Effect of Pavement Variables on Average Joint Deflections in Experimental Concrete Pavement

ANDREW BODOCSI, ISSAM A. MINKARAH, RAJAGOPAL S. ARUDI, MAHESH BHUPALAM, AND ANURAG KAK

Knowledge of the magnitude of joint deflections in a concrete pavement caused by truck traffic is important because the larger the deflection the larger the stresses and the lower the fatigue life of the pavement. For improved design of concrete pavements it is important to evaluate the effects of various factors on pavement joint deflections. For this purpose an experimental concrete pavement was built in 1972 in Chillicothe, Ohio, by the Ohio Department of Transportation. The variables built into the pavement included two types of bases, different joint spacings, one section with skewed joints, and joints with no dowels, standard dowels, and plastic-coated dowels. The University of Cincinnati researchers have investigated this pavement for several years, first in the middle 1970s and then between 1989 and 1991. This last phase included a thorough investigation of vertical joint deflections. The deflections were produced by a two-axle truck moving at 80 km/hr and were measured by an electronic transducer. The ways in which the type of base, season, joint spacing and crack patterns, presence of dowels, type of dowels, and time of day affected the joint deflections of the experimental pavement are described. The test procedures and measuring methods used are discussed, and the results, analysis, and conclusions are presented.

Among other factors the magnitude of the vertical joint deflection in a concrete pavement depends on the degree of support that the pavement receives from its base and subgrade. The magnitude of vertical joint deflection is important because the larger the deflection of the pavement under an applied wheel load the larger its strains and stresses and the lower its fatigue life.

In 1972 the Ohio Department of Transportation (ODOT) built a 983-m-long experimental jointed reinforced concrete pavement segment in southbound State Route Ros 23 in Chillicothe, Ohio. This test pavement was divided into 12 sections. Nine sections were built on a 190.5-mm-thick granular base, and the remaining three were built on a 101.6-mm-thick asphalt-treated base. Other variables included joint spacing and type of dowel. This test section was studied from 1972 to 1980 by Minkarah and Cook (*1,2*) and Cook et al. (*3*) and again from 1989 to 1992 by Minkarah et al. (*4*) for joint behavior, such as vertical joint deflection and horizontal joint movements, and for various signs of deterioration.

In the latest test phase eight joints were tested for vertical joint deflection. Each joint was tested both in the morning and in the afternoon and in each of the four seasons during the years 1990 and 1991. Table 1 lists the joints tested, with information on joint spacing, type of base, and type of dowels.

To conduct the tests a fully loaded two-axle dump truck with a rear axle load of approximately 80 kN moving at 80 km/hr was used. The resulting vertical joint deflections were measured by a linear variable differential transducer (LVDT).

The fundamental purpose of the test program was to compare vertical joint deflections at the various sections of the test pavement to establish the effect of the time of day of testing, type of base, season of testing, type of dowel, and joint spacing.

This paper presents a summary of the instrumentation, test methods, the results, a detailed analysis, and conclusions.

INSTRUMENTATION AND TESTING

LVDT and Its Placement

The LVDT is a proven device used to measure relative displacements. Its drawback is that it requires a fixed reference point. The LVDT yields a voltage-time history directly proportional to the displacement-time history of its core-to-coil position. The only error that the manufacturer's specification lists is that due to nonlinearity. The transducer used in this test phase had an error band of ±0.0635 mm. This being a bias error, it could be reduced by proper calibration techniques to yield an accuracy of ±0.0152 mm. Calibration of the LVDT was performed before each test sequence to determine the appropriate calibration factor.

Before testing a joint an LVDT was placed on the approach side of the joint, as shown in Figure 1. The required fixed reference point for the LVDT measurement was provided by driving a 3.048-m-long, 34.9-mm-diameter steel rod approximately 101.6 mm away from the pavement in a 228.6-mm-deep cutout hole adjacent to each of the eight joints tested. The top of each rod was kept approximately level with the bottom of the 228.6-mm-thick pavement slab. One joint was selected to represent the respective group in each subsection, because it was not practical to provide fixed reference points for all the joints. For each test sequence the coil assembly of the LVDT was attached to the side of the pavement at a point directly above the reference rod. The core of the LVDT was attached to the top of the reference rod. Deflection of the pavement at the approach side of the joint caused the coil assembly to move in relation to the fixed core. An output voltage proportional to the pavement deflection was produced and recorded. Power to the LVDT was supplied by a 12-V battery. The LVDT signals were recorded by an HP35660 Signal Analyzer.

