SECTION 500.00 – PAVEMENT DESIGN

SECTION 510.00 – THICKNESS DESIGN FOR FLEXIBLE PAVEMENT

The design procedure described herein is based on methods developed by the California Department of Transportation (Caltrans), which have been modified to accommodate Idaho conditions. Minimum design standards are based on recommendations of Caltrans, AASHTO, The Asphalt Institute, and local experience.

510.01 Summary of Design Factors.

1. Traffic - Expressed in terms of Traffic Index (TI) for the design period (generally 20 years) and determined as follows: State Highway Routes (On-System) - use the estimate of accumulated 8000 kg (18 kip) Equivalent Single Axle Loads (ESALs) to compute the Traffic Index directly by formula; Off-System Routes - use the estimate of current and future ADT and commercial volume percentage to compute the commercial ADT (CADT). Then use the commercial classification (truck density) and Traffic Index Chart to determine the Traffic Index graphically.

2. Structural Quality of the Subgrade Soil - Expressed in terms of Resistance Value (R-value) as measured by the Hveem Stabilometer and expansion pressure as determined by the expansion pressure test.

3. Climate - Express in terms of the Climatic Factor (F) is used to adjust the roadway structure thickness (ballast depth) to account for the detrimental effects of climate on the ability of the structural cross section to support traffic loading.

4. Stiffness - Expressed in terms of the Substitution Ratio (Gf) is used to adjust the thickness of the individual pavement layers in consideration of the cohesive strength of the binder materials, relative stiffness of unbound layers and drainage capability.

5. Economics - Design the structural cross section necessary to accommodate the estimated traffic loading for the design period, using various combinations of base and surfacing materials, that will result in the lowest overall life cycle cost.

Report all test data necessary to each method of design on the Soils Evaluation for Flexible Pavement, Form ITD-808 (Figures 510.01-1 and 510.01-2), for each profile and borrow soil sample.
# Soils Evaluation for Flexible Pavement

**Figure 510.01-1**

<table>
<thead>
<tr>
<th>Ident. Number</th>
<th>Laboratory Number</th>
<th>Station</th>
<th>Depth (in)</th>
<th>Unified Soil Classif.</th>
<th>L.L.</th>
<th>P.I.</th>
<th>Opt. Moist.</th>
<th>Expansion Pressure (kPa)</th>
<th>Recommended Thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-P</td>
<td>87-A004</td>
<td>J-6</td>
<td>0.0-305</td>
<td>ML</td>
<td>22</td>
<td>2</td>
<td>95</td>
<td>1685</td>
<td>16.5</td>
</tr>
<tr>
<td>4-P</td>
<td>87-A0190</td>
<td>J-7</td>
<td>0.0-305</td>
<td>ML</td>
<td>22</td>
<td>4</td>
<td>100</td>
<td>1842</td>
<td>13.2</td>
</tr>
</tbody>
</table>

- *W/C, C.S. Taken from 'R’ value determination.
- **W/C, C.S. Corrected for 3/4-inch material.
- ***W/C, C.S. Taken from T-74 curve on material at field gradation.

Note: The recommended thicknesses are expressed in terms of untreated aggregate base corrected for climatic factor.

Date mailed: April 1, 1987

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**Materials Supervisor, P.E.**
### Soils Evaluation for Flexible Pavement

<table>
<thead>
<tr>
<th>IDENT. NUMBER</th>
<th>LABORATORY NUMBER</th>
<th>STATION</th>
<th>DEPTH, MM</th>
<th>UNIFIED SOIL CLASSIF.</th>
<th>L.L.</th>
<th>P.I.</th>
<th>% COARSE</th>
<th>D. 0.075</th>
<th>D. 0.04</th>
<th>0.04-0.075</th>
<th>KPA</th>
<th>OPT. MOIST.</th>
<th>&quot;R&quot; VALUE</th>
<th>EXPANSION PRESSURE KPA</th>
<th>RECOMMENDED THICKNESS, MM</th>
<th>RECOMMENDED MATERIAL</th>
</tr>
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<tbody>
<tr>
<td>1-P</td>
<td>80-00291</td>
<td>—</td>
<td>0-610</td>
<td>CL</td>
<td>41</td>
<td>23</td>
<td>77</td>
<td>78</td>
<td>60</td>
<td>13</td>
<td>0</td>
<td>671</td>
<td>N</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* W/L/S: Taken from "R" value determination.

