

BACK-ESTIMATION OF SLAB CURLING AND JOINT STIFFNESS

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ABSTRACT

The analysis of the Heavy Weight Defelctometer (HWD) data from the FAA National Airport Pavement Test Facility (NAPTF) indicates that the measured Sum of two Deflections (SD) on two sides of dummy joints increase proportionally to the slab curling but are insensitive to the joint Load Transfer capability defined by Deflection (LTD). This discovery is verified and extended by finite element analysis in this paper. HWD data collected from pavements at the NAPTF are used to first back-estimate the slab curling assumed due to an equivalent temperature gradient then the shear stiffness of the dummy joints are calculated. The numerical comparison of the predicted and directly measured joint and corner deflections verifies that the back-estimated parameters are reasonable.

INTRODUCTION

Guo and Marsey (2001) recently presented a paper based on the Heavy Weight Deflectometer (HWD) tests from three Portland Cement Concrete (PCC) test items in the FAA's National Airport Pavement Test Facility (NAPTF). Three PCC test items with longitudinal doweled and transverse dummy joints rest on three subgrade classifications: weak (CBR 3-4), medium (CBR 7-9) and strong (CBR 30-40). The three pavement cross sections are designated as LRS, MRS and HRS respectively and shown in Figure 1.

HWD tests were conducted from the end of Oct. 1999 to Jan. 2000. All points indicating the position of the load plate center for the HWD shown in Figure 2 were tested. Locations of the HWD Deflection Sensors are given in Figure 3. D0 defines the position of deflection at the center of the 30.5 cm (12 in) load plate. D-1 is the deflection sensor 30.5 cm (12 inch) in front of the load plate and D1 to D5 are deflection sensors behind the load plate with 30.5cm (12 inch) spacing. The arrangement of one sensor D-1 located in front of the load plate makes it easy to obtain the load transfer at a joint in both directions.

The HWD data indicates that the shape of the slabs varied all the time but the corners of the slabs were always curled up. The deflections at the corners and in the middle of the joints measured in cold weather (later fall to winter) were significantly higher than those measured in the summer. The slabs resting on stronger subgrades always received higher deflections than the slabs resting on weaker sub-grades for the same magnitude of load.

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When a load is dropped on one side of a joint, deflections on both sides of the joint (two quantities) are recorded by the HWD's deflection sensors. Presently only one parameter (ratio of the two deflections which is defined as Load Transfer coefficients based on Deflection, LTD) has been popularly employed to show the load transfer capability of the pavement. Crovetti (1996) might be the earliest investigator to notice the importance of and take advantage of the Sum of two Deflections (SD) on two sides of a joint in PCC pavement evaluation. Slab support ratio defined by the ratio of back-calculated foundation modulus k at edge (or corner) and at center is used to evaluate the curling. Unfortunately, the equation used to obtain the back-calculated k at edge was derived based on an incorrect assumption: the value of SD equals to the free edge deflection even if the slabs are curled up. Guo and Marsey (2001) found that SDs remain almost constant for the two drops on the two sides of the joint although the corresponding LTDs were significantly different. The SDs measured in winter were significantly higher than those measured in summer. Does the parameter SD involve some significant information on the pavement structure? What would be the multiple interactions among LTDs, SDs, joint structural stiffness and environmental effects on the slab curling?

The main objective of this paper is to show why information from both SD and LTD (rather than LTD only) from the HWD test data in FAA, NAPTF was used, and how they can be used to estimate the curling of PCC slabs and the dummy joint structural stiffness. A 2-D finite element model is used to predict the average curling shape of the test items LRS, MRS and HRS in the FAA, NAPTF and compare them with the measured data.

AVAILABILITY OF THE HWD DATA

The HWD data collected and utilized for this report have been included as part of the NAPTF database. The database is available for download or direct access at the FAA Airport Technology Research and Development Branch web site: www.airporttech.tc.faa.gov. The sensor designations in this report differ from those in the database. This was done for uniformity with accepted past practices during analysis.

ANALYSIS OF THE HWD DATA

Table 1-3 presents deflections and corresponding loads for all seven sensors at the center of the fifteen slabs in items LRS, MRS and HRS. These data were used to back-calculate pavement radius of relative stiffness, l , Winkler Foundation stiffness, k , and concrete layer elastic modulus E based on the mean value of sensor readings normalized under 10,896 kg (24,000 lbs) HWD load. The results are listed in Table 4. The back-calculation method was proposed by Hall, et al., 1991. Additionally, the following k values are used for subsequent response analysis in this paper: 54.2, 108.4 and 178.9 MPa/m (200, 400 and 600 pci) for LRS, MRS and HRS respectively. A PCC E value of 55.2 MPa/m (8 million psi) is used for subsequent response analysis for all three items.

Table 1 – 3 also presents the LTDs in two directions and the corresponding sums of the deflections (SD). The average measured deflection D_0 in the middle transverse joints are 0.428, 0.555 and 0.669 mm for items LRS, MRS, HRS which indicates that curling could be larger for slabs resting on a stronger sub-grade than on a weaker sub-grade. The measured LTD values are

sensitive to the vehicle direction. All results with higher LTD value are listed on the left and LTDs with the lower values are listed on the right in the Tables. The measured values of SD are also presented in the three tables. The data shows that many values of LTD are significantly different on the two sides of the joint but the values of SD vary much less. Figure 4 presents the comparison of the means of the measured LTD and SD at the transverse joints in items LRS, MRS and HRS. The LTD values on the higher side are much higher than those on the lower side. However, the means of measured SD values in the corresponding two groups are almost the same. The finding from the HWD data is that the SD is only sensitive to the curling of slabs, higher SDs are obtained from higher curled slabs ($HRS > MRS > LRS$), but are insensitive to the joint load transfer capability LTD for the same curled slabs (within items HRS, MRS or LRS).

