An evaluation of damage caused by heavy loads in Ohio

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The effect of heavy trucks on the performance of pavements located in northern Ohio was evaluated to develop and implement more realistic damage factors caused by heavily loaded trucks. Detailed traffic measurements were made twice a year using weigh-in-motion equipment. Distress measurements consisting of cracking, faulting, Mays roughness, and PSI for rigid pavements and cracking, rutting, Mays roughness, and PSI for flexible and composite pavements, were made at the same time. The analysis showed that for rigid pavements heavy axle loads contribute more toward cracking and faulting development than to PSI loss whereas rutting is most influenced by heavy axle loads (followed by PSI and cracking, in that order) for flexible and composite pavements.

1. INTRODUCTION

This paper encompasses an analysis of damage caused by excessive loads on the highways of northern Ohio (to and from the Port of Toledo). The development of the necessary information through field tests requires many years, with test sections located in different environments and subjected to varying mixed traffic loads. This is one of the aims of the Strategic Highway Research Program (SHRP) but the results of these studies will probably not be available for some years. Therefore, interim guidelines are needed that more realistically estimate the effects of heavy vehicles; the limited study described in this paper was undertaken to provide the interim guidelines.

2. PROJECT SELECTION

At the outset of the project it was felt that at least three (3) days of traffic measurements per project would be needed to get an accurate estimate of the traffic mix and that each project should be monitored twice per year. Since one working day would be required for system installation and distress measurements, and allowing for bad weather (Ohio Department of Transportation (ODOT) policy was not to close off lanes during wet weather), it was decided to only monitor one project per week.

Climatic consideration forced field monitoring to be conducted between April 1 and October 31 each year. Since it was decided to monitor each project twice per year (in order to develop more accurate traffic data as well as to observe the changes in distress levels), at most thirteen (13) projects could be accommodated. In order to allow some latitude for equipment malfunction and other delay, twelve (12) projects were selected for monitoring. These consisted of four (4) projects each of rigid, flexible, and composite pavements.

One requirement in project selection was that most of these projects must be located on routes where the "Michigan Train" is permitted to operate (the Michigan Train consists of vehicles with up to 13 axles and a gross weight of 693 kN), i.e., on roads with access to the Port of Toledo. This requirement resulted in the projects on I-75, I-280, I-475, and US 23. Each lane was considered a separate study project. Each project is approximately 0.8 km in length.

3. TRAFFIC MEASUREMENTS

A very significant part of this study was the determination of the traffic that uses the study pavements. If damage factors are to be determined, a reasonably accurate estimate of the axle loads, numbers of axles, and axle configuration is needed. While the number of axles and axle configuration can be determined with relatively simple traffic analysis systems, the determination of axle loads requires some form of Weigh-in-Motion (WIM) equipment. A preliminary study of available WIM equipment indicated that the Golden River Weighman (TM) could be used to meet the traffic analysis needs of this study. This WIM system consists of a capacitive weighmat to sense the axle loads (only 1/2 of an axle is measured and this measurement is doubled to get the axle load) and two inductive loops that act as axle detectors.

4. DISTRESS MEASUREMENTS

The development of damage factors requires that the rate of distress formation as a function of traffic level be known. It is therefore necessary to monitor the pavements to determine the changes in observable distresses as well as to get an accurate measure of the traffic mix that is responsible for producing these changes.

Since only two years were available in this project to observe the development of distress, it was necessary to select distresses that could be measured fairly accurately and which were expected to show some changes over the monitoring period. Therefore, cracking, rutting, and roughness were selected for flexible and composite pavements and cracking, faulting, and roughness were selected for jointed concrete pavements.

The extent of rutting was measured in both wheel paths at 30 m intervals using a 2.1 m straight edge and a combination square. The location of maximum rut depth was determined by sight and measured to the nearest 0.4 mm. Measurements were always taken at the same locations; the pavement was marked with spray paint to ensure this.

Faulting measurements were made on the outside edges of the slab at about 300 mm in from the edge. The 300 mm distance was selected to be away from the painted edge lines and also to avoid any excess joint filler and/or significant joint spalling; however, measurements sometimes had to be shifted slightly to clear the obstacles. Faulting values were recorded to the nearest 0.4 mm; every joint was measured.

Cracking measurements consisted of estimating the length of each crack to the nearest 0.3 m. To facilitate this, a sketch was made of each project during the first survey

Heavy vehicles and roads: technology, safety and policy. Thomas Telford, London, 1992.

showing the location and approximate length of each crack. This allowed the changes in cracking to be recorded on these figures during subsequent surveys and resulted in much more accurate estimate of the extent of cracking than would otherwise have been possible.

Pavement roughness was measured by a K. J. Law non-contact profilometer. Measurements were always made over the entire project length. Roughness was also measured with a Mays Meter but these measurements proved to be too erratic for use.

