The method presently used for flexible pavement design in Minnesota utilizes either Average Daily Traffic (ADT) or Heavy Commercial Average Daily Traffic (HCADT), along with a designation of 5-ton, 7-ton or 9-ton spring axle loads to categorize traffic. The AASHO soil system is used to classify the subgrade soil in order to vary the required base thickness from sections designated for an A-6 soil. The relative strengths of the layers in the pavement section are indicated by granular equivalent factors. The procedures and levels of thickness required have been established based on experience and performance evaluation on Minnesota highway pavements for the past 30 years. Past experience resulted in establishment of standard cross-sections showing thickness of various materials for varying traffic volumes and load restrictions. Table 1 indicates a portion of these design standards and the method of application for various subgrade soils. Table 2 presents the gradation requirements of the materials shown in Table 1. Varying amounts of crushed particles are required depending on the class of material selected.

For the past five years the Minnesota Highway Department (MHD) has been conducting a research project (Investigation 183) which has the purpose of studying the performance of Minnesota flexible pavements and applying the results of the study to the design of flexible pavements. The results and methods developed at the AASHO Road Test have been used to define performance and to study and evaluate 50 Minnesota test sections.

The background material and analyses are presented in the 1968 Interim Report for Investigation 183 (1) and an HRB report presented in
TABLE 1
FLEXIBLE PAVEMENT DESIGN

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Ton</td>
<td>Less Than 2321</td>
<td>1-1/2&quot;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td>3&quot;</td>
<td>3</td>
<td>5&quot;</td>
<td>7&quot;</td>
<td>9&quot;</td>
</tr>
<tr>
<td>Ton</td>
<td>Less Than 2331</td>
<td>1-1/2&quot;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td>4&quot;</td>
<td>3</td>
<td>6&quot;</td>
<td>8-1/2&quot;</td>
<td>11-1/2&quot;</td>
</tr>
<tr>
<td>Ton</td>
<td>Less Than 400-1000</td>
<td>1-1/2&quot;</td>
<td>2331 1-1/2&quot;</td>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td>3&quot;</td>
<td>3</td>
<td>8&quot;</td>
<td>12&quot;</td>
<td>15&quot;</td>
</tr>
<tr>
<td>Ton</td>
<td>Less Than 150-1000</td>
<td>1-1/2&quot;</td>
<td>2331 1-1/2&quot;</td>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td>5&quot;</td>
<td>3</td>
<td>9&quot;</td>
<td>14-1/2&quot;</td>
<td>17-1/2&quot;</td>
</tr>
<tr>
<td>Ton</td>
<td>150-300</td>
<td>1-1/2&quot;</td>
<td>2341 1-1/2&quot;</td>
<td>2341 1-1/2&quot;</td>
<td>2331 1-1/2&quot;</td>
<td>6</td>
<td>5&quot;</td>
<td>3</td>
<td>8&quot;</td>
<td>14&quot;</td>
<td>21&quot;</td>
<td></td>
</tr>
<tr>
<td>Ton</td>
<td>300-500</td>
<td>1-1/2&quot;</td>
<td>2341 1-1/2&quot;</td>
<td>2341 1-1/2&quot;</td>
<td>2331 1-1/2&quot;</td>
<td>2204 4&quot;Rich or 6 6&quot;</td>
<td>4</td>
<td>6&quot;</td>
<td>3</td>
<td>6&quot;</td>
<td>18&quot;</td>
<td>25&quot;</td>
</tr>
<tr>
<td>Ton</td>
<td>600-1100</td>
<td>1-1/2&quot;</td>
<td>2351 2&quot;</td>
<td>2341 3-1/2&quot;</td>
<td>2204 4&quot;Lean or 6 5&quot;</td>
<td>4</td>
<td>6&quot;</td>
<td>3</td>
<td>6&quot;</td>
<td>21&quot;</td>
<td>29&quot;</td>
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<tr>
<td>Ton</td>
<td>More Than 1100</td>
<td>1-1/2&quot;</td>
<td>2341 2&quot;</td>
<td>2331 4-1/2&quot;</td>
<td>2204 4&quot;Lean</td>
<td>4</td>
<td>6&quot;</td>
<td>3</td>
<td>6&quot;</td>
<td>24-1/2&quot;</td>
<td>32-1/2&quot;</td>
<td></td>
</tr>
</tbody>
</table>

Design thicknesses shown in table apply only for A-6 subgrade soils. Use the following method to adjust the design thickness for other classes of subgrade soils:

1. Bituminous base, bituminous treated base, and aggregate base thicknesses are converted to an equivalent thickness of aggregate base (denoted as granular equivalent = G.E.) using the granular equivalent factors listed below. The sum of these quantities for each design is listed under the column headed "Total Base Thicknesses - Inches of G.E."

