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Publication of this paper sponsored by Committee on Pavement Condition Evaluation.

A Rational System for Design of Thickness of Asphalt Concrete Overlays

Herbert F. Southgate, Gary W. Sharpe, and Robert C. Deen, Bureau of Highways, Kentucky Department of Transportation, Lexington

A method for designing asphalt concrete overlays is presented that uses (a) the Kentucky proposed design curves, (b) an estimation of future traffic and the associated fatigue (five procedures are given according to type of information available), (c) the strength of the subgrade on the subject project (as determined by laboratory California bearing ratio tests or results of dynamic in-place tests such as road rater measurements), and (d) the present condition of the existing pavement (as determined from dynamic in-place tests, roughness measurements, or the present serviceability index). Deterioration is expressed as reduced thicknesses of new-quality materials that produce the same measured dynamic deflections. The overlay thickness required is the total thickness for the predicted traffic minus the effective or reduced thickness of the existing pavement.

The method for the design of overlay thicknesses presented in this paper has evolved from approximately 30 years of experience in thickness design. The earliest pavement-thickness design methods used in Kentucky were based on 22-kN (5000-lbf) equivalent wheel loads

(EWLs) (1). In 1973, a design procedure was proposed (2) that used 80-kN (18 000-lbf) axle loads and was similar to the procedure of the AASHO Interim Guide (3) (although the damage factors differed). The design of overlays (that is, the determination of required thicknesses) requires as inputs (a) a measurement of the load-carrying capacity of the subgrade, (b) an evaluation of the condition of the existing pavement, and (c) an estimation of expected traffic and associated fatigue.

Subgrade strength is determined by the California bearing ratio (CBR) test method. The CBR test procedure used in Kentucky differs from the American Society for Testing and Materials (ASTM) method only in the length of time of soaking before testing. The Kentucky method allows the sample to soak until swelling ceases and expresses the CBR values as Young's moduli by multiplying by 1500 (4). As expected, in-place dynamic test procedures generally give an estimated subgrade modulus greater than that obtained by the Kentucky laboratory CBR method because the in-place subgrade is not in the critical moisture-content state represented by the soaked conditions of the laboratory test. Thus, the overlay thickness should be determined by using the CBR curve equivalent to the weakest subgrade modulus obtained during in-place testing.

The proper design thickness for an overlay depends on the condition of the existing pavement. The existing condition can be expressed as a reduced modulus of the asphalt concrete (AC) or as reduced layer thicknesses of new materials that have the reference moduli. The concept of reduced thickness is used in this procedure (5, 6). The overlay thickness is that which must be added to the existing pavement so that there will be sufficient structural capacity to support the forecasted traffic or equivalent axle loads (EALs).

Normally, traffic volumes are estimated in connection with needs studies and in the planning stages for new routes and for major improvements of existing routes. However, although the anticipated traffic volume is an important consideration in the styling and geometric design of a roadway, the composition of the traffic in terms of axle loads (and possibly lane distributions) is essential for the structural design of pavements. Traffic volumes used for EAL computations should therefore be reconciled with other planning forecasts of traffic. Historically, actual growths of traffic have usually exceeded forecasts. Overriding predictions of traffic volumes may be admissible for purposes of EAL estimates when properly substantiated. Moreover, the design life of the pavement may differ from the geometric design period.

Basically, computation of the EALs involves forecasting the total number of vehicles expected on the road during its design life and multiplying by factors that convert traffic to EALs. The ideal approach would be to calculate and sum the yearly increments of EALs; this would permit including consideration of anticipated changes in legal weight limits, changes in styles of cargo haulers, and changes in routing.

DETERMINATION OF DESIGN EQUIVALENT AXLE LOADS

There are several methods of estimating the number of 80-kN EALs. For a particular design situation, the one that matches the data base available should be used.

Deacon and Deen Method

Deacon and Deen (7) have described the development and testing of a predictive method (calculation of EALs) for rural highways in Kentucky. The problem was treated as three separate but interrelated parts: (a) development of a proper methodology and identification of pertinent traffic parameters, (b) identification of relevant local conditions that could serve as indicators of the composition and loads of the traffic stream, and (c) development of significant relationships between the traffic parameters and the local conditions. The traffic parameters selected as most significant were the percentages of the various vehicle types and the average number of EALs per vehicle. These were empirically related by multiple regression and other techniques to the set of local conditions, which included road type, direction of travel, availability and quality of alternative routes, type of service provided, traffic volume, maximum allowable gross weight, geographical area, and season. The resultant methodology was judged to be sufficiently accurate, simple, reasonable, and usable to satisfy problem requirements. It is recommended for use, however, only when valid, long-term vehicle classification and load data are unavailable for the route under investigation. The relationships should be updated every two to five years to account for changes in use of vehicle types and changes in axle load limits.

Similar Situations Method

Another method of estimating EALs is by using data from similar facilities. Volume and classification data from parallel and feeder routes can be used when available. Where possible, the new facilities chosen as models should be ones for which there are recorded data representing conditions both before and after construction.

Traffic and Classification Counts

The Federal Highway Administration publishes W-4 tables each year for each state. These tables contain load data by classification of vehicle. The data are listed by site, combined into rural or urban tables, and then combined into total statewide values. If a weighing station is located near the facility being considered and the expected classification of traffic is approximately the same, the analyses should be based on that W-4 table. Otherwise, the statewide W-4 table or one covering groupings of similar sites may be more appropriate.

Several types of analyses can be made from the W-4 tables. The following procedure is suggested.

1. Express the vehicle classification counts as a ratio: C_i = classification count ÷ total number of vehicles counted, where i = vehicle classification.
2. From the W-4 tables, calculate an average damage factor (DF_i) for each vehicle classification by year by using Equation 1.

$$DF_i = \left(\sum_{j=1}^{m} N_j \times F\right) \Big/ (\text{number of weighed vehicles per classification}) \quad (1)$$

where

N = number of axles that have single axle load P_s or tandem axle load P_t (kips),
m = number of load categories (j) in the W-4 table, and
F = damage factor for AC, axle configuration, and axle load as determined from the table below.

Axle Load	F
Single	$1.2504^{(P_s - 18)}$
Tandem	$1.1254^{(P_t - 34)}$

(The coefficients in the table above were determined for

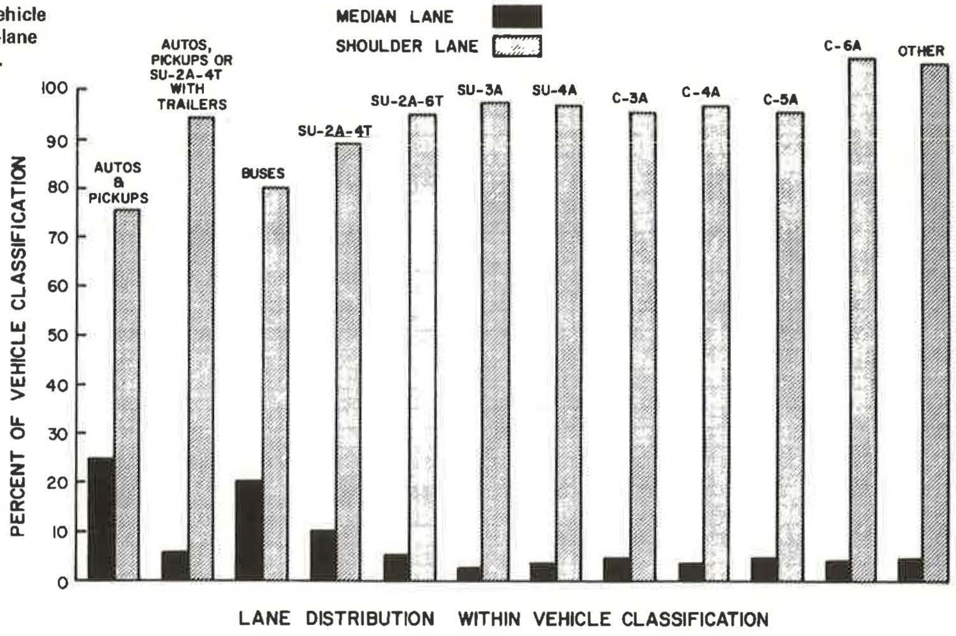
Table 1. Damage factors by vehicle classification: asphalt concrete pavements.

