Research Report
UKTRP-86-5

EVLUATION OF A FULL-DEPTH ASPHALTIC CONCRETE PAVEMENT

by

Herbert F. Southgate
Chief Research Engineer

Gary W. Sharpe
Chief Research Engineer

Mark Anderson
Research Engineer

and

Robert C. Deen
Director

Research Report
UKTRP-86-5

EVALUATION OF A FULL-DEPTH ASPHALTIC CONCRETE PAVEMENT

by

Herbert F. Southgate
Chief Research Engineer

Gary W. Sharpe
Chief Research Engineer

Mark Anderson
Research Engineer

and

Robert C. Deen
Director

Kentucky Transportation Research Program
College of Engineering
University of Kentucky
Lexington, Kentucky

Prepared for presentation to
Sixth International Conference on
Structural Design of Asphalt Pavements
Ann Arbor, Michigan
July 13-16, 1987

April 1986

EVALUATION OF A FULL-DEPTH ASPHALTIC CONCRETE PAVEMENT

Herbert F. Southgate[1], Gary W. Sharpe[1], Mark Anderson[2], and Robert C. Deen[3]

ABSTRACT

This study was initiated to verify a newly-developed set of design curves for full-depth asphaltic concrete pavements. Quality control during construction was checked using nuclear density testers, Benkelman beams, and a Road Rater. During the course of this study, an analysis system (predicated upon the elastic theory model) was developed to interpret the dynamic deflections as measured by the Road Rater. The thickness design curves were verified by elastic theory and deflection testing within the accuracy of construction variations.

Measured rut depths were analyzed in terms of potential rut depth resulting from consolidation under traffic due to lack of obtaining 100-percent of Marshall density during compaction.

Traffic was monitored using automatic traffic counters, manual classification/volume counts, and weigh-in-motion scales installed in the pavement.

INTRODUCTION

In 1968 a revision of the 1959 Kentucky thickness design curves for asphaltic concrete pavements included a new set of curves for full-depth asphaltic concrete (1). To provide performance data to verify those full-depth structural designs developed from elastic theory, an experimental pavement was constructed (2) on US 60 in Boyd County, Kentucky. Table 1 lists the design CBR´s, design and cored thicknesses, and station termini of experimental and control sections.

To monitor performance under traffic, the pavements were subjected to deflection testing, rut depths were measured, and roughness tests were made. Pavement temperatures were measured by thermistors installed at one site, and surface temperatures were obtained during deflection testing at various test sites. Pavement fatigue calculations required a knowledge of vehicle classifications, their volumes, and total vehicular loads within each classification. Thus, a weigh-in-motion system was installed at a location near the thermistor site.

DATA COLLECTION

Pavement Temperatures

Thermistors were installed at 51-mm (2-inch) increments throughout the 457-mm (18-inch) depth of asphaltic concrete. The thermistors were connected to a strip-chart recorder and monitored for approximately three years. By then approximately half of the thermistors had failed and the system was dismantled. Data were analyzed and observed temperature distributions verified predicted distributions using the procedure developed from data recorded in Maryland, New York, and Arizona (3, 4, 5).

Traffic Data

The weigh-in-motion system provided vehicle classification counts, axle loadings, and indicated that the existing axleloads were much more severe than thought and that axles within the same group of axles were not equally loaded (6, 7).

In addition to the data collected by the weigh-in-motion system, traffic counters were installed at four locations (two eastbound and two westbound) to obtain volume and lane

TABLE 1. PAVEMENT DESIGN AND CORED THICKNESSES

STATION		ASPHALTIC CONCRETE THICKNESS (INCHES)			BACK-CALCULATED
				DESIGN	DESIGN EAL (FATIGUE LIFE)
FROM	TO	DESIGN	CORE	CBR	(MILLION 18-KIP EAL
128+00	155+33	14.0	14.8	9	30.0
155+33	182+66	12.0	12.0	9	7.0
182+66	210+00	10.0	10.3	9	2.5
210+00	245+00	18.0	17.4	3	25.0
245+00	285+00	16.0	16.9	3	22.5
285+00	321+00	14.0	13.7	3	4.5
321+00	347+50	18.0	18.2	3	37.5
347+50	373+50	16.0	17.5	3	25.0
373+50	399+50	14.0	16.3	3	17.5
399+50	425+68	6.5*	6.8*	3	2.8

*Control Section -- Asphaltic concrete on 19 inches of dense-graded aggregate base
1 inch = 25.4 millimeters

---

[1] Chief Research Engineer, [2] Research Engineer, [3] Director
Transportation Research Program, University of Kentucky

distribution data. Volume data for both inner and outer lanes for all sites were recorded on punched paper tapes that were retrieved and processed by computer. Data were processed to obtain total vehicles per hour and were further summarized according to vehicles per day, week, month, and year.

Periodic classification counts were made manually for five different years at selected locations. Manual counts at the weigh-in-motion site served to verify classifications recorded when the scale system was placed in the automatic mode. Volume and classification data were used to determine lane distribution relationships and traffic growth trends that were required in the calculation of accumulated pavement fatigue.