SD ANALYSIS BY A FINITE ELEMENT PROCEDURE

A 2-D finite element computer program JSLAB-92 (Tayabji 1987 and Guo et al. 1995) with the capability of considering temperature effects and nonlinear elastic behavior was employed to analyze the characteristics of the parameter SD. The MRS pavement structure (Figure 1) is used. The concrete modulus $E = 8,000,000$ psi and foundation modulus $k = 400$ pci are selected based on the back-calculated values in Table 4. Figure 5 shows the finite element mesh. A 10,896 kg (24,000 lbs) load is applied in the middle of the transverse joint (B in Figure 5) with 6-inch center distance to the joint centerline. The loading area is square and equals the area of a 30.5 cm (12 inch) diameter HWD load plate for simulating the HWD tests. A doweled joint may be equivalently simulated by a simplified shear model defined by joint shear stiffness K_d (Brill & Guo, 2000). Both longitudinal and transverse joints are simulated by the shear model. Since the effects of the two longitudinal joints on the deflections in the middle of the transverse joint is very limited, $K_d = 690$ Mpa (100,000 psi) is used for all longitudinal joints in the analysis of SD values in the middle of the transverse joint.

It has been observed and discussed previously that all slabs in LRS, MRS and HRS were curled up (corners and joints). The slab shapes are influenced by many effects, such as:

- (1) Shrinkage or expansion of concrete material during the moisture change;
- (2) Temperature gradient along the slab depth;
- (3) Interaction between average temperature and moisture change and the interface friction behavior between PCC and the base layers;
- (4) Concrete creep developed after pavement construction;
- (5) Material properties and maintenance conditions.

It is too complicated to consider all of the above effects separately. As the first step, the shape of the slabs is assumed due to an equivalent linear temperature gradient g . The negative value indicates that the surface temperature of a slab is lower than that at the bottom so that corners and middle points of the joints are more or less curled up. The measured HWD deflections at the corners and joints are referenced to the slab curled up position so that a portion of the slab bottom was separated from the econo-concrete base. Therefore the analysis is a nonlinear procedure and the results can only be obtained by iteration to search the slab bottom contact area to make the load and the slab self weight equal to the reaction force of the slab foundation.

The deflections calculated on the loaded side $D(L)$ and the sum of deflections (SD) on two sides of the joint under temperature gradients $g = 0, -0.22, -0.44$ and -0.66 °C/cm (0, -1, -2 and -3

°F/in) were plotted vs. different K_d values assumed for the dummy transverse joint in Figure 6. Findings are summarized below:

- (1) When g (the equivalent linear temperature gradient) equals 0, or, no curling exists, the SD is independent of joint stiffness and always equals the free edge deflection ($K_d = 0$). This feature may be theoretically proved by applied mechanics.
- (2) When $g \neq 0$, Both SD and $D(L)$ increase when the magnitude of g increases and SDs in these cases are always greater than the free edge deflections.

When g is fixed (all slabs are under the same environment):

- (3) SD increases but $D(L)$ decreases when the joint stiffness K_d increases
- (4) For cases $K_d < 0.069$ MPa (10 psi), or extremely weak load transfer capability, $SD = D(L)$ because $D(U)$ (unloaded side deflection) ≈ 0 .
- (5) For cases $K_d \geq 69$ MPa (10,000 psi), the SDs almost remain the same.

The above findings support the characteristics of the SDs observed in the HWD tests at the FAA, NAPTF. The most important finding are (2) and (5) which verify that under certain conditions ($K_d \geq 69$ MPa) the SDs are sensitive to the equivalent temperature gradient but independent of the condition of the dummy joints. Therefore, we may develop a procedure to back-estimate the “equivalent temperature gradient” and the slab shape change from the values of SD under HWD loading.

THE PROCEDURE FOR BACK-ESTIMATING SLAB CURLING

Either 2-D or 3-D finite element procedures may be employed to conduct the back-estimation. The 2-D program JSLAB-92 is used in this paper to demonstrate the procedure and provide numerical examples.

- (1) Since the values of SD in the middle of the transverse joint are used to back-estimate the slab curling, the effects of two longitudinal joints may be neglected. Therefore, the curling of the pavement in Figure 5 may be modeled by a two-slab system linked by a joint with shear stiffness K_d (force/length/length) (Brill & Guo, 2000) resting on Winkler foundation with modulus k (Force/length/length/length) (Yoder et al. 1975).
- (2) The elastic modulus of concrete E and foundation modulus k may be back-calculated by using the HWD data received at the center of the slabs (Hall 1991). $k = 200, 400$ and 600 pci for LRS, MRS and HRS, and $E = 8,000,000$ psi are finally used in the back-estimation. The thicknesses of the slabs are given in Figure 1.
- (3) Environment induced deflections are calculated first. JSLAB-92 is used to calculate the two deflections in the middle of and on two sides of the transverse joint under temperature gradient $g = 0, -0.11, -0.22, -0.33, -0.44, -0.55$ & -0.66 °C/cm (0, -0.5, -1.0, -1.5, -2.0, -2.5, -3.0 °F/in). The two calculation points should be 15.25 cm (6 inch) away from the center line of the joint which are the same as the deflection sensor position in HWD tests). Any joint stiffness values K_d may be used in this calculation because the shear joint model provides no constraint on the curling if the two slabs are structurally symmetric to the joint.