** W/L/S: Corrected for 3/4-inch material.

*** W/L/S: Taken from 1-14 curve on material at field gradation.

Note: The recommended thicknesses are expressed in terms of untreated aggregate base corrected for climatic factor.

Date mailed April 1, 1987

Materials Supervisor P.E.
510.02 Traffic Evaluation. The magnitude of the axle load and the number of load repetitions are major factors in the performance of a flexible pavement structure. Since axle load data are not available for all roadways throughout the state, the data available are combined to give a figure applicable to all routes. Thus, corrections are necessary only for traffic volume and classifications.

Classify commercial vehicles into “Heavy,” “Medium,” and “Light” categories according to the percentages of two-axle and five-axle vehicles within the commercial volume. From this, the 8000 kg (18 kip) Equivalent Single Axle Loads (ESALs) can be estimated for the design period, which in turn are used to calculate the Traffic Index.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Two Axle</th>
<th>Five Axle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy</td>
<td>30 - 50</td>
<td>25 - 40</td>
</tr>
<tr>
<td>Medium</td>
<td>50 - 70</td>
<td>10 - 25</td>
</tr>
<tr>
<td>Light</td>
<td>70 - 100</td>
<td>0 - 10</td>
</tr>
</tbody>
</table>

If the two-axle classification differs from the five-axle, use the higher classification for design. Interstate highways are always classified as “Heavy.”

Lane distribution of commercial vehicle traffic should be as follows:

<table>
<thead>
<tr>
<th>Lanes Per Direction</th>
<th>% CADT in Design Lane</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100</td>
</tr>
<tr>
<td>2</td>
<td>70 - 100</td>
</tr>
<tr>
<td>3</td>
<td>60 - 80</td>
</tr>
<tr>
<td>4</td>
<td>50 - 75</td>
</tr>
</tbody>
</table>

Different methods of traffic analysis are required for on-system and off-system routes due to the availability of load data. Common to both analysis techniques is the Traffic Index, which is a direct input into the thickness design equation. The Traffic Index for both methods is based on the anticipated traffic loading for a 20-year design period and determined as follows.

510.02.01 On-System Route Traffic Index. Figure 510.02.01-1 shows the projected, cumulative ESALs for a particular asphalt pavement. When requesting these data from Headquarters Traffic Survey Unit, submit Form ITD-1151, Traffic Data Request. Two ESAL projections will be returned. One will account for truck ESAL growth on flexible pavements, the other will represent rigid pavement ESAL counts. Flexible pavement ESALs will be lower than rigid pavement ESALs.
PROJECTED COMMERCIAL AND 10,000 EQUIVALENT SINGLE AXLE LOADINGS (ESALS)