Test Procedure

A total of 140 dynamic tests (including repeated runs) with a fully loaded two-axle ODOT truck driven at a speed of 80 km/hr were

Department of Civil and Environmental Engineering, University of Cincinnati, 741 Baldwin Hall, ML 71, Cincinnati, Ohio 45221-0071.

TABLE 1 Joint Designation and Test Pavement Information

Joint #	Joint Spacing (m)	Type of Base	Type of Dowel
4	12.2	Granular	Standard (Uncoated)
21	6.4	Stabilized	Standard (Uncoated)
29	12.2	Stabilized	Standard (Uncoated)
40	5.18	Stabilized	No dowels
49	6.4	Granular	Coated
59	12.2	Granular	Coated
69	12.2	Granular	Standard (Uncoated)
89	6.4	Granular	Standard (Uncoated)

performed on the test pavement, and deflections under both front and rear axles were recorded. The front and real axle loads were approximately 40 and 80 kN, respectively, for each run. These deflections were then linearly normalized for an 80-kN axle load, resulting in a total of 280 readings. The tests were conducted on eight selected joints during four seasons in 1990 and 1991 and, typically, over a 4-day period in each season.

For each of the eight joints measurements were taken twice, in the morning on a cool pavement and later in the afternoon when the pavement had warmed up. These measurements were taken during summer and fall of 1990 and winter and spring of 1991. At each joint the truck was driven across the joint and the vertical deflection of the pavement on the approach side of the joint was measured. Usually a sequence of three runs was made for each measurement. Lines were placed on the pavement to guide the truck in maintaining a distance of 304.8 mm ± 50.8 mm from the pavement edge. Runs outside this range were repeated.

The data recorded were uncalibrated LVDT voltages. These were converted to displacements by multiplying the data by a constant scale factor that was obtained earlier from the calibration procedure.

Dynaflect readings were also taken on all joints in the test pavement to check the validity of using deflection data from one joint in each subsection to represent that group of joints. Also, the edge of the pavement was inspected at all joints to check the condition of the slab and the base. The investigation revealed uniform conditions at all joints with full support of the slab and only minor spalling of the concrete surface.

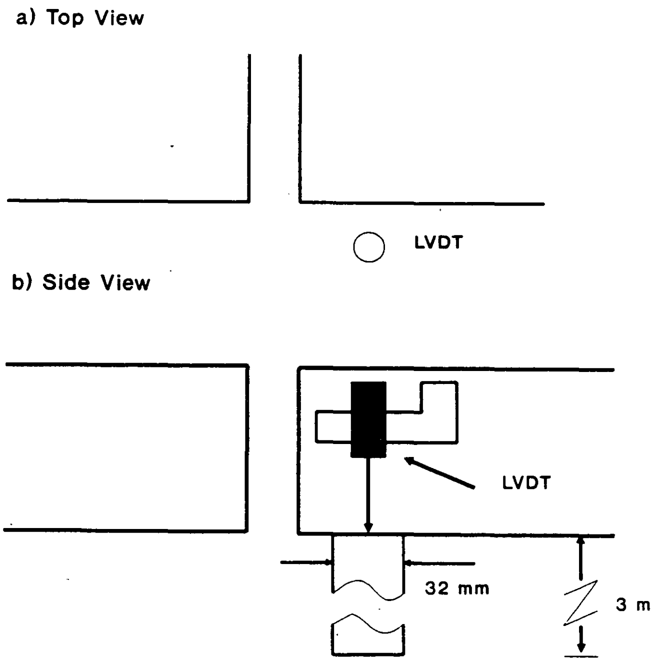

FIGURE 1 Placement of LVDT on pavement.

RESULTS

The averages of the peak LVDT deflection measurements for eight joints in the experimental concrete pavement are summarized in Table 2. The values provided are the averages of six measurements under the front and rear axles of the test truck.

