Effect of Various Load Distributions on Backcalculated Moduli Values in Flexible Pavements

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The structural adequacy of pavements is routinely evaluated by analyzing measured deflections collected with nondestructive testing devices such as the falling weight deflectometer (FWD). The FWD is an impulse loading device that closely simulates moving wheel loads in both magnitude and duration. The FWD is typically equipped with a circular loading plate and several deflection sensors positioned at discrete locations from the center of the loading plate. Virtually all available backcalculation programs that use linear elastic theory assume a circular loaded area and uniform stress distribution under the loaded area. Any deviation from these assumptions will introduce an error. To investigate the magnitude of this error, the multielastic layer computer program BISAR was used to calculate surface deflections for a limited factorial of pavement layer thicknesses and stiffnesses. Three contact stress distributions were considered: uniform (full contact), partial edge distribution (rutting), and partial circumferential distribution (weak pavement). The calculated deflections from each loading case were used to backcalculate layer moduli with the ELSDEF computer program. Results from the three cases were analyzed and the relative errors computed. The analysis indicated that if full contact is assumed when in reality it did not occur, significant errors in the backcalculated moduli values of the pavements analyzed may result.

The proliferation of nondestructive deflection testing devices has led to a dramatic increase in the use of deflection data for the structural analysis of flexible pavement systems. ("Flexible" describes conventional asphalt concrete pavement systems composed of an asphalt concrete surface layer over one or more layers of crushed aggregate resting on the natural subgrade.) Backcalculation of the elastic moduli of pavement layers is one such use. Programs based on linear elastic theory, such as ELSYM5, BISAR, ELSDEF, BISDEF, and so forth, are commonly used for this purpose.

In backcalculation of layer moduli, it is commonly assumed that the applied load is uniformly distributed over the pavement surface. Available loading plates used by falling weight deflectometers (FWDs) fall into two basic categories: segmented and nonsegmented. Both types are constructed of a semirigid upper portion with one or more layers of rubber membrane attached to the underside. It has been assumed that the rubber membranes transform the semirigid loading plate into a flexible loading plate, thus producing uniform pressure distributions over the pavement surface. To date, the authors know of no documentation that confirms this assumption.

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The objective of this study is to investigate the effect of various load pressure distributions on calculated surface deflections for a range of flexible pavement systems. The calculated deflections are then used to backcalculate layer moduli values, assuming a uniform load distribution. The error introduced in the backcalculated moduli due to the varying applied load distributions is determined. Finally, the relative error introduced because of the varying load distributions is determined.

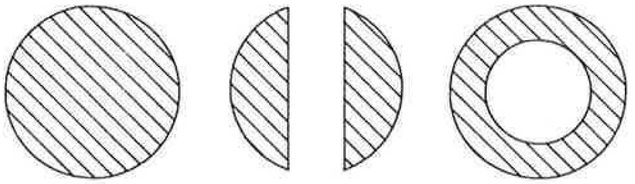
PAVEMENT LOADING SIMULATION

Pressure distributions were selected to reflect potential field conditions (i.e., pavement irregularities) that preclude uniform stress distributions. Figure 1 shows loading conditions that may result from varying pavement surface conditions. The full contact case represents the assumed "control" condition, in which uniform pressure distribution is achieved under the loading plate. The rut condition assumes that surface rutting is such that the central portion of the loading plate will not come into contact with the pavement surface. The outer rim contact case assumes that the loading plate is significantly stiffer than the pavement being tested, resulting in a rigid rather than a flexible loading plate condition.

The computer program BISAR was used to calculate surface deflections that would result from each loading case over a number of pavement systems. The individual load locations selected for each load case were chosen to best simulate the load distributions while satisfying program constraints. For all program runs, the total applied load was kept constant at 9,000 lbf. Figure 2 shows the loading geometry used to simulate loading conditions for BISAR calculations for Cases 1, 2, and 3. Table 1 gives the pressure, radius, and coordinates of each discrete circle in the loaded areas.

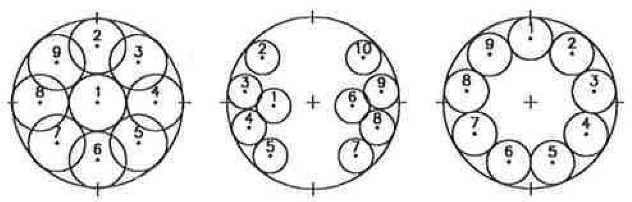
Layer moduli were varied for the asphalt concrete pavement layer to produce a factorial experiment that encompassed a realistic range of in-service pavement systems. Figure 3 shows the cross sections investigated during this study.

To validate the assumption that discretization of the loaded area will yield valid results, trial runs were conducted using BISAR, in which Case 1 (full contact) loading was investigated. Deflection basins produced from the actual full contact were compared with those produced from the simulated full contact and were found to be in excellent agreement. Figure 4 shows a typical output. The basins are essentially the same except at D_0, where there is a difference of less than 1 percent.



Case 1 *Full Contact (control)* | *Case 2* *Side Contact (rutting)* | *Case 3* *Outer rim contact (weak pavement)*

FIGURE 1 Possibilities for contact area shapes.



Case 1 *Full Contact (control)* | *Case 2* *Side Contact (rutting)* | *Case 3* *Outer rim contact (weak pavement)*

FIGURE 2 Approximations of contact areas for BISAR calculations.

TABLE 1 DISCRETIZED LOAD PARAMETERS FOR EACH LOADING CASE SHOWN IN FIGURE 2

Case No.	Circle No.	Pressure psi.	Radius in.	X-Y Coordinates in.	
1	1	82.02	1.97	0.00	0.00
	2	82.02	1.97	4.00	0.00
	3	82.02	1.97	0.00	4.00
	4	82.02	1.97	-4.00	0.00
	5	82.02	1.97	0.00	-4.00
	6	82.02	1.97	2.83	2.83
	7	82.02	1.97	2.83	-2.83
	8	82.02	1.97	-2.83	2.83
	9	82.02	1.97	-2.83	-2.83
2	1	233.56	1.108	-2.94	0.00
	2	233.56	1.108	-3.58	3.18
	3	233.56	1.108	-4.73	0.82
	4	233.56	1.108	-4.54	-1.49
	5	233.56	1.108	-3.43	-3.31
	6	233.56	1.108	2.87	-0.15
	7	233.56	1.108	3.36	-3.48
	8	233.56	1.108	4.59	-1.52
	9	233.56	1.108	4.69	0.73
	10	233.56	1.108	3.68	3.01
3	1	140.45	1.505	0.00	4.44
	2	140.45	1.505	2.37	3.45
	3	140.45	1.505	4.39	0.75
	4	140.45	1.505	3.79	-2.17
	5	140.45	1.505	1.36	-4.11
	6	140.45	1.505	-1.60	-4.06
	7	140.45	1.505	-3.80	-2.10
	8	140.45	1.505	-4.22	0.87
	9	140.45	1.505	-2.77	3.49