5. FIELD AND LABORATORY DATA

The results of the traffic measurements are shown in Table 1. In this table the day factor (the day factor is a factor which converts traffic measurements made on a specific day into ADT values) has been derived from ODOT's permanent traffic counting stations that have been operational for several years in the Toledo area (although not at the same locations), Type C vehicles (ref. 1) represent medium weight trucks belonging to FHWA Classes 4-7, (ref. 2) Type B vehicles represent heavy trucks in Classes 8-13, and Class 13 vehicles (7 or more axles, multi-units) represent the "Michigan Train." The road identification consists of: Road No.-Lane.Monitoring Period, e.g., 475-1.2 represents I-475, Lane 1, and Monitoring Period 2.

The data in Table 1 shows that average traffic volume measurements (ADT/lane) were in general quite accurate and that vehicle classification (at least as far as Type B and Type C vehicles are concerned) was also satisfactory, especially when monitoring times were greater than 4 days. However, small discrepancies were noted in classifying vehicles. For instance, it was noticed during visual cross-checks that the equipment tended to misclassify vehicles when two vehicles traveled close together (one after the other). This is especially true for Class 13 vehicles where two vehicles with a combined total of more than 6 axles were classified as one Class 13 vehicle. In most cases where a high number of Class 13 vehicles has been found, the percent of these vehicles weighing over 180 tonnes is low, indicating a high probability of misclassification.

The results of the distress measurements are presented in Table 2. In general cracking data is very consistent but there is considerable scatter in the other measurements. The PSI measurements also show some problems; however, there is some consistency of this data after the September, 1986 readings - the September, 1986 measurements are lower than they should be in all cases, yet no maintenance was done between September and December, 1986. Therefore, the September readings have been omitted from analysis.

The scatter in faulting measurements is not very large considering that measurements were made to the nearest 0.4 mm and could perhaps be explained by temperature effects, although temperature readings were not taken at the time of measurements.

Rutting measurements show erratic behavior during the monitoring periods; rut depth at times decreases with time for all pavements except I-475. There is no explanation for the anomalies in rutting measurements.

In general the distress data show that the pavement deteriorated somewhat during the 18 month monitoring period, and as will be shown later, the distresses are close to predicted values.

The cores by ODOT were subjected to the laboratory tests. The results of these tests are presented in Table 3. In this table each value is the average of three (3) tests except for thicknesses which were measured at four (4) equidistant points on each core and represent an average of all cores (approximately 30 per project). The results are consistent with expected material properties derived from field cores (aged specimens).

6. DETERMINATION OF DAMAGE MODELS

Sixteen (16) observations of distress levels were available for flexible and rigid pavements but only twelve (12) observations were made on composite pavements since I-280 underwent major rehabilitation before the third set of measurements could be carried out. In any case the total number of observations does not permit the development of damage models as a function of many variables. Therefore, for flexible pavements it was decided to use the theoretical equations developed under the Cost Allocation Study (ref. 3) since these equations were shown to be satisfactorily applicable to data from a large number of projects throughout the wet-freeze climate zone which is similar to that in the study area and since the limited amount of data made it impossible to develop similar equations for Ohio projects only.

The applicability of the cost-allocation equation (ref. 3) to the I-475 data is shown in Figures 1-3. Space does not permit the presentation of all projects; therefore typical plots are shown. The full details are presented in reference 4. The actual amount of rutting (Figure 2) is somewhat less than predicted (on the order of 1 to 2 mm; however, the agreement is generally quite good for the different damages. Cracking in Figure 3 (and Figure 6,9) represents the total amount of all cracking over the project length.

Equations similar to those used for flexible pavements are not available for rigid and composite pavements. Therefore, it was decided to develop functions for rigid and composite pavements in the form of:

$$g_i = \left(\frac{N_{18}\quad ß_i}{e^{a_i T}}\right) \qquad (1)$$

except for rutting prediction of composite pavements, which is in the form of:

$$g_i = \left(\frac{N_{18}\quad ß_i}{e^{1/a_i T}}\right) \qquad (2)$$

where

$a, ß$ = regression constants
T = is the thickness of concrete for rigid pavements and the thickness of the A.C. overlay for composite pavements.
N_{18} = Millions of equivalent axle load applications

The comparison of the predicted and measured distresses are shown in Figures 4-6 for composite pavements and Figures 7-9 for rigid pavements. These figures show that while there is some scatter in the data and although the data is limited, the measurements agree with the values predicted from the damage model quite well.

7. CONCLUSIONS

Although based on limited data, the following conclusions were reached as a result of this study.

