A PROPOSED CONVENTIONAL FLEXIBLE PAVEMENT THICKNESS DESIGN PROCEDURE

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conducted by the
TRANSPORTATION RESEARCH LABORATORY
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A PROPOSED CONVENTIONAL FLEXIBLE PAVEMENT THICKNESS DESIGN PROCEDURE

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Study was conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration

The basic concepts and the development of a proposed thickness design procedure for conventional flexible pavements are presented. Traffic (IDOT traffic factor), subgrade modulus (fine-grained soils, sandy-type soils), location in the state (pavement temperature effects), asphalt cement grade (AC-5, AC-10, AC-20), and design reliability factors are considered.

ILLI-PAVE based design algorithms are utilized in the procedure. Asphalt concrete fatigue consumption and subgrade soil stress ratio are the design criteria. "Design Time" and "Minimum Subgrade E_{R,t}" concepts are used to consider seasonal effects.

"Easy-to-use" design charts and tables are provided to facilitate the pavement design process.
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ACKNOWLEDGMENTS/DISCLAIMER

This research report is based on the results of Project IHR-510 - Mechanistic Evaluation of Illinois Flexible Pavement Design Procedures. IHR-510 is sponsored by the Illinois Department of Transportation (Division of Highways) and the U.S. Department of Transportation (Federal Highway Administration).

The contents of this research report reflect the views of the authors. The contents do not necessarily reflect the official views or policies of the Illinois Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification or regulation.
1. INTRODUCTION

A proposed mechanistic thickness design procedure for conventional flexible pavements (asphalt concrete (AC) surface and granular base) is presented in Appendix A. The mechanistic approach utilizes pavement responses (AC radial tensile strain, subgrade stress) to determine the ability of a given design to provide a required level of service. ILLI-PAVE data based algorithms presented in "MECHANISTIC DESIGN CONCEPTS FOR CONVENTIONAL FLEXIBLE PAVEMENTS" (1) are utilized. The design algorithms are presented in graphical form to facilitate utilization of the procedure. Three major inputs are required:

1) TRAFFIC
2) CLIMATE
3) MATERIALS CHARACTERIZATION

Each input is discussed in Section 2.

Pavement responses are related to pavement performance through the use of TRANSFER FUNCTIONS. For conventional flexible pavements, separate transfer functions are required to consider AC fatigue cracking and subgrade rutting. The initial forms of these functions have been discussed by Elliott and Thompson (1). Recommended application of each are discussed in Section 4 (FATIGUE) and Section 5 (RUTTING).

2. STRUCTURAL MODEL INPUTS

TRAFFIC

The design charts presented in this report are for 18 kip single axle loads. Mixed traffic is converted to 18 kip single axle loads using current ILLINOIS DEPARTMENT OF TRANSPORTATION procedures (2). The Traffic Factor (TF) is the number of 18 kip single axle loads (in millions).
CLIMATE

Climatic factors should be considered in mechanistic design. Important factors are:

1) SEASONAL TEMPERATURE VARIATIONS
2) FROST DEPTH AND DURATION
3) FREEZE THAW CYCLES
4) PRECIPITATION FREQUENCY, AMOUNT AND SEASONAL DISTRIBUTION
5) AREAL AND SYSTEM DRAINAGE CHARACTERISTICS

Due to the complexity of attempting to individually include these factors in the design procedure, they are considered through the use of a "Design Time" scheme and the various inputs to the procedure. More specifically, factors 1, 2, and 3 are considered in each of the material inputs through the use of a representative "Design Time" for different sections of the state. The AC mixture temperature at the "Design Time" given for each area accommodates the facts that the frost depth and duration and number of freeze thaw cycles are greater in the northern part of the state than in the south. Factors 4 and 5 are considered in the subgrade resilient modulus input. A more detailed discussion of the "Design Time" concept is presented in Section 3.

MATERIALS CHARACTERIZATION

Adequate characterization of the asphalt concrete, granular base and subgrade soils is an integral part of the design procedure. Review of various methods for determination of AC modulus indicated The Asphalt Institute method (3) provides a reliable estimate of the AC mixture stiffness. Incorporation of this procedure into the design methodology is discussed in Section 4 of this report.
The design procedure presented herein does not directly include a parameter to evaluate the effect of granular material properties. University of Illinois research (1) indicated structural responses predicted for varying granular material quality did not significantly differ. Overall pavement performance, in particular permanent deformation/rutting, is affected by granular material quality. In the proposed procedure, it is assumed that granular material layer related rutting will be controlled by material selection procedures and policies and good construction control.