Data from the weigh-in-motion system illustrated the need for a set of load equivalency factors for the steering axle and for tridems. Equivalency factors had not been developed for the steering axles at the AASHO Road Test, and tridem axle arrangements were not used at the AASHO Road Test. Adjustments to load equivalency factors also were required for the four-tired single axle and eight-tired tandem axles (8). Steering axleloads at the AASHO Road Test were thought to be sufficiently low and thus insignificant in terms of fatigue. Analysis of weigh-in-motion data using elastic layer concepts indicated a greater effect from front axles (particularly for heavily loaded vehicles). The Chevron N-layer computer program (9) was used to develop the load equivalency factors for both the steering axle and tridem groups.

Deflection Testing

A Model 400 Road Rater was used to monitor construction and long-term performance. Deflections were obtained on the subgrade just prior to paving and after placement of each lift of asphaltic concrete at preselected sites throughout the project (2). Upon completion of construction, Benkelman beam tests were conducted to permit the correlation of static and dynamic deflections obtained by the two pieces of equipment (10).

Construction scheduling and restrictions prevented all test sites from being tested prior to placement of the next layer of asphaltic concrete. At least three days were required for a layer to cure sufficiently to prevent the feet of the Road Rater from leaving indentation marks on the surface. Deflection measurements also were obtained at selected locations using the Road Rater each spring and fall over a 7-year period.

Construction Compaction

Density tests were conducted on each layer of asphaltic concrete after compaction had been completed. Vibratory rollers were being introduced to the construction scene, and this project was used as a test pavement to evaluate the performance of the roller (11).

PERFORMANCE EVALUATIONS

Vehicle Classification

Trends of the numbers of given vehicle classifications as a portion of the total volume were developed as a function of time. It was noted that the proportions of various vehicle styles do vary with time, indicating changes in vehicle usage. Analyses of traffic volumes showed there was an apparent equal distribution by direction. Data from manual classification counts also were evaluated to determine lane distribution and were supportive of lane distribution characteristics determined from data obtained with portable traffic counters. Lane distribution factors for various vehicle classifications had been developed previously (12) from data obtained at sites on Kentucky interstate routes and were essentially the same as observed on this test road. Volume data obtained from portable traffic counters were combined on an annual basis to determine average annual daily volumes as a function of time.

Damage Factors and Pavement Fatigue

Research in Kentucky (13, 14, 15, 16) have indicated that work and energy principles may be used as the basis for the designs of flexible pavements and have been utilized to evaluate pavement performance. Work and energy principles also have been applied to the development of traffic load equivalency factors or "damage factors" used to express pavement damage in terms of the damage attributable to an 80-kN (18-kip) axleload and to convert actual loadings for various vehicle styles and weights to equivalent 80-kN (18-kip) axleloads (EAL's).

Relationships of damage factors versus time for average statewide loadings have been determined (6, 7) using data reported in statewide W-4 tables from the Truck Weight and Vehicle Classification Studies. The trends were modified to reflect observations of vehicle weight data obtained from the weigh-in-motion facility for the various vehicle classifications. The relationships were used in the calculation of accumulated pavement fatigue (Figure 1) for US 60 in Boyd County. The range of loadings associated with various vehicle styles is summarized in Table 2.

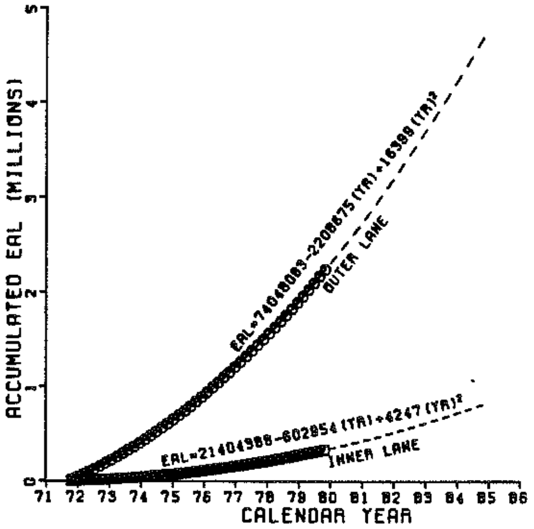

Figure 1. Accumulated 80-kN (18-kip) Equivalent Axleloads versus Calendar Year.

TABLE 2. TYPICAL LOADINGS ASSOCIATED WITH FATIGUE ESTIMATES

VEHICLE TYPE	GROSS LOADINGS (POUNDS)
Single Unit, Two Axles, Six Tires	16,000 - 26,000
Single Unit, Three Axles	42,000 - 62,000
Single Unit, Four Axles	92,000
Buses	26,000
Combination, Three Axles	40,000
Combination, Four Axles	54,000 - 60,000
Combination, Five Axles	76,000 - 85,000
Combination, Six Axles	110,000

PAVEMENT DETERIORATION CURVES

Pavement Deflection Measurements

Specific details regarding procedures for evaluation of pavement deflection measurements have been detailed previously (10, 13, 14, 17, 18 through 21). Resultant expressions of pavement structural condition involves a combination of estimated subgrade modulus and an effective thickness of asphaltic concrete (3.31-GPa (480-ksi) modulus). Such combinations are derived by evaluations of both the shape and magnitude of the measured deflection bowls matched with theoretically determined deflections.