LAST YEAR WITH DATA: 1988  CUMULATING ESALS UP TO 2010 STARTING TO CUMULATE IN 1988

<table>
<thead>
<tr>
<th>YEAR</th>
<th>PASSENGER ADT</th>
<th>PICKUP ADT</th>
<th>COMMERCIAL ADT</th>
<th>ESALS FOR BOTH LANES</th>
<th>FLEXIBLE PAVEMENT</th>
<th>ESAL (IN THOUSANDS)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>YEAR VALUE CUMULATIVE</td>
<td>DIRECTION OF TRAVEL</td>
<td>INSIDE LANE 20%</td>
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<tr>
<td>1985</td>
<td>6,810</td>
<td>2,643</td>
<td>1,510</td>
<td>594</td>
<td>297</td>
<td>59</td>
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<tr>
<td>1989</td>
<td>6,980</td>
<td>2,750</td>
<td>1,590</td>
<td>641</td>
<td>320</td>
<td>59</td>
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<td>1990</td>
<td>7,150</td>
<td>2,810</td>
<td>1,660</td>
<td>603</td>
<td>21,917</td>
<td>59</td>
</tr>
<tr>
<td>1991</td>
<td>7,320</td>
<td>2,860</td>
<td>1,740</td>
<td>733</td>
<td>302</td>
<td>59</td>
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<td>1992</td>
<td>7,490</td>
<td>2,910</td>
<td>1,810</td>
<td>787</td>
<td>342</td>
<td>59</td>
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<td>1993</td>
<td>7,660</td>
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<td>1,890</td>
<td>826</td>
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<td>3,240</td>
<td>2,040</td>
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<td>59</td>
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<td>2,270</td>
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<td>575</td>
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<td>YEAR</td>
<td>PASSENGER CAR ADT</td>
<td>PICKUP ADT</td>
<td>COMMERCIAL ADT</td>
<td>ESALS FOR BOTH LANES</td>
<td>RIGID PAVEMENT ESAL (IN THOUSANDS)</td>
<td>INSIDE LANE 20%</td>
</tr>
<tr>
<td>------</td>
<td>------------------</td>
<td>------------</td>
<td>----------------</td>
<td>-----------------------</td>
<td>-----------------------------------</td>
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<td>2,900</td>
<td>2,330</td>
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<td>3,210</td>
<td>2,640</td>
<td>1,320</td>
<td>253</td>
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<td>2009</td>
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<td>3,320</td>
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<td>3,430</td>
<td>2,865</td>
<td>1,432</td>
<td>275</td>
</tr>
</tbody>
</table>
To calculate the design Traffic Index for a 20-year design, begin by subtracting the design year’s cumulative ESALs (furthest right column) from the same column 20 years later. Shorter term analysis will require the design year’s ESALs be subtracted from the corresponding design period, cumulative ESALs. ESALs shown are in thousands. Use the following equation to compute the design Traffic Index.

\[ TI = 9.0 \left( \frac{\text{ESALs}}{10^6} \right)^{0.119} \]

**EXAMPLE:**

Refer to the flexible pavement ESAL table (Figure 510.02.01-1). The TI would be calculated in the following manner: the ESALs accumulated by 1989 are 494,000. A 20-year design (year 2009) shows cumulative ESALs of 10,074,000. The 20-year ESAL loading on this segment is the difference between the two numbers, or 9,580,000 ESALs. Calculate the TI with 9,580,000 ESALs.

\[ TI = 9.0 \left( \frac{9,580,000}{10^6} \right)^{0.119} = 11.78 \]

Round the TI to 11.8 for use in the design thickness equation (see Section 510.03).

**510.02.02 Off System Routes.** Use the estimate of current and future traffic volumes (ADT) and commercial volume percentage to compute the commercial ADT (CADT), then use the commercial classification (truck density) and TI chart (Figure 510.02.02-1) to determine the TI graphically. Round the result to the nearest half unit. Commercial vehicles are defined as having at least one dual-wheeled axle and at least 4550 kg (10,000 lb) GVW.

**510.03 Design by R-Value.** The Resistance Value (R-value) is a test value, which measures the ability of a soil to resist lateral flow due to vertically applied load. Conduct this test using the Hveem Stabilometer in accordance with Idaho T-8, wherein the soil is tested at an applied load of 1,135 kg (2,500 lbs.). Plot the R-values obtained by testing at three or more moisture conditions as shown in Figure 510.03-1.

The intersection of this curve with 1135 kg (2,500 lbs.) ordinate gives the design R-value.

Use the following formula to compute flexible pavement thickness.

\[
\begin{align*}
\text{GE (in millimeters)} & = 0.975 \ (\text{TI}) \ (100-\text{R}) \ (\text{CF}) \\
\text{GE (in meters)} & = 0.001 \ (\text{TI}) \ (100-\text{R}) \ (\text{CF}) \\
\text{GE (in feet)} & = 0.0032 \ (\text{TI}) \ (100 \ R) \ (\text{CF})
\end{align*}
\]

Where:

- \( \text{GE} \) = Equivalent thickness of gravel
- \( \text{TI} \) = Traffic index (510.02)
- \( \text{R} \) = Resistance value
- \( \text{CF} \) = Climatic Factor (510.05)
FIGURE 510.02.02-1
FIGURE 510.03-1
Design each layer in the pavement structure based on the R-value of the layer below. Round the result to the next higher 15 mm (0.05 foot). For convenience, Figure 510.03-2 can be used to solve this equation graphically. (Note: Correct for regional (climatic) factor before rounding.)

Some moisture sensitive soils will exhibit severe reductions in R-value with small increases in moulding moisture content. For these soils, it may be advisable to use lower exudation pressures to estimate design R-value. Subgrade improvement and/or use of separation geotextiles may be necessary.