Type of Vehicle	No. of Vehicles Weighed	Total No. of 80-kN EALS	Avg. No. of 80-kN EALS per Vehicle	Damage Factor by Year[a]	
				M	B
Single unit: two axles, four tires	8 564	518.2	0.0605	0.008 310	-1.812 12
Single unit: two axles, six tires	19 058	5 627.6	0.2953	0.008 400	-1.198 76
Single unit: three axles	2 848	1 818.7	0.6386	0.042 940	-2.757 30
Combination unit: three axles	4 701	2 986.7	0.6353	0.008 466	-0.834 29
Combination unit: four axles	15 217	11 434.7	0.7514	0.009 622	-0.568 25
Combination unit: five axles	21 673	13 583.1	0.6267	0.012 298	-0.606 87
Automobiles and pickup trucks			0.0501		

Note: 1 kN = 225 lbf.

[a] Damage factor(year) = M(year - 1959) + B (for years after 1958).

Figure 1. Distribution of vehicle classifications by lane: four-lane facility at level of service A.



U.S. customary units only.) The average damage factors for Kentucky traffic from 1958 through 1975 for each vehicle classification are given in Table 1.

3. Estimate the lane distribution (LD_i) for highways that have four or more lanes for each vehicle classification. Figure 1 shows a typical set of factors for each vehicle classification [single unit: two axles, four tires (SU2A4T); single unit: two axles, six tires (SU2A6T); single unit: three axles (SU3A); combination unit: three axles (C3A); combination unit: four axles (C4A); combination unit: five axles (C5A); and automobiles and pickup trucks] for level of service A on a four-lane facility (2); similar figures have been developed for other levels of service and six-lane facilities (2, 5).

4. For each year, calculate the number of 80-kN EALs by using Equation 2.

$$EAL = 365 \times AADT \times \sum_{i=1}^{n_m} [C_i \times DF_i \times LD_i] \qquad (2)$$

where

AADT = annual average daily traffic and
n_m = maximum number of vehicle classifications used.

5. Add the EALs calculated in step 4 for each year since the pavement was opened to traffic to determine the total estimated EALs to date.

6. Plot the total EALs for each year against the year or fit an equation to the data.

7. Determine the design EAL. If the graphical method was used in step 6, draw a trend line through the data and project to the design year; if an equation was developed in step 6, solve it.

Volumes and Percentages of Trucks

This procedure should be used to estimate the number of 80-kN EALs when the only data available are the traffic volume and the percentage of trucks in the traffic stream.

1. Obtain the volumes from hand counts, recorded machine counts, or published AADT maps.

2. Obtain the percentage of trucks from classification counts made by survey teams.

3. From the W-4 table for a particular year, obtain the average number of axles per truck (APT) by using Equation 3.

$$APT = \sum_{i=1}^{n} A_i \times T_i / \Sigma T_i \qquad (3)$$

where

A_i = number of axles for vehicle classification i,
T_i = number of trucks in vehicle classification i, and
n = total number of vehicle classifications in the W-4 table.

4. From the W-4 table for a particular year, obtain the average axle load (AAL) by using Equation 4.

$$AAL = \sum_{j=1}^{m} [N_j \times AL_j]/[N_S + N_T] \quad (4)$$

where

N_j = number of axles in load category j,
AL_j = axle load for load category j,
m = number of load categories in the W-4 table,
N_s = number of single axles, and
N_T = number of tandem axles.

This provides only an approximation of the average axle load because actual axle loads may range from 8.9 to 267 kN (2000 to 60 000 lbf) depending on the axle configuration and truck style.

5. Calculate the damage factor (DF_{AAL}) for the average axle load by using Equation 5.

$$DF_{AAL} = 1.2504^{(AAL - 18)} \quad (5)$$

Errors involved in using this equation are minimal compared with those involved in predicting traffic volumes.

6. Obtain the lane-distribution factors from the appropriate portion of Table 2.

7. Plot graphs as a function of time or fit equations to the data for the following parameters: volume, percentage of trucks, APT, AAL, and lane-distribution factors. From the graphs or equations, obtain the data for missing years by interpolation and projection.

8. Determine the EAL for each year by using Equation 6.

$$EAL = [(\text{percentage automobiles} \times DF_A) + (\text{percentage trucks} \times APT \times DF_{AAL})] \times AADT \times 365 \quad (6)$$

where DF_A = damage factor for automobiles. Cumulate the EALs calculated for each year since opening to traffic plus the projections to estimate the total EALs that will be applied to the pavement through the design year.

Table 2. Lane distributions at different levels of service.

	Four-Lane Facility		Six-Lane Facility			
	Level of Service		Level of Service			
Lane	A	B	A	B	C	D
Shoulder	95	90	28	26	28	35
Center			45	43	38	32
Median	5	10	27	31	35	33

Annual Traffic Volumes

This procedure should be used if the only data available are those that can be obtained from historical AADT files or maps.

1. Convert the AADT values shown on the maps to one-way values, plot those values against the year, fit a smooth curve to the data, and project to the design year.

2. Use Figure 2 and the estimated AADT for each year to obtain the percentage of each vehicle classification (C_i).

3. Obtain the average damage factor for each vehicle classification by using the procedure described above or Table 1.

4. From the appropriate portion of Figure 1 [or, for other levels of service and for six-lane facilities, the curves given by Southgate and others (2)], obtain the lane-distribution factors (LD_i) for each vehicle classification.

5. Calculate and cumulate the EALs by using Equation 7.

$$\sum_{k=1}^{p} EAL = AADT_k \times C_i \times DF_i \times LD_i \times 365 \quad (7)$$

where

k = year in question minus year opened to traffic and
p = maximum year minus year opened to traffic.

Figure 2. Relationship between AADT and vehicle-classification percentages.

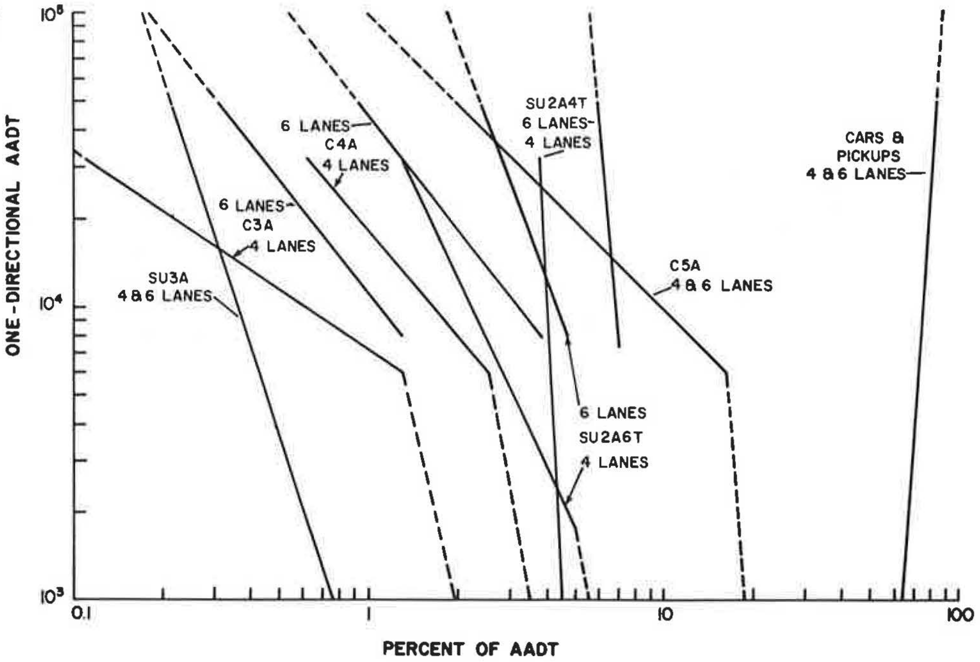


Figure 3. Relationship between roughness and time.