2. Select the appropriate soil factor corresponding to the AASHO, soil classification of the subgrade soils. The soil factor is applied to the "Total Base Thickness - In. G.E." in adjusting to the granular equivalent base thickness required for subgrade soils other than A-6 soils. Apply this adjustment to the thickness of the base (Cl. 3 & 4) only.

3. This adjustment is made algebraically using the following formula:

\[
\text{Adjusted base thickness (Cl. 3 & 4)} = \text{base thickness (Cl. 3 & 4)} + \left( \frac{\text{Total Base G.E.} \times 100 - \text{Total Base G.E.}}{0.75} \right)
\]
<table>
<thead>
<tr>
<th>Material</th>
<th>Granular Equivalent Factors</th>
<th>AASHO Soil Class</th>
<th>Soil Factors (S.F.) - %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant-Mix Surface</td>
<td>(PMS) 2341-51</td>
<td>A-1</td>
<td>50-75</td>
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<tr>
<td>Plant-Mix Surface</td>
<td>(PMS) 2331</td>
<td>A-2</td>
<td>50-75</td>
</tr>
<tr>
<td>Plant-Mix Base</td>
<td>(PMB) 2331-41-51</td>
<td>A-3</td>
<td>50</td>
</tr>
<tr>
<td>Road-Mix Surface</td>
<td>(RMS) 2321</td>
<td>A-4</td>
<td>100-130</td>
</tr>
<tr>
<td>Road-Mix Base</td>
<td>(RMB) 2321</td>
<td>A-5</td>
<td>130+</td>
</tr>
<tr>
<td>Bit. Treat. Base</td>
<td>(Rich) 2204</td>
<td>A-6</td>
<td>100</td>
</tr>
<tr>
<td>Bit. Treat. Base</td>
<td>(Lean) 2204</td>
<td>A-7-5</td>
<td>120</td>
</tr>
<tr>
<td>Aggregate Base</td>
<td>(Cl. 5, Cl. 6) 3138</td>
<td>A-7-6</td>
<td>130</td>
</tr>
<tr>
<td>Aggregate Base</td>
<td>(Cl. 3 &amp; 4) 3138</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
January, 1969 (2). A committee of MHD personnel and the authors of reference (1) was formed in August, 1968 to consider the present Minnesota flexible pavement design in light of the results and conclusions in the Interim Report.

**TABLE 2**

**MATERIAL GRADATION REQUIREMENTS**

<table>
<thead>
<tr>
<th>Total Percent Passing</th>
<th>Class 3</th>
<th>Class 4</th>
<th>Class 5</th>
<th>Class 6</th>
<th>2331</th>
<th>2341</th>
<th>2351</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sieve Size</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>2&quot;</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1&quot;</td>
<td>90-100</td>
<td>90-100</td>
<td>90-100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>3/4&quot;</td>
<td>50-90</td>
<td>50-85</td>
<td>50-85</td>
<td>65-95</td>
<td>65-90</td>
<td>70-80</td>
<td></td>
</tr>
<tr>
<td>3/8&quot;</td>
<td>35-80</td>
<td>35-70</td>
<td>35-70</td>
<td>50-70</td>
<td>50-65</td>
<td></td>
<td></td>
</tr>
<tr>
<td>#4</td>
<td>20-100</td>
<td>20-100</td>
<td>20-100</td>
<td>35-65</td>
<td>35-55</td>
<td>35-55</td>
<td>35-55</td>
</tr>
<tr>
<td>#10</td>
<td>5-50</td>
<td>5-35</td>
<td>10-35</td>
<td>10-30</td>
<td>10-35</td>
<td>10-30</td>
<td>15-30</td>
</tr>
<tr>
<td>#200</td>
<td>5-10</td>
<td>4-10</td>
<td>3-10</td>
<td>3-7</td>
<td>1-7</td>
<td>1-7</td>
<td>4-8</td>
</tr>
<tr>
<td>Maximum</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>200/40 Ratio</td>
<td>50%</td>
<td>40%</td>
<td>40%</td>
<td>40%</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The procedure recommended by the committee is presented in this summary of the Investigation 183 report (1). The procedure is dependent on the correlation between pavement spring deflections and the number of equivalent 18,000-lb single axle loads ($\Sigma W 18$) which the pavement can withstand before the Present Serviceability Index (PSI) of the section will drop to a PSI of 2.50. Since the pavement section is still relatively intact at a PSI of 2.50, this level is appropriate for considering required maintenance. The performance equation suggested is from the AASHO Road Test and is shown to be appropriate for Minnesota conditions in Reference (1). The other factors used to establish the design procedure uses the thicknesses of the surface and base layers along with the Hveen Stabilometer R-value of the embankment soil to calculate the spring deflection of the pavement section. The equations used are obtained from the Spring Recovery Study of Investigation 183 report (1) on a number of the Minnesota test sections. The relationships developed are those for MHD Standard Specification
2331, 2341 or 2351 bituminous mixtures, and Class 3, 4, 5 or 6 base materials. It is also assumed that adequate drainage has been designed for the section and the layers will be placed under present MHD density specification.