The LVDT data were analyzed, digitized, and plotted for each of the eight joints, for each one of the test runs, and for each of the four seasons. As an example, Figure 2 gives the LVDT plot of deflections for a typical joint caused by the fully loaded two-axle truck moving across the joint at a speed of 80 km/hr. As can be seen in Figure 2 there are two peaks on the curve, the first caused by the passing of the front axle of the truck over the joint and the second caused by the passing of its rear axle. The net deflection of the joint caused by either of the axles can be obtained by reading the deflection at the peak point and adjusting this reading by the zero offset at the beginning of the plot.

All the data collected were entered into a data base. The data were then sorted according to the type of base, type of dowel, time of day when each test was conducted, the span of the slabs, and typical number of cracks. All the readings were then adjusted by the zero offset and linearly normalized for a standard 80.1-kN axle load for further analysis. A separate data base was also established for the Dynaflect readings.

ANALYSIS

The Dynaflect data from each group were analyzed, and the results are shown in Table 3. As seen in Table 3 the Dynaflect deflections for the joints selected for LVDT measurements are a good representation of the mean vertical deflections for each group.

From LVDT measurements, as shown in Table 2, the absolute maximum measured deflection was 0.3990 mm. The maximum deflection was measured on Joint 4, on November 15, 1990, during the morning hours (no temperature data were available for this measurement.) The overall average deflection from all LVDT measurements was found to be 0.1226 mm. Seasonally, the average deflections were 0.1088 mm in the summer, 0.1395 mm in the fall, 0.1303 mm in the winter, and 0.1169 mm in the spring.

The variations in joint deflections caused by variables such as time of day, type of base, season, presence of dowels, type of dowels, joint spacing, and number of cracks are presented in Figures 3 through 14. Also presented in Table 4 is a statistical summary of joint deflections were reference to these variables. Table 4 gives the results of a hypothesis test performed on each of the variables. The null hypothesis (H_0) tested was the difference in means equal to 0 at a level of significance of α equal to 0.05.

TABLE 2 Average Vertical Joint Deflections as a Result of Moving an 80.1-kN Axle Load Measured by LVDT at 80 km/hr

DATE	JOINT #							
	4	21	29	40	49	59	69	89
July 10, 1990	0.074 PM							
July 11, 1990		0.075 AM		0.079 AM	0.109 PM			
July 31, 1990	0.145 AM	0.074 PM			0.130 AM			
August 1, 1990						0.064 PM	0.323 AM 0.109 PM	0.104 AM
August 8, 1990			0.038 PM			0.175 AM	0.125 PM	0.069 PM
August 9, 1990			0.114 AM	0.043 AM				
Oct 31/Nov. 1, 1990		0.091 PM	0.114 AM		0.104 PM	0.155 AM	0.084 PM	0.081 PM
Nov. 14, 1990		0.056 PM	0.053 PM	0.191 AM 0.081 PM	0.173 AM			
Nov. 15, 1990	0.399 AM 0.135 PM						0.203 AM	0.173 AM
Feb. 14, 1991	0.379 AM		0.012 PM					
Feb. 21, 1991				0.064 AM	0.112 PM	0.079 PM	0.104 PM	
Feb. 22, 1991	0.053 PM		0.172 PM					0.198 AM
April 16, 1991	0.079 AM		0.033 PM	0.022 PM	0.048 PM			
April 17, 1991				0.074 AM	0.074 AM	0.038 PM	0.051 PM	
April 23-24, 1991	0.315 AM	0.208 AM 0.046 PM	0.089 PM			0.102 PM	0.132 PM	0.391 AM 0.168 PM