All pavement sections in the US 60 project were tested with the Benkelman beam and the Road Rater. A correlation was developed (10) and used to interpret test results obtained using Benkelman beams in terms of the Road Rater.

Behavior of asphaltic concrete pavements are dependent upon the temperature distribution throughout the asphaltic concrete. The appropriate factor used to adjust deflections to an equivalent value at a reference temperature depends upon the particular piece of test equipment. Benkelman beam testing required a different set of adjustment factors (3) than those required for the Model 400 Road Rater (13, 14).

All pavement deflections were adjusted to 21.1 C (70 F) by estimating the temperature distribution in the asphaltic concrete pavement (3, 4, 5) and applying adjustment factors. Deflection data obtained in this study also were used to evaluate the seasonal variation of subgrade moduli, as shown in Figure 2 (12). Deflections could be adjusted to equivalent springtime conditions. Having adjusted measured deflections for temperature and subgrade conditions as a function of the time of year, methods were developed to express the behavior of the pavement as that of a thickness of reference-quality asphaltic concrete at a given subgrade modulus.

Normalization of Pavement Behavior

Direct comparisons of estimates of the structural conditions of the pavement sections are somewhat meaningless since expressions of pavement behavior involve a combination of subgrade modulus and effective thickness of reference-quality asphaltic concrete (3.31-GPa (480-ksi) modulus); there are an infinite number of combinations (but only a few are reasonable) that result in a theoretical deflection bowl that matches the measured deflection bowl. Therefore, it was necessary to normalize the results of pavement deflection evaluations to obtain meaningful comparisons.

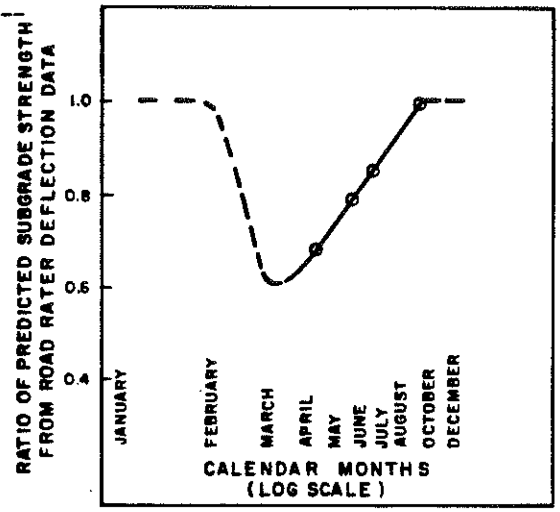

Figure 2. Adjustment Factor for Subgrade Modulus as a Function of Seasonal Variation.

Mean and 80th-percentile (weakest tail) subgrade moduli were determined for each design section. Theoretical relationships of No. 1 Sensor Road Rater deflection versus subgrade modulus were used to develop a relationship between the No. 1 Sensor deflection and pavement thickness for a constant 80th-percentile subgrade modulus for each design section. Measured No. 1 Sensor deflections were used as input into those relationships to determine an adjusted effective asphaltic concrete thickness in combination with the 80th-percentile subgrade modulus for each section. Adjusted effective asphaltic concrete thickness data were combined by design section and the statistical means were determined. Those mean adjusted effective thicknesses of asphaltic concrete were divided by the maximum effective asphaltic concrete thickness for each section to normalize effective thicknesses. Normalized values (for outside lanes only) were plotted versus accumulated 80-kN (18-kip) equivalent axleloads (Figure 3 is an example). A similar analysis was conducted for data obtained for the inner lanes but were not used since somewhat lesser levels of fatigue were observed and the levels of accumulated EAL's were significantly lesser than for the outside lanes.

Data from curves similar to Figure 3 were combined to develop pavement deterioration curves as illustrated in Figure 4, a plot of thickness versus EAL for three levels of normalized effective thickness for each design section or constructed thickness. Those relationships were used to refine the position of the lines representing the various constructed thicknesses into a family of curves for a constant level of EAL. The relationships were used further to develop the pavement deterioration curves in Figure 5, representing 51-mm (2-inch) increments of pavement thickness.

In Figure 5, the family of curves intersect the zero normalized effective thickness line at a range of EAL from 6,500,000 to 90,000,000, corresponding to 250 and 457 mm (10 and 18 inches) of asphaltic concrete. These points do not represent the projected total deterioration of the pavement structure since there is still considerable structural worth associated with unbound or granular material. However, these points do represent the projected total deterioration of the layer as asphaltic concrete.

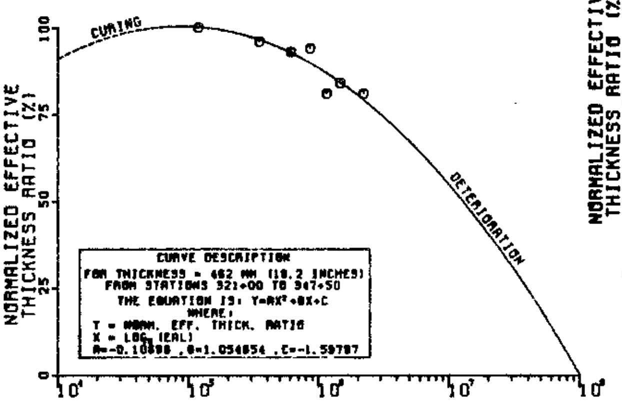

Figure 3. Normalized Effective Thickness versus Accumulated 80-kN (18-kip) Equivalent Axleloads for 462mm (18.2 inches) of Asphaltic Concrete -- Station 321+00 to 347+50.

