MEMORANDUM TO:  G. F. Kemper
State Highway Engineer
Chairman, Research Committee

SUBJECT: Research Report No. 511; "Design System for Asphaltic Concrete Overlays;"
KYHPR-75-77; HPR-PL-1(14), Part II.

Inevitably, the design of pavement structures and overlays will graduate from rules-of-thumb into highly technical processes. Criteria and mathematical models will form the framework of the system. Inputs for determining overlay requirements necessarily include condition histories and soundings of existing pavements, loading histories, and traffic forecasts. Long-range strategies become possible, and scheduling plans may be established.

The schema presented is styled for asphaltic concrete pavements. It does not directly recognize joints and cracks in the existing pavement as would be necessary in a portland cement concrete pavement. It contains a hidden, rule-of-thumb criterion against rutting of the subgrade. Another schema is being developed specifically for PCC pavements. It will recognize joints and cracks and other discontinuities but will not have the same type of rutting criterion built into it. There, the principal rutting occurs in the asphaltic layer; and support at discontinuities becomes a controlling factor. A separate model of rutting is being developed under Study KYHPR-72-72; a report, No. 502, will precede this issue.

Eventually, these and other works referenced in the present report will be merged and refined into a total, pavement design and management system -- packaged and implementable.

Respectfully submitted,

Jas. H. Havens
Director of Research

gd
Enc.
cc's: Research Committee
A method of designing asphaltic concrete overlays has been developed from (1) Kentucky's theoretical 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 has been expressed as reduced or effective thicknesses of new-quality materials producing the same measured dynamic deflections. The total thickness required for the future traffic minus the effective or reduced thickness of the existing pavement is the overlay thickness required.
DESIGN SYSTEM FOR ASPHALTIC CONCRETE OVERLAYS

KYHPR-75-77; HPR-PL-1(14), Part II

by

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in cooperation with the
U.S. DEPARTMENT OF TRANSPORTATION
Federal Highway Administration

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November 1978
INTRODUCTION

The method of design of overlays presented herein has evolved from approximately 30 years of design and experience. Kentucky's early methods of pavement design were based upon 22-kN (5-kip) EWL's (1). In 1973, it was proposed (2) to use 80-kN (18-kip) axleloads as established in the AASHTO Interim Guide (3) even though damage factors already used in Kentucky (based on California factors) differed. Design of overlays (that is, the determination of additional thicknesses needed) requires as inputs (1) a measurement of the load-carrying capability of the subgrade, (2) an evaluation of the condition and worth of the existing pavement, and (3) an estimate of expected traffic and associated fatigue loadings.

Subgrade strength is determined by the CBR test method. The Kentucky test 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 tests generally yield an estimated subgrade modulus greater than that obtained by the Kentucky laboratory CBR method since the in-place subgrade is not likely to exist in the critical moisture condition represented by the "soaked" conditions of the laboratory tests. Thus, overlay thicknesses should be designed for the CBR's (subgrade moduli) obtained from in-place testing. Lengths of design sections may be limited accordingly.

The existing pavement condition may be expressed as a reduced modulus of the asphaltic concrete or as reduced layer thicknesses of the new material. The reduced thickness concept is used in this procedure (5-7). The overlay thickness is that required in addition to the residual structural effectiveness of the existing pavement to support the forecasted traffic or 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 volume of traffic is an important consideration in the styling and geometric design of a roadway, composition of the traffic in terms of axle weights and 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 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 an estimate of the total number of vehicles during the design life and multiplying 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 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, actual 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\(_i\)) for each vehicle classification by year using the equation

\[ DF_i = \frac{\sum (N_j \times F)}{\text{(number of weighed vehicles per classification)}} \]

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 type of paving material, axle configuration, and axleload determined from the following:

For asphaltic concrete:

Single Axleload:
\[ F = (1.2504)(P_s - 18) \]

where \( P_s = \) single axle load (kips)

Tandem Axleload:
\[ F = (1.1254)(P_t - 34) \]

For portland cement concrete (from a companion study):

Single Axleload:
\[ F = (1.2875)(P_s - 18) \]

Tandem Axleload:
\[ F = (1.1500)(P_t - 29) \]

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

c. Estimate lane distribution (LD\(_i\)) for highways having four or more lanes for each vehicle classification. Figure 1a shows a typical set of factors for each vehicle classification for Level of Service A on a four-lane facility. Figures 1b-f have been developed for other levels of service and six-lane facilities.

