A Rational Thickness Design System for Asphaltic Concrete Overlays

Herbert F. Southgate*       Gary W. Sharpe†
Robert C. Deen‡

*Kentucky Department of Transportation
†Kentucky Department of Transportation
‡Kentucky Department of Transportation

This paper is posted at UKnowledge.
https://uknowledge.uky.edu/ktc_researchreports/818
A RATIONAL THICKNESS DESIGN SYSTEM
FOR ASPHALTIC CONCRETE OVERLAYS

by
H. F. Southgate, G. W. Sharpe, and R. C. Deen

ABSTRACT
A method of designing asphaltic concrete overlays has been developed making use of (1) Kentucky’s proposed design curves, (2) an estimate of future traffic and the associated fatigue (five procedures are presented according to types of information available), (3) strength of subgrade on subject project (laboratory CBR tests or results of dynamic in-place tests such as the Road Rater), and (4) present condition of the existing pavement (from dynamic in-place tests, roughness measurements, or present serviceability index). Deterioration was expressed as reduced thicknesses of new-quality materials producing the same measured dynamic deflections. The total thickness for the predicted traffic minus the effective or reduced thickness of the existing pavement is the overlay thickness required.
A RATIONAL THICKNESS DESIGN SYSTEM
FOR ASPHALTIC CONCRETE OVERLAYS

by

Herbert F. Southgate
Chief Research Engineer

Gary W. Sharpe
Research Engineer

and

Robert C. Deen
Assistant Director

Division of Research
Bureau of Highways
DEPARTMENT OF TRANSPORTATION
Commonwealth of Kentucky

offered for publication by the
Transportation Research Board

October 1978
INTRODUCTION

The overlay thickness design method presented herein has evolved from approximately 30 years of thickness design experience. Kentucky’s early pavement thickness design methods were based upon 22-kN (5-kip) EWL’s (1). In 1973, a proposed design procedure (2) made use of 80-kN (18-kip) axleloads as used by the AASHTO Interim Guide (3) even though Kentucky’s damage factors differed from AASHTO’s. Design of overlays (that is, the determination of required thicknesses) requires as inputs (1) a measurement of the load carrying capability of the subgrade, (2) an evaluation of the condition of the existing pavement, and (3) an estimate of expected traffic and associated fatigue.

Subgrade strength is determined by the CBR test method. The Kentucky CBR test procedure differs from the ASTM method only in the time of soaking prior to testing. The Kentucky method allows the sample to soak until swelling ceases. Expressing CBR values as Young’s moduli is accomplished by multiplying by 1,500 (4). As expected, in-place dynamic test procedures generally yield an estimated subgrade modulus greater than that obtained by the Kentucky laboratory CBR method since the in-place subgrade does not exist in the critical moisture content state represented by the “soaked” conditions of the laboratory tests. Thus, the overlay thickness should be determined using the CBR curve equivalent to the weakest subgrade modulus obtained during in-place testing.

The proper design thickness of an overlay depends upon the condition of the existing pavement. The existing condition may be expressed as a reduced modulus of the asphaltic concrete, or as reduced layer thicknesses of new material having the reference moduli. The reduced thickness concept is used in this procedure (5-7). The overlay thickness is that required in addition to the residual structural capacity of the existing pavement to support the forecasted traffic, or equivalent axleloads (EAL’s).

Normally, traffic volumes are estimated in connection with needs studies and in the planning stages for all new routes and for major improvements of existing routes. Whereas anticipated traffic volume is an important consideration in the styling and geometric design of a roadway, composition of the traffic in terms of axle weights (and possibly lane distributions) is essential to 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 exceeded forecasts in the majority of cases. 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 EAL's involves a forecast of the total number of vehicles expected on the road during its design life and multiplying by factors to convert traffic to EAL's. More ideally, the yearly increments of EAL's could be calculated and summed; this approach would permit consideration to be given to anticipated changes in legal weight limits, changes in styles of cargo haulers, and changes in routing.

**DESIGN EAL**

Several methods of estimating 80-kN (18-kip) EAL's are presented. The appropriate method -- to match the data base available -- should be used for a particular design situation.