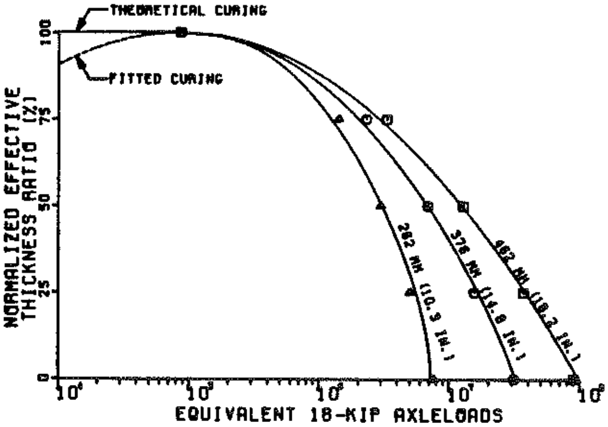

Figure 4. Normalized Effective Thickness versus Accumulated 80-kN (18-kip) Equivalent Axleloads for Constructed Thicknesses of Asphaltic Concrete.

Design EAL's were estimated using the Kentucky flexible design curves, the design thickness, and design CBR's (2) (see Table 1). In Table 1, the minimum expected design life for any pavement section is 2,500,000 EAL's and is associated with the 262-mm (10.3-inch) full-depth asphaltic concrete constructed on a CBR 9 subgrade. A review of figures similar to that in Figure 3 indicates relatively low levels of structural deterioration associated with this level of fatigue. The greatest level of structural deterioration (approximately 40 percent deterioration or less) is associated with the 262-mm (10.3-inch) full-depth asphaltic concrete. Figure 1 illustrates the accumulation of 2,500,000 EAL's that may be associated with 8.5 years service life for this pavement section. Figure 6 illustrates typical trends in roughness index or associated present serviceability index. Present serviceability indices corresponding to 8.5 years and 2,500,000 EAL's are generally greater than 3.0 and are greater than 2.5 for all sections. Therefore, it may be concluded that thickness design versus repetitions of 80-kN (18-kip) EAL's are consistent with observed pavement performance estimated on the basis of pavement roughness and associated present serviceability index.

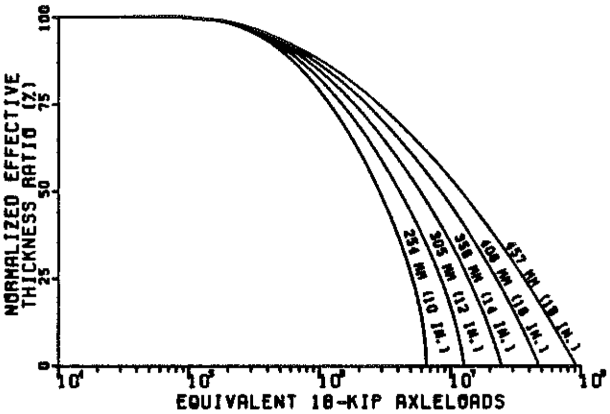

Figure 5. Pavement Deterioration for a Family of Asphaltic Concrete Thicknesses versus Accumulated Pavement Fatigue.

Curing Time

Asphaltic concrete gains strength (Young's modulus increases) with time (11). Analyses of Road Rater deflection data from this study indicated "curing" took two to three years, depending upon the thickness of the asphaltic concrete.

Deflections decreased with additional thicknesses of asphaltic concrete when sufficient time elapsed before construction of the succeeding layers (17). For those sites where another layer was constructed before the previous layer had sufficient time to cure, the magnitude of the deflections changed very little with the addition of the new lift; but eventually the deflections decreased, as was expected. Pavement deterioration curves similar to Figure 3 also reflect these observations.