1. The damage models developed to predict the formation of distress agree very closely with the measured distress and are in agreement with those developed in the Cost Allocation Study (ref. 3)
2. For rigid pavements cracking increases faster under heavy loads than do the other

Table 1. Summary of traffic survey.

Road	Length Days	Day Factor	ADT/ Lane	No. of C/day	% C	No. of B/Day	% B	No./ Day	% of ADT/LN	% of B	% over 80 KIP
75-1.1	Equipment Malfunction										
75-1.2	5.3	0.89	10809	749	6.9	975	9.0	19	.18	1.9	17
75-1.3	4.0	0.83	12476	1447	11.6	288	2.3	4	.03	1.2	23
75-2.1	6.8	0.86	7338	282	3.8	176	2.4	2	.03	1.1	13
75-2.2	6.2	1.02	7418	300	4.0	289	3.9	3	.04	1.1	47
75-2.3	6.0	0.86	6882	296	4.3	138	2.0	2	.02	1.4	17
75-3.1	6.7	0.90	11540	234	2.0	1655	14.3	11	.10	0.7	53
75-3.2	6.2	0.99	9686	218	2.3	1608	16.6	16	.17	1.0	49
75-3.3	6.0	0.98	9772	238	2.4	1066	10.9	9	.09	0.8	50
75-4.1	4.8	0.85	6378	173	2.7	315	4.9	6	.09	1.6	25
75-4.2	6.2	0.99	7222	298	4.1	626	8.7	3	.04	0.5	48
75-4.3	6.0	0.90	6715	479	7.1	563	8.4	3	.04	0.6	75
280-1.1	6.5	0.86	12770	425	3.3	1486	11.6	191	1.50	12.9	14
280-1.2	6.2	1.01	13746	357	2.6	1887	13.7	12	.09	0.6	56
280-2.1	5.7	0.85	8516	293	3.4	703	8.3	86	1.00	12.2	2
280-2.2	6.7	1.01	9071	100	1.1	832	9.2	4	.05	0.5	33
23-1.1	5.0	1.03	8962	147	1.7	1208	13.6	16	.18	1.3	51
23-1.2	7.2	0.85	8267	152	1.8	893	10.8	12	.15	1.3	66
23-1.3	5.7	0.90	7885	121	1.5	793	10.0	9	.11	1.2	65
23-1.4	6.0	0.99	7928	163	2.1	713	9.0	24	.30	3.3	28
23-2.1	4.5	1.04	5806	196	3.4	536	9.2	6	.10	1.2	27
23-2.2	6.2	0.85	6085	108	1.8	703	11.6	10	.16	1.5	45
23-2.3	5.8	0.91	7379	110	1.5	846	11.5	28	.38	3.3	58
23-2.4*	1.2	0.86	4690	354	7.5	657	14.0	60	1.28	9.1	34
475-1.1	1.0	1.03	10887	186	1.7	1623	14.9	32	.29	1.9	50
475-1.2	6.2	0.99	11372	241	2.1	1350	11.9	11	.10	.9	69
475-1.3	6.2	0.91	12952	209	1.6	947	7.3	6	.04	.6	97
475-1.4	6.0	0.85	9815	334	3.4	945	9.6	83	.85	8.7	37
475-2.1	3.7	1.04	5134	25	.5	254	5.0	1	.02	.4	25
475-2.2*	6.0	0.91	6637	49	0.7	301	4.5	16	.24	5.3	8
475-2.3*	3.3	0.95	6626	142	2.1	459	6.9	63	.95	13.7	20
475-2.4	6.0	0.85	6615	31	0.5	196	3.0	1	.02	.5	16
475-3.1	5.2	0.99	7711	42	0.6	415	5.4	2	.03	.5	64
475-3.2	0.7	0.85	6273	91	1.5	357	5.7	33	.53	9.2	4
475-3.3	0.5	0.90	6456	158	2.4	301	4.7	36	.56	12.0	11
475-3.4	6.0	0.99	8026	61	0.8	307	3.8	17	.21	5.4	3
475-4.1	4.8	0.90	11341	202	1.8	1144	10.1	8	.07	.7	16
475-4.2	6.2	0.99	12058	327	2.7	1431	11.9	152	1.26	10.6	4
475-4.3	5.3	0.99	11907	252	2.1	1521	12.8	15	.13	.9	30
475-4.4	6.0	0.85	11843	246	2.0	1048	8.9	54	.45	5.1	18

*Weightmat failed

Table 2. Field distress measurements.