1. **Deacon and Deen Method**

   Deacon and Deen (8) described the development and testing of a predictive method (calculation of equivalent axleloads) 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 serve as indicators of the composition and weights of the traffic stream, and (c) development of significant relationships between the traffic parameters and the local conditions. Percentages of the various vehicle types and the average equivalent axleloads per vehicle were selected as the most significant traffic parameters. 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 alternate 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 weight data are unavailable for the route under investigation. The relationships should be updated every two to five years to account for changes in usage of vehicle types and changes in axleload limits.

2. **Similar Situations**

   Estimates may be made using data from similar facilities. Volume and classification data from parallel and feeder routes may be used when available. Where possible, model facilities should be chosen for which there is recorded data representing conditions prior to and after the construction of the new facility.
3. Traffic and Classification Counts

The Federal Highway Administration publishes W-4 tables each year for each state. These tables contain weight 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 weigh station is located near the new facility under question and the expected classification of traffic is approximately the same, the analyses should be based on that W-4 table. Otherwise, the W-4 table covering statewide data, or other groupings of similar sites, may be more appropriate.

From the W-4 table, several essential types of analyses may be made. The following procedure is suggested.

a. Express the vehicle classification counts as a ratio:

\[ C_i = \frac{\text{(classification count)}}{\text{(total number of vehicles counted)}}, \]

where \( i \) = vehicle classification.

b. From W-4 tables, calculate an average damage factor (DF\textsubscript{i}) for each vehicle classification by year using the equation

\[ \text{DF}_i = \frac{\sum N_j 	imes F}{\text{(number of weighed vehicles per classification)}}, \]

where \( N \) = number of axles having axleload \( P_s \) or \( P_t \) (kips),

\( m \) = number of weight categories, \( j \), in W-4 table, and

\( F \) = damage factor for asphaltic concrete, axle configuration, and axleload determined from the following:

Single Axleload: \( F = \frac{(1.2504)(P_s - 18)}{P_s} \)

where \( P_s \) = single axleload (kips)

Tandem Axleload: \( F = \frac{(1.1254)(P_t - 34)}{P_t} \)

where \( P_t \) = tandem axleload (kips)

A simplified set of average damage factors for each vehicle classification may be obtained from Table 1 and are the averages for Kentucky traffic from 1958 through 1975.

c. Estimate lane distribution (LD\textsubscript{i}) for highways having four, or more, lanes for each vehicle classification. Figure 1 shows a typical set of factors for each vehicle classification for Level of Service A on a four-lane facility (2). Other figures have been developed for other levels of service and six-lane facilities (2, 5).

d. For each year, calculate the 80-kN (18-kip) EAL from

\[ \text{EAL} = 365 \times \text{AADT} \times \sum_{i=1}^{n} [C_i \times \text{DF}_i \times \text{LD}_i] \]
where $n$ = maximum number of vehicle classifications used.

e. Add calculations in Step d for each year since the pavement was opened to traffic to obtain the total estimated $EAL$ to date.

f. Plot totals for each year versus year, or fit an equation to the data.

g. To obtain the design $EAL$, draw a trend line through the data in Step f and project to the design year; or solve the equation in Step f for the desired design year.

4. Volume and Percentage Trucks

The following procedure should be used to estimate 80-kN (18-kip) $EAL$’s when the only available data are traffic volume and percentage of trucks in the traffic stream.

a. Volumes can be obtained from either hand counts, recorded machine counts, or published AADT maps.

b. Percent of trucks can be obtained from classification counts made by survey teams.

c. From the W-4 table for a particular year, obtain the average number of axles per truck by

$$APT = \frac{\sum_{i=1}^{n} A_i \times T_i}{\sum_{i=1}^{n} T_i}$$

where $APT$ = average number of axles per truck,

$A_i$ = number of axles for each vehicle classification,

$T_i$ = number of trucks weighed in vehicle classification $i$,

$i$ = vehicle classification, and

$n$ = total number of vehicle classifications in the W-4 table.

d. From the W-4 table for a particular year, obtain the average axleload by

$$AAL = \frac{\sum_{j=1}^{m} [N_j \times A_{Lj}]}{N_S + N_T}$$

where $AAL$ = average axleload,

$N_j$ = number of axles weighed in weight category $j$,

$A_{Lj}$ = axleload for weight category $j$,

$m$ = number of weight categories in the W-4 table,

$N_S$ = number of single axles weighed, and

$N_T$ = number of tandem axles weighed.