- (4) Load and environmentally caused total deflections are calculated second. JSLAB-92 is still used to calculate the two deflections under a 10,896 kg (24,000 lbs) square load, 6 inch from the joint center line, plus different temperature gradient $g = 0, -0.11, -0.22, -0.33, -0.44, -0.55 \text{ \& } -0.66 \text{ }^{\circ}\text{C/cm}$ ($0, -0.5, -1.0, -1.5, -2.0, -2.5, -3.0 \text{ }^{\circ}\text{F/in}$). The loading area is equal to the area of FWD loading plate and the loading pressure is 1.46 MPa (212.2 psi) to match the HWD load used in FAA pavement tests. Any joint stiffness $K_d > 69 \text{ MPa}$ (10,000 psi) (most joints of PCC airport pavements in service satisfy this condition) may be used in this calculation since the calculated SD values are insensitive to the parameter K_d . $K_d = 690 \text{ MPa}$ (100,000 psi) was used in this analysis.
- (5) The predicted load induced SDs referenced from different temperature gradients are calculated by minus the deflections under the temperature only in step (3) from the total deflections in step (4). And the curves for LRS, MRS and HRS are drawn as load induced deflection in terms of temperature gradients as shown in Figure 7.
- (6) The measured average SDs may be used to estimate the equivalent temperature gradient g from Figure 7 for the three pavements. The equivalent temperature gradients and the corresponding top-bottom temperature differences are presented in Table 5.

BACK-ESTIMATED JOINT STIFFNESS K_d

Figure 8 presents the LTD ($D(U)/D(L)$) curves in terms of joint stiffness K_d from 0.0069 to 69,000 Mpa (1 to 10,000,000 psi) for items LRS, MRS and HRS in FAA NAPTF under different temperature gradients. The calculations are still conducted by using J-SLAB92 with the same two-slab model. Two major findings are summarized below:

- (1) The value of LTD not only depends on the value of K_d but also depends on temperature gradient g . Comparison between Figure 8 and 6 shows the difference of behavior between LTD and SD. LTD is sensitive to both temperature gradient and joint stiffness K_d while SD is only sensitive to temperature gradient but remains almost the same when $K_d > 69 \text{ MPa}$.
- (2) For the same K_d , the higher magnitude of temperature gradient leads to the higher value of LTD. This feature indicates that the parameter LTD should not be used as an input data in 2-D or 3-D finite element analysis with consideration of curling.
- (3) When $g = 0$, or a pavement fully contacts the foundation, and the joints having the same stiffness K_d , LRS pavement would experience the highest load transfer coefficient LTD and HRS would experience the lowest.

By using the average measured LTD values ($= D(U)/D(L)$) in HWD tests (Tables 1 – 3), and the curves in Figure 8, the values of K_d for transverse joints in LRS, MRS and HRS may be obtained. Interpolation is needed to obtain the value corresponding to the back-estimated temperature gradients in Table 5. The back-estimated K_d for LRS, MRS and HRS are also listed in Table 5.

VERIFICATION OF THE ESTIMATED TEMPERATURE GRADIENTS

As previously stated, the back-estimation procedure in this paper was developed by using the HWD deflections measured in the middle of the dummy joints. The deflections obtained at the

corners (Figure 2) were not involved in developing the back-estimation procedure. Therefore, the comparison between the directly measured and predicted deflections at the corners may be used to evaluate if the back-estimated curling (defined by parameters g) and the joint stiffness K_d are reasonable.

The behavior of doweled and dummy joints are different especially when the slabs experience significant curling. The interlock of the dummy joints has no constraint on the curling if the slabs on two sides of the joint experience the same curling. Therefore, the temperature gradient induced responses for the multiple slabs linked by joints defined by the shear stiffness K_d and for any single slab in the pavement system would be the same. However, dowels can significantly reduce curling. The average measured deflections in the middle of the longitudinal joints for LRS, MRS and HRS were 0.35, 0.42 and 0.50 mm which are significantly smaller than the corresponding average values in the middle of the transverse joints (0.428, 0.555 & 0.669 mm, table 1 – 3). Therefore, though the doweled joints may be simulated by an equivalent interlock joint if an appropriate value of joint stiffness K_d is selected (Brill & Guo 2000); the bending mechanism of the dowels should still be considered in analysis with significant curling.

As a first approximation, where the longitudinal joints are also modeled by the shear stiffness, the “back-estimated” values of K_d may be obtained by the same procedure presented above. The results are also listed in Table 5, last column.

Using the back-estimated values of g and K_d as input data for program JSLAB-92, we may get the predicted $D(L)$ in the middle of the transverse joints and at the corners. A six-slab model is used as it is in test field (Figure 5). 30.5 by 30.5 cm mesh is employed. The comparison of predicted and measured deflection at joints and at the corner is listed in Table 6. The measured deflections at the corners are not used in the back-estimation procedure. The predicted and measured deflections are reasonably close with each other.

CONCLUSION

The selection of input data is important in pavement analysis. For example, the initial slab state (curling up or down) before a load is applied and the joint structural parameters are needed in obtaining the pavement responses induced by load or environmental effects or both. The back-estimation procedure proposed in this paper based on HWD data may be used to determine these input data. The sum of HWD deflections (SD) on two sides of dummy joints contains significant information on the PCC slab curling. In many cases, it can be used to back-estimate the slab curling defined by an equivalent temperature gradient g . After the pavement initial curling state has been back-estimated, the joint stiffness K_d may also be back-estimated. The above approach may be applied in conjunction with 2-D or 3-D finite element computer program. The 2-D program JSLAB-92 has been used in this paper to show the numerical back-estimation procedure step by step. The numerical comparison of the calculated and measured joint and corner deflections verifies that the back-estimated parameters are reasonable.

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P501, H=28cm(11")	P501, H=24.8cm(9 3/4")	P501, H=22.9cm(9")
P306, H=15.6cm(6 1/8")	P306, H=14.9cm(5 7/8")	P306, H=15.2cm(6 ")
P154, H=21.3cm(8 3/8")	P154, H=21.9cm(8 5/8")	P154, H=16.8cm(6 5/8")
Sub-grade CBR=3-4	Sub-grade CBR=7-8	Sub-grade CBR=30-40
LRS	MRS	HRS