Selection of a representative subgrade resilient modulus value ($E_{Ri}$) is based on engineering soil index properties (PI, % < 2 micron clay) using relations established by Thompson and Robnett (4). A spring minimum $E_{Ri}$ value is calculated and a general $E_{Ri}$ - seasonal progression estimated for the year. Based on the spring minimum value and seasonal progression, an $E_{Ri}$ value can be established to represent "Design Time" conditions.

3. DESIGN TIME PROCEDURE VALIDATION

Pavement response fluctuates throughout the year relative to climatic conditions thus impacting pavement performance. This typical fluctuation is shown in Figures 1 and 2. Monthly "fatigue lives" were calculated and plotted using constant AC thickness and subgrade resilient modulus values. A weighted design period value was calculated using Miner's hypothesis.
\[ N(f) = \frac{M}{\Sigma \left(\frac{1}{N(a)}\right)} \]

- \( N(a) \) = The number of allowable load repetitions for the conditions for month \( a \).
- \( N(f) \) = The number of load applications to failure considering traffic is applied throughout the year.
- \( M \) = The number of months in the design period (usually taken as 12).

Figures 1 and 2 are for a 12-month period. The horizontal lines across the diagram are the values of \( N(f) \). The yearly weighted traffic, \( N(f) \), crosses the monthly progression in two locations; once around early to mid May and again in September. To examine the effect of subgrade \( E_{Ri} \) on "Design Time", different modulus values were used. Subgrade \( E_{Ri} \), by itself has little effect on the "Design Time". Climatic effects (moisture, freeze thaw) are considered in establishing the "Design Time" \( E_{Ri} \) value. The selection of the "Design Temperature" (Asphalt concrete temperature at the "Design Time") incorporates the temperature effect on AC mixture modulus.

**ASPHALT CONCRETE THICKNESS EFFECTS**

Asphalt concrete thickness effects were included in the study of subgrade effects on "Design Time". Comparisons were made between 3 and 5 inch AC surfaced pavements. The difference between the AC temperatures for the "Design Time" was between 2.4 to 2.7 degrees Fahrenheit. Depending on the initial "Design Temperature", one degree difference effects approximately 0.1 to 0.2 of an inch change in asphalt concrete thickness. For example, in
Southern Illinois, a design based on a 3-inch AC "Design Time" temperature results in a 5-inch thick AC surface course. The AC thickness would be approximately 5.5 inches thick if the design was based on a 5 inch "Design Time" AC temperature.

Since AC surfaces for conventional flexible pavements are generally between 3 to 6 inches thick, it was concluded that one set of "Design Time" temperatures (in - pavement) could be developed for Illinois based on an AC thickness of 5 inches. This is slightly conservative for AC thicknesses less than 5 inches and has little significance for an AC thickness of 6 inches. Design temperature regions for Illinois are shown in Figure 3.

4. FATIGUE CRACKING EVALUATION

Fatigue cracking is evaluated on the basis of load induced flexural strain at the bottom of the asphalt concrete surface course layer. The proposed (5) AC fatigue relation (for Class I type AC mixtures) is:

\[ N = 5 \times 10^{-6} \times (1/\varepsilon_{AC})^{3.0} \]

\( N \) = The predicted number of load applications until crack initiation
\( \varepsilon_{AC} \) = Tensile strain at the bottom of the asphalt layer

AC strain is a function of the AC modulus \( E_{AC} \), AC thickness \( t_{AC} \), granular layer thickness \( t_{G} \), and subgrade resilient modulus \( E_{R1} \) as indicated in the algorithms shown in Table 1. Selection of the design \( E_{AC} \) and subgrade resilient modulus values is discussed in the following sections.

PREDICTING ASPHALT CONCRETE MODULUS

Asphalt concrete modulus is estimated from The Asphalt Institute equation developed by Witczak (3). Research documented in the PROPOSED FULL-DEPTH ASPHALT CONCRETE THICKNESS DESIGN PROCEDURE (5) showed that The Asphalt Institute equation adequately predicted AC modulus.
Input variables to the equation are:

1) TEMPERATURE
2) VISCOSITY OF ASPHALT BINDER
3) FREQUENCY OF LOADING
4) ASPHALT CONTENT OF AC MIXTURE
5) PERCENT AIR VOIDS IN AC MIXTURE
6) PERCENT AGGREGATE IN THE MIXTURE PASSING THE #200 SIEVE

Values representative of Illinois Class I mixes, various traffic conditions, and pavement thicknesses were used as constants for variables 2 through 5. Mix temperature and AC moduli relations were established as shown in Figure 4. This approach is identical to that in the PROPOSED FULL-DEPTH ASPHALT CONCRETE THICKNESS DESIGN PROCEDURE (5).

