Comparing Measured and Theoretical Depth Deflections Under a Falling Weight Deflectometer Using a Multidepth Deflectometer

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Installation and use of the multidepth deflectometer (MDD) for monitoring pavement response are described. The MDD measures depth deflections in pavements. MDDs are installed in specially drilled holes and up to six modules may be placed in a single hole. This device measures the relative deflection of each layer with respect to an anchor point located approximately 7 ft below the surface. Three sections at the Texas Transportation Institute Research Annex have been instrumented with MDDs. These sections have the same materials but varying layer thicknesses. An effort was made to measure the movement of the anchor. Measuring the anchor movement permits calculation of the absolute depth deflection at each MDD sensor. Surface and depth deflections were measured under FWD loadings. The MODULUS computer program was used to backcalculate the layer moduli from surface deflections. These moduli values along with the layer thickness information were entered into the BISAR layered elastic program to predict the theoretical deflections at depths corresponding to the MDD sensor locations and at the anchor. The analysis was conducted for an infinite subgrade and for a 20-ft depth to bedrock. A comparison of measured versus calculated deflections revealed that a better match was obtained between the two with the bedrock at 20-ft depth.

The procedure used by several investigators to verify modulus backcalculation procedures is to compare the results obtained from an appropriate theoretical analysis of nondestructive test (NDT) data to those obtained from laboratory testing of the pavement materials. Resilient modulus tests are commonly performed on base course and subgrade materials using a triaxial test apparatus. For thin surfacing, repeated load diametral tests are performed. The problem with this approach is that it is difficult, if not impossible, to duplicate field loading conditions in the laboratory. The problem is particularly acute for granular base materials, where laboratory specimens have to be remolded to the same moisture and density as in the field, and then subjected to loading conditions as close as possible to those under moving vehicles. Despite the problems inherent in this approach, verification of modulus backcalculation procedures remains a crucial concern, particularly with the publication of the new *AASHTO Design Guide* (*1*), which advocates NDT evaluations for pavement maintenance and rehabilitation designs.

Three research pavement sections at the TTI Research Annex were instrumented with multidepth deflectometers (MDDs). These devices measure the transient deflection between a particular location in the pavement and an anchor located about 7 ft below the surface. By simultaneously measuring surface and depth deflections under FWD loadings, a procedure is presented to evaluate the effectiveness of modulus backcalculation procedures. The surface deflections are used to backcalculate layer modulus E values; these are then used to predict depth deflections. The error between measured and calculated deflections is defined.

A unique feature of this work is that the movement of the MDD anchor has been recorded using a geophone mounted on the center core. The analysis therefore uses absolute, rather than relative, deflections.

In the next section, the MDD system and the installation procedures are described. The experimental setup at the TTI Research Annex is then presented, followed by a description of the test procedure, results obtained, and details of the analysis.

THE MULTIDEPTH DEFLECTOMETER

The Texas Transportation Institute (TTI) has been evaluating multidepth deflectometers (MDDs) as pavement instrumentation tools since early 1988 (*2*). The system was developed in South Africa and has been used extensively as an integral part of their accelerated loading program (*3*). The MDD is typically installed at the layer interfaces and is used to measure both the transient relative depth deflection profile and the permanent deformations in each layer. Figure 1 shows a schematic of a typical MDD that consists of modules with linear variable differential transformers (LVDTs).

The LVDTs are positioned at different depths in the pavement to measure any movement in these layers. The modules are locked in position by turning the clamping nut, which forces the steel balls outward, clamping them against the sides of the hole. The interconnecting rod is adjustable and contains LVDT cores at spacings that coincide with the module placement. A typical MDD installation is shown in Figure 2. In practice, up to six modules may be placed in a single hole. The interconnecting rod is fixed to an anchor located at approximately 7 ft below the pavement surface. When data are being acquired, a connector cable is attached to the data capture system. When the MDD is not in use, a brass surface

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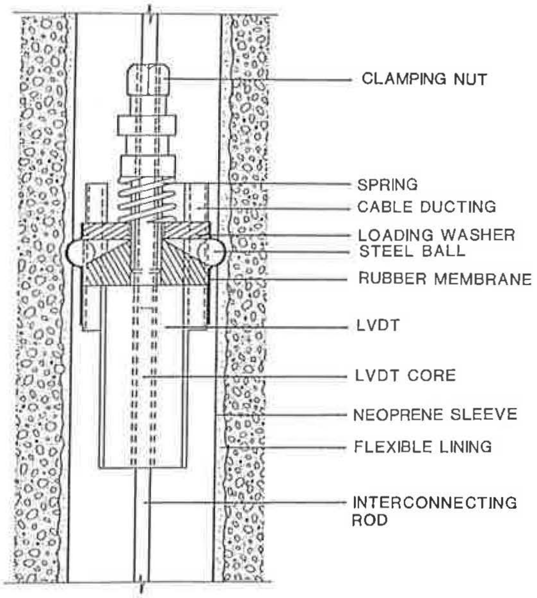


FIGURE 1 Components of MDD module.

cap, which is flush with the surface, completely seals the hole. The brass cap is lined with a rubber ring on the inside to prevent the intrusion of dirt and moisture.