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

\[ \text{EAL} = 365 \times \text{AADT} \times \sum \left( C_i \times DF_i \times LD_i \right) \]

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.
# Table 1: Damage Factors by Vehicle Classification for Asphaltic Concrete Pavements

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Number of Vehicles 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</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>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</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 Axles, 6 Tires</td>
<td>19,058</td>
<td>5,627.6</td>
<td>0.2953</td>
<td>0.008400 -1.19876</td>
</tr>
<tr>
<td>SINGLE UNIT</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 Axles</td>
<td>2,848</td>
<td>1,818.7</td>
<td>0.6386</td>
<td>0.008466 -0.83429</td>
</tr>
<tr>
<td>Combination Unit</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>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</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>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</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>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></td>
<td>0.0501</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.
Figure 1a. Vehicle Classifications by Lane; Four-Lane Facility, Level of Service A.

Figure 1b. Vehicle Classifications by Lane; Four-lane Facility, Level of Service B.
Figure 1c. Vehicle Classifications by Lane; Six-Lane Facility, Level of Service A.

Figure 1d. Vehicle Classifications by Lane; Six-Lane Facility, Level of Service B.
Figure 1e. Vehicle Classifications by Lane; Six-Lane Facility, Level of Service C.

Figure 1f. Vehicle Classifications by Lane; Six-Lane Facility, Level of Service D.
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 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

\[
APT = \frac{\sum_{i=1}^{n} A_i T_i}{\sum T_i}
\]

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

\[
AAL = \frac{\sum_{j=1}^{m} [N_j \times AL_j] / [N_S + N_T]}{N_S + N_T}
\]

where
- \( AAL \) = average axleload,
- \( N_j \) = number of axles weighed in weight category \( j \),
- \( AL_j \) = 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.

e. Calculate the damage factor \( DF_A \) for the average or mean axleload by the equation

\[
DF_A = (1.2504)(AAL - 18).
\]

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,
4. average axleload, 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

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

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_{ij}) or from Table 1.

d. Choose the appropriate portion of Figures 1a-f and obtain the lane distribution factors (LD_{ij}) for each vehicle classification.

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

\[
\sum_{k=1}^{p} EAL = AADT_k \times C_i \times DF_{ij} \times LD_{ij} \times 365
\]

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

<table>
<thead>
<tr>
<th>LANE</th>
<th>Level of Service A</th>
<th>Level of Service B</th>
<th>Level of Service C</th>
<th>Level of Service D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shoulder</td>
<td>95</td>
<td>90</td>
<td>28</td>
<td>26</td>
</tr>
<tr>
<td>Center</td>
<td>45</td>
<td>43</td>
<td>38</td>
<td>32</td>
</tr>
<tr>
<td>Median</td>
<td>5</td>
<td>10</td>
<td>27</td>
<td>31</td>
</tr>
</tbody>
</table>

#### Figure 2. AADT versus Vehicle Classification Percentages.
6. Compound Interest Equation

If there are no extended volume data which seem 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 \( k \)th 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.

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 may be plotted versus time to obtain an estimate of when the critical RI might be expected. Figure 3 (9) is an example.
   b. If RI data do not exist for the particular pavement, 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):
      \[ RI = 2.33X + 180 \]
      For 1976 and later (for asphaltic concrete pavements) (5):
      \[ RI = 3.20X + 212 \]
      where \( X = \) Mays Ride Meter value.