Note: All deflection values are average of three runs

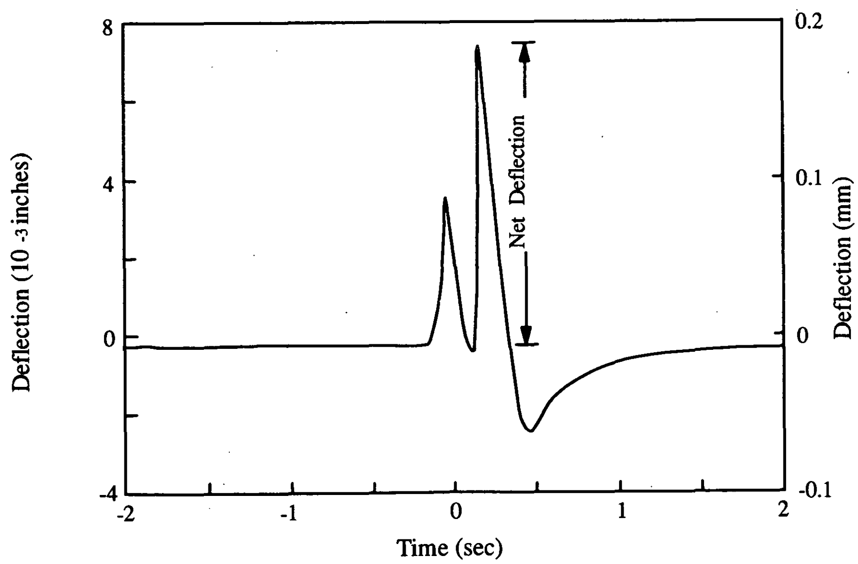

FIGURE 2 LVDT deflections for Joint 59.

TABLE 3 Analysis of Dynaflect Deflection Data

Group #	# of Joints	Mean Vertical Joint Deflection, mm	Standard Deviation, mm	Coeff. of Varn. = (SD/MEAN) X 100, (%)	Joint Selected for Detailed Studies	Deflection at Joint Selected, mm
1	7	23.876	4.826	20.6	4	25.908
2	8	10.414	1.27	11	21	10.16
3	12	9.652	1.27	14.1	29	10.16
4	10	12.446	1.27	9.6	40	11.684
5	10	23.114	8.89	38.8	49	22.352
6	11	22.352	5.588	24.6	59	20.32
7	9	22.860	4.826	21.1	69	No Data
8	10	19.812	7.366	36.4	89	16.51

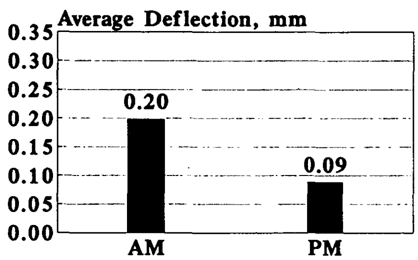

FIGURE 3 Effect of time of day (a.m. versus p.m. deflections).

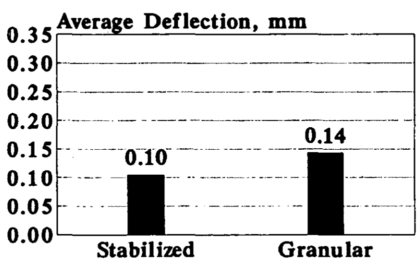

FIGURE 4 Effect of base (stabilized versus granular deflections.)

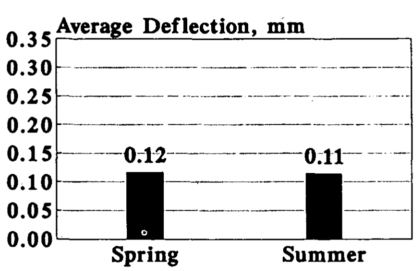

FIGURE 5 Effect of seasons (spring versus summer deflections).

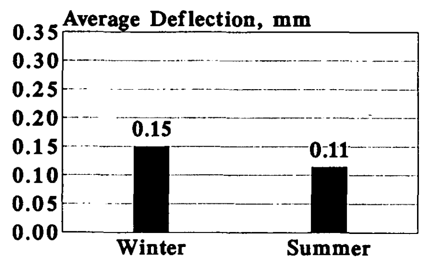

FIGURE 6 Effect of seasons (winter versus summer deflections).

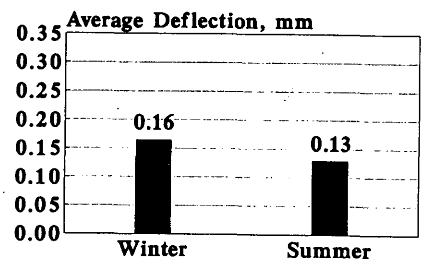

FIGURE 7 Effect of seasons (winter versus summer, granular base only).