Installation Procedure

In order for the MDD to operate effectively, special care has to be exercised in installing the MDD unit. The test hole for instrumentation of the pavement section has to be drilled vertically. Percussion drills and a specially designed drilling rig are used for the drilling procedure. A 1.5-in.-diameter hole is drilled to a depth of approximately 7 ft. The top 1 in. of the pavement is drilled with a special 2.5-in. drilling bit for installation of the top cap. The top cap is mounted flush with the surface. The top of the MDD has to be level with the pavement to avoid any point loading on it after installation.

The hole is then lined with a 0.1-in. rubber lining tube and the voids between the tube and the wall are filled with rubber grout. The lining prevents the adjacent material from dislodging when under stress and guides the MDD anchor pin and rod for correct installation. The rubber grout is asphalt based and is strong enough to hold back the layer material from protruding into the hole under load; at the same time, it should not affect the pavement material behavior.

The MDD anchor pin is then led through the hole and locked in place using a cement and sand paste. This procedure fixes the anchor pin, so that the LVDT movements are relative to the anchor pin. This is followed by installing a pilot rod, which is used to guide the MDD modules vertically and to the right position. The MDD modules are installed into the correct predetermined position using an installation tool specially made for the purpose. The module is guided to the correct position in the test hole and secured by turning the clamping nut at the top of the MDD module. This forces the steel balls against the wall, holding the module in place. Similarly all the other modules are installed. The modules are numbered from the shallowest to the deepest in ascending order. The modules having been fixed in place, they must be calibrated before operation. The complete installation takes approximately 1½ days. The hole is drilled and lined, and the anchor is installed on the first day. The rubber grout takes approximately 12 hr to set, depending on the temperature. On the second day, the MDD modules are installed and calibrated.

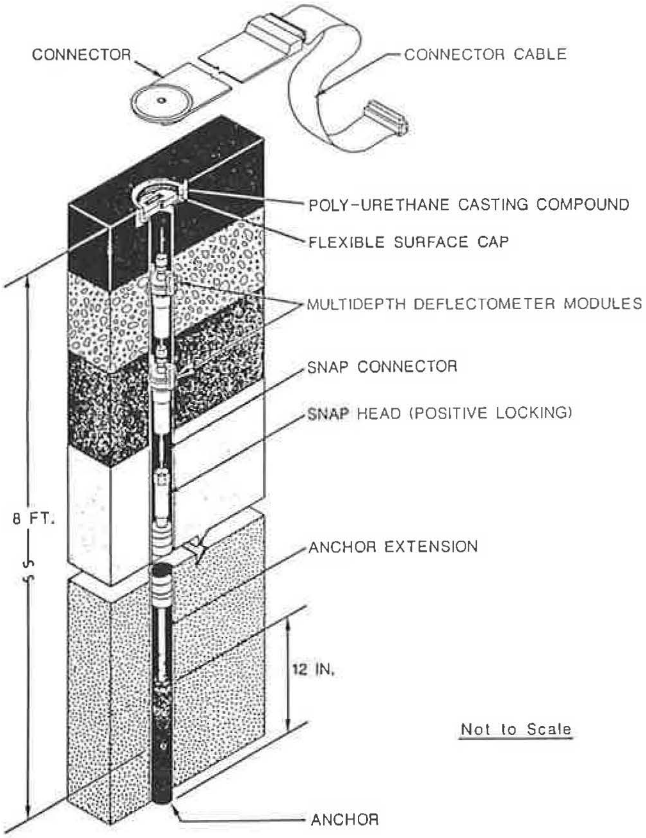


FIGURE 2 Typical cross section of MDD after installation.

Calibration

Before operation of the MDD, the LVDT modules have to be calibrated to remove any zero error. In order to calibrate the MDD unit, a signal conditioner box, and a calibrator unit fitted with a dial gage mounted on a screw adjusting mechanism, are used. The potentiometer settings on the signal conditioner are first adjusted to be the same as obtained from calibration in the laboratory. The MDD core is moved up and down against the modules manually to determine its mid-zero position. The calibrator unit is then placed above the MDD hole, and the core to one of the LVDTs is connected to it. The screw mechanism is turned until the module reads zero on the conditioner unit. The dial gage is set to a zero reading and the screw mechanism is turned until the dial gage reads 0.30 in. (maximum displacement range of a Schaevitz E300 LVDT). With the dial gage at 0.30 in., the conditioner unit should read 10 (volts). If not, it should be adjusted to read 10 (volts). As a check, the dial gage is reset to zero displacement and the conditioner observed to see if it gives a zero reading. The procedure is repeated for each module installed in the MDD unit. With the calibration procedure over, the final potentiometer settings are noted.

After the MDD is calibrated, it is sealed off with a brass cap, which is screwed flush with the pavement surface. The surface cap is removed during a measuring operation to enable a cable to be connected from the MDD to a computerized data acquisition system (Figure 2).

MDD Recovery

One of the major advantages of the MDD is that the unit can be retrieved in case the test site has to be abandoned or the LVDTs are to be replaced. With reference to Figure 2, the only parts of the system that cannot be retrieved are the anchor and the rubber lining. The MDD modules, center core, snap head connector, and surface cap can be recovered for future use. Replacing MDD modules in an existing hole can be accomplished in 1 day.

LVDT Selection

There are several factors that must be considered when selecting the appropriate LVDT. These include range, sealed versus unsealed, and type of LVDT. To date, both the E300 (range ±0.30 in.) and the E100 (range ±0.10 in.) have been used. The E300 LVDTs are preferred for long-range testing over the E100 LVDTs, because they have a wider range.