Route Number	Thickness mm	Date	No. of 80 kN Load appl.	Total Cracking (m)	Average Faulting (mm)	Date	No. of 80 kN Load appl.	PSI (ODOT)
I-75-1.1	238	07/15/86	7,367,617	475	2.06	09/86	7,507,472	2.82
I-75-1.2		10/02/86	7,556,544	566	2.29	12/86	7,738,111	3.05
I-75-1.3		07/21/87	8,277,903	574	1.88	02/87	7,885,327	2.81
I-75-1.4		09/09/87	8,388,315	585	2.29	12/87	8,628,767	2.82
						03/88	8,849,591	2.80
I-75-2.1	240	07/07/86	1,566,081	409	0.28	09/86	1,593,804	3.28
I-75-2.2		10/10/86	1,605,746	434	0.41	12/86	1,633,895	3.54
I-75-2.3		07/21/86	1,727,725	440	0.81	02/87	1,659,485	3.42
I-75-2.4		09/09/87	1,746,917	446	0.33	12/87	1,788,714	none
						03/88	1,827,099	3.40
I-75-3.1	235	06/24/86	6,699,692	429	1.65	09/86	6,838,610	2.72
I-75-3.2		09/24/86	6,859,982	434	1.78	12/86	7,006,024	3.03
I-75-3.3		07/14/87	7,367,567	441	1.83	02/87	7,112,884	2.84
I-75-3.4		09/23/87	7,502,923	459	1.75	12/87	7,652,527	none
						03/88	7,812,817	2.73
I-75-4.1	231	07/01/86	3,768,668	429	1.73	09/86	3,839,668	3.10
I-75-4.2		09/17/86	3,844,668	448	2.06	12/86	3,933,668	3.17
I-75-4.3		07/01/87	4,133,668	454	2.26	02/87	3,993,668	2.20
I-75-4.4		09/23/87	4,121,668	501	1.93	12/87	4,296,668	2.71
						03/88	4,386,668	3.07
					Rutting, mm			
I-280-1.1	104	07/22/86	10,412,966	187	8.56	09/86	10,621,368	3.37
I-280-1.2		10/15/86	10,619,220	191	7.87	12/86	10,764,815	3.51
						02/87	11,002,415	3.58
						12/87	11,802,335	3.64
I-280-2.1	99	07/16/88	2,945,354	176	6.81	09/86	3,007,607	3.49
I-280-2.2		10/22/86	3,012,708	191	8.08	12/86	3,049,070	3.80
						02/87	3,113,690	3.40
						12/87	3,331,244	none
US-23-1.1	101	04/01/86	1,456,785	225	2.74	09/86	1,648,107	3.48
US-23-1.2		08/12/86	1,582,770	225	2.49	12/86	1,704,083	3.73
US-23-1.3		07/14/87	1,914,042	225	2.62	02/87	1,802,813	3.69
US-23-1.4		09/03/87	1,963,417	227	2.62	12/87	2,135,204	3.68
						03/88	2,233,934	3.38
US-23-2.1	99	04/02/86	1,176,784	185	3.05	09/86	1,329,114	3.56
US-23-2.2		07/28/86	1,267,017	214	2.84	12/86	1,375,716	3.91
US-23-2.3		06/16/87	1,522,085	208	2.67	02/87	1,450,875	3.66
US-23-2.4		09/10/87	1,590,797	185	2.90	12/87	1,703,910	none
						03/88	1,779,069	3.52
I-475-1.1	139	05/07/86	5,695,480	126	3.20	09/86	5,914,872	3.74
I-475-1.2		08/20/86	5,872,022	126	3.30	12/86	6,024,568	4.02
I-475-1.3		06/02/87	6,415,360	142	2.41	02/87	6,178,828	3.62
						03/88	6,657,799	3.70
I-475-2.1	144	04/14/86	1,346,896	192	2.01	09/86	1,403,884	3.74
I-475-2.2		08/28/86	1,400,684	194	1.63	12/86	1,440,813	3.99
I-475-2.3		05/05/87	1,501,836	204	1.88	02/87	1,476,939	3.64
I-475-2.4		08/19/87	1,538,754	230	2.16	12/87	1,591,739	none
						03/88	1,621,844	3.57
I-475-3.1	143	04/22/86	1,412,708	152	2.06	09/86	1,480,948	3.48
I-475-3.2		09/10/86	1,478,562	152	1.47	12/86	1,511,488	3.97
I-475-3.3		04/15/87	1,583,546	163	1.78	02/87	1,554,436	3.47
I-475-3.4		08/12/87	1,624,585	189	2.46	12/87	1,690,916	none
						03/88	1,658,975	3.57
I-475-4.1	140	04/29/86	4,160,056	45	3.30	09/86	4,326,930	3.73
I-475-4.2		09/03/86	4,394,044	46	3.58	12/86	4,500,534	4.00
I-475-4.3		04/06/87	4,805,410	57	3.68	02/87	4,670,364	3.64
I-475-4.4		08/05/87	4,934,544	75	4.24	12/87	5,210,046	3.69
						03/88	5,351,571	3.74

Table 3. Summary of laboratory test.