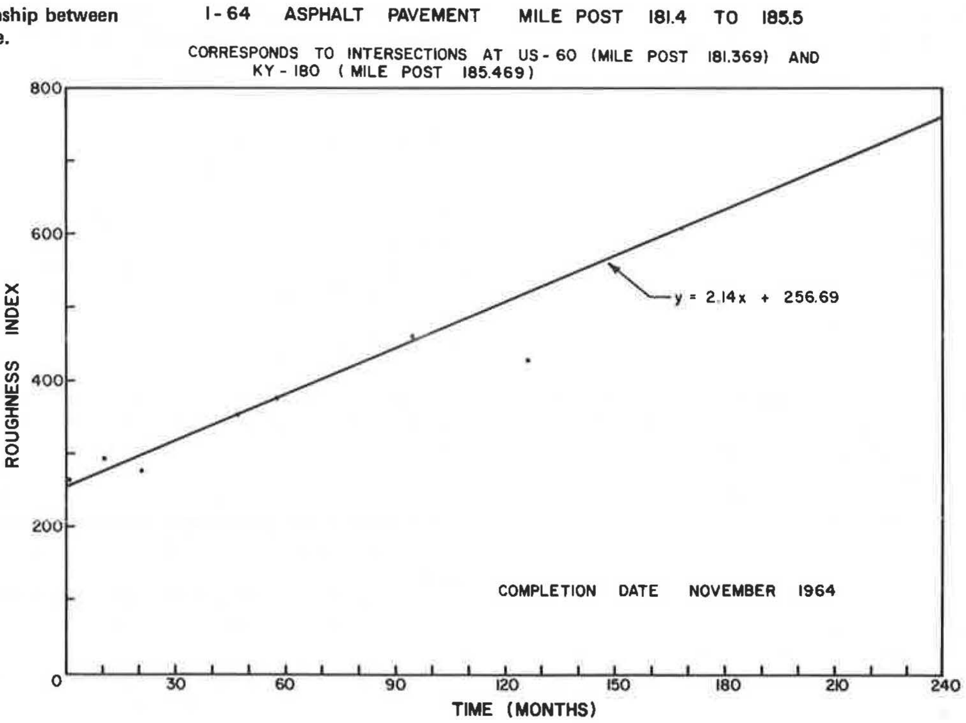
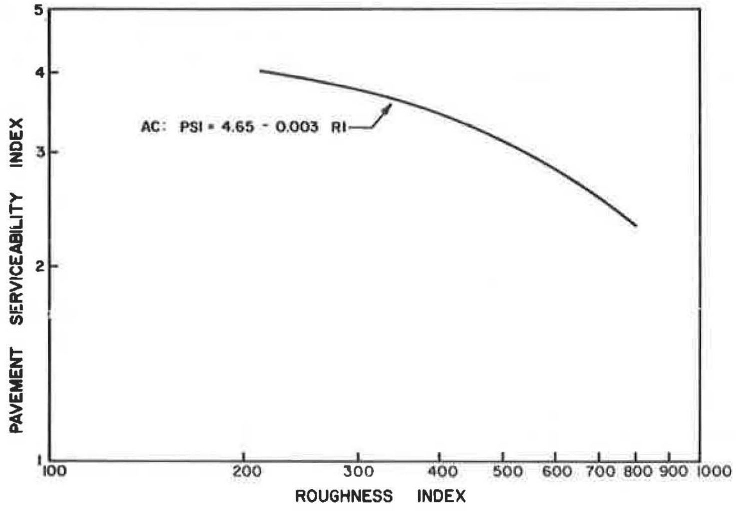


Figure 4. Relationship between serviceability and roughness indices.



6. Review the estimated total EALs for the design year and determine whether additional lanes or alternative routes should be considered.

Compound Interest Equation

If there are no volume data that seem appropriate for the facility under investigation, estimate the traffic volume by using the compound interest equation.

$$AADT_k = AADT_1 (1 + r)^p \quad (8)$$

where

r = yearly growth factor and
p = number of years from the beginning.

Sum the $AADT_k$s through p years to estimate the total traffic over the design life.

CRITERIA FOR OVERLAY DESIGN

The proposed curves for thickness design (2) are the same as the curves for thickness design of new pavements. These design curves are based on elastic theory and permissible values of strains. The normal inputs into the overlay design procedure are a CBR value (or subgrade modulus), a design or projected number of 80-kN EALs, and the existing or equivalent crushed-stone-base [dense-graded aggregate (DGA)] thickness. For a constant DGA thickness, increasing the ratio of the AC thickness to the total thickness directly increases the AC thickness. Thus, the change in AC thickness is the AC overlay thickness.

METHOD FOR OVERLAY DESIGN

The following procedure can be used to design the thickness of an AC overlay to be applied to an existing AC pavement.

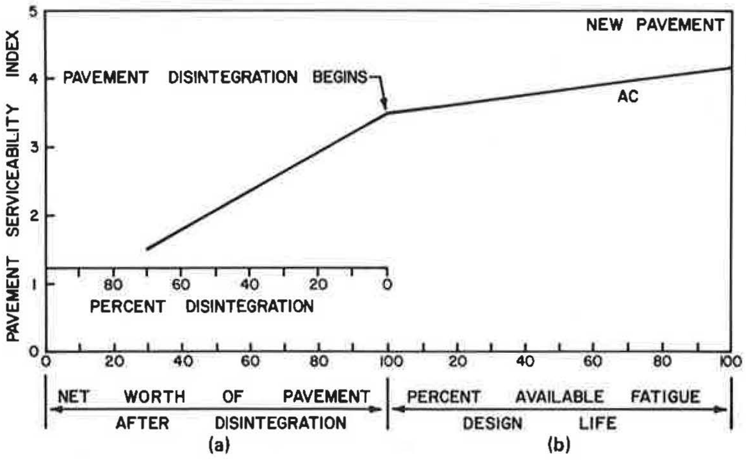


Figure 5. Relationship between serviceability index and (a) present worth of pavement structure after beginning of disintegration and (b) designed fatigue life.

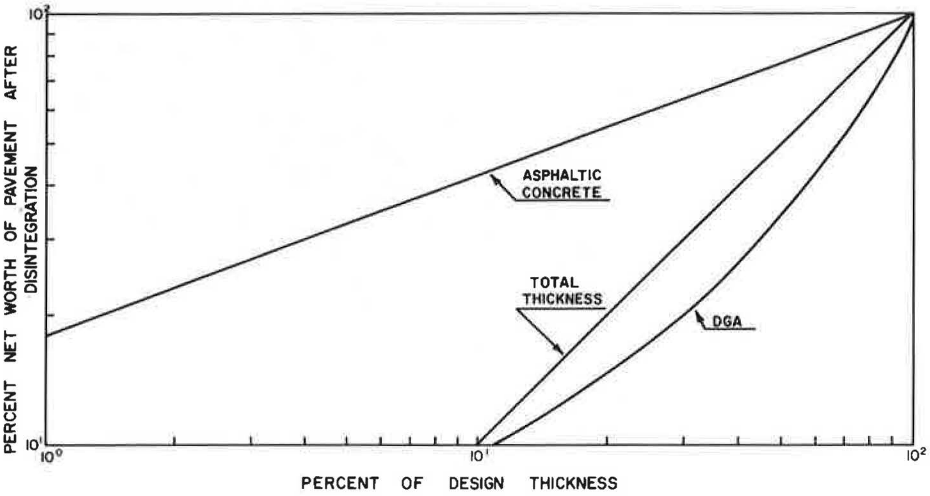
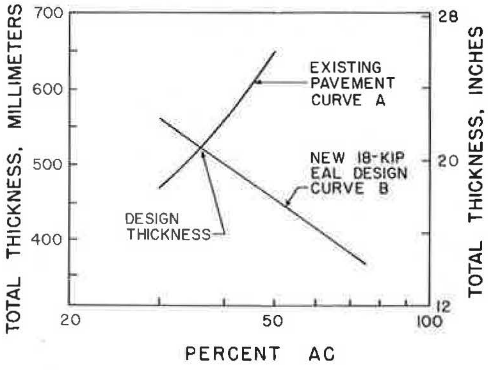


Figure 6. Relationship between percentage of net worth of pavement after beginning of disintegration and percentage of design thickness.

Figure 7. Relationship between total design thickness and percentage of total thickness due to AC.



1. Determine the estimated number of 80-kN EALs (accumulated and projected) by the most appropriate method.

2. Use pavement-roughness measurements (5, 8) to estimate the present serviceability index (PSI) and use this in turn to estimate the residual value (present worth), or remaining life, of the existing pavement structure. There are several methods of estimating the roughness index (RI): (a) historical RI data can be compiled for each project and plotted against time to obtain an estimation of when the critical RI might be expected [Figure 3 (8) shows an example of this procedure]; (b) if no RI data exist for the particular pavement, RI tests can be made; and (c) in lieu of RI tests, a Mays ride meter can be used to test the pavement for roughness and the Mays ride meter value (X) used to obtain the approximate RI value:

$$RI = 2.33X + 180 \quad [\leq 1975\ (6)] \qquad (9a)$$

$$RI = 3.20X + 212 \quad [\geq 1976\ (5)] \qquad (9b)$$

3. Convert the RI values to the estimated PSI by using Figure 4 (5, 8).

4. Estimate the existing pavement thicknesses from historical files or by using a road rater (5) or Dynaflect to determine an effective structure. If the road rater or Dynaflect is used, go to step 7.

5. After determining the PSI, estimate the present worth or residual value of the existing pavement structure from Figure 5 (5, 6).