Asphalt Concrete Layer
H_{AC} = 4", 8", 12" u = 0.35
E_{AC} = 200 ksi, 600 ksi, 1000 ksi

Aggregate Base Course Layer
H_{BC} = 8" u = 0.40
E_{BC} = 30 ksi, 80 ksi

Subgrade
H_{SG} = semi infinite u = 0.40
E_{SG} = 15 ksi

FIGURE 3 Pavement cross sections investigated.

Table 2 gives the surface deflections calculated for each pavement system under each loading case. The full contact loading case (9,000-lbf load, 5.91-in. radius) defines the exact solution. Case 1 was used as the control to define the deflections that would have been expected with the FWD had a uniform distribution been modeled by discrete loads. The calculated deflections from Cases 2 and 3 represent the deflections that would have been measured by the FWD if the actual load distributions had been altered because of local conditions to resemble Case 2 and Case 3 model loadings.

BACKCALCULATION OF LAYER MODULI

The calculated deflections for Cases 1, 2, and 3 were used as inputs to ELSDEF to backcalculate the elastic modulus of each pavement layer, assuming a uniformly distributed load over a radius of 5.91 in. During program runs, the tolerance of deflection variation was set at 5 percent. Seed moduli values and allowable moduli ranges were varied as shown in Tables 3 through 6. The assumption of a uniformly distributed load was made to simulate the common practice of backcalculation using FWD deflections. Tables 7 through 10 give the backcalculated layer moduli for each system investigated.

The tables indicate that the backcalculated moduli values for each layer vary significantly from the exact solution for Cases 2 and 3. This behavior is shown in Figures 5 through 11, in which the backcalculated moduli values are plotted against the exact moduli values. It is evident that a trend exists. The surface moduli tend to be overestimated, whereas the second-layer moduli tend to be underestimated, and errors produced at the subgrade level were relatively smaller. The variation for Case 1 can be used to estimate the error introduced by discretizing the load.

Even if the exact moduli of the pavement system are provided as inputs during the backcalculation process (Tables 7 and 9), significant errors may still result for the backcalculated surface and base moduli. This impact is markedly reduced for backcalculated subgrade moduli.

FIELD LOADING CONDITIONS

To this point, this paper has been limited to a theoretical analysis of the pavement's response to varying loading

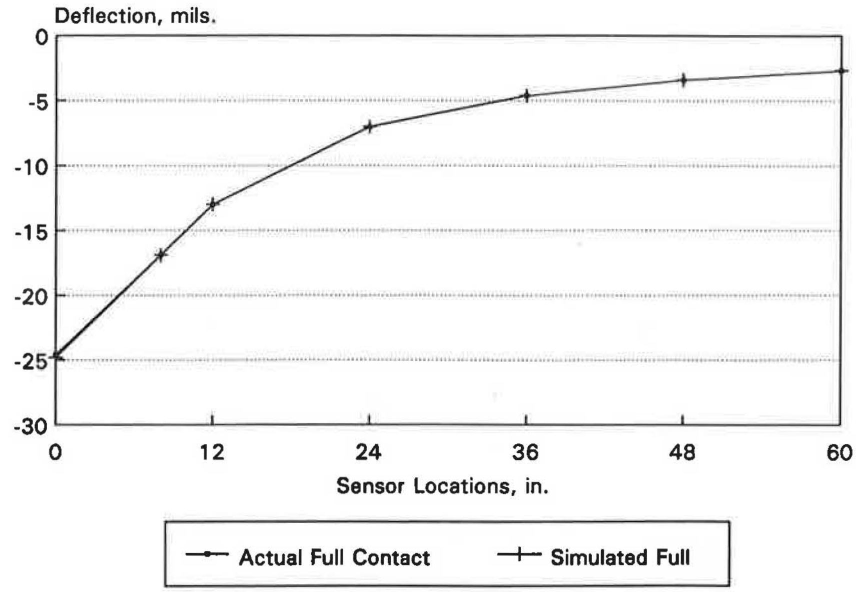


FIGURE 4 Deflection basins of uniform and simulated uniform contact pressures.

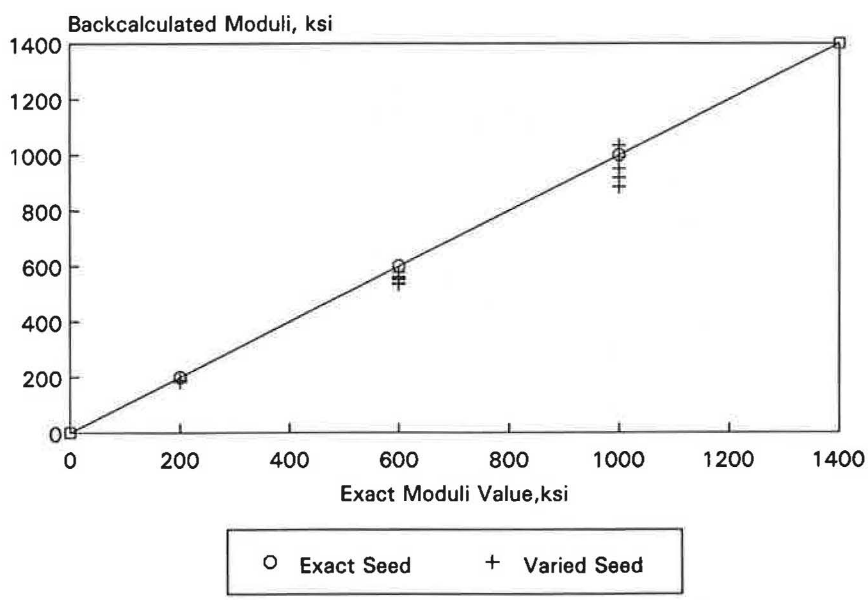


FIGURE 5 Asphalt concrete moduli comparison—full contact.