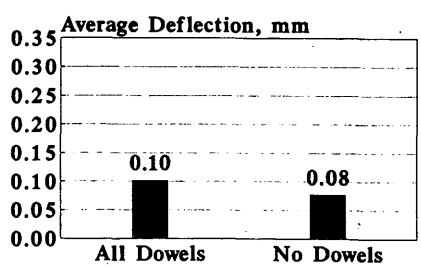

FIGURE 8 Effect of dowels (stabilized base).

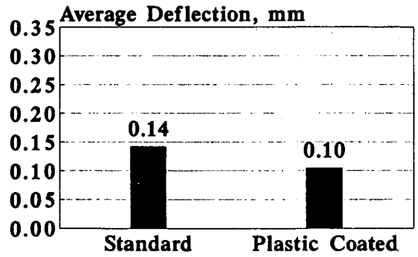

FIGURE 9 Effect of dowels (standard versus plastic coated).

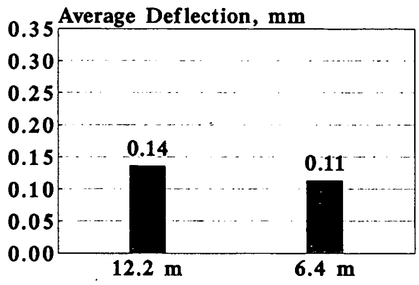

FIGURE 10 Effect of joint spacing (12.2 versus 6.4 m).

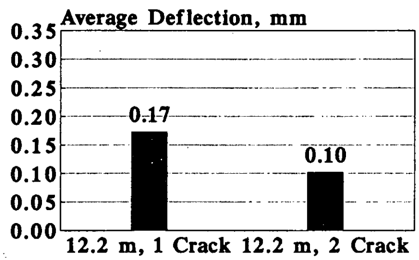

FIGURE 11 Effect of joint spacing (12.2 m, one crack versus 12.2 m, two cracks on granular base).

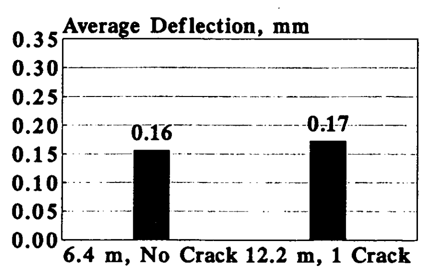

FIGURE 12 Effect of joint spacing (6.4 m, no crack versus 12.2 m, one crack on granular base).

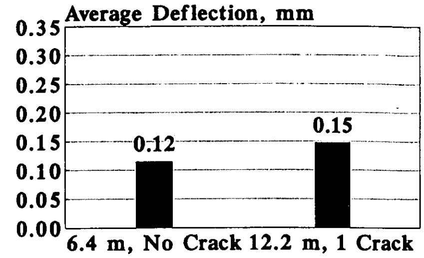

FIGURE 13 Effect of joint spacing (6.4 m, no crack versus 12.2 m, one crack on granular and stabilized base).

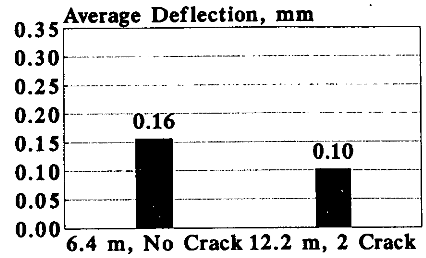

FIGURE 14 Effect of joint spacing (6.4 m, no crack versus 12.2 m, two cracks on granular base).

Figure 3 shows joint deflection results in a bar-chart format comparing average morning (a.m.) and afternoon (p.m.) deflections, regardless of season or type of base. The average a.m. deflection of 0.1984 mm was more than twice the average p.m. deflection of 0.0889 mm. This agrees well with the observations of Minkarah and Cook (*1,2*) and Cook et al. (*3*). In the morning the top surface temperature of the pavement is usually colder than its bottom, causing the pavement slab to curl upward. When the wheel load is applied a curled pavement deflects more because it is poorly supported near the joint. The statistical test performed to compare the averages of the two groups reveals that time of day (a.m. versus p.m.) has a significant effect on joint deflections (Table 4).