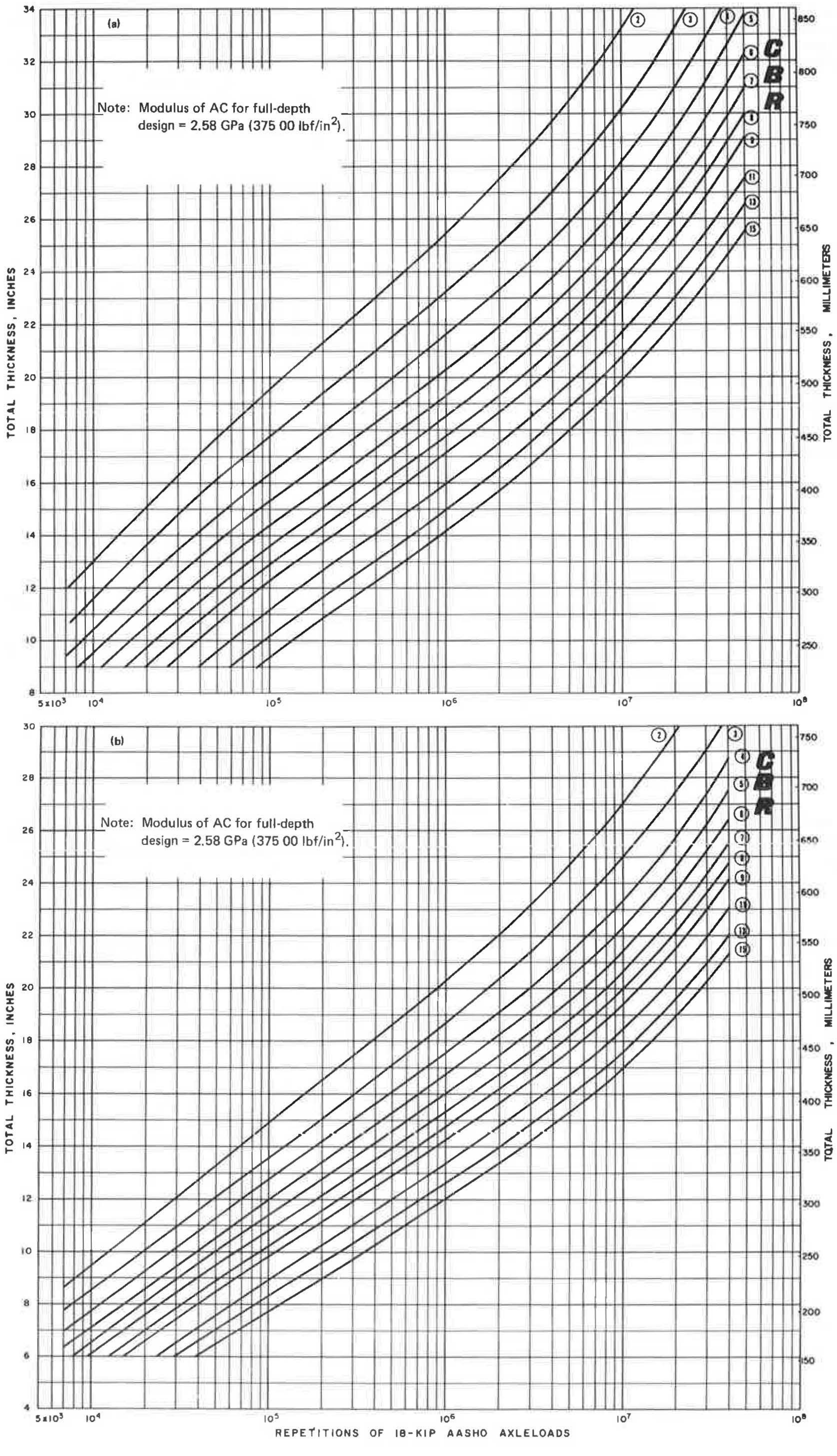
6. Use the present worth of the pavement structure as determined from step 5 in Figure 6 and determine the adjustment factors (5) appropriate to the layers of the pavement system.

7. Obtain the equivalent layer thicknesses by using the adjustment factors obtained in step 6 and the original thickness obtained in step 5 in Equation 10.

$$\text{Total equivalent thickness} = (AF_{AC} \times \text{AC thickness}) + (AF_{DGA} \times \text{DGA thickness}) \qquad (10)$$

where

Figure 8. Simplified thickness-design curves: thickness of AC layer = (a) 33, (b) 50, and (c) 67 percent, respectively, of total pavement thickness.



Note: Modulus of AC for full-depth design = 2.58 GPa (375 00 lbf/in²).

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Figure 8. Continued.

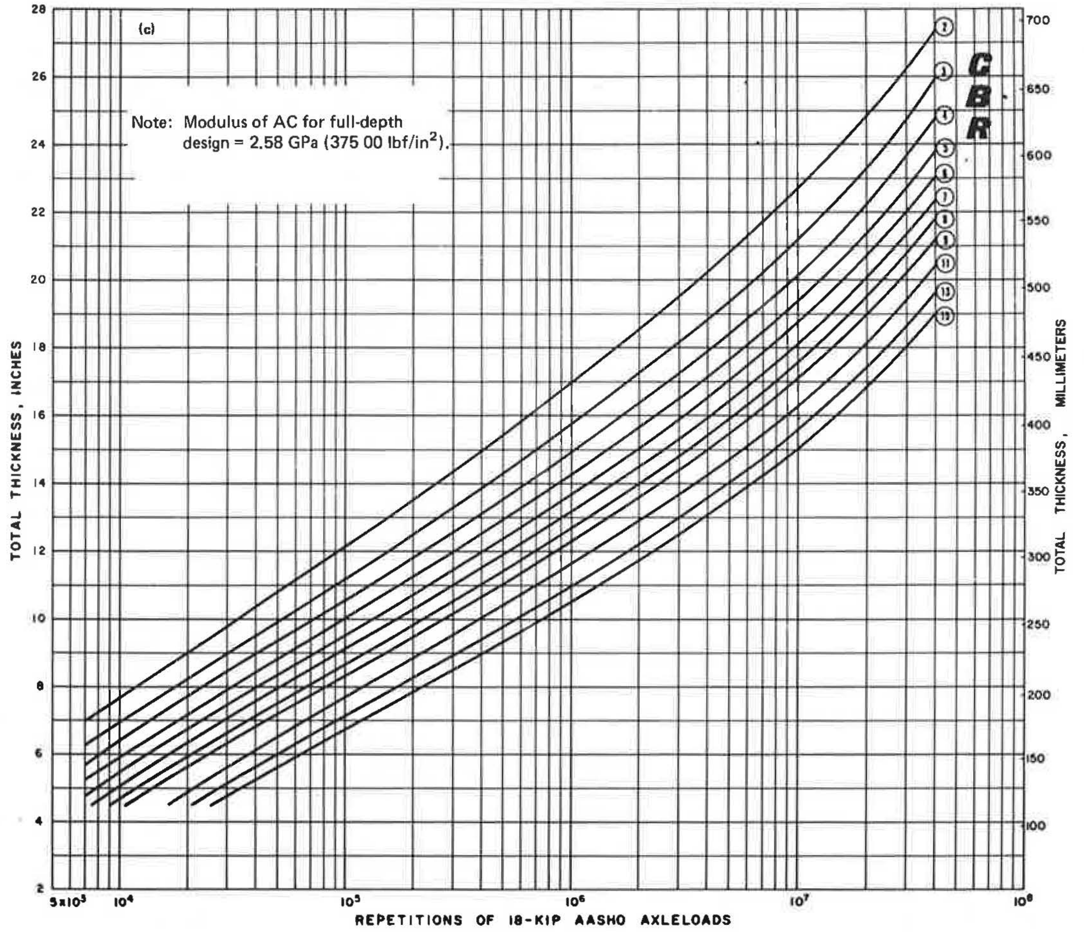


Figure 9. Coal-haul special truck.

AF_{AC} = adjustment factor for AC and
AF_{DGA} = adjustment factor for DGA.

8. Develop a design thickness curve by using the present-worth thickness of the DGA as the basic thickness (curve A of Figure 7) and determine the total thickness for the various AC-thickness percentages of the total thickness by using Equation 11.

$$\text{Total thickness} = 100 \times \text{adjusted DGA thickness} \div (100 - \text{percentage AC of design thickness}) \qquad (11)$$

9. Determine the CBR design value for the subgrade by using a laboratory test, a soils survey, or a nondestructive testing instrument such as the Dynaflect, the falling weight deflectometer, or the road rater (5). In Kentucky, the weakest in-place subgrade modulus value as determined from dynamic tests is recommended for designing overlay thicknesses.