This provides only an approximation of the average axleload since actual axleloads may range from 8.9 kN (2 kips) to 266.9 kN (60 kips), depending on the axle configuration and truck style.

e. Calculate the damage factor $DF_{A}$ for the average axleload by the equation

$$DF_{AAL} = (1.2504)(AAL - 18).$$
Errors involved in using this equation are minimal compared to those involved in predicting traffic volumes.

f. Lane distribution factors should be obtained from the appropriate portion of Table 2. Values to be used are those labeled "Total".

g. Graphs, as a function of time, should be made or equations fitted to the data for the parameters

1. volume,
2. percent trucks,
3. average number of axles per truck, as calculated in 4c above,
4. average axleload, as calculated in 4d above, and
5. lane distribution factors.

From the graphs or equations, data for missing years may be obtained by interpolation and projection. The EAL for each year can then be calculated from

\[
EAL = \left[ \text{Percent Cars} \times DF_{\text{car}} + \text{Percent Trucks} \times APT \times DF_{\text{AAL}} \right] \\
\times AADT \times 365.
\]

Accumulating the EAL calculated for each year since opening to traffic plus projections will yield the estimated total EAL to be applied to the pavement through the design year.

5. Annual Traffic Volumes

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

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

b. From Figure 2, enter with the estimated AADT for each year and obtain the percentage of each vehicle classification \( C_i \).

c. Obtain the average damage factor for each vehicle classification by the procedure outlined in Method 3, Step b \( DF_i \), or from Table 1.

d. Choose the appropriate portion of Figure 1 and obtain the lane distribution factors \( LD_i \) for each vehicle classification (for other levels of service and for six-lane facilities, see Reference 2).

e. Calculate and accumulate the equivalent axleload (EAL) by the equation

\[
\sum_{k=1}^{p} EAL_k = AADT_k \times C_i \times DF_i \times LD_i \times 365
\]
where \( k \) = year in question less year opened to traffic and 
\( p \) = maximum year less year opened to traffic.

f. Review the estimated total EAL for the design year to determine if additional lanes or alternate routes should be considered.

6. Compound Interest Equation

If there is no extended volume data which seems appropriate for the facility under investigation, the volume can be estimated using the compound interest equation:

\[
AADT_k = AADT_1 (1 + r)^p
\]

where \( AADT_k \) = AADT in the kth year,
\( AADT_1 \) = beginning AADT,
\( r \) = yearly growth factor, and
\( p \) = number of years from the beginning.

Summation of the \( AADT_k \)'s through \( p \) years will provide an estimate of the total traffic over the design life.

CRITERIA FOR OVERLAY DESIGN

The proposed thickness design curves (2) are the same as for thickness design of a new pavement. Thus, the criteria for and development of the overlay design curves are contained in Reference 2 and have not been changed. The design curves are based upon elastic theory and permissible values of strains. The normal inputs into the overlay design procedure is a CBR value (or subgrade modulus), a design or projected 80-kN (18-kip) EAL, and the existing or equivalent crushed stone base thickness. For a constant crushed stone thickness, increasing the percentage of asphaltic concrete thickness of the total thickness directly increases the asphaltic concrete thickness. Thus, the change in asphaltic concrete thickness is the asphaltic concrete overlay thickness.

OVERLAY DESIGN METHOD

The following procedure may be used to design the thickness of an asphaltic concrete overlay to be applied to an existing asphaltic concrete pavement.