If an LVDT is proposed to be used for long-term monitoring of pavements, the hermetically sealed LVDTs may be opted. In hermetically sealing the LVDT, it is enclosed in a heavy-wall, stainless steel housing with an integral stainless steel bore liner (*4*). The hermetic sealing provides air-tight protection to the LVDTs from the moist and corrosive environment. Unsealed LVDTs are in use at the Texas A&M Research Annex since the fall of 1987 without problems (*2*). At the Research Annex, the LVDT holes are sealed by a brass cap on top of the MDD. This procedure prevents excessive moisture from entering the hole; however, condensation buildup has occurred.

Before the present study at the Research Annex, only ac LVDTs have been used. This study will also investigate the dc LVDTs. The main difference between the two LVDT types is the signal conditioner box. The dc LVDT has an integrated signal conditioning feature, eliminating the need for a separate signal conditioner box as in the ac LVDT. As a result of built-in signal conditioning, the dc LVDT need only be calibrated once, after installation.

Data Logging System of the MDD

The MDD voltage output is first processed by a six-channel signal conditioner box. The signal conditioner box converts MDD output into computer form. The signal conditioner box has six channels because up to six LVDTs can be installed in each MDD unit. Each channel is set to give a calibrated output of ±10 volts for the full range of the LVDT on 100 percent scale. The conditioner box has several features including a scaling switch that permits the user to select the full-range scale (2, 5, 10, 20, 40, 50, or 100 percent), a zero-offset potentiometer, and digital output. The range setting makes the system more sensitive and permits the monitoring of small displacements. For example, on 100 percent scaling, 10 volts is equal to a movement of 0.30 in. (Schaevitz E300 LVDT); on 10 percent scaling, 10 volts LVDT output would be equal to 0.030 in. Loads are applied to the system by either NDT equipment or truck. The LVDTs monitor the differential movement between the pavement layers and the fixed anchor. TTI has developed a specialized data acquisition system for logging MDD pulses under falling weight deflectometer (FWD) and truck loads. A Compaq 386/20 microcomputer is used with a Data Translation circuit board. A sampling rate of 5,000 readings per channel per second is used. Under FWD loading, a 60-ms recording interval is used. Triggering has been automated on the basis of a response of any sensor greater than a preset trigger level. The pretrigger information, 100 data points, is stored and is included in the output record. For recording truck data, the truck length and speed are input. The sampling rate is automatically calculated and the triggering is automated. For trucks, 1,000 data points per channel are stored. The files created are read directly into LOTUS for display and analysis.

Data Cleanup and Scaling

Figure 3a shows a typical MDD trace under an FWD loading. Along with the trace of the FWD drop, it also shows the 100 pretrigger points that the data acquisition system has stored. These pretrigger points are useful in calculating the average scaling factor. Figure 3a shows a high-frequency noise present in the signal. The source of the noise has not been detected. The noise has been reported in both truck loading as well as FWD testing. The noise was problematic in that it made it difficult to determine the true maximum deflection, particularly when low-magnitude (<2 mils) signals were being analyzed.

To clean up the signal, therefore, a filter program has been developed. This program performs a fast Fourier transform on the signal. The noise has been determined to have a frequency of 130 Hz. The spectrum of the signal was filtered and the frequency components that were over 120 Hz were attenuated. This procedure is followed by an inverse Fourier transform to return the signal to the time domain. The filtered signal is shown in Figure 3b. The whole trace has now come close to the horizontal axis, making it easier to reduce the actual deflection.

USES OF MDD

The MDD is used to monitor the pavement response under a single load or performance in repeated load tests. Under a single load, the MDD measures the relative deflection between its position and the anchor. When the MDD is installed, the no-load output voltage is recorded. After repeated load, changes in the no-load reading measure the permanent deformation that has occurred. By placing the MDDs at layer interfaces,