Project	75-1	75-2	75-3	75-4	23-1	23-2	280-1	280-2	475-1	475-2	475-3	475-4
Com. Strength, MPa	50.5	50.7	47.4	44.1	62.3	48.3	50.5	53.8				
Split Tensile St. MPa		3.67		3.41	3.64	4.03	4.00	3.70				
Modulus, 10^6 GPa	30.1	33.5	32.5	30.1	36.7	36.4	33.4	35.0				
Conc. Thick, mm	238	240	235	231	232	231	220	228				
AC Thick, mm					64	64	91	74	249	260	258	252
σY (Dry), MPa					1.16	1.32	1.29	0.99	1.29	1.25	1.64	1.57
σ (Immersion), MPa					1.10	1.28	1.17	0.85	0.85	0.74	1.22	1.01
Index Ret. Str. (1)					0.95	0.97	0.91	0.88	0.66	0.59	0.74	0.64
M_R, GPa					6.38	7.15	5.58	3.81	6.09	5.28	6.52	8.18
Creep Comp. 1/Pa (2)									0.497	0.303	0.226	0.519
Perm Strain, 10^{-6} mm/mm (2)									506	266	157	439
Bitumen Content, %					4.8	5.8	5.5	5.2	-	5.5	5.5	5.2

(1) Ratio of 4 (σY immersion to σY dry)
(2) At 1000 seconds

distresses.

3. For flexible pavement rutting increases faster under heavy loads than do roughness or cracking. The damage model also indicates that rutting increases with increasing pavement thickness.
4. For composite pavements rutting is insignificant for asphalt thickness less than about 75 mm but if the AC layer is greater than 75 mm heavy loads contribute more to rutting than to roughness and cracking, in that order.
5. The damage factors developed in this study are in close agreement with those developed in the Cost Allocation Study (ref. 3).
6. Portable WIM equipment can be used with reasonable accuracy to determine axle loads and vehicle classification if reasonable care is exercised in data analysis. The Golden River Weighman (TM) system used in this study tended to misclassify vehicles when two vehicles traveled close together (one after the other) and sometimes resulted in erroneous axle weights (about 1 to 2 percent of the time); however, these errors could be accounted for in most instances and it was felt that these problems did not significantly increase errors in ADT or E18 determinations.

8. RECOMMENDATIONS

1. Since heavy axle loads contribute significantly more to rutting than to PSI (for flexible and composite pavement), and since these are less important for cracking development, it is recommended that (for pavements where a significant number of heavy axle loads are expected):
   a) Asphalt layer thickness (402 and 404 mixes) be kept to a minimum in flexible and composite pavement design;
   b) Asphalt mixes should be designed with high stability and low flow (i.e., low permanent deformation properties), even at the expense of fatigue characteristics.
2. Although heavy loads increase the amount of cracking and faulting more than they decrease PSI, significant changes in rigid pavement design are not recommended if adequate drainage is provided to carry away the excess water entering the pavement structure through increased cracking. However, pavement thickness should be increased in areas where pumping is considered to be a problem.

9. ACKNOWLEDGEMENTS

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4. Ilves, G.J., and Majidzadeh, K., Reevaluation of the Methods for Calculation of Load Equivalency and Damage Ratios, FHWA/OH-89/018.

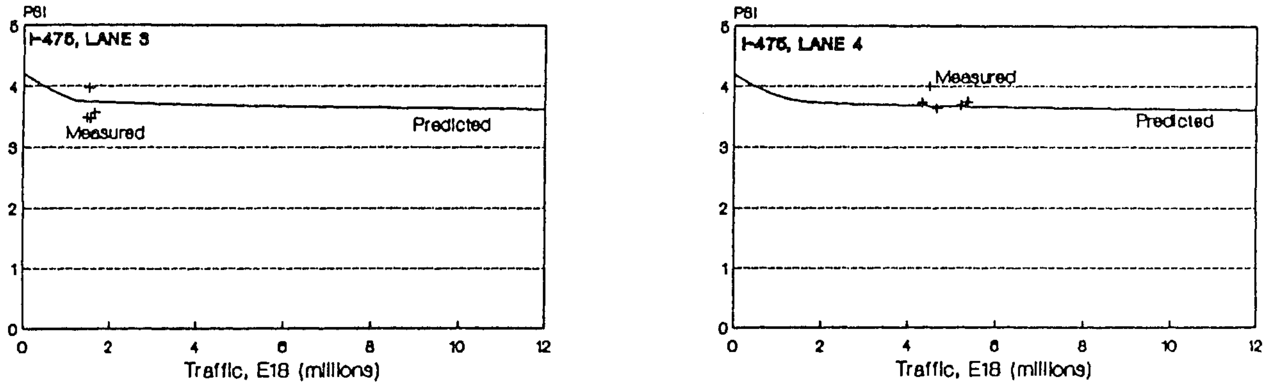

Figure 1. Comparison of predicted and measured PSI values, flexible pavements.