1. Determine the estimated 80-kN (18-kip) EAL (accumulated and projected) by the most appropriate method.

2. Pavement roughness measurements (5, 9) may be used to estimate the Present Serviceability Index (PSI), which in turn is used to estimate the residual value (present
worth), or remaining life, of the existing pavement structure. Several methods of estimating
the roughness index (RI) can be used and are discussed:

a. Historical RI data could be compiled for each project. Thus, the RI data can
be plotted versus time to obtain an estimate of when the critical RI might be expected.
Figure 3 (9) is an example.

b. If no RI data exists for the particular pavement, RI tests may be made.

c. In Kentucky, RI tests are made by the Division of Research. In lieu of RI tests,
the Division of Maintenance has used a Mays Ride Meter to test pavements for roughness.
The following equations may be used to obtain approximate RI values:

For 1975 and earlier (for asphaltic concrete pavements) (7):
\[ RI = 2.33 \times X + 180 \]
For 1976 and later (for asphaltic concrete pavements) (5):
\[ RI = 3.20 \times X + 212 \]
where \( X \) = Mays Ride Meter value.

3. RI values may be converted to estimated Pavement Serviceability Index (PSI) by
the curves in Figure 4 (5, 9).

4. Obtain an estimate of existing pavement thicknesses from historical files. An
alternate method would be the use of a Road Rater (5) or Dynaflect to determine an
"effective" structure. If this alternate is employed, go to Step 7.

5. Having determined a PSI, estimate the present worth or residual value of the existing
pavement structure by the curves in Figure 5 (5, 7).

6. With the present worth of the pavement structure as determined from Step 5,
enter Figure 6 to determine factors (5) appropriate to the layers of the pavement system.

7. The "equivalent" layer thicknesses are obtained using adjustment factors from Step
6 and the original thickness from Step 5 in the following equation:

\[ \text{Total Equivalent Thickness} = AF_{AC} \times \text{Asphaltic Concrete Thickness} + AF_{DGA} \times \text{Dense-Graded Aggregate Thickness}, \]
where \( AF_{AC} \) = adjustment factor for asphaltic concrete and
\( AF_{DGA} \) = adjustment factor for dense-graded aggregate.

8. In Figure 7, Curve A is created using the present worth thickness of the DGA
(unbound crushed stone base) as the basic thickness. Determine the total thickness for
the various percentages of AC thickness of the total thickness by the following equation:
Total thickness = \left[ \frac{100 \times (Adjusted\ Dense-Graded\ Aggregate\ thickness)}{(100 - \text{percent\ Asphaltic\ Concrete\ of\ design\ thickness})} \right]

9. Determine the CBR design value for the subgrade by laboratory test, a soils survey, or by using non-destructive dynamic testers such as the Dynaflect, the falling deflectometer as developed by Shell Oil, or the Road Rater (5). For Kentucky, the weakest in-place subgrade modulus value as determined from dynamic tests is recommended for designing overlay thicknesses.

10. With the estimated EAL from Step 1 and the CBR design value from Step 9, enter Figures 8 a-c to determine design thicknesses. Plot these values versus percent AC of the total thickness as illustrated by Curve B in Figure 7. Figures 8 a-c may also be used for determining the design thickness for a pavement using new material (2, 5).

11. The total pavement thickness (existing pavement and overlay) is determined by the intersection of Curves A and B in Figure 7.

12. The overlay thickness is the difference between the total design thickness and the effective thickness of the existing pavement and is determined from

\text{Overlay\ thickness} = \text{Total\ Thickness\ from\ Step\ 11} - \text{Total\ Equivalent\ Thickness\ from\ Step\ 7}.

**EVALUATION OF AN OVERLAID PAVEMENT**

KY 33 is an access road to an electrical generating plant which 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. Coal would be transferred by truck to the plant over KY 33. Such a change in traffic conditions requires an appropriate upgrading of the pavement structure to support anticipated loads.

The following assumptions were made to estimate the 80-kN (18-kip) EAL:

1. Available space at the river would limit the size of trucks to a single unit having three axles.

2. Capacity of the unloading machinery would be limited to six trucks per hour (48 trips per day).

3. A barge would be located at the facility 125 working days each year.

4. The equivalent damage factor per trip is 22.5 EAL for this size and style of truck. This particular truck is known as the "coal-haul special." It is a single unit with a tandem rear axle, has an empty weight of approximately 133.4 kN (30 kips), and a gross weight
capacity of 311.4 kN (70 kips). A typical vehicle has a front axleload of 66.7 kN (15 kips) and a rear tandem axleload of 244.7 kN (55 kips).