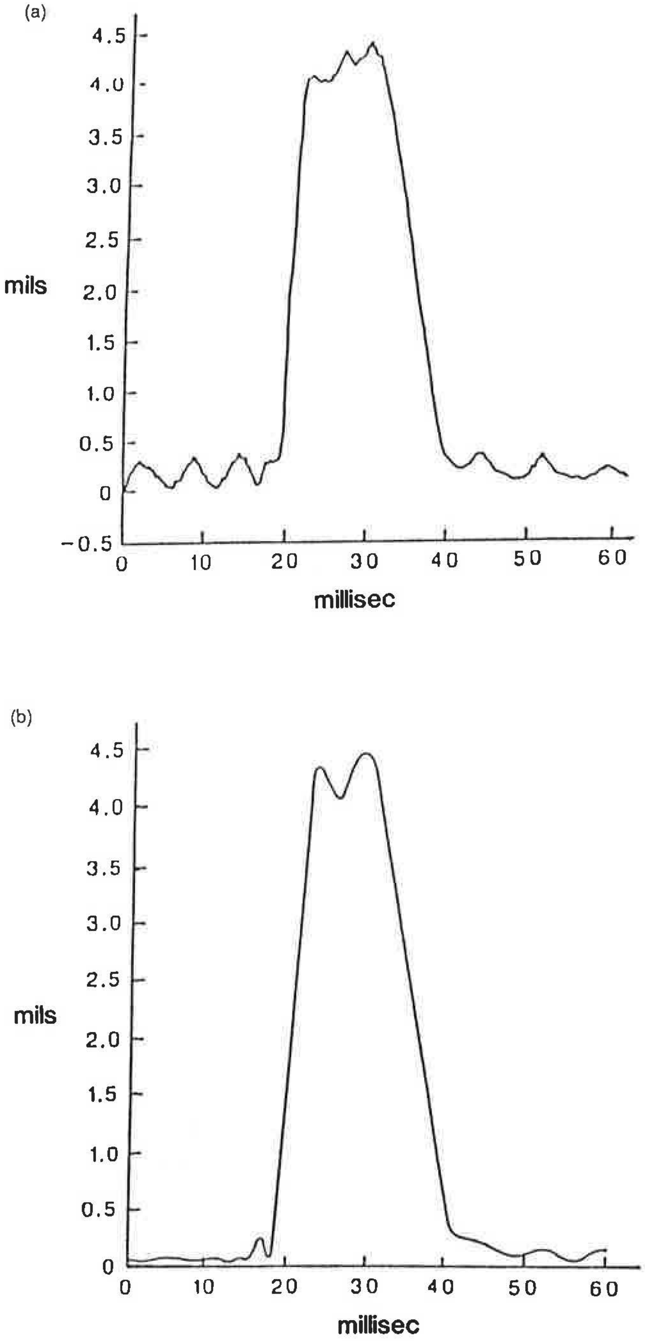


FIGURE 3 MDD response (a) before filtering and (b) after filtering.

it is possible to monitor the deformation that has occurred in each layer of the structure.

South African investigators have conducted numerous accelerated load tests over the past decade using their heavy vehicle simulators (HVSs) (*5*). The results of one of these investigations are shown in Figure 4 (*6*). This figure shows the performance of a lightly cemented granular base and thin surfacing under heavy loads. As shown, the induced rutting was measured to occur primarily in the cemented layer.

In the remainder of this paper, observations of pavement response under the FWD are presented.

MDD INSTALLATION AT TTI RESEARCH ANNEX

Three pavement test sections at the Texas Transportation Institute (TTI) Research Annex have been instrumented with MDDs. The MDD installation is shown in Figure 5. These sections have similar materials but varying layer thicknesses. Section 9 has thinner base and subbase than Section 12. Section 11 has a thin AC layer.

Figure 6 shows the setup used to measure the anchor movement. One of the geophones of the FWD is attached to a circular plate screwed on top of the core. When the FWD load was dropped, the seventh sensor would read the anchor movement, whereas the remaining six geophones would provide the surface deflection. The movement of the core thus obtained was added to the individual peak deflections to obtain total absolute deflection at the LVDT location.

The FWD was used as the loading device in the study. The FWD is an impulse loading machine capable of imparting a range of loads by varying the drop heights. The FWD sensors were located at 1-ft intervals for each test reported in this paper. The FWD load plate was placed as close as possible to the MDD hole, and surface and depth deflections were recorded. The load plate was then moved approximately 18 and 30 in. from the MDD hole and the drop sequence repeated. The electronics at Sections 11 and 12 prevented positioning the FWD on top of the MDD. At each location, the MDD anchor movement was recorded. The FWD positions at which the MDD responses were acquired are shown in Figure 7.

ANALYSIS PROCEDURE

The analysis procedure used consisted of the following steps:

1. From FWD surface deflections, the layer moduli were backcalculated using the MODULUS backcalculation program (*7*).
2. These backcalculated layer moduli, along with the layer thickness information, are entered in the BISAR layered elastic program to forward calculate the deflections and movements at the desired locations including the anchor positions.
3. The accuracy of the calculated movements is verified by calculating percent difference between measured and calculated movements at the anchor as well as at the MDD modules.

For this study, while performing the backcalculation, two depths to bedrock have been investigated. The first is an infinite depth, and the second is a depth to bedrock of 240 in. from the surface. The depth to bedrock of 240 in. was selected on the basis of seismic studies of the area, which indicate a stiff layer at about 20 ft. In the analysis, the test sections have been modeled as three-layered systems. Section 9 has been modeled as 5 in. of AC over 8 in. of crushed limestone (CLS) base over subgrade (infinite or 240-in. depth to bedrock from surface). Section 11 has been modeled as 1 in. of AC over 16 in. of CLS base over subgrade (infinite or 240-in. depth to bedrock from surface). Section 12 has been modeled as 5 in. of AC over 24 in. of CLS base over subgrade (infinite or 240-in. depth to bedrock from surface). The