SELECTION OF AN AIR-MIX TEMPERATURE RELATION

The asphalt concrete mixture temperature discussed in the previous section is obtained through a relationship between the air and pavement temperatures. Validation of the SHELL air-mix temperature procedure (6) was achieved in previous IHR-510 work (5). The SHELL method relates mean monthly air temperature to mean monthly pavement temperature for various asphalt thicknesses (See Figure 5). The effect of pavement thickness on mix temperature is noted to be very small, especially at low air temperatures. An average thickness of three inches was used in this study.
SUBGRADE RESILIENT MODULUS SELECTION

Selection of a representative $E_{Ri}$ value along the right of way of a given section of pavement is sensitive to:

1) VARIABILITY OF SOIL TYPES
2) GRADE-LINE POSITION
3) CHANGING MOISTURE/FREEZE-THAW CONDITIONS

FWD deflection data for typical Illinois pavements were converted to estimated subgrade resilient modulus values for comparison with predicted values for various projects under study by the Illinois DOT. Fall $E_{Ri}$ values were estimated from the regression equation presented in the report "RESILIENT PROPERTIES OF SUBGRADE SOILS" by Thompson and Robnett (4). The equation is for AASHTO T-99 optimum water content conditions and the inputs are percent clay (< 2 micron) and plasticity index (PI) of the soil. Spring $E_{Ri}$ values were calculated using the AASHTO soil classification and adjusting for increased levels of saturation.

The study results showed the predicted Spring $E_{Ri}$ values were very sensitive to AASHTO classification. Prediction of the Spring $E_{Ri}$ value is extremely important for estimating the "Design Time" $E_{Ri}$ value and subgrade stress ratio (discussed in Section 5). It is therefore important to accurately determine the proper AASHTO classification by performing the necessary testing if this prediction equation is to be used.

In addition to the variability in engineering properties (PI, clay content) for a soil series, each project typically traverses several soil series and one or more soil associations. It is evident that since many different soils will be encountered, additional $E_{Ri}$ variance will occur.
To determine the effect of $E_{RI}$ variance on estimated pavement life, various $E_{RI}$ seasonal progressions were used in the ILLI-PAVE algorithms. A typical 3-inch asphalt concrete plus 8-inch granular base section was considered. Changes in base thickness or mean monthly temperatures have virtually no affect on the relationship between various $E_{RI}$ progressions and the predicted number of load applications to failure.

Three different $E_{RI}$ progressions were studied using a minimum value of 2 ksi and maximum of 11 ksi. It was determined that an $N(f)$ increase not greater than approximately 10 - 11 percent might be expected between the optimum and least favorable conditions based on an AC fatigue evaluation calculated on a monthly basis. Additional studies were conducted to review the effects of varying the "Design Time" $E_{RI}$ prediction. It was concluded that 2 representative values (2 and 5 ksi) could be used for the design time $E_{RI}$ resulting in only a 0.2 to 0.5 inch AC surface course difference in required pavement thickness.

Resilient modulus laboratory testing of subgrade soils can be performed but may not be an effective means (in terms of cost, time, and accuracy) for determining the yearly variability of any given soil series. Extensive testing is probably only justified for large projects where samples can be obtained of the major series encountered and tested under various moisture/density conditions.

For most projects, the $E_{RI}$ input variable can be estimated with sufficient accuracy based on soil index tests ($\% < 2$ micron clay, PI) of the major soil series encountered, consideration of in-situ moisture conditions, and a procedure to determine the minimum/spring modulus value. Seasonal FWD deflection testing of existing pavements in similar soil areas is perhaps the most effective procedure for estimating in-situ $E_{RI}$ values.
Thompson and Robnett (4) have developed a regression equation for predicting $E_{RI}$ at optimum water content and 95% of maximum dry density (AASHTO T-99).

$$E_{RI} \text{ (OPT)} = 4.46 + 0.098(\% \text{CLAY}) + 0.119(\text{PI})$$

($E_{RI}$ in ksi units)

The extensive IHR-603 resilient testing data base (4) was utilized to establish typical "$E_{RI}$ decrease/1% moisture content increase" for various USDA textural classifications. The following values are satisfactory for pavement design activities:

<table>
<thead>
<tr>
<th>USDA TEXTURAL CLASSIFICATION</th>
<th>$E_{RI}$ DECREASE/1% MOISTURE INCREASE (ksi/%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>clay, silty clay, and silty clay loam</td>
<td>0.7</td>
</tr>
<tr>
<td>silt loam</td>
<td>1.5</td>
</tr>
<tr>
<td>loam</td>
<td>2.1</td>
</tr>
</tbody>
</table>

Minimum and $E_{RI}$ (OPT) values should be obtained by taking a weighted average (based on length of occurrence along the project) of the major soil series encountered. For fatigue design, a "Design Time" $E_{RI}$ value of 2 ksi or 5 ksi is selected. The "Design Time" is early to mid May. The $E_{RI}$ value for this time should be considered slightly above the minimum value and below the optimum average fall value obtained for the project.