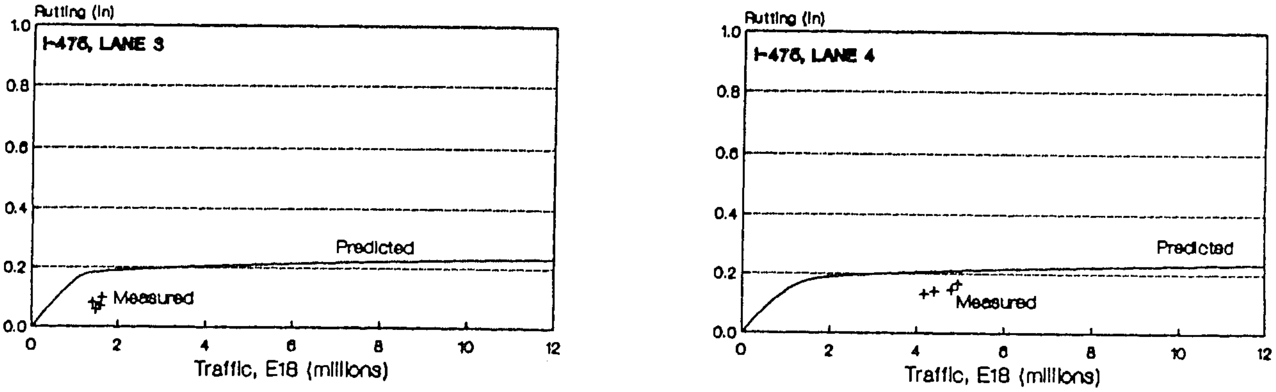

Figure 2. Comparison of predicted and measured rut depths, flexible pavements.

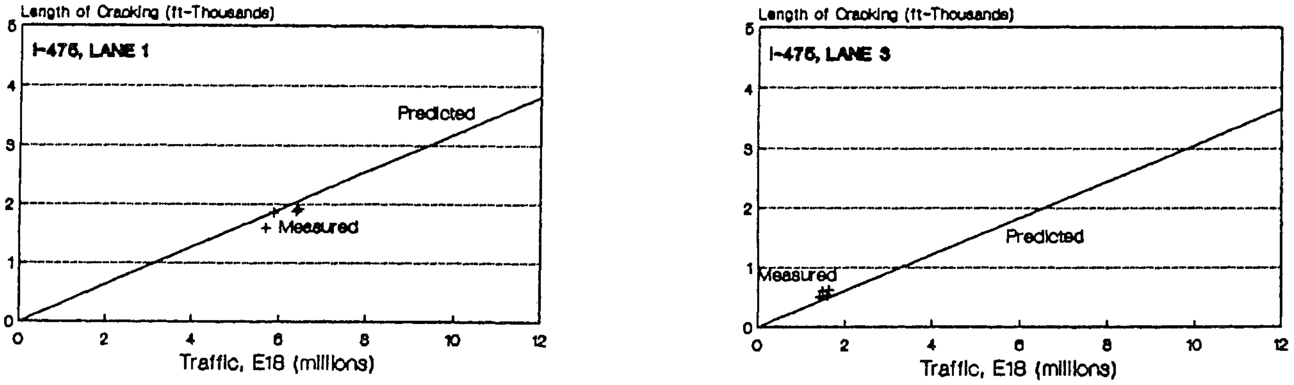

Figure 3. Comparison of predicted and measured cracking, flexible pavements.

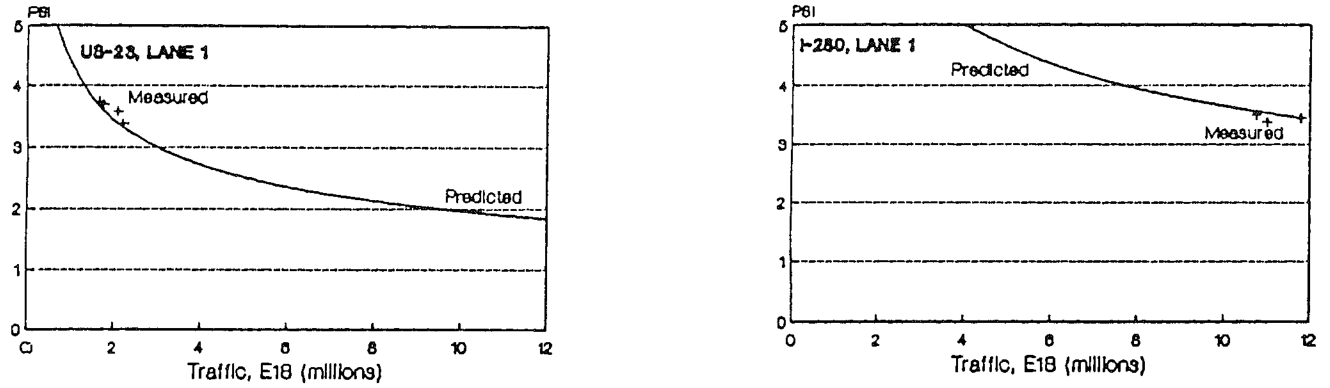

Figure 4. Comparison of predicted and measured PSI values, composite pavements.