The effect of the type of base on joint deflection is shown in Figure 4. Figure 4 compares the average joint deflection on asphalt-stabilized base (0.1049 mm) with that on granular base (0.1435 mm). Clearly, joints supported on asphalt-stabilized base had smaller vertical deflections than those supported on granular base. This observation also agrees well with those of Minkarah and Cook (*1,2*) and Cook et al. (*3*). The statistical test revealed that type of base (granular versus stabilized) has a significant effect on joint deflections (Table 4).

To study the effect of the season on joint deflections, the average joint deflection from all measurements during the spring was plotted versus the average from all deflections during the summer (Figure 5). Similarly, the winter deflections were plotted versus the summer deflections in Figure 6. The average spring deflection of 0.1166 mm was slightly higher than the summer deflection of 0.1143 mm, whereas the winter deflection of 0.1501 mm was higher than both. Furthermore, the average winter joint deflections on granular base only were compared with the summer deflections at the same joints (Figure 7). The difference between winter and summer deflections was even larger than when all joints, regard-

TABLE 4 Effect of Pavement Variables: Summary Statistics

Variable		Sample Size	Mean vertical joint deflection, mm	Significant Difference between Means	Level of Significance (Probability of error)
Time of day	AM PM	41 75	0.1984 0.0889	Yes	3.775E-11
Base	Granular Stabilized	86 49	0.1435 0.1049	Yes	0.0198
Seasons	Spring Summer	32 47	0.1166 0.1143	No	0.907
	Winter Summer	20 47	0.1501 0.1143	No	0.1103
	Winter Summer (Granular Base)	14 29	0.1646 0.1295	No	0.2597
Dowels	Standard Plastic coated	85 33	0.1425 0.1049	Yes	0.0403
	No dowels(skewed) All dowels (Stabilized Base)	17 31	0.0774 0.1017	No	0.1434
Joint Spacing	12.2 m 6.4 m	71 63	0.1361 0.1133	No	0.1318
	12.2 m, 1 crack 12.2 m, 2 cracks (Granular Base)	37 17	0.1725 0.1019	Yes	0.0221
	6.4 m, No crack 12.2 m, 1 crack (Granular Base)	16 37	0.1565 0.1725	No	0.6431
	6.4 m, No crack 12.2 m, 1 crack (Gran. & Stab. Base)	47 54	0.1151 0.1471	No	0.1013
	6.4 m, no crack 12.2 m, 2 cracks (Granular Base)	16 17	0.1565 0.1018	No	0.0546

less of base, were considered. It should be noted that the winter of 1991 was mild and wet in Chillicothe, Ohio, causing larger than typical joint deflections. The statistical tests, on the other hand, do not show any significant effect of season on the mean vertical joint deflections (Table 4). Therefore, it is recommended that more tests be run to investigate this point.

In Figure 8 the effect of dowels on the average joint deflection in the pavement slabs on stabilized base is shown. The bar charts indicate that the joints with no dowels undergo smaller deflections (0.0774 mm) than the ones with dowels (0.1017 mm). The undoweled joints are all skewed, and therefore, as the test truck moves across these joints, the effective load causing the deflection is smaller than for the nonskewed doweled joints. The statistical test indicated that this difference was insignificant (Table 4). In other words, joint deflections on the asphalt-stabilized base are minimally affected by the presence of dowels. The asphalt-stabilized base was still in excellent condition, as seen from cores taken from the pavement and from visual inspection at the edges.

Figure 9 presents bar charts showing the average of all joint deflections as affected by the type of dowel, standard or plastic coated. The joint deflections were somewhat larger with standard dowels (0.1425 mm) than with plastic-coated dowels (0.1049 mm). This difference was statistically insignificant (Table 4). Even though plastic-coated dowels are slightly more effective than standard dowels in reducing joint deflections, the difference is not appreciable.