5. SUBGRADE RUTTING DESIGN PROCEDURE

The stress ratio criteria (subgrade deviator stress divided by the unconfined compressive strength) for evaluating subgrade rutting was discussed by Elliott and Thompson (1). An ILLI-PAVE based subgrade stress ratio algorithm (see Table 1) has been developed. Inputs to this equation are
AC thickness ($T_{AC}$), granular base thickness ($T_G$), AC dynamic modulus ($E_{AC}$), and resilient subgrade modulus ($E_{RI}$). AC and granular base thicknesses are initially established by AC fatigue design criteria. A stress ratio value is then calculated for the "Design Time" conditions.

Subgrade stress ratio monthly trends for a given set of conditions indicate the maximum stress ratio does not always occur at the "Design Time". Graphs depicting these trends are shown for Champaign and Cairo (Figures 6 and 7). The maximum stress ratio for thinner pavement sections usually occurs in March at the time of minimum subgrade strength. As pavement thickness increases, the subgrade modulus becomes less important and asphalt concrete modulus effects begin to dominate. To more accurately estimate the maximum stress ratio, the AC and subgrade modulus values must be determined before or after the design time according to the pavement thickness.

To control subgrade rutting in higher Traffic Factor situations, it is recommended that the stress ratio be equal to or less than 0.5. For lower traffic volume roads, stress ratios greater than 0.5 may be acceptable. Values greater than 0.5 can be reduced by either increasing granular base or asphalt concrete thickness. The design procedure has been developed on the basis of increasing the stone base thickness.

Since a stress ratio value of 0.5 is typically only exceeded by pavement sections with AC layers less than 4 inches thick, a conservative stress ratio value can be estimated by using the "Design Time" AC temperature and the minimum $E_{RI}$ value expected for the subgrade. If the allowable stress ratio value is to be reduced below 0.5, thereby decreasing the subgrade rutting potential, it is recommended that the project be examined on a monthly basis.
6. TWO-INCH AC SURFACE PAVEMENT SECTIONS

The proposed design procedure utilizes a "Design Time" concept, (fatigue cracking evaluation based on strain in the asphalt, and a "check" of the subgrade rutting potential by use of a stress ratio algorithm) and is valid for asphalt concrete surfaces between 3 and 6 inches.

In the development of the AC strain algorithm, it was noted that the strain in the bottom of a 1.5-inch AC layer was less than that in a 3-inch layer. This AC thickness transition effect is shown in Figure 8. Since the behavior of the AC layer is different in the 1.5 to 3-inch range (membrane - structural layer transition), an alternate procedure is provided for the "design" of 2 and 2.5-inch AC pavements. The "design" is a policy governing the use of 2 and 2.5-inch AC surfaces and a proposed procedure to select a granular base thickness to control subgrade rutting by limiting the stress ratio.

Based on current information and present knowledge and observations of thin pavement sections, it appears reasonable to allow the following traffic ranges for 2 and 2.5-inch AC thicknesses depending on their location in the

<table>
<thead>
<tr>
<th>SECTION OF THE STATE</th>
<th>IDOT TRAFFIC FACTOR</th>
<th>AC THICKNESS (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NORTHERN</td>
<td>&lt; 0.05</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>0.05 - 0.1</td>
<td>2.5</td>
</tr>
<tr>
<td>CENTRAL</td>
<td>&lt; 0.025</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>0.025 - 0.075</td>
<td>2.5</td>
</tr>
<tr>
<td>SOUTHERN</td>
<td>&lt; 0.01</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>0.01 - 0.05</td>
<td>2.5</td>
</tr>
</tbody>
</table>

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state. The values have been compared with present IDOT, National Crushed Stone Association, and the Corps of Engineers minimum requirements to insure compatibility (see Table 2). The Table 2 values do not consider the design reliability concept discussed in Section 7 of this report. The thicknesses are appropriate for tire pressures in the 80 psi range but need to be further considered for the higher radial tire pressures (100 psi average) associated with 20k single axle - 34 kip tandem axle type traffic. Thompson (9) recently considered the effects of the increased pressures. They are particularly significant and detrimental for thin AC surface courses.