Figure 1 Cross Section of Three PCC Items

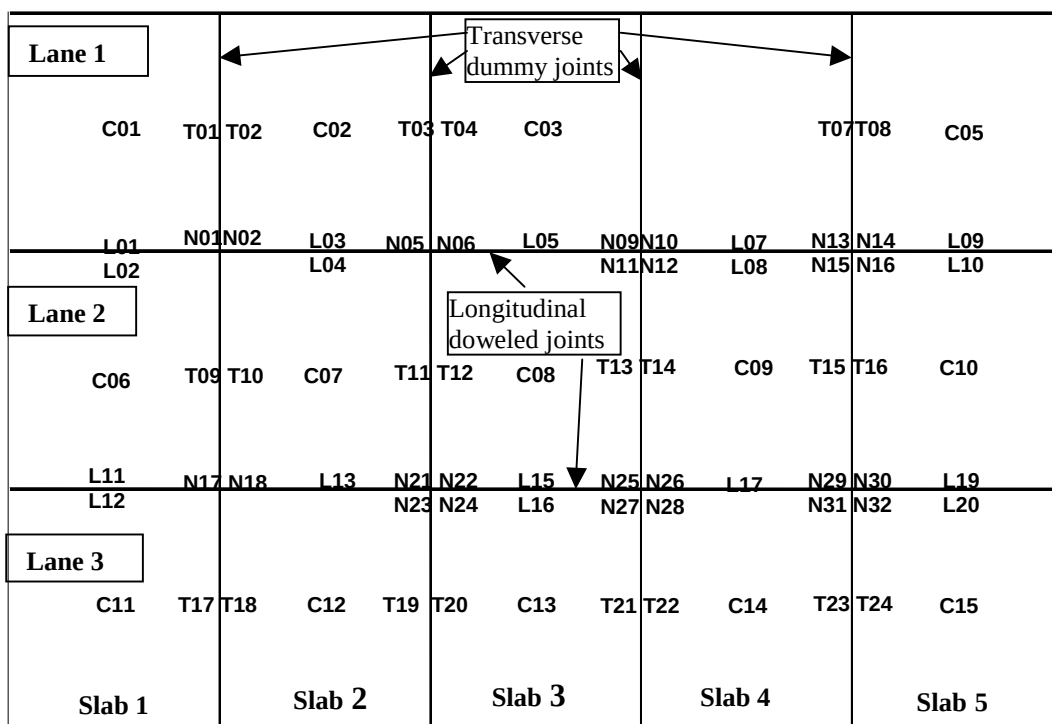


Figure 2 Definition of HWD testing location for PCC items LRS, MRS and HRS.