5. The design should last for six years.

6. Volume of automobile traffic is considered to be relatively insignificant for this location.

The calculated 80-kN (18-kip) EAL required is:

\[
EAL = 48 \text{ trips per day} \times 125 \text{ days per year} \times 6 \text{ years} \times 22.5 \text{ EAL per trip} = 4,810,000 \text{ EAL.}
\]

The Kentucky Road Rater was used to evaluate the existing pavement. Historical records were searched to determine the thicknesses of each layer. Cores were taken at the test sites. Elevations were measured on 305-mm (12-inch) 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 complete compilation of all data recorded for one test site on KY 33 is presented in Figure 9. The shaded areas on Figure 9 indicate field measurements without any adjustments for the specific site. The layer thicknesses for the test site and the mean air temperature for the previous 5 days is also shaded on Figure 9. The 5-day mean air temperature history can be obtained from US Weather Bureau records.

A temperature distribution for the asphaltic concrete layer was obtained using the pavement surface temperature, time of day, and 5-day mean air temperature (6, 7). A corresponding distribution of moduli was obtained using Figure 2 of Reference 6. A mean pavement temperature and asphaltic concrete modulus can be determined and used to select the appropriate factor required to adjust field measured Road Rater deflections to reference conditions: 21.1°C (70°F), 25 Hz, \( E_1 = 8.27 \text{ GPa (1,200 ksi)} \) (6). The mean pavement temperature, mean pavement modulus, the adjustment factor, and the Road Rater deflections adjusted to reference conditions are shown in the unshaded areas of Figure 9. Graphs of temperature and modulus versus pavement depth (temperature and modulus distributions) which were used to determine the mean pavement temperature and mean modulus are shown in Figure 10.

The relationship between the No. 1 Sensor deflection and the No. 1 projection is shown in Figure 11a. The theoretical relationship between Road Rater deflections and subgrade modulus of elasticity for the No. 1 and No. 2 Sensors is presented in Figure 11b. The graphs in Figure 11 illustrate these relationships for the layer thicknesses, as
determined from core measurements, and for reference conditions. Field measured deflections adjusted to reference conditions are indicated by points. Enter Figure 11b with field measured Road Rater No. 2 Sensor deflections adjusted to reference conditions. Use the line labeled "No. 2 Sensor Theoretical Relationship", read the subgrade modulus corresponding to the No. 2 Sensor deflection, and for this estimated subgrade modulus plot the No. 1 Sensor deflection. The relationship of field data for No. 1 Sensor deflections versus estimated subgrade moduli may be compared to the theoretical relationship. If the field deflections and the estimated subgrade moduli match the theoretical values for the original structure, the pavement is performing as expected. If pavement performance (deflections) does not match the original theoretical structure line, the pavement is performing as a thinner, "effective" structure. A plot of No. 1 measured (field) deflections versus corresponding No. 1 projections is also shown in Figure 11a. This plot can be used to identify variations in the pavement structure by comparing field data with the theoretical relationship (6).

The measured deflections and corresponding estimates of subgrade modulus (shown in Figure 11b) do not match the theoretical relationship. The determination of the thinner, effective structure is shown in Figure 11b. A line of parallel offset to the theoretical structure line (log deflection versus log subgrade modulus) is drawn through field points of greatest magnitude. A ratio of deflection (R) for field behavior to that of theoretical behavior can be calculated for a constant subgrade modulus. This ratio can be used to determine the "effective" or behavioral layer thicknesses. For the example shown in Figure 11b, the original layer thicknesses were determined by cores to be 114.5 mm (4.5 inches) asphaltic concrete on 127.0 mm (5.0 inches) dense-graded aggregate. However, the pavement was effectively behaving as 81.3 mm (3.2 inches) asphaltic concrete on 121.9 mm (4.8 inches) dense-graded aggregate.