The procedure to establish granular base thickness is identical to that described in Section 5. A stress ratio value is determined for the given AC thickness, AC modulus, and minimum \( E_{Ri} \) resilient modulus. The stress ratio can be decreased by increasing the granular base thickness or the AC thickness. Acceptable stress ratio values vary depending on Traffic Factor. For low Traffic Factors, acceptable stress ratios may be as large as 0.6 to 0.7. A stress ratio of 0.5 is satisfactory for high TF situations. Higher stress ratio values may be used with less "moisture sensitive" soils (clay, silty clay, silty clay loam) than for more "moisture sensitive" soils (silt loam, loam).

7. DESIGN RELIABILITY CONSIDERATIONS

Pavement response and performance data indicate "pavement life" is not a "fixed value", but shows considerable variability (i.e. "all of the pavement" does not "fail" at the same number of load applications). Statistical analysis of Illinois conventional pavement surface NDT deflection data indicate typical coefficient of variation values ((standard deviation/average) x 100) are in the range of 15% - 35%.
Pavement fatigue life has been correlated with surface deflection. Pavement life-deflection relations are widely utilized in various pavement analysis and design problems.

Based on the IHR-510 algorithm relating asphalt concrete strain to surface deflection and the IHR-510 proposed AC fatigue equation, a relation between pavement fatigue life and surface deflection was established.

\[ N_{18} = \frac{9.3 \times 10^9}{\Delta^{3.34}} \]

- \( N_{18} \) = Number of 18k SAL to "fatigue" failure
- \( \Delta \) = Surface deflection for 18k moving axle load, mils

Note:

\[ \log S_{AC} = 1.1126 \log \Delta + 0.9102 \]

\[ N = 5 \times 10^{-6} \left( \frac{1}{\varepsilon_{AC}} \right)^{3.0} \]

Where:

- \( S_{AC} \) = AC radial tensile strain (microstrain)
- \( \varepsilon_{AC} \) = Tensile strain @ bottom of AC layer
- \( N \) = Number of strain repetitions to failure

If expected surface deflection variations (average +/- variation) are imposed, see Figure 9, a "design reliability" concept can be established. Design reliability is the probability that a pavement segment will sustain the IDOT "Traffic Factor" (TF) number of load applications prior to failure. It is assumed that the algorithm and input values provide a 50% "design reliability" (on the average 50% of the pavement will fail before the TF number of 18k SAL applications and 50% will not fail). For a coefficient of variation of 25%, and conventional AC pavements with 2 - 6 inch AC surfaces,
the following approximate "multiplier" - design reliability relations are appropriate. "Multiplier" values for other levels of design reliability can easily be established.

<table>
<thead>
<tr>
<th>&quot;Multiplier&quot; *</th>
<th>Design Reliability **</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>50 (AVERAGE)</td>
</tr>
<tr>
<td>2</td>
<td>80 (INTERMEDIATE)</td>
</tr>
<tr>
<td>3</td>
<td>92 (HIGH)</td>
</tr>
</tbody>
</table>

* The "Multiplier" is applied to the IDOT Traffic Factor (TF). If the TF is 1 \(1 \times 10^6\) 18k SAL a pavement designed for \(2 \times 10^6\) SAL would have an 80% probability of sustaining \(1 \times 10^6\) SAL without failure. To achieve 92% reliability, the pavement would be designed for \(3 \times 10^6\) SAL.

** For an assumed surface deflection coefficient of variation of 25%.

8. CONVENTIONAL FLEXIBLE VERSUS FULL DEPTH AC

DESIGN COMPARISON

Comparisons were made between the maximum standard conventional flexible pavement design \(T_{AC} = 6 \text{ inches}, T_C = 8 \text{ inches}\) and various full depth AC design thicknesses to verify the convergence between the two ILLI-PAVE based mechanistic design procedures. Figures 10 and 11 indicate that the conventional flexible design falls between the 6 and 7 inch full depth designs as would be expected since the conventional design includes 8 inches of stone. For most full-depth AC designs the "Design AC Modulus" will be between 600 to 400 ksi where the convergence between the full-depth AC and conventional designs is most pronounced.
9. DESIGN SUMMARY

The basic concepts and the development of a proposed CONVENTIONAL FLEXIBLE ASPHALT CONCRETE THICKNESS DESIGN PROCEDURE are presented. Traffic (IDOT Traffic Factor), subgrade modulus, $(E_R)_t$, location in the state (pavement temperature effects), asphalt cement grade (AC-5, AC-10, AC-20), design reliability factors, and a comparison to THE PROPOSED FULL DEPTH AC THICKNESS DESIGN PROCEDURE (5) are considered. The procedure can be easily modified to accommodate conditions other than those considered in the procedure presented in Appendix A.
REFERENCES