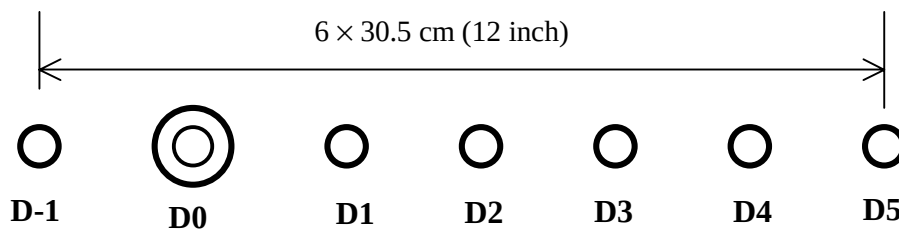


Figure 3 Locations of Deflection Sensors. D0 is Center of Loading Plate

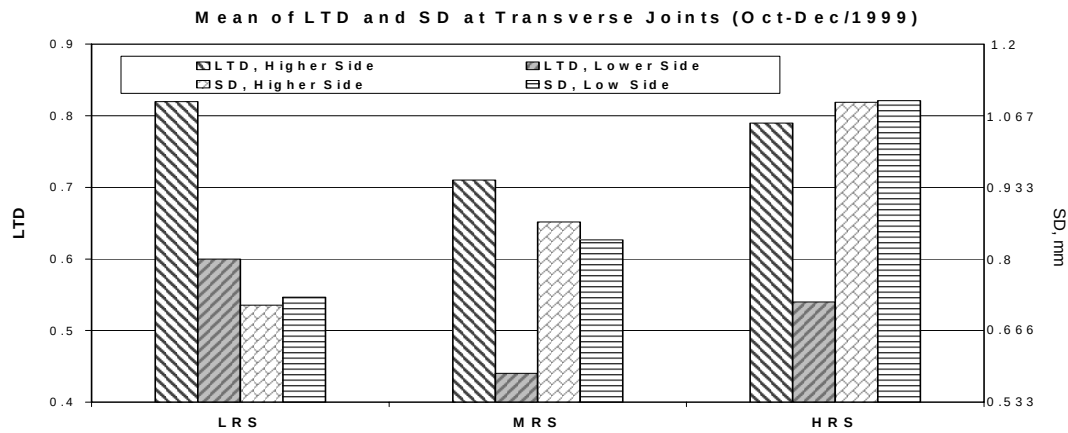


Figure 4 Comparison of the Characteristics between LTD and SD

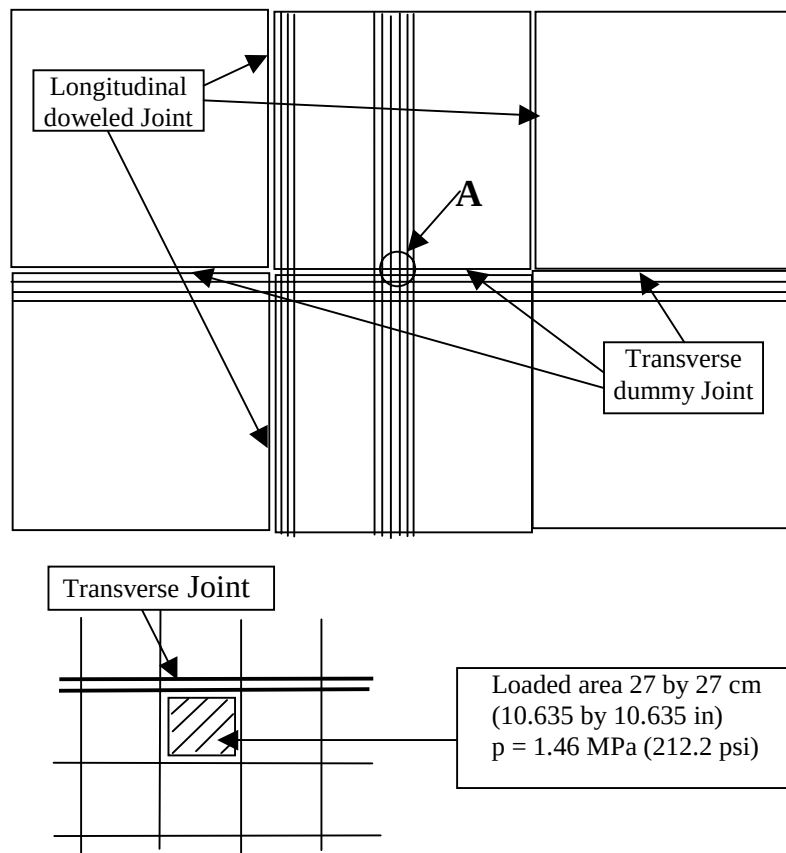


Figure 5 Six-slab Model for Finite Element Analysis. Slab size 6.1 m by 6.1 m (20 ft by 20 ft). Element size 30.5 cm by 30.5 cm (12 in by 12 in).

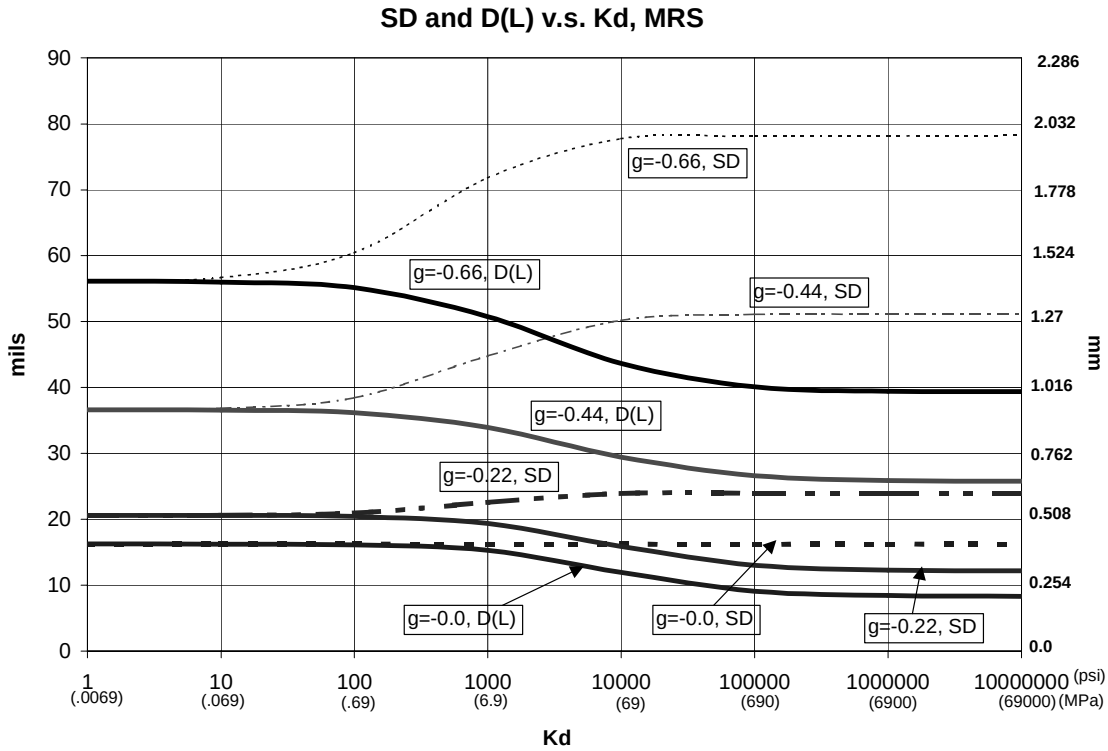


Figure 6 Sensitivity of SD and D(L) by Different Joint Shear Stiffness

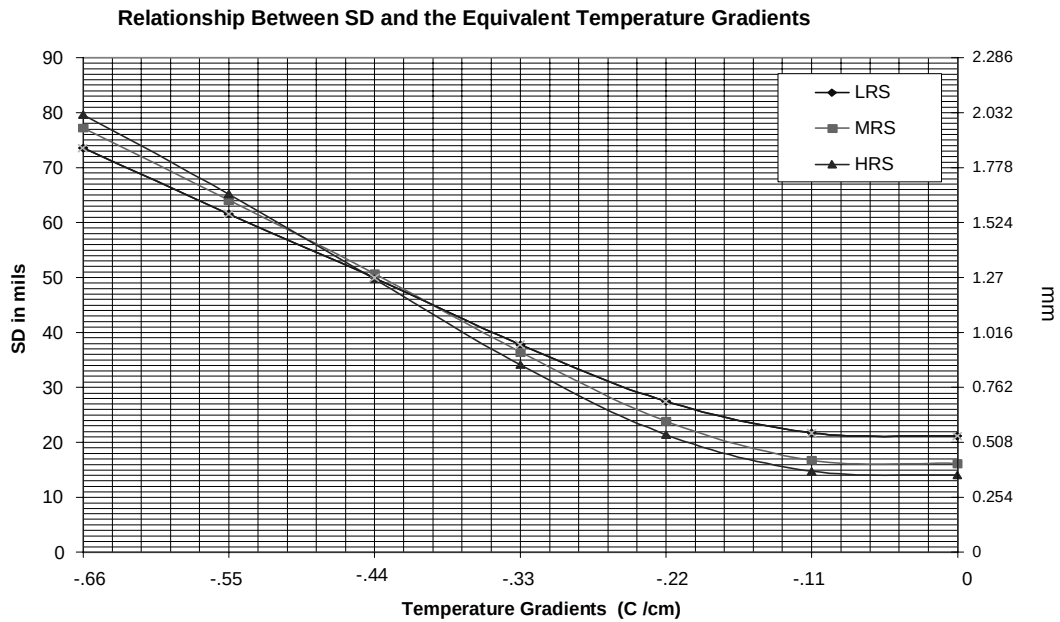


Figure 7 Curves Used to Back-estimate “Equivalent” Temperature Gradient for LRS, MRS and HRS