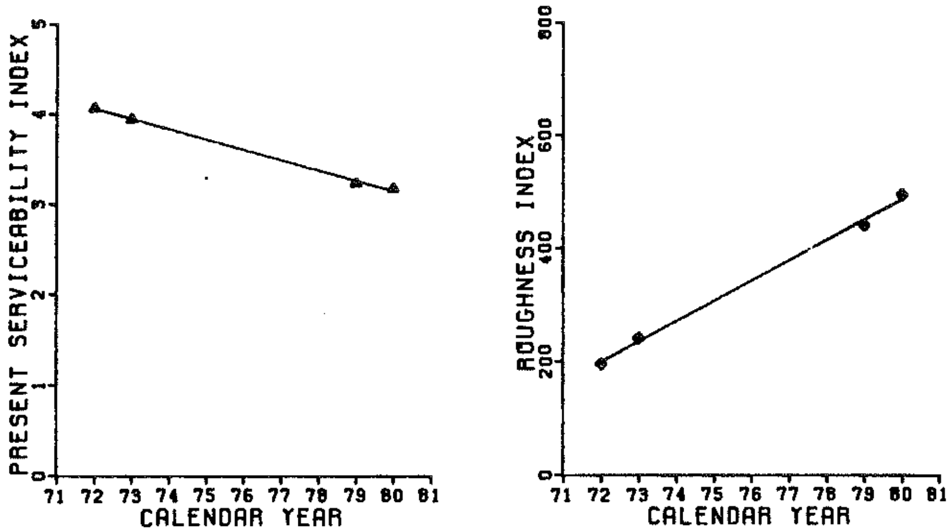

Figure 6. Percent Serviceability Index and Roughness Index versus Calendar Year -- 262mm (10.3 inches) of Asphaltic Concrete -- Station 182+66 to 210+00.

Rutting

Based on a laboratory study by Shook and Kallas (22), a relationship (23) was developed to reflect the change in modulus as a function of degree of compaction and/or variations in asphalt cement content. A mean compactive effort of 95 percent of Marshall density is achieved on many construction projects. During the life of the AASHO Road Test, a 76-mm (3-inch) overlay was placed over a number of sections. A detailed study of the data for the Road Test sections revealed that 3.8-mm (0.15-inch) ruts were measured within 3 months after paving. Assuming the overlay at the AASHO Road Test was compacted to 95 percent, then 0.05 x 76 mm = 3.8 mm rut. This concept may explain, in part, the difference between the constructed and behavioral thicknesses for US 60.

Each pavement section was cored upon completion of construction (2) and the thickness of each layer measured. Those thicknesses were used to estimate the potential rutting. Compacted densities of the asphaltic concrete were recorded as a percent of the target density. Potential rutting was calculated by taking the difference between the target density and the achieved density, divided by 100, multiplied by the layer thickness, and accumulated for the total thickness. Table 3 contains representative examples of detailed data used to calculate the potential rutting.

For many test sites, the behavioral thickness was less than the cored thickness. Assuming the same subgrade moduli, the core thickness minus the accumulated potential rutting very nearly equaled the behavioral thickness. Table 4 indicates amazingly close agreement, considering that only one core was taken from each pavement design section.

Measured rutting data compared to potential rutting are presented in Table 4. The potential rut depth was accumulated, layer by layer, from the pavement surface downward until the total thickness at which the accumulated potential rut depth equaled the measured rut depth was obtained. That thickness was divided by the total thickness of the asphaltic concrete and expressed as a percentage. The measured rut depth was converted to a percentage of the total potential rut depth. Figure 7 illustrates the relationship between the measured rut depth expressed as a percentage of the total potential rut depth and the thickness to 100-percent compaction expressed as a percentage of the total thickness of asphaltic concrete.

Measured rut depths exceeding the calculated potential rutting are likely related to other factors, which may include shearing and/or plastic flow. Trenches were cut in two pavement sections on US 60. Visual inspections indicated rutting to be restricted to the top one third of the pavement section. Thus, one hypothesis is that rutting greater than the calculated potential may be associated with plastic flow of the pavement structure under the application of high tire pressures. Plastic flow may be related to low stability of the asphalt mixture. However data were not obtained in this study to definitely indicate such a conclusion.

In some instances, the number of passes of the rollers was inconsistent from station to station and section to section. As a result, compacted densities ranged from 82.9 percent to 102.0 percent of the target density. Thus, heavy truck loads probably completed, or partially completed, the compactive effort not obtained during construction.

Pavement Roughness and Serviceability

Pavement roughness data were obtained for four years between 1972 and 1979 using both the Surface Dynamics Profilometer and the Mays Ridemeter. Data from each device were converted to a roughness index (RI) as described in earlier research (24, 25, 26),

TABLE 3. RUTTING POTENTIALLY ATTRIBUTED TO DEGREE OF COMPACTION DURING CONSTRUCTION

	LAYER		PERCENT COMPACTION (Note 1)	POTENTIAL RUTTING (INCHES) (Note 2)	ACCUMULATED RUTTING (INCHES) (Note 3)
STATION	NO.	THICKNESS (INCHES)			
155+00	S	1.1	94.2	0.0638	0.0638
	4	4.9	93.2	0.3332	0.3970
	3	3.1	89.0	0.3410	0.7380
	2	3.1	94.7	0.1643	0.9023
	1	2.6	94.1	0.1534	1.0557
215+00	S	1.1	95.8	0.0462	0.0462
	5	2.8	90.4	0.2688	0.3150
	4	3.8	94.7	0.2014	0.5164
	3	3.0	91.9	0.2430	0.7594
	2	3.1	91.9	0.2511	1.0105
	1	3.6	92.6	0.2664	1.2769
264+00	S	1.1	95.8	0.0462	0.0462
	5	3.2	98.9	0.0352	0.0814
	4	3.9	86.2	0.5382	0.6196
	3	3.3	91.9	0.2673	0.8869
	2	3.5	89.0	0.3850	1.2719
	1	1.9	89.8	0.1938	1.4657
295+50	S	1.0	95.8	0.0420	0.0420
	4	3.0	91.9	0.2430	0.2850
	3	3.8	98.9	0.0418	0.3268
	2	3.1	94.7	0.1643	0.4911
	1	2.8	91.3	0.2436	0.7347
396+50	S	1.0	94.2	0.0580	0.0580
	4	4.1	90.4	0.3936	0.4516
	3	5.0	93.2	0.3400	0.7916
	2	3.2	96.1	0.1248	0.9164
	1	3.0	92.6	0.2220	1.1384
407+50	S	1.1	96.8	0.0352	0.0352
	2	2.9	89.0	0.3190	0.3542
	1	2.8	92.6	0.2072	0.5614