TABLE 1

ILLI-PAVE ALGORITHMS FOR CONVENTIONAL FLEXIBLE PAVEMENTS

1. \( \log S_{AC} = 2.9496 + 0.1289 \left( T_{AC} \right) - 0.5195 \left( \log T_G \right) / T_{AC} \)
   \(-0.0807 \left( \log E_{AC} \right) T_{AC} - 0.0408 \left( \log E_{Ri} \right) \)
   \( R^2 = .980 \quad \text{SEE} = .036 \)

2. \( \log S_r = 0.3056 + 0.0560 \left( T_{AC} \right) - 0.0222 \left( T_G \right) \)
   \(-0.0495 \left( \log E_{AC} \right) T_{AC} - 0.4242 \left( \log E_{Ri} \right) \)
   \( R^2 = .974 \quad \text{SEE} = .061 \)

\( T_{AC} \) = AC layer thickness, in inches
\( T_G \) = Aggregate base course thickness, in inches
\( E_{AC} \) = AC modulus, in ksi
\( E_{Ri} \) = Subgrade modulus at breakpoint, in ksi
\( S_{AC} \) = Asphalt concrete tensile strain, in microstrain
\( S_r \) = Subgrade stress ratio -

(deviator stress/unconfined compressive strength)
### TABLE 2

MINIMUM AC THICKNESS REQUIREMENTS

<table>
<thead>
<tr>
<th>AGENCY</th>
<th>SUBGRADE</th>
<th>$5 \times 10^6$ EAL</th>
<th>$1 \times 10^6$ EAL</th>
<th>$5 \times 10^5$ EAL</th>
<th>$2 \times 10^5$ EAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Illinois Dept. of Transportation (IDOT-Bureau of Design)</td>
<td>IBR = 2</td>
<td>4*</td>
<td>4</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>IBR = 3</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>IBR = 5</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>National Crushed Stone Association (NCSA)</td>
<td>CBR = 2</td>
<td>3.5</td>
<td>3</td>
<td>2.5</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>CBR = 3</td>
<td>3.5</td>
<td>3</td>
<td>2.5</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>CBR = 5</td>
<td>3.5</td>
<td>3</td>
<td>2.5</td>
<td>2.5</td>
</tr>
<tr>
<td>Corps of Engineers</td>
<td>CBR = 50**</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>CBR = 80**</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>CBR = 100**</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>$1 \times 10^5$ EAL</th>
<th>$1 \times 10^4$ EAL</th>
<th>$1 \times 10^3$ EAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Illinois Dept. of Transportation (IDOT-Local Roads &amp; Streets)</td>
<td>IBR = 2</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>IBR = 3</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>

* - AC thickness, inches

** - Granular Base CBR

18
FIGURE 2

DESIGN TIME CONCEPT

TRAFFIC FACTOR

AC = 10
Tac = 5"
Tg = 8"

MONTH

JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
FIGURE 5

SHELL AIR-PAVEMENT TEMPERATURE RELATIONSHIP

AC MIXTURE TEMPERATURE (F)

AIR TEMPERATURE (F)

2" AC
4" AC
6" AC
FIGURE 7

STRESS RATIO MONTHLY TRENDS
CAIRO

STRESS RATIO

AC - 10

MONTH

Tac = 2'
Tac = 3'
Tac = 4'
Tac = 5'
Tac = 6'
FIGURE 8. AC Strain-AC Thickness Relation for Conventional Flexible Pavements.
$\Delta_{\text{Avg}} = 26$ mils
$\text{CV} = 25\%$
$\sigma = 6.5$ mils
$N_i = \text{Pavement Life for Indicated Design Reliability}$

FIGURE 10. Conventional Versus Full Depth Design Comparison ($E_{Ri} = 2$ ksi).
FIGURE 11. Conventional Versus Full Depth Design Comparison ($E_{RI} = 5$ ksi).
APPENDIX A

PROPOSED THICKNESS DESIGN PROCEDURE
FOR
CONVENTIONAL FLEXIBLE PAVEMENTS

DESIGN INPUTS

TF - Traffic Factor from current IDOT Pavement Design Manual procedures. TF is the number of equivalent 18 kip single axle loads (18k SALs) in millions (TF of 1 = 1x10^6). The thickness design procedure is based on 18k SALs and 80 psi tire pressure conditions (NOTE 1).

Design E_{ri} - Subgrade E_{ri} for "Design Time"

The "Design Time" is early-May for Southern Illinois; early to mid-May for Central Illinois; and mid-May for Northern Illinois. A Design E_{ri} value of 5 ksi (Fair Soils) or 2 ksi (Poor Soils) is selected, based on clay content and PI data and expected in-situ moisture conditions (optimum, wet of optimum). Repeated load testing and/or FWD NDT data are also helpful in establishing subgrade Design E_{ri}. Sandy-type soils are considered "Fair Soils" in utilizing the procedure (NOTE 2).