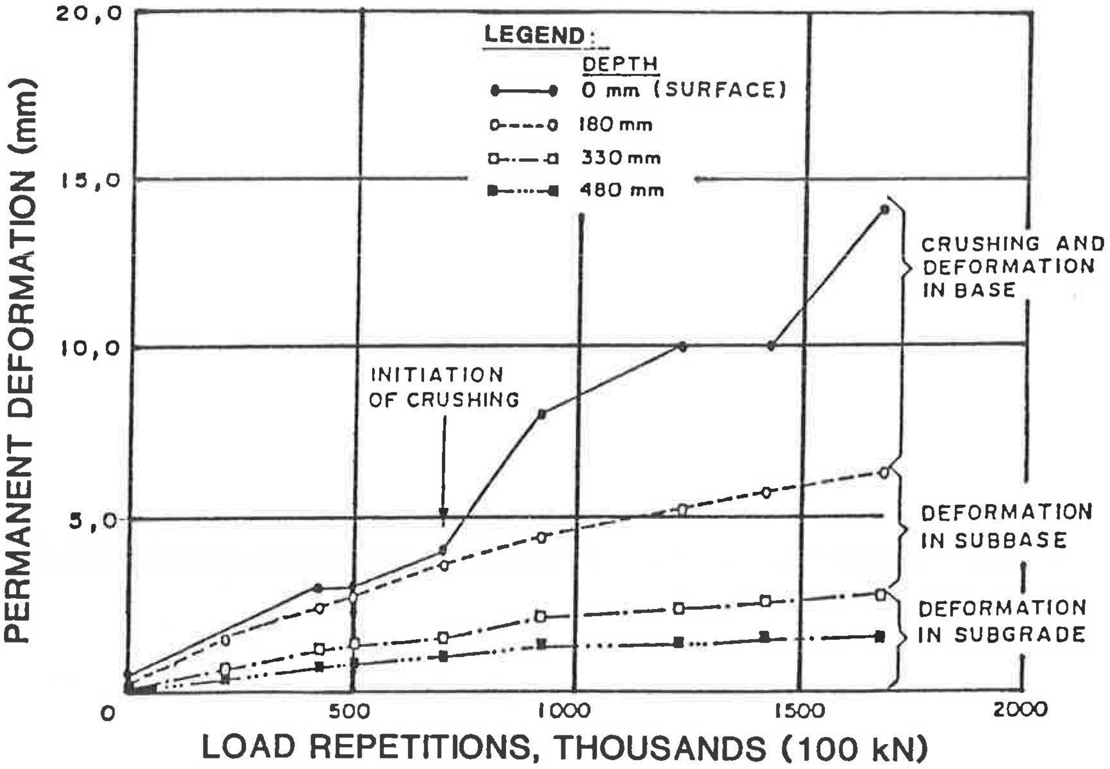


FIGURE 4 MDD results from accelerated road tests (*6*).

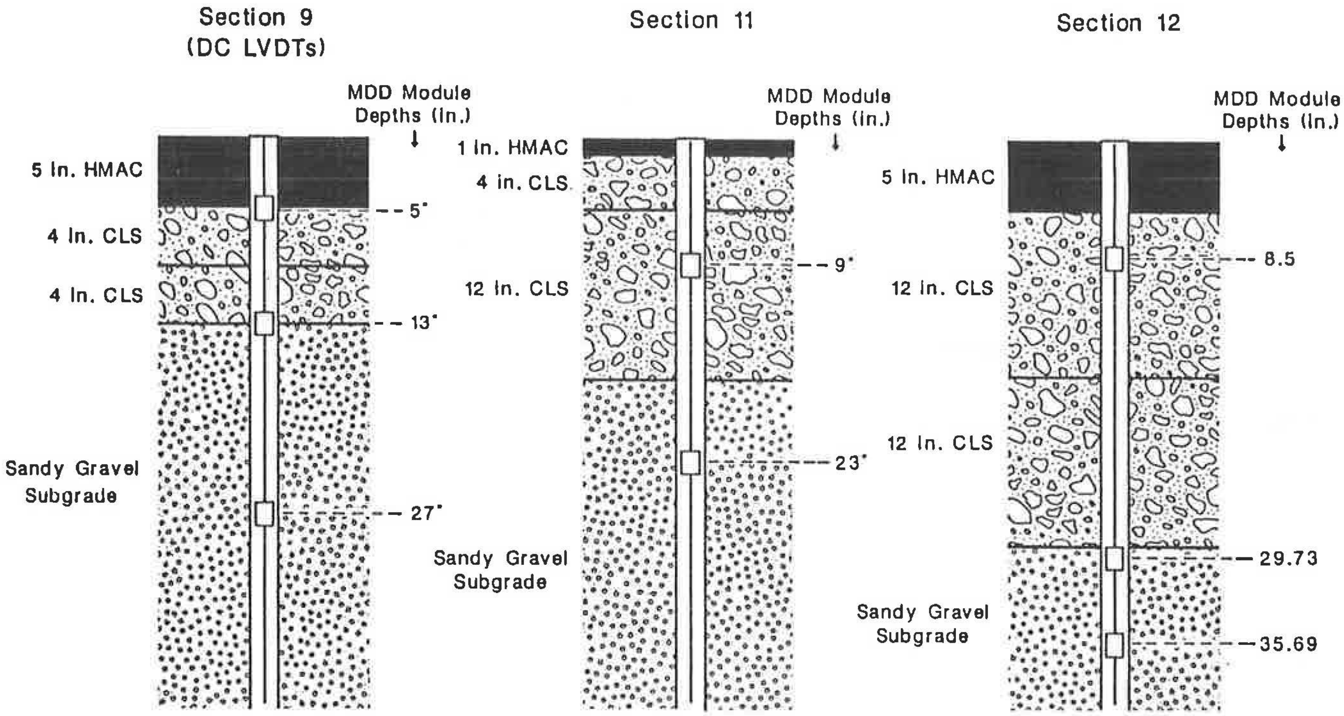


FIGURE 5 MDD installation at TTI Research Annex.