Note 1. Data from Ref 2

Note 2. Calculated as: (100 - Percent Compaction) x (Layer Thickness) / 100

Note 3. Accumulated Potential Rutting = Sum starting at surface and extending downward through asphaltic concrete

1 inch = 25.4 millimeters

and then converted to an estimate of pavement serviceability index (PSI). Trends of average pavement roughness versus service life and also pavement serviceability versus service life by design section, similar to Figure 6, were developed for each design section. A scale for accumulated equivalent axleloads (EAL´s) may be superimposed on the service life scale, using information presented in Figure 1.

The roughness index generally increases with increasing service life (or accumulated EAL´s), and the pavement serviceability index decreases in a similar fashion. Linear models generally provided an acceptable description of the variation of the data. Roughness measurements expressed as a pavement serviceability index generally confirmed that the level of serviceability of 3.5 to 3.0 coincided with early visible signs of surface distress.

SUMMARY

Measured temperature distributions verified the temperature estimation system (3, 4, 5) used in the methodology to evaluate the behavior of pavement sections.

Construction procedures produced wide variations in the subgrade, the asphaltic concrete mixture, compacted densities within any given layer and between layers, and total thickness. Those variations may be related to variations in behavioral thicknesses and subgrade moduli. However, for the same subgrade moduli (design CBR), construction variations in compaction and asphalt content may have contributed to decreases in thickness (consolidation) under traffic loadings until it very nearly matched the behavioral thickness. Temperature of the uncompacted asphaltic concrete should be no less than 105 C (220 F), and compaction

TABLE 4. RUTTING POTENTIALS AND MEASUREMENTS TAKEN SEPTEMBER 1979
IN INNER WHEELTRACK OF OUTER LANE

STATION	PAVEMENT (CORE) THICKNESS (INCHES)	MEASURED RUT DEPTH-INNER WHEEL TRACK (INCHES)	MEASURED RUT AS PERCENTAGE OF POTENTIAL RUT	DEPTH TO FULL CONSOLIDATION AS PERCENTAGE OF TOTAL THICKNESS	POTENTIAL RUTTING (INCHES)	CORE MINUS POTENTIAL RUTTING (INCHES)	BEHAVIORAL THICKNESS (INCHES)
135+00	14.8	0.750	87.0*	86.0	0.86	13.9	14.0
140+00	14.8	0.563	42.0	40.5			
145+00	14.8	0.813	82.0	71.0			
150+00	14.8	0.563	53.0	58.0			
155+00	14.8	0.938	89.0	86.5	1.06	13.7	13.3
160+00	12.0	0.875	106.0	100.0+	0.83	11.2	11.3
215+00	17.4	0.625	48.9	52.0	1.28	16.1	16.0
262+00	16.9	0.688	67.8	75.1	1.01	15.9	15.7
264+00	16.9	0.688	46.9	53.5	1.47	15.4	15.5
268+50	16.9	0.813	69.3	85.0			
271+00	16.9				1.17	15.7	15.7
279+50	16.9	0.688	49.6	69.1	1.39	15.5	15.5
289+50	13.7	0.625	93.7	97.0			
295+50	13.7	0.688	93.6	96.1	0.73	13.0	12.9
299+00	13.7	0.625	103.0	100.0+	0.61	13.1	12.0
306+00	13.7	0.750	109.0	100.0+	0.75	12.9	13.0
306+50	13.7	0.750	100.0	100.0			
307+00	13.7	0.750	86.1	85.0			
359+00	17.5				1.11	16.4	16.3
360+50	17.5	0.375	60.6	62.9	1.03	16.5	16.3
376+50	16.3	0.625	51.4	31.9	1.22	15.1	15.0
396+50	16.3	0.750	65.9	58.2	1.14	15.2	15.2
403+50**	6.8	0.625	192.0	100.0+	0.33	6.5	6.5
405+50**	6.8	0.625	84.4	85.3			
407+50**	6.8	0.563	100.3	100.0+	0.56	6.2	5.8
410+00**	6.8	0.625	102.3	100.0+	0.61	6.2	6.0
414+00**	6.8	0.500	60.3	55.4	0.83	6.0	5.8

* See Table 3 for example of how these figures are calculated
** 6.8 inches asphaltic concrete over 19.0 inches dense-graded aggregate
1 inch = 25.4 millimeters