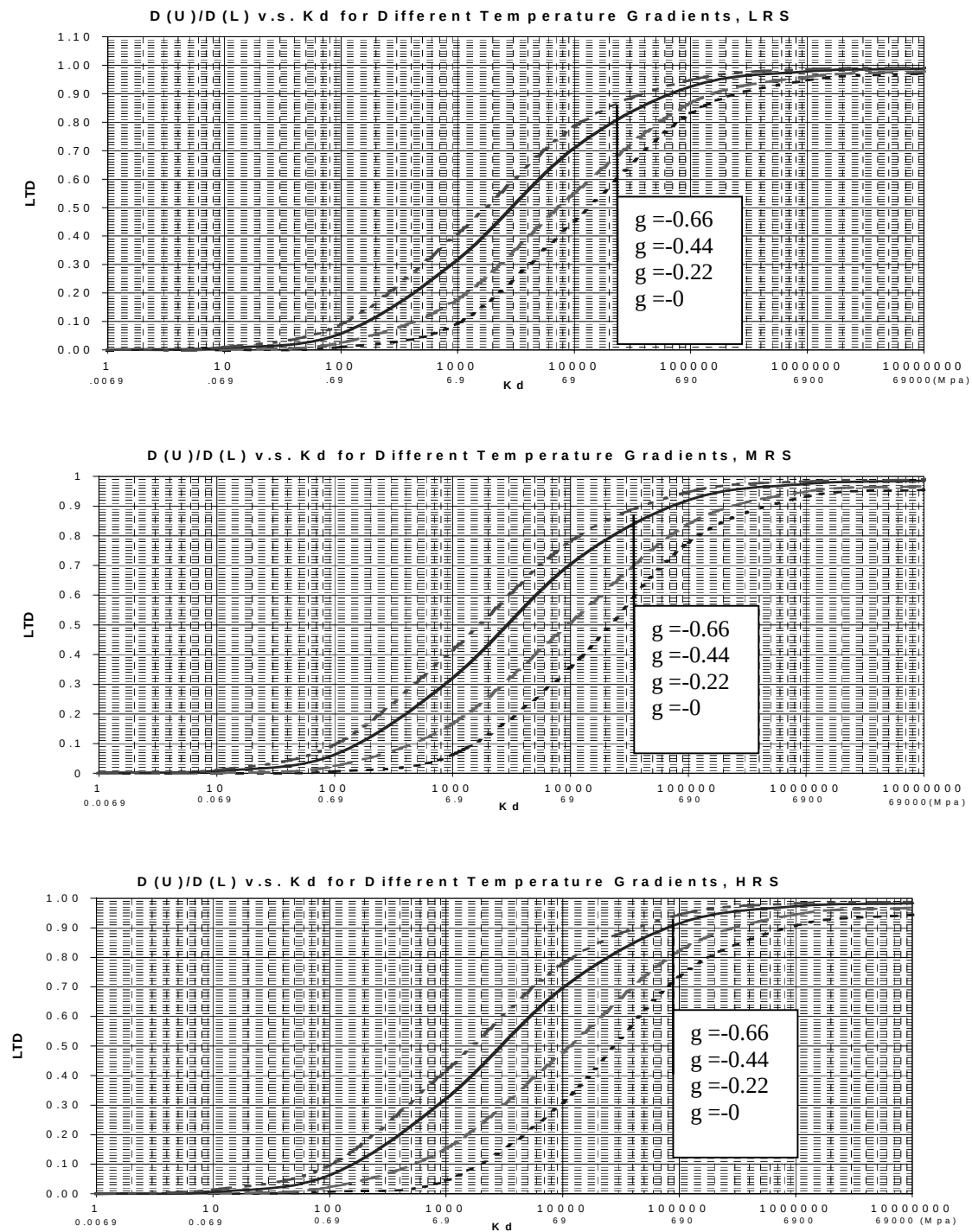


Figure 8 Predicted Load Transfer Capability v.s. the Shear Stiffness of Joint under Different Temperature Gradients g ($^{\circ}\text{C}/\text{cm}$). 1 psi = 0.0069 MPa

TABLE 1 RESULTS FOR ITEM LRS (Oct.22, 1999, target load 10896 kg (24kps), pavement average temperature from 8:00am to 3:00pm was 13.6 °C (56.4 °F)

(a) At Center of Slabs

Deflection, original readings load in kg, deflection in mm									Normalized	
Points	LOAD	D-1	D0	D1	D2	D3	D4	D5	D0	D5
C01	11400	0.171	0.184	0.171	0.154	0.141	0.128	0.112	0.176	0.107
C02	11408	0.178	0.193	0.179	0.165	0.149	0.132	0.118	0.184	0.113
C03	11496	0.158	0.170	0.161	0.150	0.137	0.125	0.112	0.161	0.106
C04	11532	0.168	0.180	0.172	0.157	0.145	0.132	0.120	0.170	0.113
C05	11546	0.180	0.197	0.186	0.172	0.159	0.142	0.127	0.186	0.120
C06	11703	0.172	0.188	0.176	0.161	0.142	0.128	0.114	0.176	0.106
C07	11672	0.170	0.183	0.171	0.152	0.141	0.128	0.116	0.170	0.109
C08	11770	0.163	0.174	0.159	0.144	0.130	0.118	0.108	0.161	0.100
C09	11686	0.146	0.157	0.147	0.137	0.126	0.118	0.109	0.146	0.101
C10	11627	0.165	0.177	0.161	0.144	0.130	0.115	0.099	0.166	0.093
C11	11703	0.172	0.188	0.176	0.161	0.142	0.128	0.114	0.176	0.106
C12	11673	0.185	0.201	0.188	0.173	0.154	0.137	0.120	0.188	0.112
C13	11769	0.187	0.203	0.191	0.173	0.159	0.144	0.132	0.188	0.122
C14	11839	0.168	0.183	0.171	0.158	0.142	0.128	0.116	0.168	0.107
C15	11815	0.170	0.185	0.175	0.161	0.146	0.132	0.121	0.171	0.111
average									0.172	0.108