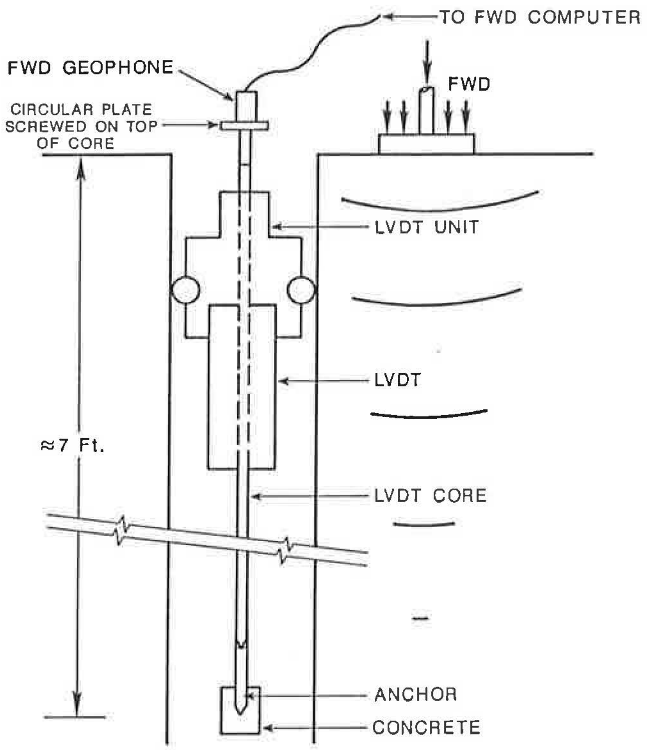


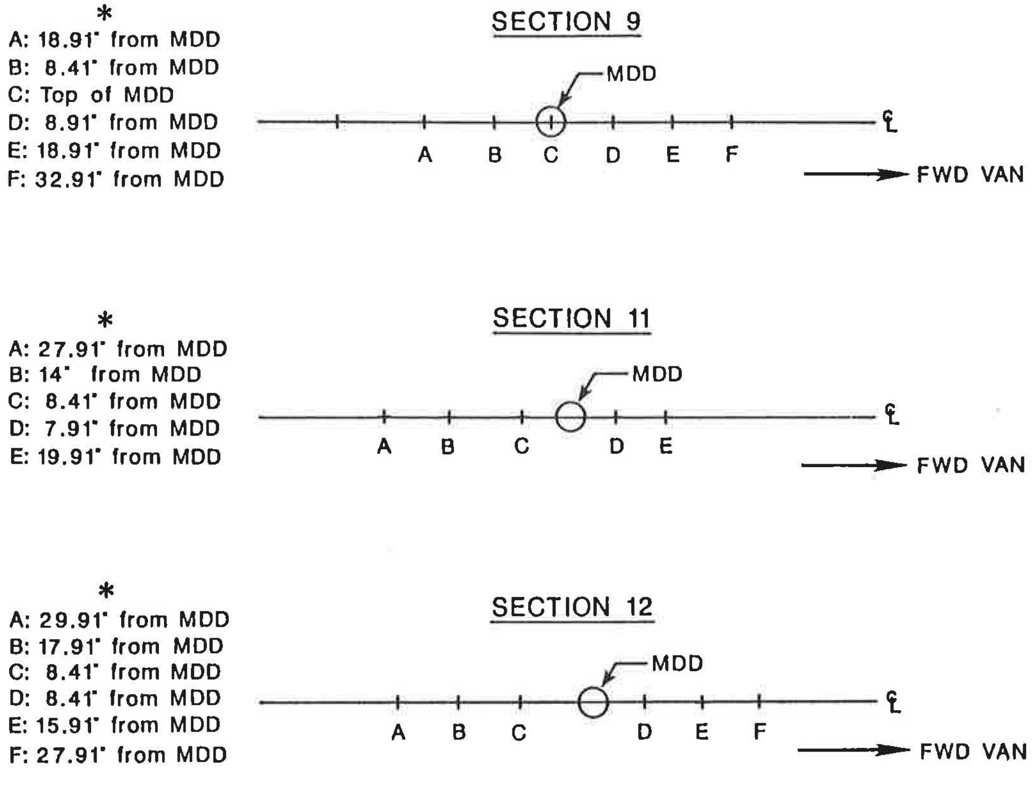
FIGURE 6 Setup to measure anchor movement.

FWD loads that have been considered are in the range of 9,000 lb, to resemble the response of an 18-kip, single-axle truck.

DISCUSSION OF RESULTS

Table 1 presents the surface deflections (W1–W6) and the depth deflections (D1–D3) measured under approximately a 9,000-lb-load FWD at different positions with respect to the MDD at Section 12. The distance from MDD is the distance measured from the center of the FWD loading plate to the center of the MDD hole. The FWD positions that are considered simulate a truck approaching the MDD. The anchor movements are also measured at the same time. Table 2 shows the moduli values backcalculated from the surface deflections (W1–W6) using the MODULUS backcalculation program. The moduli values have been backcalculated for an infinite subgrade (Table 2a) as well as assuming a bedrock at 240 in. from the surface (Table 2b). In both cases, the pavement section has been analyzed as a three-layered system (5 in. of AC over 24 in. of CLS base over subgrade). A lower percent error per sensor was observed in case of infinite subgrade than in the case of a 240-in. depth to bedrock.

Tables 3 and 4 show the depth deflections calculated at the MDD sensor locations and at the anchor. The differences in loads in Tables 2a and 2b and Tables 3 and 4 are attributed



*All distances from center of FWD loading plate to MDD.

FIGURE 7 FWD positions from MDD.