As mentioned, the design procedure involves the R-values of the soil, \( N \geq 18 \), granular equivalent factors of each layer, and Benkelman beam deflections. Each of these factors will be discussed briefly as they relate to the design procedure.

1. Hveem Stabilometer R-value

   The design procedure presented in this report is for flexible pavements which are being built starting with the embankment soil. The method consists of sampling the proposed construction area to determine the predominant soil type and establishing the AASHO classification and strength of representative soil samples in the laboratory. The strength is determined using the stabilometer R-value as a criterion. The procedure to be used for determining the R-value is contained in Reference (3).

   The use of R-value as a criterion for analysis of soil strength was recommended after consideration of the several practical methods of soil tests and classification systems. The best correlation was established between field E-modulus and R-value (1). This relates field conditions to the laboratory test results. The results of this study indicate the best correlation was obtained using the R-value determined at an exudation pressure of either 200 or 240 psi.

   The stabilometer R-value test is not considered to be the ultimate test for evaluating the strength of an embankment soil, but it is the most practical test available at this time.

2. Equivalent 18,000 lb. Axle Loads (\( N \geq 18 \))

   The loading on a highway pavement is composed of applications of a distribution of axle loads of various weights. At the AASHO Road
Test, sections of highway were subjected to repetitions of the same load and the performance of the pavement structure was evaluated. Using this performance information, the relative effect of various loadings on a pavement structure can be calculated. The relative effect of various loadings can then be used to convert each load repetition to an equivalent number of repetitions of a base load. Using an equivalent axle load of 15,000 lb., the equivalent load effect may be considered by summing up all equivalent loads applied over a design period. A program has been set up for the MHD computer which makes it possible to predict EN 18 for design purposes and also the EN 18 that have been on a section since it was built. Traffic can be predicted for any number of years into the future, so stage construction may be utilized if desired.

3. Granular Equivalent Factors

The pavement sections obtained for a new design procedure have minimum thicknesses of surface and base materials. These thicknesses are essentially the same as those in the design method currently in use by the MHD.

The present Minnesota design procedure uses the granular equivalent concept to define the pavement structure. The granular equivalent is defined by Equation 1.

\[ G.E. = a_1D_1 + a_2D_2 + a_3D_3 \ldots \]  \hspace{1cm} (1)

where: G.E. = Granular equivalent thickness, in.

\[ a_1, a_2, a_3 \ldots \] = Constants which define the relative effect of the given layer (such as values in Table 3)

\[ D_1, D_2, D_3 \ldots \] = Thickness of individual layers, inches

For the granular equivalent in Minnesota the constant "a" for a Class 5 or 6 base material is taken as 1.00 and the other constants rate the strength of the various other materials relative to the granular bases. The constants thus define the equivalency between layers. Table 3 is a list of these factors presently used for the Minnesota flexible pavement design procedure.
These factors have been set up primarily from experience in Minnesota and other locations.