The above-stated effects of plastic-coated dowels on the vertical deflection of joints was not observed when the test pavement was new in the early 1970s. Then the plastic-coated dowels seemed to have little or no effect on vertical joint deflections (*1–3*). Cores taken through the joints in 1985 and 1990 showed little deterioration of the dowels. To shed more light on this question, ODOT and the researchers are planning to cut out several doweled joints for inspection when this pavement is rehabilitated in the near future.

Another parameter of interest was the effect of joint spacing on joint deflection. The bar charts in Figure 10 show that joint spacing had only a small effect on joint deflections. Specifically, the overall average joint deflection of the 12.2-m slabs (0.1361 mm) was slightly higher than that of the 6.4-m slabs (0.1133 mm). This comparison was done for all joints, on all bases, and with all dowel combinations. The statistical test indicated no significant effect of joint spacing on vertical deflection (Table 4). This was perhaps because many slabs, particularly the 12.2-m slabs, developed midslab cracks that reduced the effective lengths of the slabs. Hence a more detailed analysis of the effect of joint spacing was made by considering the effect of the number and spacing of cracks in each type of slab.

In the first case the average joint deflections of 12.2-m slabs on granular base were compared. From this, the 12.2-m slabs with one crack at midslab showed a greater average joint deflection than the 12.2-m slabs with two cracks at the third points. As shown by the bar charts in Figure 11 the average deflection of slabs with one crack was 0.1725 mm, whereas it was 0.1018 mm for slabs with two cracks. Similarly, the statistical test showed that the difference in averages was significant. The probable reason for this difference is the greater curl of the slab with the longer span, that is, the one with only one crack.

In the second case the average joint deflection of 12.2-m slabs with one crack at midslab was compared with the average joint deflection of 6.4-m slabs with no crack, both on granular bases (Figure 12). The results indicate no significant difference in the average deflections (Table 4). An explanation for this is that in both cases the curling spans are approximately the same, 6.1 and 6.4 m. Similar results were obtained from comparing the average deflections of these slabs on all bases, both granular and stabilized (Figure 13). However, the average deflections were smaller.

In the third case the average joint deflection of 6.4-m slabs without cracks was compared with that of the 12.2-m slabs with two cracks, with both types again being on a granular base. As shown in Figure 14 the average deflection of the 6.4-m slabs was greater than that of the 12.2-m slabs (0.1565 m versus 0.1018 mm). However, the statistical test indicated that there was no significant difference between the two.

CONCLUSIONS

On the basis of the detailed analysis of the data, the following conclusions can be made:

1. The overall mean vertical joint deflection was found to be 0.1226 mm, which compared very well with the mean deflection measured when the pavement was new. Note that the pavement and the base are still in good condition.
2. The maximum measured deflection was 0.3990 mm. This occurred in the fall in the morning and on granular base.
3. The overall average deflection of the joints in the morning was significantly greater than the overall average deflection in the afternoon. The direction of pavement curl because of a temperature differential was the probable cause.
4. The joints on stabilized base deflected significantly less than the ones on granular base. This was expected, because the stabilized base should provide better support with less deflection. It also minimizes pumping and erosion.
5. Although the average vertical joint deflections during winter and spring were greater than those during summer, the difference was not statistically significant. More tests are recommended for further study.
6. There was no significant difference between the average joint deflections of doweled and undoweled joints on stabilized base.
7. The effect of dowel type, plastic-coated versus standard (uncoated) dowels, on vertical deflection was statistically significant. Joint deflections were somewhat larger with standard dowels. This was not the case in earlier reports on this pavement, when there was no significant difference in vertical deflections between the two types.
8. Slab dimension or joint spacing had little effect on the average vertical joint deflection. However, when the cracks in the pavement were considered, the difference in average deflections was much more noticeable. Specifically, the following observations were made:
   - The 12.2-m slabs with one crack had greater average deflection than the 12.2-m slabs with two cracks;
   - The average deflection of 12.2-m slabs with one crack was close to the average deflection of the 6.4-m slabs with no cracks; and
   - The average deflection of the 12.2-m slabs with two cracks was smaller than the average deflection of the 6.4-m slabs with no cracks, but the difference was not statistically significant.

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