TABLE 1 MEASURED DEFLECTIONS—SECTION 12[a]

Distance From MDD (in.)	Load (lbs)	Surface Deflections (mils)						Depth Deflections (mils)			Anchor (mils)
		W1	W2	W3	W4	W5	W6	D1	D2	D3	
29.91	8560	9.99	5.91	3.08	1.96	1.47	1.18	2.57	2.32	2.32	1.33
17.91	8816	9.46	5.99	3.15	2.04	1.55	1.30	4.43	3.16	2.97	1.46
8.41	8656	9.46	5.82	3.12	1.92	1.42	1.06	6.76	3.79	3.40	1.50

[a] **Simultaneously measured surface and depth deflections:**

(W1, W2, W3, W4, W5, W6): Surface deflections at 1 foot spacings

(D1, D2, D3): Absolute depth deflections (MDD value plus anchor movement)

Anchor movement measured using setup shown in Figure 6.

TABLE 2 MODULI VALUES BACKCALCULATED FROM MODULUS (7)—SECTION 12, INFINITE SUBGRADE AND 20-FT DEPTH TO BEDROCK

Section A[a]

Station	Load (lb)	Measured Deflection (mils)							Calculated Moduli Values (psi)				Absolute Percent Error/Sensor
		R1	R2	R3	R4	R5	R6	R7	Surface (E1)	Base (E2)	Subbase (E3)	Subgrade (E4)	
1.000	8,655	9.46	5.82	3.12	1.92	1.42	1.06	0.00	785,347	34,886	0	34,886	1.35
1.000	8,815	9.46	5.99	3.15	2.04	1.55	1.30	0.00	680,784	40,886	0	32,351	2.44
1.000	8,559	9.99	5.91	3.08	1.96	1.47	1.18	0.00	573,279	37,637	0	33,296	0.90
Mean		9.64	5.91	3.12	1.97	1.48	1.18	0.00	679,803	37,803	0	33,511	1.56
Std. dev.		0.31	0.09	0.04	0.06	0.07	0.12	0.00	106,037	3,003	0	1,281	0.79
Var. coeff. (%)		3.18	1.44	1.13	3.10	4.43	10.17	0.00	15.60	7.94	0.00	3.82	50.44

Section B[b]

Station	Load (lb)	Measured Deflection (mils)							Calculated Moduli Values (psi)				Absolute Percent Error/Sensor
		R1	R2	R3	R4	R5	R6	R7	Surface (E1)	Base (E2)	Subbase (E3)	Subgrade (E4)	
1.000	8,655	9.46	5.82	3.12	1.92	1.42	1.06	0.00	723,960	41,702	0	25,802	2.50
1.000	8,815	9.46	5.99	3.15	2.04	1.55	1.30	0.00	637,865	49,502	0	23,184	5.28
1.000	8,559	9.99	5.91	3.08	1.96	1.47	1.18	0.00	519,832	45,575	0	24,118	3.90
Mean		9.64	5.91	3.12	1.97	1.48	1.18	0.00	627,219	45,593	0	24,368	3.89
Std. dev.		0.31	0.09	0.04	0.06	0.07	0.12	0.00	102,480	3,900	0	1,327	1.39
Var. coeff. (%)		3.18	1.44	1.13	3.10	4.43	10.17	0.00	16.34	8.55	0.00	5.44	35.71

[a] District 17, County 23, Annex 12.

	Thickness (in.)	*Moduli Range (psi)*	
		Minimum	*Maximum*
Pavement	5.00	100,000	1,000,000
Base	24.00	15,000	250,000
Subbase	0.00	0	0
Subgrade	Infinity	10,000	10,000

[b] District 17, County 23, Annex 12.

	Thickness (in.)	*Moduli Range (psi)*	
		Minimum	*Maximum*
Pavement	5.00	100,000	1,000,000
Base	24.00	15,000	250,000
Subbase	0.00	0	0
Subgrade	211.00	10,000	10,000

TABLE 3 DEPTH DEFLECTIONS CALCULATED FROM BISAR—SECTION 12, INFINITE SUBGRADE

Distance From MDD (in.)	Load (lb)	MDD Depth Deflections (mils) D1	D2	D3	Anchor Movement[a] (mils)
29.91	8,560	2.43	2.20	2.08	1.41
17.91	8,816	4.08	3.27	2.84	1.59
8.41	8,656	6.28	3.27	2.84	1.54

[a] Depth 72 in.

TABLE 4 DEPTH DEFLECTIONS CALCULATED FROM BISAR—SECTION 12, 20-FT DEPTH TO BEDROCK

Distance From MDD (in.)	Load (lb)	MDD Depth Deflections (mils) D1	D2	D3	Anchor Movement[a] (mils)
29.91	8,560	2.52	2.30	2.14	1.27
17.91	8,816	4.11	3.20	2.83	1.47
8.41	8,656	6.15	3.51	3.00	1.42

[a] Depth 72 in.

TABLE 5 COMPARISON OF MEASURED AND CALCULATED DEPTH DEFLECTIONS—SECTION 12, FWD LOCATED 29.91 in. FROM MDD, LOAD 8,560 lb

MDD Sensor No.	MDD Deflections (mils) Measured	Calculated Infinite S/G	Calculated 20-ft Bedrock	Percent Difference (%) Infinite Subgrade	Percent Difference (%) 20-ft Bedrock
1 (at 8.5 in.)	2.57	2.43	2.52	5.45	1.95
2 (at 29.75 in.)	2.32	2.20	2.30	5.17	0.86
3 (at 35.69 in.)	2.32	2.08	2.14	10.34	7.76
Anchor (at 72 in.)	1.33	1.41	1.27	6.01	4.51
Average Difference/Sensor				6.74	3.77