TABLE 2 CALCULATED SURFACE DEFLECTIONS FOR EACH LOADING CASE

Layer Moduli Values (ksi)			Layer Thickness (in.)		Case 1 - Full Contact Model: Calculated Surface Deflections, (mils.)							Case 2 - Side Contact Model: Calculated Surface Deflections, (mils.)							Case 3 - Rim Contact Model: Calculated Surface Deflections, (mils.)						
AC	Base	SG	AC	Base	D0	D6	D12	D24	D36	D48	D60	D0	D6	D12	D24	D36	D48	D60	D0	D6	D12	D24	D36	D48	D60
200	30	15	4	8	24.80	16.90	13.00	7.01	4.60	3.39	2.68	22.80	15.90	12.40	6.87	4.55	3.36	2.67	22.70	17.00	13.00	7.04	4.62	3.40	2.69
600	30	15	4	8	19.80	15.30	12.50	7.14	4.66	3.40	2.68	18.90	14.70	12.10	7.00	4.60	3.37	2.66	18.90	15.30	12.50	7.17	4.67	3.41	2.68
1000	30	15	4	8	17.50	14.30	12.00	7.21	4.73	3.43	2.68	17.00	13.80	11.70	7.08	4.67	3.40	2.66	16.90	14.20	12.00	7.23	4.74	3.43	2.69
200	30	15	8	8	16.90	12.80	10.90	6.99	4.79	3.52	2.75	15.40	12.30	10.60	6.88	4.74	3.49	2.73	15.30	12.80	10.90	7.01	4.80	3.53	2.75
600	30	15	8	8	12.00	10.30	9.28	6.71	4.88	3.65	2.84	11.50	10.10	9.14	6.64	4.83	3.62	2.82	11.50	10.30	9.28	6.72	4.89	3.66	2.85
1000	30	15	8	8	10.20	9.12	8.40	6.42	4.85	3.71	2.91	9.93	8.98	8.30	6.36	4.81	3.68	2.89	9.91	9.11	8.40	6.42	4.86	3.72	2.92
200	30	15	12	8	13.30	10.10	8.90	6.45	4.77	3.63	2.86	11.90	9.77	8.74	6.38	4.73	3.61	2.85	11.80	10.10	8.90	6.46	4.78	3.64	2.87
600	30	15	12	8	8.79	7.61	7.08	5.73	4.58	3.67	2.97	8.33	7.49	7.01	5.68	4.55	3.65	2.95	8.30	7.62	7.08	5.73	4.58	3.67	2.97
1000	30	15	12	8	7.33	6.60	6.24	5.26	4.37	3.60	2.98	7.06	6.52	6.20	5.23	4.34	3.59	2.97	7.04	6.60	6.24	5.27	4.37	3.61	2.98
200	80	15	4	8	18.40	13.30	11.10	7.02	4.81	3.53	2.76	16.80	12.70	10.80	6.92	4.77	3.50	2.74	16.70	13.40	11.10	7.04	4.82	3.54	2.75
600	80	15	4	8	15.50	12.30	10.50	6.88	4.80	3.55	2.77	14.80	11.90	10.30	6.78	4.76	3.53	2.76	14.80	12.40	10.50	6.89	4.81	3.56	2.77
1000	80	15	4	8	14.30	11.80	10.20	6.82	4.81	3.57	2.78	13.80	11.50	10.00	6.74	4.76	3.54	2.77	13.70	11.80	10.20	6.84	4.81	3.57	2.79
200	80	15	8	8	14.10	10.60	9.26	6.54	4.79	3.63	2.85	12.70	10.30	9.08	6.47	4.75	3.61	2.84	12.60	10.70	9.27	6.55	4.80	3.64	2.86
600	80	15	8	8	10.50	9.01	8.20	6.21	4.73	3.66	2.91	10.00	8.85	8.10	6.15	4.69	3.64	2.89	10.00	9.01	8.20	6.21	4.73	3.67	2.91
1000	80	15	8	8	9.23	8.21	7.60	5.97	4.66	3.67	2.94	8.93	8.09	7.53	5.93	4.63	3.65	2.92	8.90	8.20	7.60	5.97	4.66	3.67	2.94
200	80	15	12	8	11.80	8.79	7.79	5.93	4.60	3.63	2.92	10.40	8.50	7.67	5.88	4.57	3.61	2.91	10.30	8.84	7.80	5.93	4.61	3.63	2.92
600	80	15	12	8	8.08	6.96	6.49	5.34	4.37	3.58	2.95	7.63	6.85	6.43	5.31	4.35	3.56	2.94	7.60	6.97	6.49	5.34	4.37	3.58	2.95
1000	80	15	12	8	6.87	6.17	5.84	4.97	4.19	3.51	2.94	6.60	6.10	5.80	4.95	4.17	3.49	2.93	6.58	6.17	5.84	4.97	4.19	3.51	2.94

Case 1 Full Contact Load Modeling **Case 2 Partial Contact Load Modeling (Rutting Simulation)** **Case 3 Circumferential Load Modeling (Weak Pavement)**

TABLE 3 INPUT VALUES USED FOR ELSDEF PROGRAM RUNS WITH EXACT SEED MODULI (BASE COURSE MODULUS = 30 ksi)

Layer Thickness (in.)		"Exact" Moduli (Ksi.)			"Seed" Moduli (Ksi.)			Moduli Ranges, Ksi.					
								Asphalt Layer		Base Layer		Subgrade	
AC	Base	AC	BC	SG	AC	BC	SG	Min	Max	Min	Max	Min	Max
4	8	200	30	15	200	30	15	50	2000	10	75	5	30
4	8	600	30	15	600	30	15	50	2000	10	75	5	30
4	8	1000	30	15	1000	30	15	50	2000	10	75	5	30
8	8	200	30	15	200	30	15	50	2000	10	75	5	30
8	8	600	30	15	600	30	15	50	2000	10	75	5	30
8	8	1000	30	15	1000	30	15	50	2000	10	75	5	30
12	8	200	30	15	200	30	15	50	2000	10	75	5	30
12	8	600	30	15	600	30	15	50	2000	10	75	5	30
12	8	1000	30	15	1000	30	15	50	2000	10	75	5	30

Case 1 Full Contact Load Modeling
Case 2 Partial Contact Load Modeling (Rutting Simulation)
Case 3 Circumferential Load Modeling (Weak Pavement)