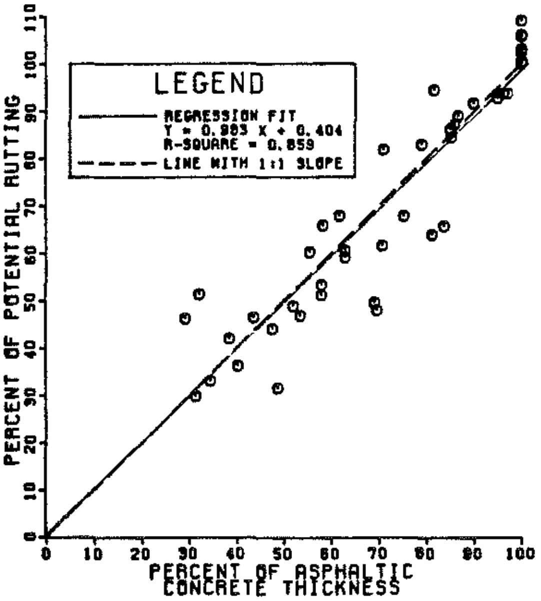

Figure 7. Measured Rut Depth as a Percentage of Potential Rut Depth due to Incomplete Compaction during Construction versus Depth from Surface for Fully Consolidated Asphaltic Concrete as Percentage of Total Thickness of Asphaltic Concrete.

should be completed before the temperature drops below 82.2 C (180 F).

The degree of compaction obtained during construction can be used to calculate the potential consolidation (rutting) that may occur under traffic. Since the measured rutting was closely approximated by this measure of potential rutting, rutting on this project was probably the result of consolidation rather than displacement by shearing.

Traffic volume, classification counts, limited weight data from the weigh-in-motion system, and an updated and expanded set of damage factors for various axle configurations combined to verify the full-depth thickness design curves. Measured ruts and roughness measurements combined to add additional data in verifying the pavement serviceability rating system.

Dynamic deflections as measured by the Road Rater have been used to determine the behavioral thickness of asphaltic concrete pavements. Analyses of data from this study provided for the testing of pavement evaluation methodologies. The current analysis procedure has been used over wide ranges of subgrade conditions, from thin to moderately thick pavement sections, for pavements with and without dense-graded aggregate bases, and from tests at the same locations "before and after" overlay construction.

Evaluation methods to interpret measured deflections and to quantify them in terms of behavioral thicknesses and estimated subgrade moduli resulted in their acceptance as a tool in the annual rehabilitation program within the pavement management program of the Kentucky Transportation Cabinet. City streets have been tested and evaluated. Significant savings or more effective utilization of funds have resulted either by placing thinner overlays than had been anticipated by more traditional approaches, or by requiring greater thicknesses than had been anticipated so as to prevent or minimize premature failures.

Confirmation of the fatigue relationship for asphaltic concrete pavements has permitted the development of criteria used to develop thickness design methods for other pavement systems (for example, portland cement concrete pavements (27, 28), for asphaltic concrete pavements having a pozzolanic base (29), and for evaluating fragmented portland cement concrete as input to an overlay design).

Heavily loaded trucks with new axle configurations necessitated the reassessment of load equivalency relationships for steering axles, single axles, tandem axles, and tridem axle groups. The need to determine their effect upon the rate of accumulation of pavement fatigue was a direct result of analyses of weigh-in-motion data obtained in this study. Adjustment factors were developed to account for uneven load distributions on the axles within the tandem (6) and tridem axle assemblies (7).