10. Use the number of EALs estimated in step 1, the CBR design value estimated in step 9, and Figure 8 to determine the design thicknesses. Plot these values against the AC percent of the total thickness as illustrated by curve B in Figure 7. [Figure 8 can also be used to determine the design thickness for a pavement that uses new material (2, 5).]

11. Determine the total pavement thickness (existing pavement and overlay) from the intersection of curves A and B in Figure 7.

12. Determine the overlay thickness by using Equation 12.

$$\text{Overlay thickness} = \text{total thickness (from step 11)} - \text{total equivalent thickness (from step 7)} \qquad (12)$$

EVALUATION OF AN OVERLAID PAVEMENT

KY-33 is an access road to an electrical generating plant that uses coal as fuel and water from the Kentucky River for cooling. Future plans call for building a facility on the river for unloading coal barges and transferring the coal by truck to the plant over KY-33. Such a change in traffic conditions will require an appropriate upgrading of the pavement structure to support the anticipated loads.

The following assumptions were made:

1. The space available at the river will limit the size of trucks to single three-axle units [coal-haul specials (see Figure 9)].
2. This size and style of truck has a tandem rear axle, an empty loading of approximately 133.4 kN (30 000 lbf), and a gross loading capacity of 311.4 kN (70 000 lbf). A typical vehicle has a front axle load of 66.7 kN (15 000 lbf) and a rear tandem axle load of 244.7 kN (55 000 lbf). Its equivalent damage factor per trip is 22.5 EALs.
3. The capacity of the unloading machinery will be limited to 6 trucks/h (48 trips/day).
4. A barge will be located at the facility 125 working days a year.
5. The design should last for six years.
6. Volume of automobile traffic is considered to be relatively insignificant for this location.

The calculated number of 80-kN EALs is 48 trips/day × 125 days/year × 6 years × 22.5 EALs/trip = 4 810 000 EALs.

The Kentucky road rater was used to measure the deflections of the existing pavement. Historical records were searched to determine the thickness of each layer. Cores were taken at the test sites. Elevations were measured on 305-mm (12-in) intervals across the pavement at each test site. Surface temperature, time of day, frequency of testing, and road rater deflections were measured at each site. A compilation of the data recorded for one test site on KY-33 is shown in Figure 10. In this figure, the unadjusted field measurements, the layer thicknesses, and the mean air temperature for the previous five days (which can be obtained from U.S. Weather Bureau records) are shaded.

The method described by Sharpe in the previous paper of this Record and by Southgate (6) was used to evaluate the pavement. A temperature distribution for the AC layer was obtained by using the pavement surface temperature, the time of day, and the five-day mean air temperature. A corresponding distribution of moduli was obtained by using Figure 2 of Sharpe's paper. The mean pavement temperature and AC modulus were determined and used to select the appropriate factor to adjust the field-measured road rater deflections to the reference conditions [21°C (70°F), 25 Hz, and $E_1 = 8.27$ GPa (1 200 000 lbf/in^2)]. The mean pavement temperature, mean pavement modulus, the adjustment factor, and the road rater deflections adjusted to the reference conditions are shown in the unshaded areas in Figure 10. The graphs of temperature and modulus against pavement depth (temperature and modulus distributions) that were used to determine the mean pavement temperature and mean modulus are shown in Figure 11.

The relationship between the no. 1 sensor deflection and the no. 1 projection is shown in Figure 12a. The theoretical relationship between road rater deflections and subgrade modulus of elasticity for the no. 1 and no. 2 sensors is shown in Figure 12b. These graphs illustrate these relationships for the layer thicknesses, as determined from core measurements, and the reference conditions. Field-measured deflections adjusted to reference conditions are indicated by points. By using Figure 12b and the field-measured road rater no. 2 sensor deflections adjusted to reference conditions, the subgrade modulus corresponding to the no. 2 sensor deflection can be determined by using the line labeled "no. 2 sensor theoretical relationship," and this estimated subgrade modulus can be used to plot the no. 1 sensor deflection. The relationship between the field data for no. 1 sensor deflections and estimated subgrade moduli can be compared with the theoretical relationship. If the field deflections and the estimated subgrade moduli agree with the theoretical values for the original structure, the pavement is performing as expected. If pavement performance (deflections) does not agree with the original theoretical structure line, the pavement is performing as a thinner, effective structure. The relationship between the no. 1 measured (field) deflections and the corresponding no. 1 projections shown in Figure 12a can be used to identify variations in the pavement structure by comparing field data with the theoretical relationship.

The measured deflections and corresponding estimates of subgrade modulus (Figure 12b) do not agree with the theoretical relationship. The thinner, effective structure can be determined in the following way: A parallel line offset to the theoretical structure line (logarithm of the deflection versus logarithm of the subgrade modulus) is drawn through the field point of greatest magnitude. Then, the ratio of deflection (R) for field behavior to that of theoretical behavior is calculated for a constant subgrade modulus and this ratio is used to determine the effective or behavioral layer thicknesses. For the example shown in Figure 12b, the original layer thicknesses were determined by cores to be 114.5 mm (4.5 in) of AC on 127.0 mm (5.0 in) of DGA. However, the pavement was effectively behaving as 81 mm (3.2 in) of AC on 122 mm (4.8 in) of DGA.

Estimation of an effective structure is an iterative process. The first step involves an estimation of the effective structure. This step is accomplished by using the ratios of the deflections for field behavior to the deflections for the theoretical structure. The second step involves a comparison of field behavior with the theoretical behavior of the effective structure. This step is accomplished by completing a second analysis of the field data using the effective structure as the basis for the analysis. A new mean pavement temperature and modulus should be computed and used to determine the associated deflection adjustment factor. The original road rater deflections can now be adjusted to the reference conditions and used to estimate subgrade moduli. Field-measured no. 1 sensor deflections can be plotted against the predicted subgrade moduli and compared with the theoretical relationship for the effective structure. The data used to complete the estimation of the effective structure of the pavement described in Figure 10 are shown in Figure 13 and illustrated graphically in Figure 14. As Figure 14a indicates, all portions of the pavement structure are performing as expected. As can be seen from Figure 13b, the field deflection measurements are very nearly duplicated by the theoretical relationship for the effective structure of 81 mm of AC on 122 mm of DGA. If, for some reason, the field behavior does not agree with the theoretical behavior for the effective structure, then the estimation procedure is repeated until field behavior is duplicated by theory.

The line offset to the theoretical deflection-subgrade modulus line through the point of greatest magnitude provides a shortcut procedure that reduces the number of iterations. Investigations (6) have shown that this shortcut can reduce the number of iterations to one.

Approximately three months after construction of the overlay, the road rater was used to reevaluate the test site on KY-33. Elevations were taken at the same intervals across the pavement as before and were used to determine the average overlay thickness. The average overlay thickness was 76 mm (3.0 in). The procedure described above was used to analyze the road rater test data. The field data used are shown in Figure 15. The layer thicknesses used in evaluating the after-overlay data consisted of the residual or effective layer thicknesses before overlay plus the overlay thickness. The effective structure after overlay is 158 mm (6.2 in) of

Figure 10. Road-rater-data sheet: site no. 1 on KY-33—test data and analysis before overlay and assuming layer thicknesses from records.

Data Sheet
ROAD RATER MEASUREMENTS

Division of Research
Bureau of Highways
Kentucky Department of Transportation
Lexington, Kentucky

LOCATION KY 33, MERCER CO., #1
TIME OF TESTING 11:15 AM
DATE OF TESTING MARCH 25, 1975
MEAN PAVEMENT TEMPERATURE 48°F
SURFACE TEMPERATURE 38°F
MEAN MODULUS OF ELASTICITY (ASPHALTIC CONCRETE) 2.18×10^6 PSI
5-DAY MEAN AIR TEMPERATURE 58.5°F
DEFLECTION ADJUSTMENT FACTOR 1.10
LAYER THICKNESSES 4.5 IN. AC
5.0 IN. DGA
FREQUENCY 25 HZ

FIELD DEFLECTION MEASUREMENTS [UNITS IN. $\times 10^{-5}$] SENSORS			
No. 1	No. 2	No. 3	No. 1 PROJECTED
59	37	21	65.2
69	41	23	73.1
88	54	30	97.2
59	37	22	62.2
73	43	24	77.0
90	47	23	96.0

ADJUSTED DEFLECTIONS [UNITS IN. $\times 10^{-5}$] SENSORS			
No. 1	No. 2	No. 3	No. 1 PROJECTED
64.9	40.7	23.1	71.7
75.9	45.1	25.3	80.4
96.8	59.4	33.0	106.9
64.9	40.7	24.2	68.4
80.3	47.3	26.4	84.7
88.0	51.1	25.3	105.7

PREDICTED SUBGRADE MODULUS OF ELASTICITY [UNITS PSI]
19,500
17,500
12,500
19,500
16,500
15,000

Figure 11. Distributions of temperature and modulus of elasticity with depth of AC: site no. 1 on KY-33 before overlay.