TABLE 4 INPUT VALUES USED FOR ELSDEF PROGRAM RUNS WITH SLIGHTLY VARYING SEED MODULI (BASE COURSE MODULUS = 30 ksi)

Layer Thickness (in.)		"Exact" Moduli (Ksi.)			"Seed" Moduli (Ksi.)			Moduli Ranges, Ksi.					
								Asphalt Layer		Base Layer		Subgrade	
AC	Base	AC	BC	SG	AC	BC	SG	Min	Max	Min	Max	Min	Max
4	8	200	30	15	200	50	10	50	2000	1	75	5	30
4	8	600	30	15	600	50	10	50	2000	1	75	5	30
4	8	1000	30	15	1000	50	10	50	2000	1	75	5	30
8	8	200	30	15	200	50	10	50	2000	1	75	5	30
8	8	600	30	15	600	50	10	50	2000	1	75	5	30
8	8	1000	30	15	1000	50	10	50	2000	1	75	5	30
12	8	200	30	15	200	50	10	50	2000	1	75	5	30
12	8	600	30	15	600	50	10	50	2000	1	75	5	30
12	8	1000	30	15	1000	50	10	50	2000	1	75	5	30

Case 1 Full Contact Load Modeling
Case 2 Partial Contact Load Modeling (Rutting Simulation)
Case 3 Circumferential Load Modeling (Weak Pavement)

TABLE 5 INPUT VALUES USED FOR ELSDEF PROGRAM RUNS WITH EXACT SEED MODULI (BASE COURSE MODULUS = 80 ksi)

Layer Thickness (in.)		"Exact" Moduli (Ksi.)			"Seed" Moduli (Ksi.)			Moduli Ranges, Ksi.					
								Asphalt Layer		Base Layer		Subgrade	
AC	Base	AC	BC	SG	AC	BC	SG	Min	Max	Min	Max	Min	Max
4	8	200	80	15	200	80	15	50	2000	10	125	5	30
4	8	600	80	15	600	80	15	50	2000	10	125	5	30
4	8	1000	80	15	1000	80	15	50	2000	10	125	5	30
8	8	200	80	15	200	80	15	50	2000	10	125	5	30
8	8	600	80	15	600	80	15	50	2000	10	125	5	30
8	8	1000	80	15	1000	80	15	50	2000	10	125	5	30
12	8	200	80	15	200	80	15	50	2000	10	125	5	30
12	8	600	80	15	600	80	15	50	2000	10	125	5	30
12	8	1000	80	15	1000	80	15	50	2000	10	125	5	30

Case 1 Full Contact Load Modeling
Case 2 Partial Contact Load Modeling (Rutting Simulation)
Case 3 Circumferential Load Modeling (Weak Pavement)

TABLE 6 INPUT VALUES USED FOR ELSDEF PROGRAM RUNS WITH SLIGHTLY VARYING SEED MODULI (BASE COURSE MODULUS = 80 ksi)

Layer Thickness (in.)		"Exact" Moduli (Ksi.)			"Seed" Moduli (Ksi.)			Moduli Ranges, Ksi.					
								Asphalt Layer		Base Layer		Subgrade	
AC	Base	AC	BC	SG	AC	BC	SG	Min	Max	Min	Max	Min	Max
4	8	200	80	15	200	50	10	50	2000	1	125	5	30
4	8	600	80	15	600	50	10	50	2000	1	125	5	30
4	8	1000	80	15	1000	50	10	50	2000	1	125	5	30
8	8	200	80	15	200	50	10	50	2000	1	125	5	30
8	8	600	80	15	600	50	10	50	2000	1	125	5	30
8	8	1000	80	15	1000	50	10	50	2000	1	125	5	30
12	8	200	80	15	200	50	10	50	2000	1	125	5	30
12	8	600	80	15	600	50	10	50	2000	1	125	5	30
12	8	1000	80	15	1000	50	10	50	2000	1	125	5	30

Case 1 Full Contact Load Modeling
Case 2 Partial Contact Load Modeling (Rutting Simulation)
Case 3 Circumferential Load Modeling (Weak Pavement)

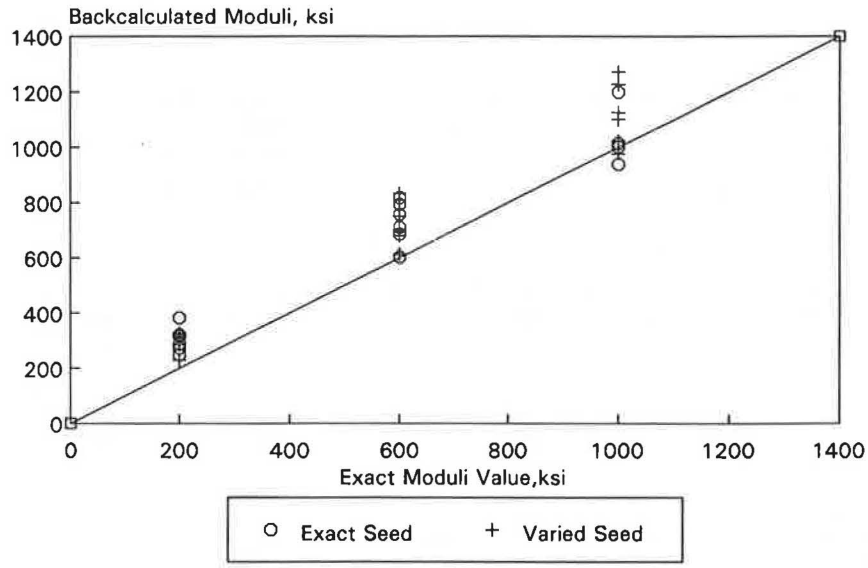


FIGURE 6 Asphalt concrete moduli comparison—rut condition.