REFERENCES

1. J. H. Havens, R. C. Deen, and H. F. Southgate, "Design Guide for Bituminous Concrete Pavement Structures," Research Report 376, Division of Research, Kentucky Bureau of Highways, Lexington, September 1973.
2. J. D. Ross and H. F. Southgate, "Construction of Full-Depth Asphaltic Concrete Pavements," Research Report 340, Division of Research, Kentucky Department of Highways, Lexington, September 1972.
3. H. F. Southgate, "An Evaluation of Temperature Distribution within Asphalt Pavements and Its Relationship to Pavement Deflection," Research Report 295, Division of Research, Kentucky Department of Highways, Lexington, April 1968.
4. H. F. Southgate and R. C. Deen, "Temperature Distribution within Asphalt Pavements and Its Relationship to Pavement Deflection," Record 291, Highway Research Board, Washington, D. C., 1969.
5. H. F. Southgate and R. C. Deen, "Temperature Distribution within Asphalt Pavements," Record 549, Transportation Research Board, Washington, D. C., 1975.
6. R. C. Deen, H. F. Southgate, and J. G. Mayes, "The Effect of Truck Design on Pavement Performance," Proceedings of the Association of Asphalt Paving Technologists, Volume 49, Louisville, Kentucky, 1980.
7. H. F. Southgate and R. C. Deen, "Variations of Fatigue due to Unevenly Loaded Axles within Tridem Groups," Research Report UKTRP-84-11, Kentucky Transportation Research Program, College of Engineering, University of Kentucky, Lexington, April 1984.
8. J. H. Havens, R. C. Deen, and H. F. Southgate, "Fatigue Damage of Flexible Pavements under Heavy Loads," Record 725, Transportation Research Board, Washington, D. C., 1980.
9. J. Michelow, "Analysis of Stresses and Displacements in an N-Layered Elastic System under a Load Uniformly Distributed on a Circular Area," Unpublished, Richmond, CA, September 24, 1963.
10. G. W. Sharpe and H. F. Southgate, "Road Rater and Benkelman Beam Pavement Deflections," Research Report 523, Division of Research, Kentucky Bureau of Highways, Lexington, June 1979.
11. J. D. Ross, H. F. Southgate, and D. C. Newberry, Jr., "Comparative Evaluation of Raygo 404 Vibratory Roller," Research Report 328, Division of Research, Kentucky Department of Highways, Lexington, April 1972.
12. H. F. Southgate, R. C. Deen, J. H. Havens, and W. B. Drake, "Kentucky Research: A Flexible Pavement Design and Management System," Proceedings, Fourth International Conference on the Structural Design of Asphalt Pavements, University of Michigan, Ann Arbor, 1977.
13. G. W. Sharpe, H. F. Southgate, and R. C. Deen, "Pavement Evaluation Using Road Rater Deflections," Research Report 501, Division of Research, Kentucky Bureau of Highways, Lexington, August 1978.
14. G. W. Sharpe, H. F. Southgate, and R. C. Deen, "Pavement Evaluation Using Dynamic Deflections," Research Record 700, Transportation Research Board, 1979.
15. H. F. Southgate, R. C. Deen, and J. H. Havens, "Development of a Thickness Design System for Bituminous Concrete Pavements," Research Report UKTRP-81-20, Kentucky Transportation Research Program, College of Engineering, University of Kentucky, Lexington, November 1981.
16. J. H. Havens, R. C. Deen, and H. F. Southgate, "Design Guide for Bituminous Concrete Pavement Structures," Research Report UKTRP-81-17, Kentucky Transportation Research Program, College of Engineering, University of Kentucky, Lexington, August 1981.
17. H. F. Southgate and R. C. Deen, "Deflection Behavior of Asphaltic Concrete Pavements," Research Report 415, Division of Research, Kentucky Bureau of Highways, Lexington, January 1975.
18. H. F. Southgate, G. W. Sharpe, R. C. Deen, and J. H. Havens, "Structural Capacity of In-Place Asphaltic Concrete Pavements from Dynamic Deflections," Proceedings, Fifth International Conference on the Structural Design of Asphalt Pavements, The University of Michigan and The Delft University of Technology, The Netherlands, August 23-26, 1982.
19. R. C. Deen, H. F. Southgate, and G. W. Sharpe, "Evaluation of Asphaltic Pavements for Overlay Design," presented to American Society for Testing and Materials Symposium on Pavement Maintenance and Rehabilitation, December 7, 1983, Bal Harbour, FL (publication pending).

20. R. C. Deen, H. F. Southgate, and G. W. Sharpe, "Evaluation of Asphaltic Pavements for Overlay Design," presented to Federal Highway Administration Workshop on Pavement Rehabilitation, May 15, 1984, Oklahoma City, OK (publication pending).

21. H. F. Southgate, G. W. Sharpe, and R. C. Deen, "Pavement Testing -- Before and After an Overlay," International Symposium on Bearing Capacity of Roads and Airfields, Trondheim, Norway, June 23-25, 1982.

22. J. F. Shook and B. F. Kallas, "Factors Influencing Dynamic Modulus of Asphaltic Concrete," Proceedings of The Association of Asphalt Paving Technologists, Volume 38, Los Angeles, 1969.

23. H. F. Southgate, "Effects of Construction Variations upon Dynamic Moduli of Asphaltic Concrete," Proceedings of The Association of Asphalt Paving Technologists, Volume 51, Kansas City, 1982.

24. G. W. Sharpe, D. H. Cain, H. F. Southgate, J. H. Havens, and R. C. Deen, "Pavement Roughness in Kentucky," Research Report UKTRP-82-9, Kentucky Transportation Research Program, College of Engineering, University of Kentucky, Lexington, July 1982.

25. R. L. Rizenbergs, J. L. Burchett, and L. E. Davis, "Pavement Roughness: Measurement and Evaluation," Record 471, Highway Research Board, Washington, D. C., 1973.

26. R. L. Rizenbergs, "Accelerometer Method of Riding Quality Testing," Research Report 223, Division of Research, Kentucky Department of Highways, Lexington, February 1965.

27. H. F. Southgate, J. H. Havens, R. C. Deen, and D. C. Newberry, Jr., "Development of a Thickness Design System for Portland Cement Concrete Pavements," Research Report UKTRP-83-5, Kentucky Transportation Research Program, College of Engineering, University of Kentucky, Lexington, February 1983.

28. H. F. Southgate and R. C. Deen, "Thickness Design Curves for Portland Cement Concrete Pavements," Research Report UKTRP-84-3, Kentucky Transportation Research Program, College of Engineering, University of Kentucky, Lexington, February 1984.

29. G. W. Sharpe, R. C. Deen, H. F. Southgate, and M. Anderson, "Pavement Thickness Designs Using Low-Strength (Pozzolanic) Base and Subbase Materials," Research Report UKTRP-84-23, Kentucky Transportation Research Program, College of Engineering, University of Kentucky, Lexington, August 1984.