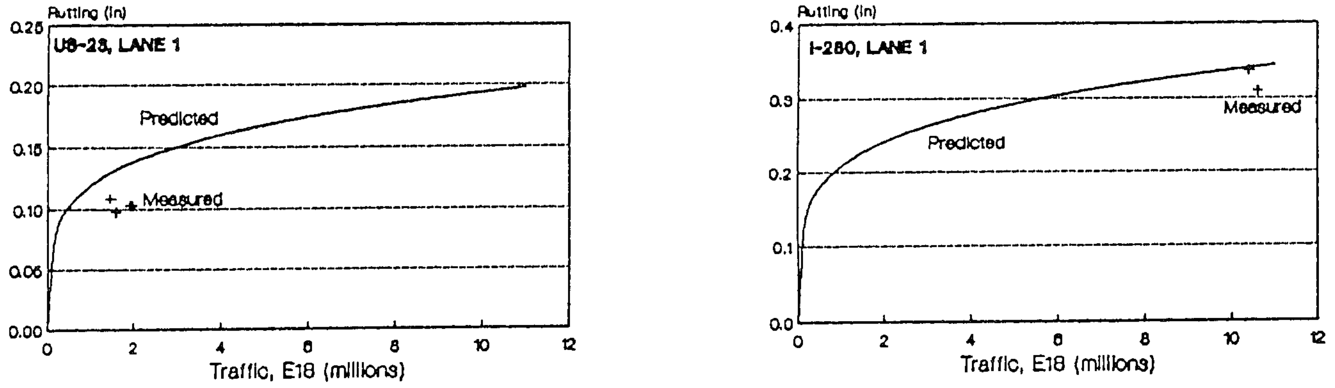

Figure 5. Comparison of predicted and measured rutting, composite pavements.

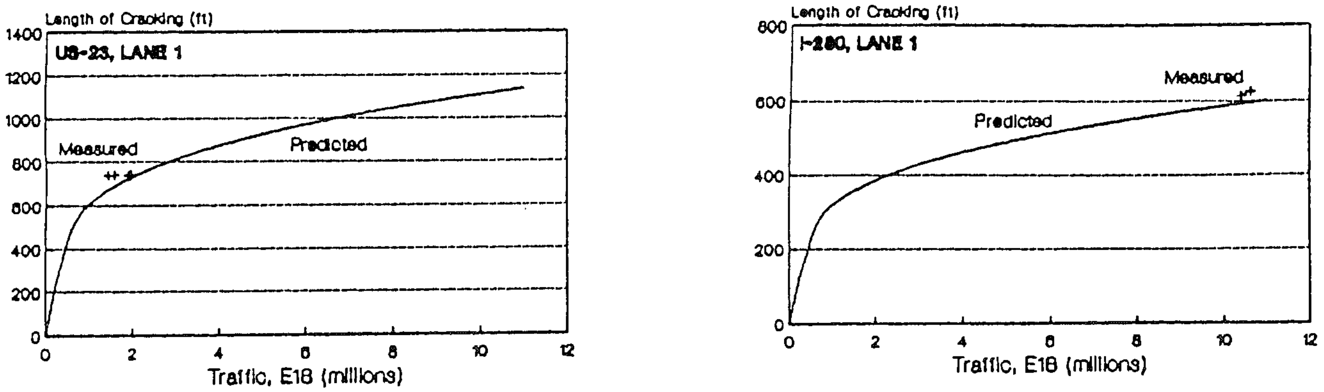

Figure 6. Comparison of predicted and measured cracking, composite pavements.