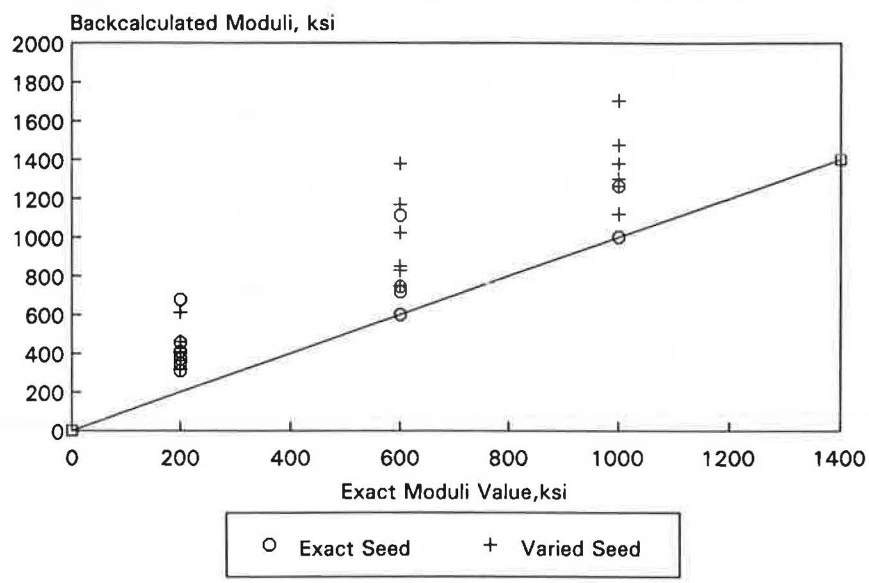


FIGURE 7 Asphalt concrete moduli comparison—rim contact.

TABLE 7 BACKCALCULATED LAYER MODULI FOR ELSDEF PROGRAM RUNS WITH EXACT SEED MODULI (BASE COURSE MODULUS = 30 ksi)

Layer Thickness (in.)		Backcalculated Pavement Moduli Values, Ksi.												Percent Difference from Exact Solution								
		Case 1				Case 2				Case 3				Case 1			Case 2			Case 3		
AC	BC	AC	BC	SG	% Err *	AC	BC	SG	% Err *	AC	BC	SG	% Err *	AC	BC	SG	AC	BC	SG	AC	BC	SG
4	8	200.0	30.0	15.0	1.21	247.6	32.8	15.5	2.03	370.9	24.6	15.2	3.32	0.0	0.0	0.0	23.8	9.3	3.3	85.4	−18.0	1.3
4	8	600.0	30.0	15.0	1.12	602.1	34.1	15.3	1.61	600.0	30.0	15.0	4.46	0.0	0.0	0.0	0.4	13.7	2.0	0.0	0.0	0.0
4	8	1000.0	30.0	15.0	0.72	938.0	36.3	15.2	1.20	1000.0	30.0	15.0	3.88	0.0	0.0	0.0	−6.2	21.0	1.3	0.0	0.0	0.0
8	8	200.0	30.0	15.0	1.22	286.7	22.4	15.5	0.78	345.9	10.0	16.8	3.94	0.0	0.0	0.0	43.3	−25.3	3.3	72.9	−66.7	12.0
8	8	600.0	30.0	15.0	1.10	756.9	14.7	16.0	0.38	600.0	30.0	15.0	4.07	0.0	0.0	0.0	26.1	−51.0	6.7	0.0	0.0	0.0
8	8	1000.0	30.0	15.0	0.93	1198.0	19.7	15.4	4.42	1000.0	30.0	15.0	2.55	0.0	0.0	0.0	19.8	−34.3	2.7	0.0	0.0	0.0
12	8	200.0	30.0	15.0	1.47	272.8	13.7	16.4	4.82	308.7	10.0	15.9	5.71	0.0	0.0	0.0	36.4	−54.3	9.3	54.3	−66.7	6.0
12	8	600.0	30.0	15.0	2.09	710.7	10.0	16.2	1.29	716.0	10.0	15.8	3.98	0.0	0.0	0.0	18.5	−66.7	8.0	19.3	−66.7	5.3
12	8	1000.0	30.0	15.0	2.09	1000.0	30.0	15.0	4.16	1000.0	30.0	15.0	4.69	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

* Absolute Error of Convergence from ELSDEF Program Runs

Case 1 Full Contact Load Modeling.
Case 2 Partial Contact Load Modeling (Rutting Simulation).
Case 3 Circumferential Load Modeling (Weak Pavement).

TABLE 8 BACKCALCULATED LAYER MODULI FOR ELSDEF PROGRAM RUNS WITH SLIGHTLY VARYING SEED MODULI (BASE COURSE MODULUS = 30 ksi)

Layer Thickness (in.)		Backcalculated Pavement Moduli Values, Ksi.												Percent Difference from Exact Solution								
		Case 1				Case 2				Case 3				Case 1			Case 2			Case 3		
AC	BC	AC	BC	SG	% Err *	AC	BC	SG	% Err *	AC	BC	SG	% Err *	AC	BC	SG	AC	BC	SG	AC	BC	SG
4	8	186.5	30.4	15.0	1.02	229.1	34.2	14.3	1.83	403.6	23.8	15.0	4.69	−6.8	1.3	−0.3	14.5	14.0	−4.7	101.8	−20.6	−0.2
4	8	561.8	31.1	14.9	0.67	612.8	33.6	15.2	0.79	827.8	26.7	14.7	4.72	−6.4	3.5	−0.5	2.1	12.0	1.3	38.0	−11.2	−1.9
4	8	992.0	29.8	15.0	0.86	976.1	34.7	15.1	0.75	1378.6	19.1	15.5	2.08	−0.8	−0.5	−0.3	−2.4	15.6	0.7	37.9	−36.5	3.3
8	8	191.2	31.3	14.9	0.60	284.3	23.8	15.3	1.34	362.1	8.2	17.6	4.04	−4.4	4.3	−0.4	42.2	−20.7	2.0	81.1	−72.8	17.0
8	8	551.3	35.8	14.9	0.51	750.1	14.0	16.1	1.21	1378.6	19.1	15.5	2.08	−8.1	19.3	−0.7	25.0	−53.3	7.3	129.8	−36.5	3.3
8	8	918.2	39.6	14.8	0.38	1124.7	19.5	15.5	0.20	1300.9	5.2	17.8	0.43	−8.2	31.9	−1.3	12.5	−35.1	3.3	30.1	−82.6	18.8
12	8	183.6	36.1	14.8	0.96	311.0	8.3	16.8	1.59	317.5	7.9	16.7	4.96	−8.2	20.4	−1.1	55.5	−72.2	11.7	58.8	−73.6	11.1
12	8	537.3	44.6	14.8	0.81	698.6	7.6	16.8	2.62	747.0	2.9	20.3	2.33	−10.5	48.6	−1.3	16.4	−74.8	12.3	24.5	−90.5	35.3
12	8	950.8	27.4	15.3	1.11	1099.4	7.5	16.4	3.68	1118.9	3.5	18.7	3.53	−4.9	−8.8	2.0	9.9	−74.9	9.3	11.9	−88.3	24.4

* Absolute Error of Convergence from ELSDEF Program Runs

Case 1 Full Contact Load Modeling.
Case 2 Partial Contact Load Modeling (Rutting Simulation).
Case 3 Circumferential Load Modeling (Weak Pavement).