**TABLE 3**

**GRANULAR EQUIVALENT FACTORS**

<table>
<thead>
<tr>
<th>Material</th>
<th>Granular Equivalent Factors ( (a_1, a_2, a_3) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant-Mix Surface (PM) 2341-51</td>
<td>2.25</td>
</tr>
<tr>
<td>Plant-Mix Surface (PM) 2331</td>
<td>2.00</td>
</tr>
<tr>
<td>Plant-Mix Base (PM) 2331-41-51</td>
<td>2.00</td>
</tr>
<tr>
<td>Road Mix Surface (RMS) 2321</td>
<td>1.50</td>
</tr>
<tr>
<td>Road Mix Base (RMB) 2321</td>
<td>1.50</td>
</tr>
<tr>
<td>Bit. Treated Base 2204 (Rich)</td>
<td>1.50</td>
</tr>
<tr>
<td>Bit. Treated Base 2204 (Lean)</td>
<td>1.25</td>
</tr>
<tr>
<td>Aggregate Base (Cl. 5, Cl. 6)</td>
<td>1.00</td>
</tr>
<tr>
<td>Aggregate Base (Cl. 3, Cl. 4)</td>
<td>0.75</td>
</tr>
<tr>
<td>Selected Granular Material (&lt;12% passing No. 200 sieve)</td>
<td>0.50</td>
</tr>
</tbody>
</table>

It has been shown with the elastic theory that pavement deflections can be predicted if the elastic properties of the materials are determined under the same conditions of test as in the field \((4, 5, 6)\). An equation of the form shown in Equation 2 can be fitted to the elastic theory prediction of deflection.

\[
\log d = a_0 - a_1 D_1 - a_2 D_2 - a_3 \log E
\]  
(2)

where: \(d\) = Deflection, 0.001 in.

\(D_1\) = Surface thickness, in.

\(D_2\) = Granular base thickness, in.

\(E\) = Elastic modulus of embankment soil, psi.

\(a_0, a_1, a_2, a_3\) = Constants determined from multiple regression analysis.

The spring deflections measured on the spring recovery test sections \(1\) have been correlated with the thickness of the pavement layers and the strength of the embankments using the model of Equation 2. For each test section the spring Benkelman beam deflection for 1965, 1966 and 1967, surface, base and subbase thickness and \(\log R\) (rather than \(\log E\) which is related to \(\log R\))
were put into the computer. By means of a mathematical operation, known as multiple regression analysis, values of $a_0$, $a_1$, $a_2$ and $a_3$ were determined such that the equation best fits the data points. Equation 2 is rewritten and Equations 3, 4 and 5 result using the data obtained during 1965, 1966 and 1967, respectively.

$$\log d_{sr} = 3.125 - 0.070 D_1 - 0.027 D_2 - 0.024 D_3 - 0.601 \log R$$

$$r^2 = 0.95$$

Standard Error = 15%

$$\log d_{sr} = 2.781 - 0.056 D_1 - 0.016 D_2 - 0.019 D_3 - 0.507 \log R$$

$$r^2 = 0.85$$

Standard Error = 15%

$$\log d_{sr} = 2.733 - 0.056 D_1 - 0.019 D_2 - 0.025 D_3 - 0.416 \log R$$

$$r^2 = 0.80$$

Standard Error = 17%

$\log d_{sr} =$ Spring Benkelman beam deflection, 0.001 in. using a 9-ton axle load.

$r^2 =$ Correlation accuracy, 1.00 equals perfect fit

The other terms are as described in Equation 2.

As previously defined the equivalency for granular base is assigned a value of 1.00. The granular equivalency for bituminous surfacing is then determined by dividing the surfacing constant $a$, by the granular base constant $a_2$. For the lower base equivalency, $a_3$ is divided by $a_2$. Table 4 is a listing of layer equivalencies implied from Equations 2, 4 and 5.

Generally, the equivalencies found from deflections measured or estimated during the spring in Minnesota for sections on plastic embankment soils are somewhat lower than those calculated from the Road Test data. This reflects the wider range of materials in the Minnesota sections as opposed to the constant materials at the Road Test.
TABLE 4
EQUIVALENCIES BETWEEN SURFACE AND BASE MATERIALS USING EQUATIONS
DEVELOPED FROM MINNESOTA SPRING RECOVERY TEST SECTIONS

<table>
<thead>
<tr>
<th>Year</th>
<th>Surface</th>
<th>Equivalency Factors</th>
<th>Base (Cl. 5 &amp; 6)</th>
<th>Base (Cl. 3 &amp; 4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1965</td>
<td>2.59</td>
<td>1.00</td>
<td>0.89</td>
<td></td>
</tr>
<tr>
<td>1966</td>
<td>3.50</td>
<td>1.00</td>
<td>1.20</td>
<td></td>
</tr>
<tr>
<td>1967</td>
<td>2.95</td>
<td>1.00</td>
<td>1.32</td>
<td></td>
</tr>
</tbody>
</table>

The granular equivalencies shown in Table 4 appear to be liberal in comparison with those presently used and shown in Table 3. These limited data, however, will not be used to change the present granular equivalencies until further evaluation of the equivalencies has been made.

