *Pavement Condition Evaluation Utilizing Dynamic Deflection Measurement.* Final Report Ohio-DOT-13-77. U.S. Department of Transportation, June 1977.
2. R. A. Mutti. *A Laboratory Study of the Deflection Response Characteristics of a Model Concrete Pavement Subjected to Static and Dynamic Loads with Known Voids Present.* Ph.D. dissertation. Purdue University, West Lafayette, Ind., Dec. 1985.
3. J. J. Sudol and J. W. Muncaster. Undersealing Concrete Pavements: The Indiana Method. *Public Works,* August 1986, pp. 40–42.
4. B. W. Love. *Undersealing Savings Due to Dynaflect Testing Research by the Division of Research and Training.* Interdepartment communication, File R-86-7-55. Indiana Department of Highways, Indianapolis, May 1986.
5. J. J. Sudol. *Pavement Deflection Improvement Due to Asphalt Undersealing in 1983.* Internal Report. Division of Research and Training, Indiana Department of Highways, West Lafayette, Nov. 1983.

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