TABLE 9 BACKCALCULATED LAYER MODULI FOR ELSDEF PROGRAM RUNS WITH EXACT SEED MODULI (BASE COURSE MODULUS = 80 ksi)

Layer Thickness (in.)		Backcalculated Pavement Moduli Values. Ksi.												Percent Difference from Exact Solution								
		Case 1				Case 2				Case 3				Case 1			Case 2			Case 3		
AC	BC	AC	BC	SG	% Err *	AC	BC	SG	% Err *	AC	BC	SG	% Err *	AC	BC	SG	AC	BC	SG	AC	BC	SG
4	8	200.0	80.0	15.0	1.44	382.2	77.0	15.1	2.73	678.2	54.5	14.9	1.83	0.0	0.0	0.0	91.1	-3.8	0.7	239.1	-31.9	-0.7
4	8	600.0	80.0	15.0	1.04	684.4	84.5	15.2	1.25	1111.7	64.4	15.0	2.04	0.0	0.0	0.0	14.1	5.6	1.3	85.3	-19.5	0.0
4	8	1000.0	80.0	15.0	1.32	1013.2	85.9	15.2	0.73	1000.0	80.0	15.0	3.83	0.0	0.0	0.0	1.3	7.4	1.3	0.0	0.0	0.0
8	8	200.0	80.0	15.0	1.39	320.7	63.4	15.2	0.69	455.6	33.8	15.7	4.28	0.0	0.0	0.0	60.3	-20.8	1.3	127.8	-57.8	4.7
8	8	600.0	80.0	15.0	1.28	816.5	55.5	15.3	1.26	600.0	80.0	15.0	4.54	0.0	0.0	0.0	36.1	-30.6	2.0	0.0	0.0	0.0
8	8	1000.0	80.0	15.0	1.84	1000.0	80.0	15.0	4.98	1000.0	80.0	15.0	2.89	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	8	200.0	80.0	15.0	1.95	316.3	44.5	15.5	2.39	407.8	5.4	19.5	3.20	0.0	0.0	0.0	58.2	-44.4	3.3	103.9	-93.3	30.0
12	8	600.0	80.0	15.0	1.99	792.5	22.3	16.1	1.78	744.0	28.4	15.9	4.50	0.0	0.0	0.0	32.1	-72.1	7.3	24.0	-64.5	6.0
12	8	1000.0	80.0	15.0	1.69	1000.0	80.0	15.0	4.90	1262.7	4.6	18.3	3.95	0.0	0.0	0.0	0.0	0.0	0.0	26.3	-94.3	22.0

* Absolute Error of Convergence from ELSDEF Program Runs

Case 1 Full Contact Load Modeling.

Case 2 Partial Contact Load Modeling (Rutting Simulation).

Case 3 Circumferential Load Modeling (Weak Pavement).

TABLE 10 BACKCALCULATED LAYER MODULI FOR ELSDEF PROGRAM RUNS WITH SLIGHTLY VARYING SEED MODULI (BASE COURSE MODULUS = 80 ksi)

Layer Thickness (in.)		Backcalculated Pavement Moduli Values. Ksi.												Percent Difference from Exact Solution								
		Case 1				Case 2				Case 3				Case 1			Case 2			Case 3		
AC	BC	AC	BC	SG	% Err *	AC	BC	SG	% Err *	AC	BC	SG	% Err *	AC	BC	SG	AC	BC	SG	AC	BC	SG
4	8	188.9	81.2	15.0	1.06	328.1	87.9	15.0	3.13	611.8	56.1	15.0	2.82	-5.5	1.5	0.0	64.1	9.9	0.0	205.9	-29.9	0.0
4	8	534.4	84.2	15.0	0.73	680.4	87.0	15.1	1.90	1168.8	66.5	14.9	4.32	-10.9	5.3	0.0	13.4	8.8	0.7	94.8	-16.9	-0.7
4	8	885.5	83.8	15.0	0.82	1022.3	86.7	15.2	1.67	1703.0	58.9	15.1	2.52	-11.5	4.7	0.0	2.2	8.4	1.3	70.3	-26.4	0.7
8	8	183.7	86.7	15.0	0.74	323.1	62.6	15.2	0.54	459.9	33.2	15.6	3.68	-8.2	8.4	0.0	61.6	-21.8	1.3	130.0	-58.5	4.0
8	8	556.3	87.8	15.0	1.13	832.5	65.8	15.0	4.47	1023.1	15.8	16.5	1.87	-7.3	9.7	0.0	38.8	-17.8	0.0	70.5	-80.3	10.0
8	8	885.5	97.0	14.9	1.77	1226.1	60.9	15.1	1.94	1474.0	14.6	16.5	1.07	-11.5	21.3	-0.7	22.6	-23.9	0.7	47.4	-81.8	10.0
12	8	185.6	87.9	15.0	0.72	316.0	45.5	15.4	1.97	407.6	5.4	19.4	3.19	-7.2	9.9	0.0	58.0	-43.1	2.7	103.8	-93.3	29.3
12	8	576.7	81.8	15.2	2.43	808.3	23.7	15.7	3.15	848.9	6.2	18.1	3.01	-3.9	2.2	1.3	34.7	-70.4	4.7	41.5	-92.3	20.7
12	8	1034.5	52.3	15.4	1.21	1271.2	8.5	16.9	2.30	1263.1	4.5	18.3	4.17	3.5	-34.6	2.7	27.1	-89.4	12.7	26.3	-94.4	22.0

* Absolute Error of Convergence from ELSDEF Program Runs

Case 1 Full Contact Load Modeling.

Case 2 Partial Contact Load Modeling (Rutting Simulation).

Case 3 Circumferential Load Modeling (Weak Pavement).