NOTE 1 - Current (1988) IDOT Local Roads and Streets Policy limits AC + granular base pavements to TF of 0.3 or less (based on IBR of 3). The previous (1976) policy limited conventional flexible pavements to TF of 0.1 or less.

NOTE 2 - For typical "Design E_{AC}" Values, AC strains are similar for "Fair Soils" and typical sandy soils (see Appendix B).
Minimum \( E_{RI} \) - Subgrade \( E_{RI} \) for Stress Ratio Calculation

Minimum \( E_{RI} \) values should be estimated (based on clay content, PI, and expected in-situ moisture conditions) or established by other procedures (in-situ testing, laboratory testing, FWD data, etc.) for each major pedologic soil series encountered on the project. Sandy soil "equivalent" minimum \( E_{RI} \) values are greater than 4 ksi.

Design pavement AC mixture temperature - The "Design Pavement AC Mixture Temperature" is selected from Figure A-1.

Design \( E_{AC} \) - The "Design \( E_{AC} \)" is the AC mixture modulus (ksi) in the pavement corresponding to the "Design Pavement AC Mixture Temperature." \( E_{AC} \) is selected from the appropriate \( E_{AC} \) - AC Mixture Temperature Relation shown in Figure A-2 for typical Class I mixtures (AC-5, AC-10, or AC-20 asphalt cements; AC content around 5%, approximately 5% passing the no. 200 sieve, air void content in the range of 2 to 3.5%). Figures A-2 and A-3 are "mixture dependent." Other AC mixture types can also be accommodated.

**THICKNESS DESIGN PROCESS**

The proposed procedure establishes the required thicknesses of the AC surface and granular base.

AC surface thicknesses ≥ 3-inches are established from fatigue analyses. For AC surface thicknesses of 2 and 2.5 inches and surface treatments, permissible Traffic Factor (TF) ranges are assigned based on current IDOT policy and related criteria from other highway agencies. Tentative guidance is presented in Table A-1.

Granular base thickness requirements are based on subgrade stress ratio (subgrade deviator stress/subgrade compressive strength) considerations.
AC THICKNESS GREATER THAN 3 INCHES

The "Design AC Strain" is established from Figure A-3. "Design Reliability" is considered and may vary from "AVERAGE" (50%), to "INTERMEDIATE" (80%), to "HIGH" (92%). Enter the appropriate design chart (Figure A-4 or A-5) with the "Design E_{AC}" and "Design AC Strain" to determine the required T_{AC} (AC surface thickness for a standard 8-inch granular base).

For minimum E_{R1} values \leq 4 ksi, enter Figure A-6, A-7, or A-8 (depending on the minimum E_{R1}) and determine the Subgrade Stress Ratio. Divide maximum permissible stress ratio (0.5 for TF \geq 0.1) by the value obtained from Figure A-6, A-7, or A-8 and enter Figure A-9 (Y-axis). The required "Granular Base Thickness" is indicated on the X-axis of Figure A-9. Note that Figure A-9 is based on an 8-inch standard granular base thickness.

AC THICKNESS LESS THAN 3 INCHES

Enter Figure A-6, A-7, or A-8 with the "Design Inputs" (selected T_{AC}; Design E_{AC}) to determine the Subgrade Stress Ratio. Divide the maximum permissible stress ratio (0.5 or greater value) by the value obtained from Figure A-6, A-7, or A-8 and enter Figure A-9 (Y-axis). The required Granular Base thickness for the AC thickness selected is indicated on the X-axis of Figure A-9.

SURFACE TREATMENT

Granular base thickness for A-2 or A-3 surface treatment construction is based on subgrade stress ratio considerations. Subgrade Stress Ratio - Granular Base Thickness - Subgrade Minimum E_{R1} relations are shown in Table A-2. Permissible subgrade stress ratios may vary depending on TF. A minimum value of 0.5 and a maximum value of 0.8 are reasonable. For minimum subgrade E_{R1} values less than 3 ksi, subgrade treatment procedures (lime modification, etc.) should be considered.
TABLE A-1
SURFACE COURSE SELECTION GUIDE

<table>
<thead>
<tr>
<th>IDOT TF</th>
<th>SURFACE COURSE</th>
<th>Northern Zone</th>
<th>Southern Zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 0.01</td>
<td>A-2 or A-3 Surface Treatment</td>
<td>2 inch AC</td>
<td>2.5 inch AC</td>
</tr>
<tr>
<td>0.01 - 0.05</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.05 - 0.10</td>
<td></td>
<td>2.5 inch AC</td>
<td>3 inch AC</td>
</tr>
<tr>
<td>&gt; 0.10</td>
<td>Design AC Surface Course utilizing thickness design procedure</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