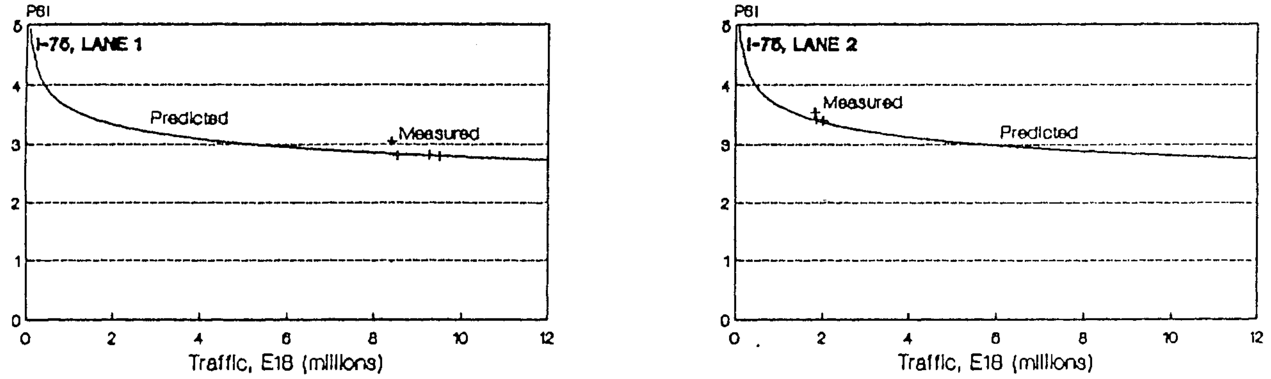

Figure 7. Comparison of predicted and measured PSI values, rigid pavements.

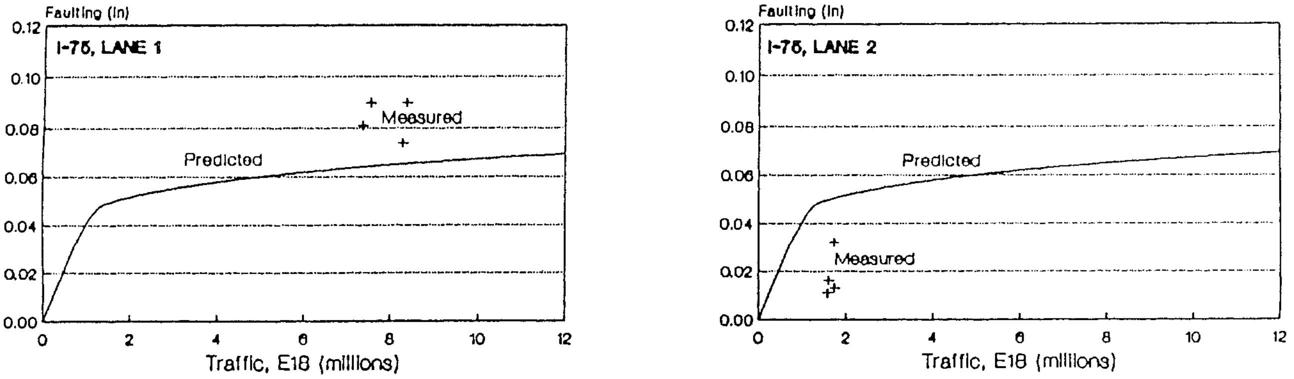

Figure 8. Comparison of predicted and measured faulting, rigid pavements.

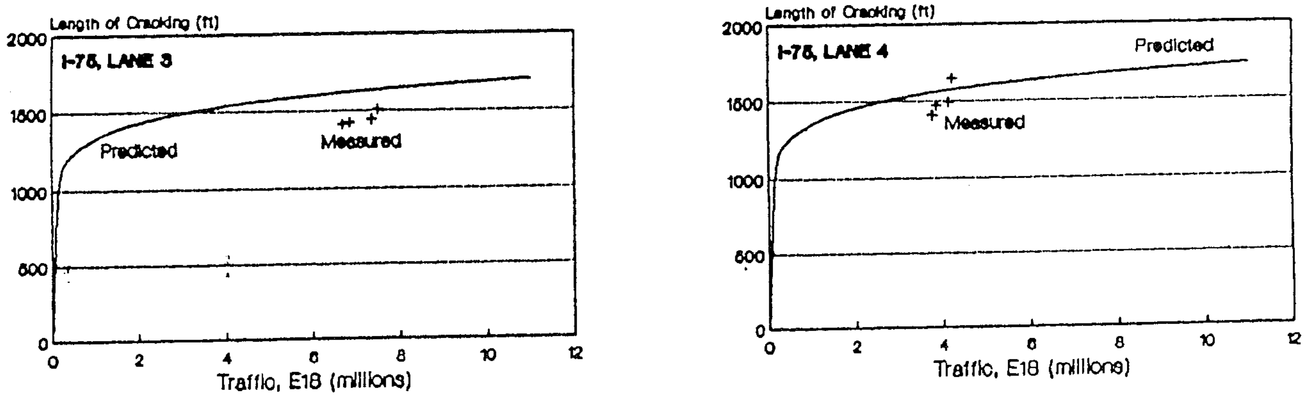

Figure 9. Comparison of predicted and measured cracking, rigid pavements.