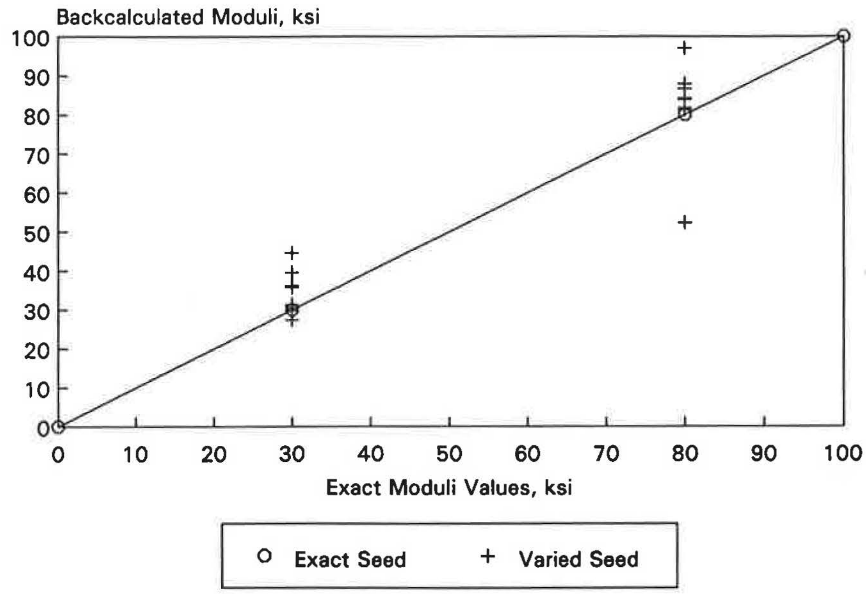


FIGURE 8 Base course moduli comparison—full contact.

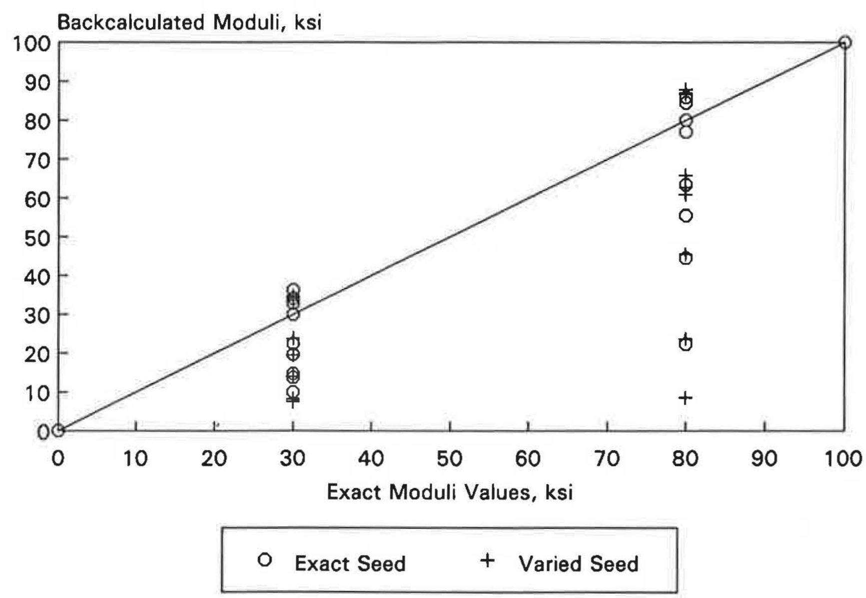


FIGURE 9 Base course moduli comparison—rut condition.

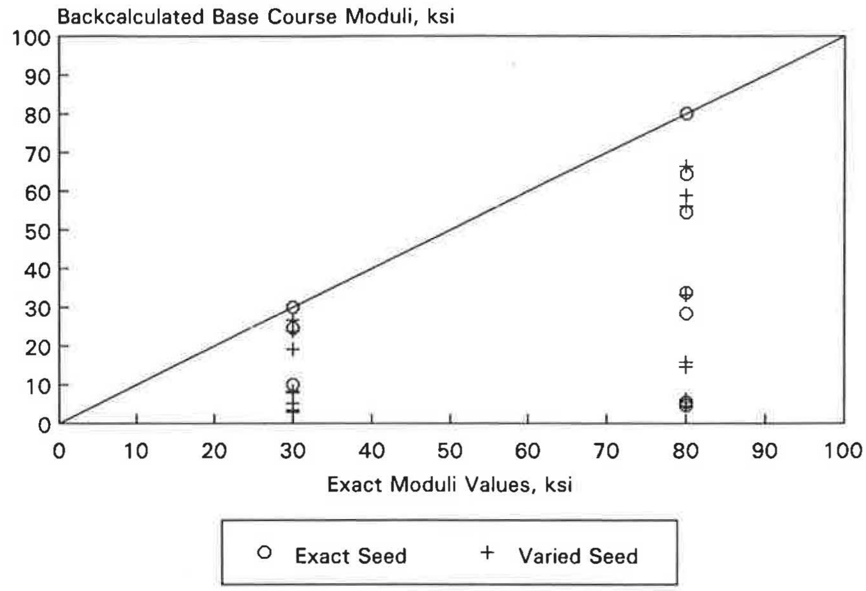


FIGURE 10 Base course moduli comparison—rim contact.

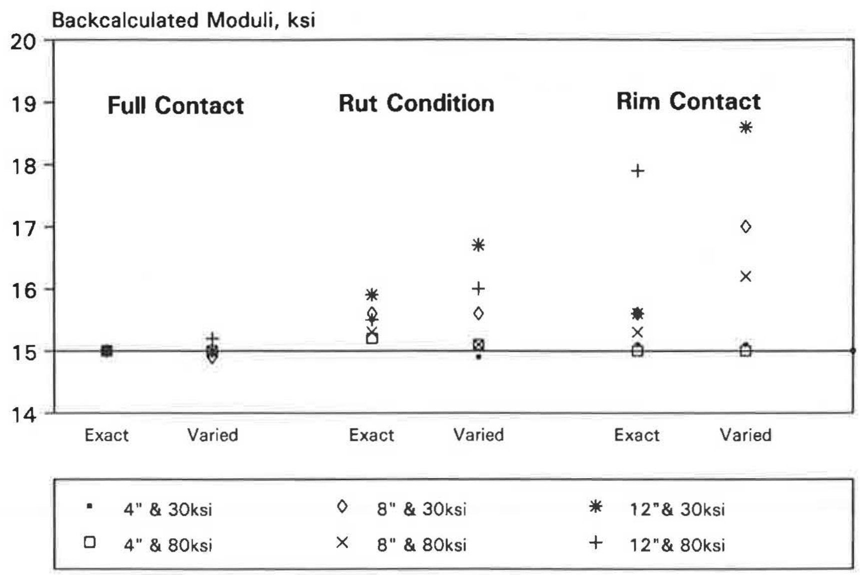


FIGURE 11 Average subgrade moduli comparison—all cases.

conditions. It has been generally assumed by the pavement community that all FWD loading systems produce relatively uniform stress distributions under the entire loading plate for all but severely rutted pavements. Data that significantly alter this viewpoint have been collected.