TEMPERATURE AND AC MODULUS DISTRIBUTIONS
STATION No. 1
KY 33 MERCER COUNTY
TEST DATE MARCH 25, 1975
STRUCTURE 114.5 mm AC (4.5"); 127.0 mm DGA (5.0")
EFFECTIVE STRUCTURE 81.3 mm AC (3.2"); 121.9 mm DGA (4.8")

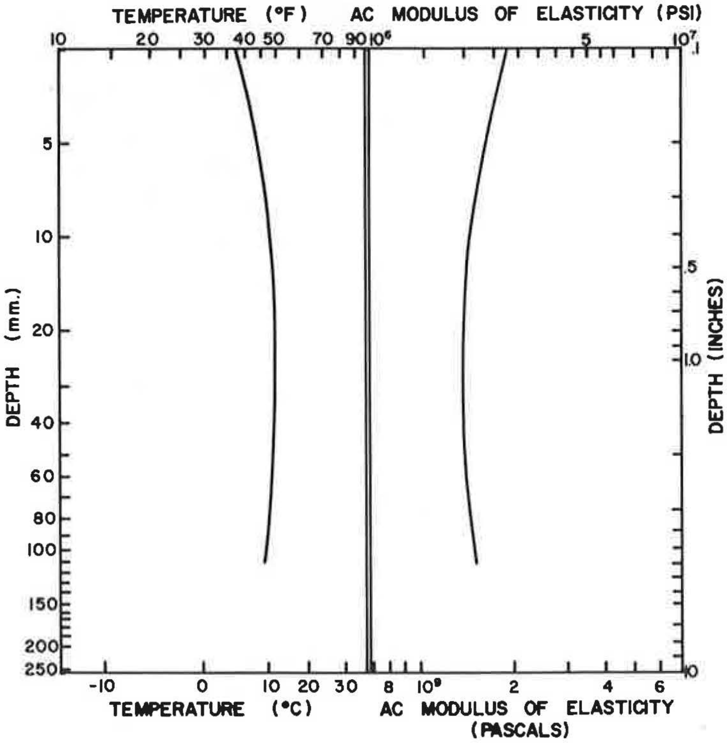


Figure 12. Analysis of road rater data (data from Figure 10): site no. 1 on KY-33 before overlay.

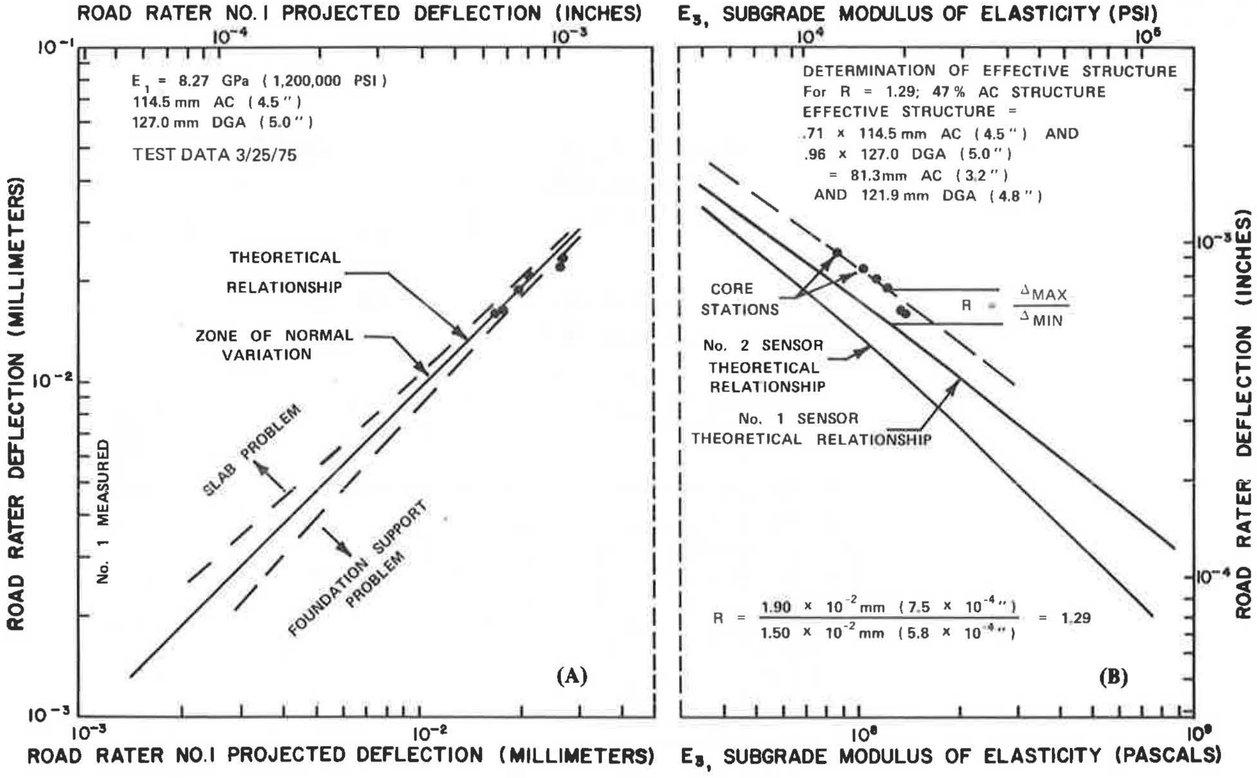
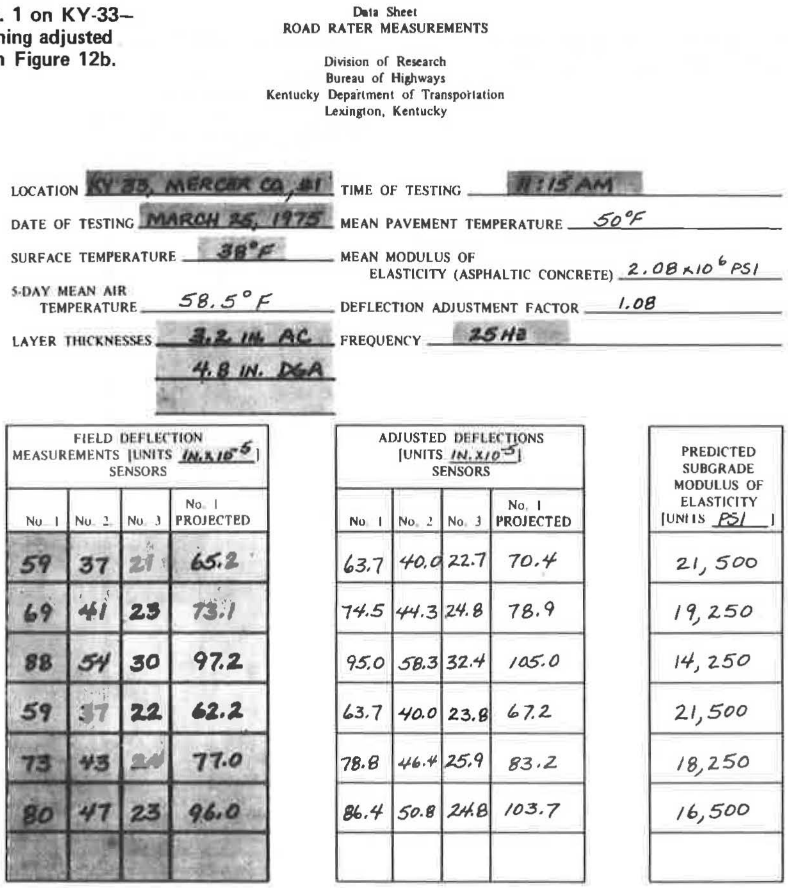


Figure 13. Road-rater-data sheet: site no. 1 on KY-33–test data and analysis before overlay assuming adjusted effective layer thicknesses as determined in Figure 12b.