TABLE A-2
SUBGRADE STRESS RATIOS

<table>
<thead>
<tr>
<th>Minimum Subgrade $E_{Ri}$ (ksi)</th>
<th>Stress Ratio* for Granular Base Thickness (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>8</td>
</tr>
<tr>
<td>3</td>
<td>0.81</td>
</tr>
<tr>
<td>5</td>
<td>0.78</td>
</tr>
<tr>
<td>6</td>
<td>0.76</td>
</tr>
<tr>
<td>8</td>
<td>0.74</td>
</tr>
<tr>
<td>9</td>
<td>0.72</td>
</tr>
<tr>
<td>10</td>
<td>0.71</td>
</tr>
<tr>
<td></td>
<td>0.70</td>
</tr>
</tbody>
</table>

* Stress Ratio = $1.311 - 0.05 T_G - 0.2 \log E_{Ri}$

$R^2 = 0.90 \quad $SEE = 0.1

where:

$T_G$ - Granular base thickness, inches

$E_{Ri}$ - Subgrade resilient modulus, ksi
FIGURE A-2. Asphalt Concrete Modulus-Mixture Temperature Relations.
FIGURE A-3. Design Asphalt Concrete Strain-Traffic Factor Relations.
FIGURE A-4. Asphalt Concrete Thickness Requirement ("Poor" Subgrade).
FIGURE A-6. Subgrade Stress Ratios for Subgrade $E_{Ri} = 2$ ksi.
FIGURE A-7. Subgrade Stress Ratios for Subgrade $E_{Ri} = 3$ ksi.
FIGURE A-8. Subgrade Stress Ratios for Subgrade $E_{Ri} = 4$ ksi.
APPENDIX B

SANDY/GRANULAR SUBGRADE SOILS

The development of the procedures presented in this report were based on fine-grained cohesive subgrade soils, which predominate in Illinois. For pavements with an AC surface > 2 inches on the 8-inch minimum granular base thickness, the subgrade stress design criterion will not control for sandy/granular type subgrade soils.

Comparative ILLI-PAVE analyses were conducted for typical pavement sections on sandy grades. Resilient testing data for typical Illinois sandy subgrade soils are sparse. Sandy subgrade resilient properties were estimated from available data in the literature and Minnesota DOT FWD deflection data. The "sandy subgrade" condition was modeled as:

a) Upper 15 inches - "stress hardening" sand

\[ E_R = 2000 \theta^{0.6}; \text{ cohesion } = 0; \phi = 30^\circ \]

(Er and \( \theta \) in psi)

b) Remainder of subgrade depth modeled as a "constant modulus" material with \( E_R = 20 \text{ ksi} \)

The ILLI-PAVE data indicated that AC strain/fatigue considerations are approximately comparable (Table B-1) to those based on the "FAIR" cohesive soil subgrade (Figure A-5) for AC moduli of less than 500 ksi.

For surface treatment type construction, the sufficiency of a surface treatment plus 8-inch granular base should be considered. Illinois DOT (2) assumes sandy/ granular soils will have IBR's (similar to CBR) greater than 10. A-3 (sandy) soils are assigned an IBR of 10. A review of surficial soils distribution data indicated that in only 3% of Illinois soils is there a probability of encountering A-3 soils in the B or C horizons. CBR-based
analyses (7) indicate the 9-inch flexible pavement section (1-inch surface treatment + 8-inch minimum granular base) is adequate (10,000 ESALs can be accommodated) for a design subgrade CBR of 10. National Stone Association recommendations (8) also indicate the adequacy of the minimum section.

**TABLE B-1**

<table>
<thead>
<tr>
<th>AC Thickness (inches)*</th>
<th>AC Modulus (ksi)</th>
<th>AC Radial Tensile Strain (Micro-strain)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Sandy Subgrade</td>
</tr>
<tr>
<td>3.0</td>
<td>200</td>
<td>405</td>
</tr>
<tr>
<td>4.5</td>
<td>200</td>
<td>408</td>
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<tr>
<td>6.0</td>
<td>200</td>
<td>343</td>
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<tr>
<td>3.0</td>
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<tr>
<td>6.0</td>
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<tr>
<td>3.0</td>
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<td>184</td>
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<td>4.5</td>
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<td>130</td>
</tr>
<tr>
<td>6.0</td>
<td>1500</td>
<td>89</td>
</tr>
</tbody>
</table>

*NOTE: 8-inch crushed stone base