Estimation of the effective structure is an iterative process. The first step involves an estimation of the "effective" structure. This step is accomplished 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 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 may now be adjusted
to reference conditions and used to estimate subgrade moduli. Field measured No. 1 Sensor deflections may be plotted versus the predicted subgrade moduli and compared to the theoretical relationship for the "effective" structure. The data used to complete the estimation of the "effective" structure is presented in Figure 12 and is illustrated graphically in Figure 13. Figure 13a indicates that all portions of the pavement structure are performing as expected. It can be seen from Figure 13b that field deflection measurements are very nearly duplicated by the theoretical relationship for the "effective" structure of 81.3 mm (3.2 inches) asphaltic concrete on 121.9 mm (4.8 inches) dense-graded aggregate. If for some reason the field behavior did not match the theoretical behavior for the effective structure, then the estimation procedure would be repeated until field behavior was duplicated by theory.

The line of equal offset to the theoretical deflection-subgrade modulus line through the point of greatest magnitude is a "short-cut" procedure to reduce the number of iterations. Investigations (7) have shown that this "short cut" reduced the iterations to one cycle.

Approximately 3 months after construction of an overlay, the Road Rater was again used to evaluate the same 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 for each test site. The average overlay thickness was 76 mm (3.0 inches). The same procedure as previously presented was used to analyze the Road Rater test data. The field data used in evaluating the pavement after overlay is shown in Figure 14. Layer thicknesses used in evaluating the after-overlay data consisted of the "residual" or "effective" layer thicknesses prior to overlay plus the overlay thickness. The "effective" structure after overlay is 157.5 mm (6.2 inches) asphaltic concrete on 121.9 mm (4.8 inches) dense-graded aggregate. Temperature and moduli distributions and the associated mean pavement temperature and modulus were determined. The mean pavement temperature and modulus are used to determine the appropriate deflection factor needed to adjust field deflections to reference conditions. Plots of temperature and asphaltic concrete modulus distributions are presented in Figure 15. The relationships between measured and projected deflections and subgrade moduli for both theory and field behavior are presented in Figure 16. From Figure 16b, the after-overlay test data indicate a behavior equivalent to the "effective" structure plus the overlay thickness.
SUMMARY

A system to rationally design an asphaltic concrete overlay has been presented in a step-by-step format. Evaluation for one of many test sites has been presented to illustrate the before-and-after conditions and how test data have been matched by theory.

REFERENCES

6. Sharpe, G. W.; Southgate, H. F.; and Deen, R. C.; *Pavement Evaluation from Dynamic Deflections*, to be issued; also offered to the Transportation Research Board for publication, 1978.
7. Southgate, H. F.; Sharpe, G. W.; and Deen, R. C.; *Case Histories of Pavement Evaluations Using Dynamic Deflections*, to be issued.
ACKNOWLEDGEMENTS

The concepts, data, and analyses reported in this paper are a result in part of Research Study KYHPR-75-77, Development of a Rational Overlay Design Method for Pavements, conducted as a part of Work Program HPR-PL-1(14), Part II, funded by the Federal Highway Administration and the Kentucky Department of Transportation. The contents of the report reflect the views of the authors who 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 nor of the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.
### Table 1. Damage Factors by Vehicle Classification for Asphaltic Concrete Pavements

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Number of Veh. Weighed</th>
<th>Total Equivalent 80-kN(18-kip) Axleloads</th>
<th>Average Equivalent 80-kN(18-kip) Axleloads per Vehicle</th>
<th>Damage Factor* by Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Unit 2 Axles, 4 Tires</td>
<td>8,564</td>
<td>518.2</td>
<td>0.0605</td>
<td>0.008310 -1.81212</td>
</tr>
<tr>
<td>Single Unit 2 Axles, 6 Tires</td>
<td>19,050</td>
<td>5,627.6</td>
<td>0.2953</td>
<td>0.008400 -1.19876</td>
</tr>
<tr>
<td>Single Unit 3 Axles</td>
<td>2,843</td>
<td>1,813.7</td>
<td>0.6386</td>
<td>0.042940 -2.75730</td>
</tr>
<tr>
<td>Combination Unit 3 Axles</td>
<td>4,701</td>
<td>2,986.7</td>
<td>0.6353</td>
<td>0.008466 -0.83429</td>
</tr>
<tr>
<td>Combination Unit 4 Axles</td>
<td>15,217</td>
<td>11,434.7</td>
<td>0.7514</td>
<td>0.009622 -0.56825</td>
</tr>
<tr>
<td>Combination Unit 5 Axles</td>
<td>21,673</td>
<td>13,583.1</td>
<td>0.6267</td>
<td>0.012298 -0.60687</td>
</tr>
<tr>
<td>Automobiles and Pickups</td>
<td></td>
<td></td>
<td>0.0501</td>
<td></td>
</tr>
</tbody>
</table>

*Damage Factor(year) = M (year - 1959) + B (for years after 1958)

Note: Data from Kentucky W-4 Tables for 1959-1973, except for Automobiles and Pickups.