Data Sheet
ROAD RATER MEASUREMENTS

Division of Research
Bureau of Highways
Kentucky Department of Transportation
Lexington, Kentucky

LOCATION KY 33, MERCER CO, #1
TIME OF TESTING 11:15 AM
DATE OF TESTING MARCH 25, 1975
MEAN PAVEMENT TEMPERATURE 50°F
SURFACE TEMPERATURE 38°F
MEAN MODULUS OF ELASTICITY (ASPHALTIC CONCRETE) 2.08 x 10^6 PSI
5-DAY MEAN AIR TEMPERATURE 58.5° F
DEFLECTION ADJUSTMENT FACTOR 1.08
LAYER THICKNESSES 3.2 IN. AC
4.8 IN. DGA
FREQUENCY 25 Hz

FIELD DEFLECTION MEASUREMENTS [UNITS IN. x 10^-5] SENSORS			
No. 1	No. 2	No. 3	No. 1 PROJECTED
59	37	21	65.2
69	41	23	73.1
88	54	30	97.2
59	37	22	62.2
73	43	24	77.0
80	47	23	96.0

ADJUSTED DEFLECTIONS [UNITS IN. x 10^-5] SENSORS			
No. 1	No. 2	No. 3	No. 1 PROJECTED
63.7	40.0	22.7	70.4
74.5	44.3	24.8	78.9
95.0	58.3	32.4	105.0
63.7	40.0	23.8	67.2
78.8	46.4	25.9	83.2
86.4	50.8	24.8	103.7

PREDICTED SUBGRADE MODULUS OF ELASTICITY [UNITS PSI]
21,500
19,250
14,250
21,500
18,250
16,500

Figure 14. Analysis of road rater data (data from Figure 13): site no. 1 on KY-33 before overlay.

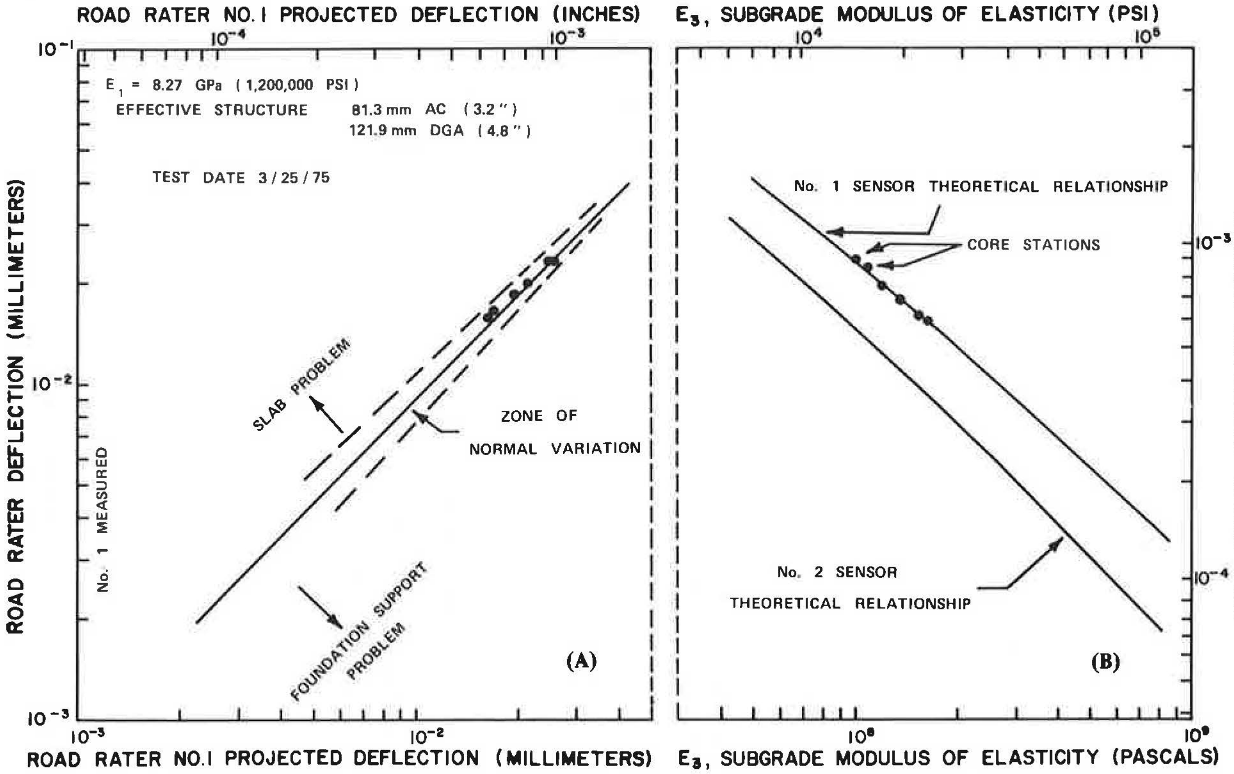
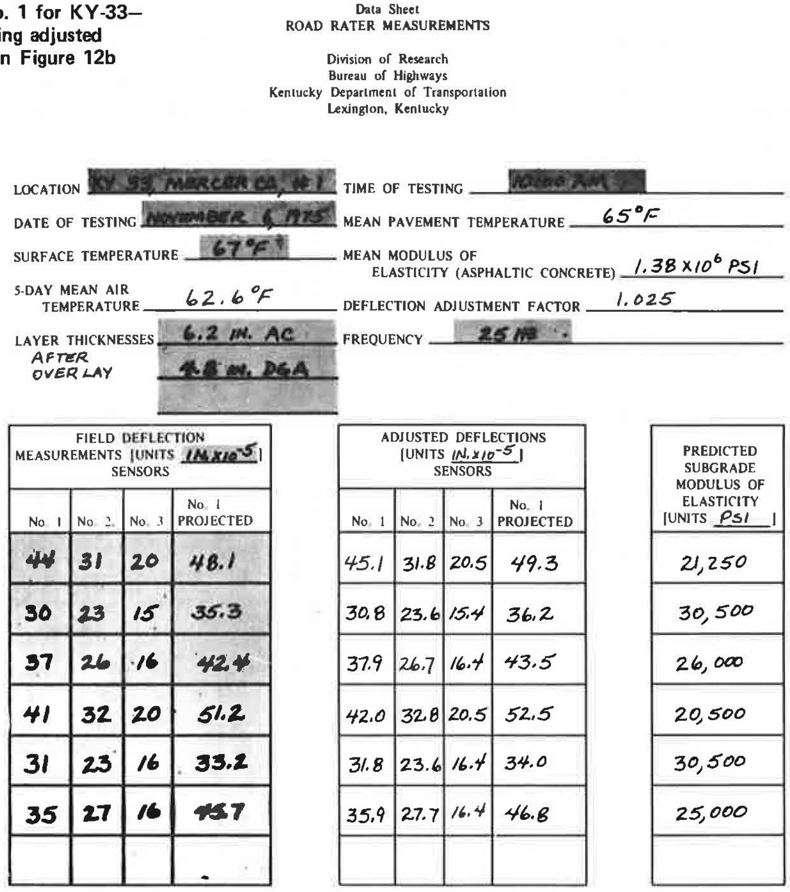


Figure 15. Road-rater-data sheet: site no. 1 for KY-33—test data and analysis after overlay assuming adjusted effective layer thicknesses as determined in Figure 12b plus overlay thickness.



Data Sheet
ROAD RATER MEASUREMENTS

Division of Research
Bureau of Highways
Kentucky Department of Transportation
Lexington, Kentucky

LOCATION KY 33, MERCER CO, #1
TIME OF TESTING 10:00 AM
DATE OF TESTING NOVEMBER 6, 1975
MEAN PAVEMENT TEMPERATURE 65°F
SURFACE TEMPERATURE 67°F
MEAN MODULUS OF ELASTICITY (ASPHALTIC CONCRETE) 1.38 x 10^6 PSI
5-DAY MEAN AIR TEMPERATURE 62.6 °F
DEFLECTION ADJUSTMENT FACTOR 1.025
LAYER THICKNESSES AFTER OVERLAY 6.2 IN. AC
4.8 IN. DGA
FREQUENCY 25 HZ

FIELD DEFLECTION MEASUREMENTS [UNITS IN. x 10^{-5}] SENSORS			
No. 1	No. 2	No. 3	No. 1 PROJECTED
44	31	20	48.1
30	23	15	35.3
37	26	16	42.4
41	32	20	51.2
31	23	16	33.2
35	27	16	45.7

ADJUSTED DEFLECTIONS [UNITS IN. x 10^{-5}] SENSORS			
No. 1	No. 2	No. 3	No. 1 PROJECTED
45.1	31.8	20.5	49.3
30.8	23.6	15.4	36.2
37.9	26.7	16.4	43.5
42.0	32.8	20.5	52.5
31.8	23.6	16.4	34.0
35.9	27.7	16.4	46.8

PREDICTED SUBGRADE MODULUS OF ELASTICITY [UNITS PSI]
21,250
30,500
26,000
20,500
30,500
25,000

Figure 16. Distributions of temperature and modulus of elasticity with depth of AC: site no. 1 on KY-33 after overlay.