4. Performance Prediction

At the AASHO Road Test Benkelman beam deflection tests were run on each of the test sections periodically. The deflections were run to determine the variation in strength of the sections and to see if the strength of the pavement measured in the field could be used to predict the performance of the sections.

Four equations were developed relating deflection to performance. The equation best suited to Minnesota conditions is shown as Equation 6 which uses a PSI of 2.5.

\[
\log (\Sigma N 18)_{2.5} = 11.06 - 3.25 \log d_s \\
\]

\[
r^2 = 0.78 \\
\text{Standard Error} = 0.21
\]

where: \((\Sigma N 18)_{2.5}\) = Summation of equivalent 18,000-lb axle loads to a PSI level of 2.5

d_s = Benkelman beam deflection taken during the spring period, 0.001 in.

\(r^2\) = Squared correlation coefficient
Figure 1 shows a plot of Equation 6 which is a straight line on a semi-log plot. Also plotted on Figure 1 is a line indicating the standard error of Equation 6. This line is one standard error below the "best-fit" line and indicates the level above which 5/6 of the data points occur when they reach a PSI of 2.5.

In order to see how well Equation 6 relates to Minnesota conditions, spring deflections measured on the Spring Recovery test sections are plotted against $\Sigma N\ 18$ of the test section through 1966. The spring deflections have generally been consistent for the four spring periods in which testing has been performed. As more data are obtained it will be possible to see if the deflections tend to increase or decrease with age and condition of the pavement.

The deflections on roads which have been restricted during the critical spring period have been reduced accordingly. For instance, if a road has been restricted to 7-ton axle loads during the spring the measured 9-ton deflection is reduced by $7/9$, to obtain the deflection for 7-ton axle load. The linear relationship between deflection and load for normal loads used on highway sections is justified in References 1 and 7.

Using the data adjusted in this manner, it has been recommended the best-fit line from the Road Test represented by Equation 6 be used for design purposes.

Using the relationships developed from the spring recovery program, spring deflections have been estimated for the test sections on which deflections have not been run during the spring period. These estimated spring deflections for each year are plotted against $\Sigma N\ 18$ through 1966 in Figure 2. The deflections on sections which have axle load restrictions during the spring period have been appropriately reduced as indicated previously.

The position of the points in Figure 1 and 2 suggests that the line representing Equation 6 could be used to predict $\Sigma N\ 18$ a pavement can withstand under a given level of spring deflection. If the serviceability of the
Figure 1. Variation of Measured Spring Deflections With Total Equivalent 18,000-lb Axle Loads Through 1966
Figure 2. Variation of Predicted Spring Deflections With Total Equivalent 18,000-lb Axle Loads Through 1966

Summation of 18,000-lb Axle Loads.
test sections is determined periodically in future years it will be possible to see if another line would be more appropriate than the line represented by Equation 6. If all of the sections are observed to FSI of 2.5 it will be possible to establish more precisely a trend line for Minnesota conditions.

The advantage of using a strength test such as Benkelman beam deflection to predict performance is that all localized conditions such as drainage, poor quality base material, and such are evaluated. Using only thickness as an evaluation this is not possible.

5. New Design Development

In Table 3 the present Granular Equivalent factors were presented. These factors are justified further in Reference 1 and are used in the new design procedure.

In order to develop the design procedure based on granular equivalent thicknesses, it was necessary to correlate deflections to thickness and R-value using an equation of the form of Equation 7 (similar to form of Equation 2).

\[
\log d_s = a_0 - a_1 (GE) - a_2 \log R
\]

(7)

where: 
\(d_s\) = Spring deflection, 0.001 in.
GE = Granular Equivalent Thickness using the coefficients in Table 3.
R = Stabilometer R-value

Equation 8 resulted from the correlation using the maximum deflections measured on the Spring Recovery test sections during the Spring, 1967.

\[
\log d_s = 2.587 - 0.0230 (GE) - 0.306 \log R
\]

(8)

\(r^2 = 0.73\)

Standard Error = 17%

Equation 9 resulted from the correlation using spring deflections calculated from deflections run on all the test sections throughout the Summer, 1967.

\[
\log d_s = 2.799 - 0.0219 (GE) - 0.521 \log R
\]

(9)
\[ r^2 = 0.80 \]

Standard Error = 28%

The squared correlation coefficient for Equation 9 is somewhat higher than for Equation 3. This is because there is a wider range of granular equivalents and R-value represented for Equation 9. However, the error in predicting deflection is about 11% higher using all of the sections.