---

### Table 2. Lane Distributions for Levels of Service

<table>
<thead>
<tr>
<th>Lane</th>
<th>Four Lanes</th>
<th>Six Lanes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Level of Service</td>
<td>Level of Service</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>Shoulder</td>
<td>95</td>
<td>90</td>
</tr>
<tr>
<td>Center</td>
<td>45</td>
<td>43</td>
</tr>
<tr>
<td>Median</td>
<td>5</td>
<td>10</td>
</tr>
</tbody>
</table>
Figure 1. Vehicle Classifications by Lane for Four-Lane Facility for Level of Service A.
Figure 2. AADT versus Vehicle Classification Percentages.
Figure 3. Roughness versus Time (Months).
Figure 4. Serviceability Index versus Roughness Index.

AC: PSI = 4.65 - 0.003 RI

Figure 5. Serviceability Index Related to (a) Designed Fatigue Life and (b) Present Worth of Pavement Structure after Beginning of Disintegration.
Figure 6. Percentage of Net Worth of Pavement after Disintegration Begins versus Percentage of Design Thickness.

Figure 7. Total Design Thickness versus Percentage of the Asphaltic Concrete Thickness of the Total Thickness.
Figure 8a. Simplified Thickness Design Curves for Pavement Structures Having 33 Percent Asphaltic Concrete Thickness of the Total Pavement Thickness.
Figure 8b. Simplified Thickness Design Curves for Pavement Structures Having 50 Percent of Asphaltic Concrete Thickness of the Total Pavement Thickness.
Figure 8c. Simplified Thickness Design Curves for Pavement Structures Having 67 Percent of Asphaltic Concrete Thickness of the Total Pavement Thickness.
Figure 9. Road Rater Data Sheet: Test Data and Analysis for KY 33, Site No. 1; Before Overlay, Assuming Layer Thicknesses from Records.
Figure 10. Temperature and Modulus of Elasticity Distributions with Depth of Asphalitic Concrete: KY 33, Site No. 1; Before Overlay.
Figure 11. Analysis of Road Rater Data: KY 33, Site No. 1; Before Overlay (Data from Figure 9).
**Data Sheet**

**ROAD RATER MEASUREMENTS**

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

<table>
<thead>
<tr>
<th>LOCATION</th>
<th>KY 33, MERCER CO, #1</th>
</tr>
</thead>
<tbody>
<tr>
<td>DATE OF TESTING</td>
<td>MARCH 25, 1975</td>
</tr>
<tr>
<td>MEAN PAVEMENT TEMPERATURE</td>
<td>50°F</td>
</tr>
<tr>
<td>MEAN MODULUS OF ELASTICITY (ASPHALTIC CONCRETE)</td>
<td>2.08 x 10^6 PSI</td>
</tr>
<tr>
<td>DEFLECTION ADJUSTMENT FACTOR</td>
<td>1.08</td>
</tr>
<tr>
<td>FREQUENCY</td>
<td>25 Hz</td>
</tr>
</tbody>
</table>

### Field Deflection Measurements [Units: in x 10^-5]

<table>
<thead>
<tr>
<th>No. 1</th>
<th>No. 2</th>
<th>No. 3</th>
<th>No. 1 PROJECTED</th>
</tr>
</thead>
<tbody>
<tr>
<td>59</td>
<td>37</td>
<td>21</td>
<td>65.2</td>
</tr>
<tr>
<td>69</td>
<td>41</td>
<td>23</td>
<td>73.1</td>
</tr>
<tr>
<td>88</td>
<td>54</td>
<td>30</td>
<td>97.2</td>
</tr>
<tr>
<td>59</td>
<td>37</td>
<td>22</td>
<td>62.2</td>
</tr>
<tr>
<td>73</td>
<td>43</td>
<td>24</td>
<td>77.0</td>
</tr>
<tr>
<td>80</td>
<td>47</td>
<td>23</td>
<td>96.0</td>
</tr>
</tbody>
</table>