TABLE 6 COMPARISON OF MEASURED AND CALCULATED DEPTH DEFLECTIONS—SECTION 12, FWD LOCATED 17.91 in. FROM MDD, LOAD 8,816 lb

MDD Sensor No.	MDD Deflections (mils) Measured	Calculated Infinite S/G	Calculated 20-ft Bedrock	Percent Difference (%) Infinite Subgrade	Percent Difference (%) 20-ft Bedrock
1 (at 8.5 in.)	4.43	4.08	4.11	7.90	7.22
2 (at 29.75 in.)	3.16	3.27	3.20	3.48	1.26
3 (at 35.69 in.)	2.97	2.84	2.83	4.38	4.71
Anchor (at 72 in.)	1.46	1.59	1.47	8.90	0.68
Average Difference/Sensor				6.17	3.47

to the rounding off that MODULUS performs in matching the deflection basins. These were calculated assuming both an infinite subgrade as well as a 240-in. depth of bedrock. The moduli values backcalculated from surface deflections and the layer thickness information were entered in the BISAR layered elastic program to calculate the deflections.

The deflections calculated at the three sensors and the anchor were then compared with those measured by the MDD for each of the three locations. The results are presented in Tables 5 through 7. Table 5 suggests that by using the backcalculated *E* values, the average error in predicting deflections within the pavement was 6.7 percent assuming an infinite subgrade and 3.8 percent assuming a depth to bedrock of 20 ft. The average percent difference per sensor was found to be less at each position of the FWD with the bedrock assumed to be 240 in. from the surface.

Tables 8 and 9 present a summary of this process for Sections 9 and 11. For both of these sections as well, a 240-in.

TABLE 7 COMPARISON OF MEASURED AND CALCULATED DEPTH DEFLECTIONS—SECTION 12, FWD LOCATED 8.41 in. FROM MDD, LOAD 8,856 lb

MDD Sensor No.	MDD Deflections (mils)			Percent Difference (%)	
		Calculated			
	Measured	Infinite S/G	20-ft Bedrock	Infinite Subgrade	20-ft Bedrock
1 (at 8.5 in.)	6.76	6.28	6.15	7.10	9.02
2 (at 29.75 in.)	3.79	3.27	3.51	13.72	7.39
3 (at 35.69 in.)	3.40	2.84	3.00	16.50	11.76
Anchor (at 72 in.)	1.50	1.54	1.42	2.67	5.33
Average Difference/Sensor				10.00	8.38

TABLE 8 COMPARISON OF MEASURED AND CALCULATED DEPTH DEFLECTION—SECTION 11, SUMMARY

Distance From MDD (in.)	Load (lbs)	Measured Depth Deflection (mils)			Calculated Depth Deflection (mils)						Avg. Diff/Sensor	
					Infinite Subgrade			Bedrock: 20' Deep				
		D1	D2	Anchor	D1	D2	Anchor	D1	D2	Anchor	Infinite S/Grade	Bedrock 20' Deep
27.91	8752	3.33	3.44	2.00	2.94	2.82	2.00	3.17	3.00	1.91	9.91	7.37
14.00	8656	8.07	6.44	2.33	5.50	4.31	2.33	5.97	4.68	2.29	21.64	18.36
8.41	8608	12.27	8.12	2.50	7.80	5.04	2.46	8.22	5.49	2.44	25.32	22.60

TABLE 9 COMPARISON OF MEASURED AND CALCULATED DEPTH DEFLECTION—SECTION 9, SUMMARY

Distance From MDD (in.)	Load (lbs)	Measured Depth Deflection (mils)				Calculated Depth Deflection (mils)								Avg. Diff/Sensor	
						Infinite Subgrade				Bedrock: 20' Deep					
		D1	D2	D3	Anchor	D1	D2	D3	Anchor	D1	D2	D3	Anchor	Infinite S/Grade	Bedrock 20' Deep
18.91	8760	5.08	5.17	3.87	1.54	4.76	4.48	3.56	1.83	4.96	4.77	3.68	1.62	11.34	4.76
8.41	8640	8.94	8.06	4.77	1.58	9.45	7.03	4.48	1.90	8.26	7.23	4.82	1.80	11.30	8.22

depth to bedrock results in a smaller average percent difference than for an infinite subgrade.

CONCLUSIONS

The following conclusions can be drawn:

1. Setting a depth to bedrock of 20 ft produced a better fit between measured and calculated depth deflections.
2. The average errors on the thicker sections (9 and 12) were acceptable (less than 9 percent per sensor), indicating that linear elasticity for backcalculating *E* values is reasonable for thick pavements.
3. The average errors on the thin pavement (1 in. asphalt over 16 in. granular base) were high. The errors were greater than 20 percent, indicating that linear elasticity does a relatively poor job at predicting deflections within these thin pavements. The theoretical deflection consistently underpredicted measured deflections. Difficulty of backcalculating layer moduli for thin pavements may result in a poor match.

Work is now under way to determine if, by making different assumptions in the modeling process, the percent error could be reduced. The nonlinearity of the thin pavement is probably due to stiffening of the underlying granular layers. This makes it a candidate for analysis by other methods. Finite element techniques, for example, account for material stress sensitivity and use the Mohr-Coulomb failure criteria in analyzing pavement response. Work is under way to determine how the nonlinearity of the thin pavement may be accounted for.

The MDD appears to be an excellent tool for validating backcalculation procedures and its use is recommended over the traditional laboratory testing approach.

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