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Figure 3. Roughness versus Time (Months).
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, 9).

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:

\[
\text{Total Equivalent Thickness} = \frac{AF_{AC} \times \text{Asphaltic Concrete Thickness} + AF_{DGA} \times \text{Dense-Graded Aggregate Thickness}}{100 - \text{percent Asphaltic Concrete of design thickness}}
\]

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 effective 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:

\[
\text{Total thickness} = \frac{100 \times (\text{Adjusted Dense-Graded Aggregate thickness})}{(100 - \text{percent Asphaltic Concrete of design thickness})}
\]

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). The weakest in-place subgrade modulus value as determined from dynamic tests establish the lengths and overlay thicknesses of the design sections in a project.

10. With the estimated EAL from Step 1 and the CBR design value from Step 9, enter Figures 8 a-e to determine design thicknesses. Plot these values versus percent asphaltic concrete of the total thickness as illustrated by Curve B in Figure 7. Figures 8 a-e 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:

\[
\text{Overlay thickness} = \text{Total Thickness from Step 11} - \text{Total Equivalent Thickness from Step 7}
\]
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 Onset of Disintegration versus Percentage of Design Thickness.
Figure 7. Total Design Thickness versus Percentage of Asphaltic Concrete Thickness.
Figure 8a. Simplified Thickness Design Curves for Pavement Structures Having 33 Percent Asphalritic Concrete Thickness.
Figure 8b. Simplified Thickness Design Curves for Pavement Structures Having 50 Percent Asphaltic Concrete Thickness.
Figure 8c. Simplified Thickness Design Curves for Pavement Structures Having 67 Percent Asphaltic Concrete Thickness.
Figure 8d. Simplified Thickness Design Curves for Pavement Structures Having 75 Percent Asphaltic Concrete Thickness.
DESIGN CURVES
PERCENT OF TOTAL THICKNESS COMPOSED
OF ASPHALTIC CONCRETE • 100%
MODULUS OF ASPHALTIC CONCRETE FOR
FULL-DEPTH DESIGN • 375 KSI

Figure 8e. Simplified Thickness Design Curves for Pavement Structure Having 100 Percent Asphaltic Concrete Thickness.
EVALUATION OF AN OVERLAID PAVEMENT

KY 33 is an access road to a steam-generating electrical plant which uses coal. Future plans call for 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 a strengthening of the pavement structure.

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 unloading 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.
5. The design should last 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:

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

The 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 theoretical relationship between Road Rater deflections and subgrade modulus of elasticity for the No.-1 and No.-2 Sensors is presented in Figure 11. The relationship between the No.-1 Sensor deflection and the No.-1 projection is also shown in Figure 11. The graphs in Figure 11 illustrate these relationships for the layer thicknesses, as determined from measurements of cores, and for reference conditions. Field measured deflections adjusted to reference conditions are indicated by points. Enter Figure 11 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 between No.-1 Sensor deflections and 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 line of parallel offset to the theoretical relationship is shown in Figure 11. This plot can be used to identify variations in the pavement structure by comparing field data to the theoretical relationship (6).

The measured deflections and corresponding estimates of subgrade modulus (shown in Figure 11) do not match the theoretical relationship. The determination of the thinner, effective structure is shown in Figure 11. 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 response 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 11, the original layer thicknesses were determined from 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.
**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 Asphaltic 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).
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 are presented in Figure 12 and are illustrated graphically in Figure 13. It can be seen from Figure 13 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, 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 actual 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 overlaying are 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 overlaying 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 deflections and subgrade modulus for both theory and field behavior are presented in Figure 16. From Figure 16, 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.
Figure 12. Road Rater Data Sheet: Test Data and Analysis for KY 33, Site No. 1; Before Overlay, 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).
Figure 14. Road Rater Data Sheet: Test Data and Analysis for KY 33, Site No. 1; After Overlay, 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).
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.