### Adjusted Deflections [Units: in x 10^-5]

<table>
<thead>
<tr>
<th>No. 1</th>
<th>No. 2</th>
<th>No. 3</th>
<th>No. 1 PROJECTED</th>
</tr>
</thead>
<tbody>
<tr>
<td>63.7</td>
<td>40.0</td>
<td>22.7</td>
<td>70.4</td>
</tr>
<tr>
<td>74.5</td>
<td>44.3</td>
<td>24.8</td>
<td>78.9</td>
</tr>
<tr>
<td>95.0</td>
<td>58.3</td>
<td>32.4</td>
<td>105.0</td>
</tr>
<tr>
<td>63.7</td>
<td>40.0</td>
<td>23.8</td>
<td>67.2</td>
</tr>
<tr>
<td>78.8</td>
<td>46.4</td>
<td>25.9</td>
<td>83.2</td>
</tr>
<tr>
<td>86.4</td>
<td>50.8</td>
<td>24.8</td>
<td>103.7</td>
</tr>
</tbody>
</table>

### Predicted Subgrade Modulus of Elasticity [Units: PSI]

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>21,500</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>19,250</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>14,250</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>21,500</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>18,250</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>16,500</td>
</tr>
</tbody>
</table>

**Figure 12.** Road Rater Data Sheet: Test Data and Analysis for KY 33, Site No. 1; Before Overlay, Assuming Adjusted Effective Layer Thicknesses Determined from Figure 11(b).
Figure 13. Analysis of Road Rater Data: KY 33, Site No. 1; Before Overlay (Data from Figure 12).
**Data Sheet**

**ROAD RATER MEASUREMENTS**

<table>
<thead>
<tr>
<th>Location</th>
<th>KY 33, Mercer Co. #1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date of Testing</td>
<td>November 6, 1975</td>
</tr>
<tr>
<td>Time of Testing</td>
<td>10:00 AM</td>
</tr>
<tr>
<td>Mean Pavement Temperature</td>
<td>65°F</td>
</tr>
<tr>
<td>Surface Temperature</td>
<td>67°F</td>
</tr>
<tr>
<td>Mean Modulus of Elasticity (Asphaltic Concrete)</td>
<td>$1.38 \times 10^6$ psi</td>
</tr>
<tr>
<td>5-Day Mean Air Temperature</td>
<td>62.6°F</td>
</tr>
<tr>
<td>Deflection Adjustment Factor</td>
<td>1.025</td>
</tr>
<tr>
<td>Layer Thicknesses</td>
<td>After Overlay: 6.2 in. AC, 4.8 in. PSA</td>
</tr>
<tr>
<td>Frequency</td>
<td>25 Hz</td>
</tr>
</tbody>
</table>

| MEASUREMENTS [UNITS $\times 10^{-5}$] |
|---|---|---|---|---|
| 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 |

| DEFLECTIONS [UNITS $\times 10^{-5}$] |
|---|---|---|---|---|
| No. 1 | No. 2 | No. 3 | No. 1 Projected |
| 45.1 | 31.8 | 20.5 | 49.3 |
| 30.8 | 25.6 | 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 MODULUS OF ELASTICITY [UNITS PSI] |
|---|---|---|---|
| 21,250 |
| 30,500 |
| 26,000 |
| 20,500 |
| 30,500 |
| 25,000 |

**Figure 14.** Road Rater Data Sheet: Test Data and Analysis for KY 33, Site No. 1; After Overlay, Assuming Adjusted Effective Layer Thicknesses from Figure 11(b) Plus Overlay Thickness.
Figure 15. Temperature and Modulus of Elasticity Distributions with Depth of Asphaltic Concrete: KY 33, Site No. 1; After Overlay.
Figure 16. Analysis of Road Rater Data: KY 33, Site No. 1; After Overlay (Data from Figure 14).
Coal-Haul Special