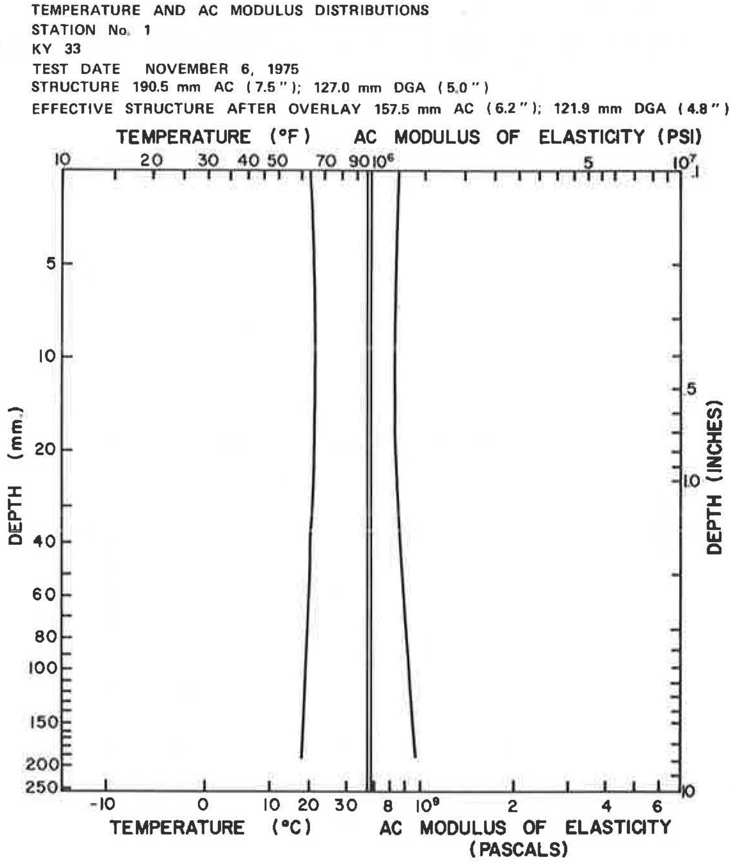
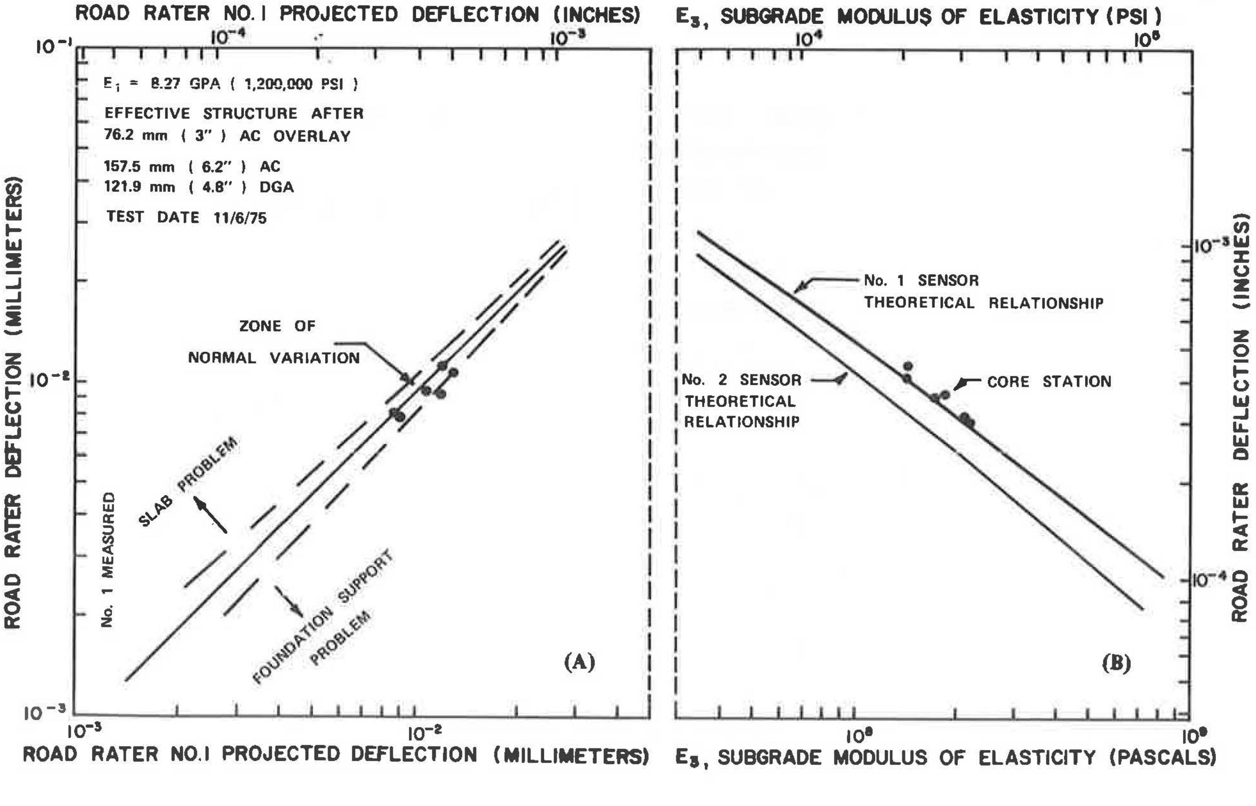


Figure 17. Analysis of road-rater-data sheet (data from Figure 15): site no. 1 on KY-33 after overlay.



AC on 122 mm (4.8 in) of DGA. Temperature and moduli distributions and the associated mean pavement temperature and modulus were determined. The mean pavement temperature and modulus were used to determine the deflection factor needed to adjust the field deflections to reference conditions. Plots of temperature and AC modulus distributions are shown in Figure 16. The relationships between measured and projected deflections and subgrade moduli for both theory and field behavior are shown in Figure 17; the after-overlay test data shown in Figure 17b indicate a behavior equivalent to the effective structure plus the overlay thickness.

SUMMARY

A system for the rational design of an AC overlay has been presented in a step-by-step format. Evaluation of one of many test sites has been presented to illustrate the before-and-after conditions and the agreement between the test data and the theory.

ACKNOWLEDGMENT

The concepts, data, and analyses reported in this paper are a result in part of a research study on the development of a rational overlay design method for pavements that was conducted as a part of a program funded by the Federal Highway Administration and the Kentucky Department of Transportation. The contents of the report reflect our views; we are responsible for the facts and accuracy of the data presented. The contents do not necessarily reflect the official views or policies of the Kentucky Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

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Publication of this paper sponsored by Committee on Pavement Rehabilitation Design.

Overlay Design Based on Falling Weight Deflectometer Measurements

R. C. Koole, Koninklijke/Shell-Laboratorium, Amsterdam

The technique used for measuring deflections in an asphalt pavement by means of a falling weight deflectometer is described in some detail. Two models of the deflectometer that have different force ranges have been developed at Koninklijke/Shell-Laboratorium, Amsterdam. The deflectometer is used for the routine evaluation of pavements. The data it produces are of sufficient quantity and quality to serve as input for an analytical method of overlay design. The validity of the data and the interpretation method has been verified by wave-propagation measurements. The basic principles of the new Shell design method are outlined, with specific reference to the determination of overlay thicknesses. It is shown that the required thickness of an overlay depends on one of two criteria, subgrade strain and asphalt-fatigue strain, and that all designs must be checked to determine which of the two criteria is the limiting one. To illustrate this, several examples are given. Some possible refinements to the basic overlay design procedure are discussed, such as the incorporation of various mix characteristics and the procedure for use if the type of mix to be used for the overlay differs significantly from that of the existing pavement.

The economic growth of the 1950s and early 1960s was accompanied by rapid expansion of the existing road network in almost all of the countries of North America and western Europe. Many of the roads constructed at that time, however, are now nearing the end of their structural design lives and in need of major repair.

The structural strength of a pavement refers to its ability to limit strains to such an extent that, during its design life, virtually no cracking occurs in any part of the structure and there is no excessive permanent deformation in the subgrade.

Structural strength is not the only factor that determines the serviceability of a road. Skid resistance and rut depth, for example, are also important in determining the acceptability of a pavement as a riding surface. The recently published Shell Pavement Design Manual (1) specifically recognizes that rut depth due to permanent