(b) In middle of the dummy transverse joints

		On Side with High LTD				Normalized		On Side with Low LTD				Normal.
Points	LOAD	D(L)	D(Un)	LTD	SD	D(L)	D(Un)	LTD	SD	D0		
T01	11117					0.542	0.255	0.470	0.781	0.532		
T02	11208	0.459	0.369	0.800	0.806					0.447		
T03	11294					0.422	0.347	0.820	0.742	0.407		
T04	11251	0.408	0.375	0.920	0.759					0.395		
T05	11650	0.334	0.262	0.790	0.558					0.312		
T06	11361					0.447	0.351	0.780	0.764	0.428		
T07	11425					0.424	0.343	0.810	0.731	0.404		
T08	11383	0.395	0.348	0.880	0.711					0.378		
T09	11529	0.400	0.345	0.860	0.703					0.378		
T10	11391					0.522	0.180	0.350	0.672	0.500		
T11	11562	0.434	0.314	0.720	0.704					0.409		
T12	11385					0.577	0.098	0.170	0.645	0.552		
T13	11526					0.427	0.250	0.590	0.640	0.403		
T14	11611	0.354	0.262	0.740	0.578					0.332		
T15	11496	0.441	0.350	0.790	0.750					0.418		
T16	11145					0.635	0.153	0.240	0.770	0.621		
T17	11461					0.435	0.363	0.840	0.759	0.414		
T18	11521	0.418	0.374	0.900	0.750					0.395		
T19	11514					0.514	0.273	0.530	0.744	0.486		
T20	11429	0.484	0.358	0.740	0.802					0.461		
T21	11563	0.409	0.355	0.870	0.720					0.386		
T22	11546					0.439	0.342	0.780	0.737	0.415		
T23	11571	0.409	0.348	0.850	0.713					0.386		
T24	11557					0.448	0.357	0.800	0.759	0.422		
Average				0.822	0.713			0.598	0.729	0.428		
Standard Derivation				0.067	0.076			0.244	0.049	0.069		
Coefficient of Variation				8.2	10.7			40.7	6.7	16.1		

TABLE 2 RESULTS FOR ITEM MRS (Dec.21,1999, target load 10896 kg (24 kps), average pavement temperature from 8:00am to 3:00pm was 10.3 °C (50.6 °F))
(a) At Center of Slabs

Deflection, original readings load in kg, deflection in mm									Normalized	
Points	LOAD	D-1	D0	D1	D2	D3	D4	D5	D0	D5
C01	10684	0.151	0.168	0.151	0.130	0.104	0.087	0.072	0.171	0.074
C02	10590	0.149	0.164	0.147	0.128	0.109	0.095	0.081	0.169	0.083
C03	10621	0.139	0.154	0.139	0.123	0.103	0.090	0.078	0.158	0.080
C04	10629	0.140	0.158	0.145	0.125	0.105	0.091	0.077	0.163	0.079
C05	10653	0.142	0.160	0.147	0.125	0.106	0.090	0.077	0.163	0.079
C06	10626	0.141	0.160	0.147	0.128	0.107	0.092	0.079	0.164	0.081
C07	10662	0.139	0.156	0.140	0.119	0.100	0.085	0.072	0.159	0.073
C08	10681	0.137	0.152	0.137	0.117	0.098	0.084	0.072	0.155	0.074
C09	10645	0.138	0.154	0.139	0.121	0.101	0.086	0.074	0.158	0.076
C10	10657	0.139	0.157	0.141	0.119	0.097	0.082	0.068	0.161	0.069
C11	10654	0.135	0.150	0.134	0.116	0.097	0.083	0.070	0.153	0.072
C12	10658	0.127	0.145	0.129	0.112	0.098	0.085	0.073	0.148	0.075
C13	10579	0.135	0.154	0.138	0.120	0.101	0.087	0.076	0.159	0.079
C14	10643	0.135	0.150	0.137	0.121	0.104	0.090	0.080	0.154	0.082
C15	10603	0.135	0.149	0.137	0.118	0.101	0.087	0.075	0.153	0.077
average									0.159	0.077

(b) At Center of the Dummy Transverse Joints

On Side with High LTD						On Side with Low LTD				Normal.
Points	LOAD	D(L)	D(Un)	LTD	SD	D(L)	D(Un)	LTD	SD	D0
T01	10338					0.539	0.258	0.480	0.841	0.568
T02	10374	0.453	0.378	0.830	0.873					0.476
T03	10350					0.569	0.245	0.430	0.857	0.599
T04	10378	0.501	0.360	0.720	0.904					0.526
T05	10315	0.522	0.398	0.760	0.971					0.551
T06	10103					0.696	0.198	0.280	0.964	0.751
T07	10460					0.417	0.321	0.770	0.769	0.434
T08	10445	0.388	0.340	0.880	0.760					0.405
T09	10454					0.523	0.328	0.630	0.887	0.545
T10	10352	0.517	0.354	0.680	0.917					0.545
T11	10411					0.542	0.246	0.450	0.824	0.567
T12	10411	0.578	0.266	0.460	0.883					0.605
T13	10380	0.595	0.275	0.460	0.914					0.625
T14	10305					0.739	0.073	0.100	0.858	0.781
T15	10465	0.418	0.356	0.850	0.805					0.435
T16	10500					0.523	0.239	0.460	0.790	0.543
T17	10462	0.456	0.342	0.750	0.832					0.475
T18	10396					0.459	0.338	0.740	0.835	0.481
T19	10303					0.608	0.131	0.210	0.781	0.643
T20	10414	0.486	0.273	0.560	0.795					0.509
T21	10314	0.546	0.434	0.790	1.035					0.577
T22	10184					0.756	0.078	0.100	0.893	0.809
T23	10462					0.442	0.258	0.580	0.729	0.461
T24	10470	0.390	0.313	0.800	0.732					0.406
Average				0.712	0.868					0.436
Standard Derivation				0.145	0.088					0.064
Coefficient of Variation				20.3	10.2					19.7