Two FWD loading plates, segmented and nonsegmented, were used under field testing conditions. Pressure-sensitive film, manufactured by Fuji Film I & I, was used to obtain a footprint of the pressure distribution under each loading plate at an applied load of approximately 14,000 lbf. The Fuji Prescale Film is available in widths of 270 mm on continuous rolls 5 m long and sensitive in the range of 70 to 350 psi. This film is composed of an A-film, featuring a layer of microencapsulated color-forming material in between, and a C-film, featuring a layer of color-developing material. When pressure is applied, the microcapsules on the A-film are broken, and the noncolored, color-forming material is released and absorbed by the color-developing material of the C-film, which in turn reacts with the color-developing material to generate the colors of the C-film. The microcapsules of color-forming material are designed to break at different pressure levels, thus allowing for determination of the pressure distribution throughout the material. The intensity of the color indicates the pressure applied; darker color indicates higher pressure.

Tests were conducted on three different pavement types, as follows:

1. A smooth, newly paved asphalt pavement that had received very few traffic loadings;
2. A relatively strong, heavily trafficked asphalt pavement with a rut depth of ⅛ in. measured across the radius of loading (Figure 12); and
3. A relatively weak, lightly trafficked chip-seal pavement with a flat profile under the loading plate.

Before pavement testing, 18-in. strips of A-film and C-film were cut from the film rolls and taped together to form a sandwich of prescale film with approximate dimensions of 18 × 10.6 in. The segmented loading plate was positioned on the pavement surface so that a spray-painted outline of the loading plate could be made. Next, the prescale film sandwich was taped onto the pavement surface to cover the loading plate outline (11.81-in. diameter) as completely as possible. The FWD was switched to computer operation to produce one load at approximately 14,000 lbf (127 psi). The prescale sandwich was removed and the FWD driven off the pavement surface.

The second FWD, equipped with a nonsegmented loading plate, was positioned so that the loading plate would fall within the previously painted loading plate outline. A second prescale film sandwich was taped to the pavement surface. A single load at approximately 14,000 lbf was applied to the pavement using the nonsegmented loading plate. The prescale sandwich was removed, and the FWD was driven off the pavement surface.

Figure 13 shows digitized copies of the original pressure distributions obtained for each field loading condition. The nonsegmented loading plate produces variable stress distributions depending on the type of pavement tested. A rut depth as small as ⅛ in. produced significant alteration of the stress distribution applied with the nonsegmented plate. Conversely, the segmented loading plate provided relatively uniform stress distributions regardless of the pavement's surface condition.

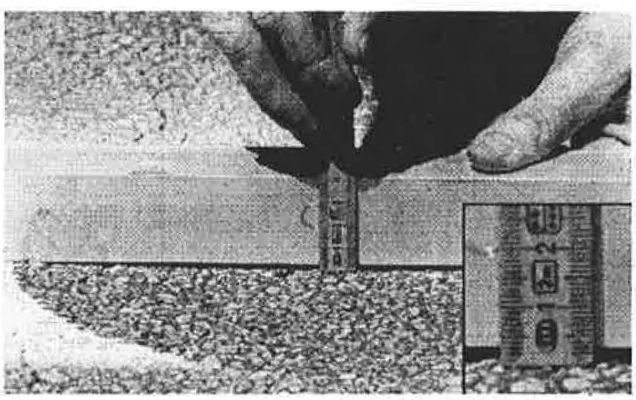


FIGURE 12 Rut measurement (3 mm) on a relatively strong, heavily trafficked asphalt pavement.

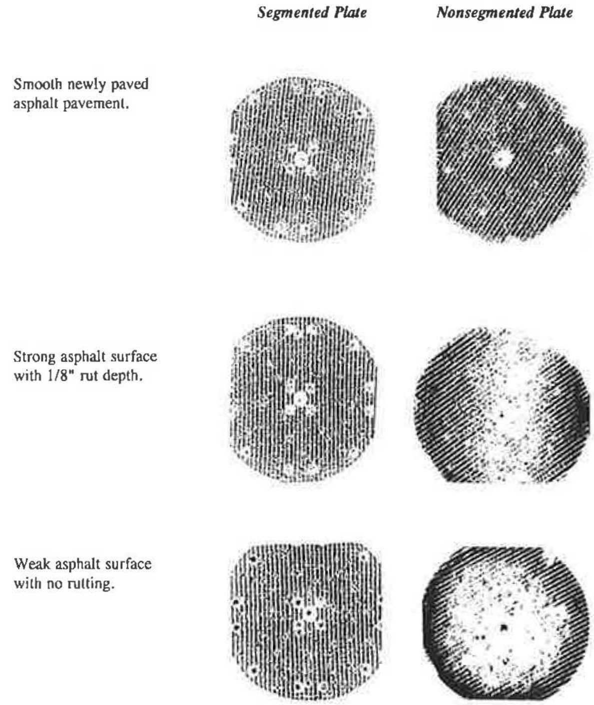


FIGURE 13 Actual pressure distribution under rigid and segmented plates.

SUMMARY AND CONCLUSIONS

A theoretical analysis of deflection variation as a function of load shape for a variety of asphalt pavement systems has been presented. The calculated deflections were used as input to determine the backcalculated layer moduli of the pavement systems. It has been demonstrated that significant error can be introduced into the pavement analysis process if measured deflections are obtained with anything but a uniform stress distribution. The error stems from one of the assumptions used by the analysis programs—uniform pressure distribution over the pavement surface. The error is present even if the exact moduli of the pavement system are provided as inputs during backcalculation.

Field tests covering a variety of pavement surface conditions have been made. The results indicate that the pressure distributions obtained from the nonsegmented plate were neither uniform nor consistent for all cases considered. However, consistently uniform distributions were obtained from the segmented plate. The implication is that a significant source of error may be introduced into a detailed pavement analysis that uses FWD deflections if the exact pressure distribution at the time of loading was unknown.