Equation 5 is the result of the correlation using the same deflection data but allowing the coefficients on thickness to be determined from the correlation. The standard error is about the same but the squared correlation coefficient is somewhat higher. This indicates that using the various granular equivalent coefficients does not appreciably affect the error in predicting spring deflection.

It is felt the Equation 9 should be used to predict deflections from granular equivalent and R-value of the embankment soil because it has been derived from a wider range of independent variables. Each year as more data are accumulated relating these variables, the relationship represented by Equation 9 can be improved.

For relatively high traffic roads (more than 90,000≤N 18 for design life) the design recommended is obtained by using Equations 6 and 9. When these equations are combined and the spring deflection relationship (Equation 9) is substituted in Equation 6, Equation 10 results.

\[ \log (\varepsilon N 18)_{2.5} = 11.06 - 3.25 (2.799 - 0.0219 \log (GE) - 0.521 \log R) \]

rearranging and solving for GE results in:

\[ GE = 14.0 \log (\varepsilon N 18)_{2.5} - 23.8 \log (R) - 27.5 \quad (10) \]

Even though there is some error involved with estimating deflection from granular equivalent and R-value in Equation 9 it is felt that Equation 10 is appropriate for design because, 1) the deflection used for determining strength is the average value plus two standard deviations and thus represents close to the weakest condition of the pavement section, and 2) the deflection-performance equation is a line which includes all of the sections considered.
through 1967. All of these sections to the left of this line are performing well except TS 50 as indicated in Figures 1 and 2. A number of sections have exceeded the performance predicted by this relationship which is the best-fit line through the AASHO Road Test deflection-performance data. Part of the continuing evaluation of Minnesota flexible pavements will be the verification of these equations.

For low traffic roads Equation 10 is assumed to be appropriate until the spring design deflection goes up to 0.075 in. In Reference 7 it is stated that a light traffic road can withstand repeated applications of deflections up to this magnitude. To establish minimum designs for 9-ton loads the respective R-values along with the 0.075 in. deflection are substituted into Equation 10 to predict a granular equivalent necessary to limit the deflection. To establish minimum designs for a road to be limited to a 7-ton maximum spring axle load an allowable 9-ton deflection is 9/7 (0.075) in. = 0.096 in. This deflection with the respective R-values yields the minimum granular equivalent thicknesses using Equation 10. Justification for using a linear ratio of the loads to predict deflections under other loads can be found in Reference 7 and Chapter XII of Reference 1. According to this criterion a section designed by this procedure could withstand 9-ton axle loads during the critical spring period if the R-value is 30 or greater.

Figure 3 shows a semi-log plot of the required granular equivalent thicknesses dependent on embankment R-value and $E/N$. The thicknesses shown are a combination of present MND design plus a plot of Equations 6 and 9. The thicknesses of the upper layers can also be obtained from Table 5; thicknesses of Class 3 and 4 materials will vary dependent on the R-value obtained.

**DESIGN PROCEDURE**

The following method is recommended to design an appropriate flexible pavement:

1. Determine R-value of embankment soil to be used for design by running appropriate laboratory tests.
FLEXIBLE PAVEMENT DESIGN CHART FOR ALL TRAFFIC RELATING STABILOMETER R-VALUE AND EQUIVALENT 18,000-LB AXLE LOADS TO REQUIRED GRANULAR EQUIVALENT THICKNESS