TABLE 3 RESULTS FOR ITEM HRS (Dec. 22, 1999, target load 10896 kg, 24 kps, average pavement temperature from 8:00am to 3:00pm was 7.7 °C (45.9 °F))
(a) At Center of the Slabs

Deflection, original readings load in kg, deflection in mm									Normalized	
Points	LOAD	D-1	D0	D1	D2	D3	D4	D5	D0	D5
C01	10860	0.106	0.121	0.107	0.087	0.074	0.063	0.054	0.122	0.054
C02	10837	0.108	0.123	0.109	0.090	0.075	0.065	0.055	0.124	0.055
C03	10848	0.104	0.117	0.106	0.089	0.076	0.066	0.057	0.118	0.057
C04	10880	0.102	0.119	0.102	0.087	0.075	0.067	0.058	0.119	0.058
C05	10880	0.103	0.120	0.111	0.099	0.086	0.076	0.068	0.120	0.068
C06	10829	0.098	0.110	0.093	0.078	0.062	0.052	0.044	0.111	0.045
C07	10915	0.096	0.112	0.096	0.081	0.070	0.059	0.053	0.112	0.053
C08	10864	0.101	0.113	0.100	0.083	0.067	0.058	0.050	0.114	0.050
C09	10837	0.116	0.130	0.111	0.094	0.077	0.065	0.057	0.131	0.057
C10	10880	0.103	0.123	0.111	0.099	0.083	0.073	0.065	0.123	0.065
C11	10813	0.111	0.126	0.109	0.090	0.076	0.066	0.057	0.127	0.057
C12	10907	0.109	0.126	0.109	0.094	0.076	0.066	0.057	0.125	0.057
C13	10848	0.106	0.121	0.108	0.092	0.077	0.068	0.060	0.122	0.060
C14	10856	0.100	0.113	0.100	0.087	0.073	0.065	0.056	0.114	0.056
C15	10844	0.100	0.117	0.109	0.096	0.083	0.074	0.065	0.118	0.066
average									0.120	0.057

(b) At Center of the Dummy Transverse Joints

On Side with High LTD						On Side with Low LTD				Normal.
Points	LOAD	D(L)	D(Un)	LTD	SD	D(L)	D(Un)	LTD	SD	D0
T01	10140					0.797	0.209	0.260	1.082	0.857
T02	10411	0.537	0.454	0.850	1.037					0.562
T03	10222					0.773	0.236	0.310	1.076	0.824
T04	10447	0.604	0.397	0.660	1.043					0.629
T05	10407					0.601	0.419	0.700	1.067	0.629
T06	10443	0.556	0.456	0.820	1.055					0.580
T07	10419					0.631	0.486	0.770	1.168	0.660
T08	10399	0.620	0.528	0.850	1.203					0.650
T09	10506					0.623	0.470	0.760	1.133	0.646
T10	10494	0.574	0.490	0.850	1.104					0.596
T11	10443					0.705	0.348	0.490	1.099	0.735
T12	10431	0.590	0.472	0.800	1.109					0.616
T13	10407	0.646	0.488	0.760	1.187					0.676
T14	10175					0.832	0.218	0.260	1.124	0.891
T15	10242					0.818	0.371	0.450	1.265	0.870
T16	10380	0.692	0.533	0.770	1.286					0.727
T17	10337					0.705	0.313	0.440	1.072	0.743
T18	10438	0.528	0.474	0.900	1.046					0.551
T19	10399					0.694	0.338	0.490	1.081	0.727
T20	10458	0.658	0.362	0.550	1.062					0.686
T21	10526					0.526	0.409	0.780	0.968	0.544
T22	10478	0.522	0.421	0.810	0.980					0.543
T23	10517					0.556	0.406	0.730	0.996	0.576
T24	10502	0.523	0.443	0.850	1.002					0.543
Average				0.789	1.093			0.537	1.094	0.669
Standard Derivation				0.097	0.090			0.203	0.077	0.108
Coefficient of Variation				12.3	8.3			37.8	7.0	16.1

TABLE 4. BACK-CALCULATED PAVEMENT PARAMETERS

	l , cm (inch)	k , MPa/m (pci)	E , MPa $\times 10^3$ (psi $\times 10^6$)
LRS	118 (46.6)	54.5 (201)	57.5 (8.34)
MRS	87.9 (34.6)	107 (396)	50.7 (7.36)
HRS	79.2 (31.2)	178.9 (660)	68.3 (9.90)

TABLE 5 The Back-Estimated Equivalent Linear Temperature Gradients and Joint Shear Modules K_d

Item	g °C/cm (°F/in)	Equivalent Top-Bottom Temperature Difference	Back-estimated K_d MPa (kpsi)	
			Transverse	Longitudinal
LRS	-0.24 (-1.1)	6.72 °C (12.1 °F)	166(24)	380(55)
MRS	-0.30 (-1.37)	7.44 °C (13.4 °F)	97(14)	414(60)
HRS	-0.39 (-1.8)	9.0 °C (16.2 °F)	72(10.5)	276(40)

TABLE 6 Comparison of the Measured and Predicted Maximum Deflections at Transverse Joints and Corners (mm)

Location	LRS		MRS		HRS	
	measured	predicted	measured	predicted	Measured	predicted
At Joint	0.43	0.40	0.55	0.45	0.67	0.57
At Corner	0.78	0.77	0.96	0.98	1.16	1.31