18,000-lb Single Axle Loads for Design Lane
### TABLE 5

**SURFACE AND BASE THICKNESS AND GRANULAR EQUIVALENT THICKNESS**

Presented by the Surface plus Base (Class 5 & 6) for various traffic levels*

<table>
<thead>
<tr>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;60,000***</td>
<td>1-1/2&quot;</td>
<td>2331</td>
<td>1-1/2&quot;</td>
<td>2331</td>
<td>3&quot;</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>60,000 - 90,000***</td>
<td>1-1/2&quot;</td>
<td>2331</td>
<td>1-1/2&quot;</td>
<td>2331</td>
<td>3&quot;</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>≤90,000</td>
<td>1-1/2&quot;</td>
<td>2331</td>
<td>1-1/2&quot;</td>
<td>2331</td>
<td>3&quot;</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>90,000 - 150,000</td>
<td>1-1/2&quot;</td>
<td>2331</td>
<td>1-1/2&quot;</td>
<td>2331</td>
<td>3&quot;</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>150,000 - 250,000</td>
<td>1-1/2&quot;</td>
<td>2331</td>
<td>1-1/2&quot;</td>
<td>2331</td>
<td>5&quot;</td>
<td>5</td>
<td>11</td>
</tr>
<tr>
<td>250,000 - 650,000</td>
<td>3&quot;</td>
<td>2341</td>
<td>1-1/2&quot;</td>
<td>2331</td>
<td>5&quot;</td>
<td>6</td>
<td>14-3/4</td>
</tr>
<tr>
<td>650,000 - 1,700,000</td>
<td>3&quot;</td>
<td>2341</td>
<td>1-1/2&quot;</td>
<td>2331</td>
<td>4&quot;</td>
<td>2204 or (Rich)</td>
<td>6&quot;</td>
</tr>
<tr>
<td>1,700,000 - 3,800,000</td>
<td>3-1/2&quot;</td>
<td>2351</td>
<td>3-1/2&quot;</td>
<td>2331</td>
<td>4&quot;</td>
<td>2204 or (Lean)</td>
<td>5&quot;</td>
</tr>
<tr>
<td>&gt;3,800,000</td>
<td>3-1/2&quot;</td>
<td>2351</td>
<td>4-1/2&quot;</td>
<td>2331</td>
<td>4&quot;</td>
<td>2204 (Lean)</td>
<td>6</td>
</tr>
</tbody>
</table>

*Total thickness not shown because base thickness depends on subgrade strength. The Total Granular Equivalent thickness required including base (Class 3 & 4) is shown in Figure 3.

***7-Ton Design, Remainder of Designs are for 9-Ton.
2. Determine $\Sigma N_{18}$ by having a traffic analysis made. $\Sigma N_{18}$ will be the total number of equivalent 18,000 lb. axle loads, to be sustained by one design lane of the pavement during the design life.

3. Enter Figure 3 with the values of $R$ and $\Sigma N_{18}$ (from #1 and 2 above) and read off granular equivalent (G.E.) from the left-hand side of Figure 3.

4. Divide total G.E. (from #3 above) into G.E. thicknesses of the various materials shown on Figure 3.

5. Convert G.E. thickness (from #4 above) to actual thickness of material using G.E. factors in Table 3. (Actual thicknesses can also be found in Table 5).

6. If desired, substitution of material with higher equivalencies as listed in Table 3 can be made so that the total G.E. adds up to the total obtained in Figure 3.

Examples of each step above follows:

1. Assume a stabilometer test was run in the laboratory which resulted in $R = 20$.

2. Assume a traffic analysis was made which resulted in $\Sigma N_{18} = 1,000,000$.

3. Using the above values, a G.E. of 26 in. is obtained from Figure 3.

4. From Figure 3 the total G.E. can be divided into the following:
   
   $2341 = 6.75$ in. G.E.
   $2331 = 3.25$ in. G.E.
   Cl. 6 or 2204 (rich) = 6.00 in. G.E.
   Cl. 3 and 4 = 10.00 in. G.E.

5. Using conversion factors from Table 3 the following values are obtained:
   
   $2341 = 6.75/2.25 = 3$ in.
   $2331 = 3.25/2.00 = 1-1/2 +$ in.
   Cl. 6 = 6.00/1.00 = 6 in.
   Cl. 3 and 4 = 10.00/0.75 = 13 + in.
6. 10 inches of Class 6 could be substituted for 13 inches of Class 3 and 4 (G.E. is the same). Additional Class 3 and 4 could not be substituted for the initially required 6 inches of Class 6 since Class 3 and 4 had a lower equivalency factor.

In addition to using the design procedure for new construction, it can be applied to bituminous overlay of existing pavements. A procedure has been formulated, but will require further field study to verify the results. It is anticipated this information will be available in the near future.
REFERENCES CITED