**510.04 Design by Expansion Pressure.** Given the expansion pressure data from Idaho T-8, plot a curve as shown in Figure 510.03-1.

Obtain the design expansion pressure where this curve intersects the diagonal balance line, using Figure 510.04-1. The balance line represents the condition at which the ballast requirement from R-value, at the governing TI, is equal to that from expansion pressure. The overlying material must provide sufficient to prevent any volume change in the subgrade soil caused by expansion. For design purposes, the unit weight of this material is assumed to be 2100 kg/m³ (130 pcf) for most granular materials, with the exception of some volcanic aggregates. The thickness in meters (feet) necessary to confine soil with expansive properties is computed with the following formula:

\[
B \text{ (meters)} = \frac{\text{Expansion pressure (kPa)} \times 102}{\text{Unit weight of aggregate (kg/m}^3)}
\]

\[
B \text{ (feet)} = \frac{\text{Expansion pressure (kPa)} \times 144}{\text{Unit weight of aggregate (lb/ft}^3)}
\]

For convenience, Figure 510.08-1 can be used to solve this equation graphically.

**510.05 Design Adjustments for Climatic Factor.** The Climatic Factor (CF) is used to adjust the required pavement structure thickness to compensate for the detrimental effects of severe climate on the ability of the pavement to carry traffic.

Apply the climatic factor (CF) as shown in 510.03

Where:
- CF = 1.00 for Region 1
- CF = 1.05 for Region 2
- CF = 1.10 for Region 3
- CF = 1.15 for Region 4

The various regions were defined through a study of precipitation records during the periods when the 30-year mean temperature remained below 0°C (32°F) and from the experience of the District Maintenance Engineers. Figure 510.08-1 illustrates the climatic regions to be used.
FIGURE 510.03-2
FIGURE 510.04-1

SELECT THE PROPER BALANCE LINE ACCORDING TO TRAFFIC INDEX, AND TRANSFER TO FORM ITD-803
Using EXPANSION PRESSURE intersects proper DENSITY LINE and read total BALLAST THICKNESS.
510.06 Design Adjustments for Material Cohesion, Stability and Drainage. The cohesion of compacted asphalt treated mixtures gives additional strength to the pavement structure. In consideration of this cohesive strength, it is then reasonable to adjust the total pavement thickness determined from R-value design after adjustment for climatic effects. Likewise, the stability and drainage capacity of unbound mixtures affects the strength of the pavement structure. Adjust the total pavement thickness in accordance with the relative strength of the unbound materials.

Obtain the adjustment in pavement thickness by use of Substitution Ratios (Gf) as follows:

\[
\text{Layer Thickness} = \frac{\text{Design Thickness}}{G_f}
\]

<table>
<thead>
<tr>
<th>Traffic Index</th>
<th>Plant Mix Pavement</th>
<th>Road Mix Pavement and ATB</th>
<th>(ATPB) Asphalt Treated Permeable Base</th>
<th>Untreated Aggregate Base*</th>
<th>Granular Subbase **</th>
</tr>
</thead>
<tbody>
<tr>
<td>14.5-16.5</td>
<td>1.4</td>
<td>1.10</td>
<td>1.2</td>
<td>1.0</td>
<td>0.85</td>
</tr>
<tr>
<td>12.7-14.4</td>
<td>1.5</td>
<td>1.20</td>
<td>1.2</td>
<td>1.0</td>
<td>0.85</td>
</tr>
<tr>
<td>10.0-12.6</td>
<td>1.6</td>
<td>1.30</td>
<td>1.2</td>
<td>1.0</td>
<td>0.85</td>
</tr>
<tr>
<td>8.1-9.9</td>
<td>1.8</td>
<td>1.45</td>
<td>1.2</td>
<td>1.0</td>
<td>0.85</td>
</tr>
<tr>
<td>6.7-8.0</td>
<td>2.0</td>
<td>1.60</td>
<td>1.2</td>
<td>1.0</td>
<td>0.85</td>
</tr>
<tr>
<td>5.6-6.6</td>
<td>2.2</td>
<td>1.75</td>
<td>1.2</td>
<td>1.0</td>
<td>0.85</td>
</tr>
<tr>
<td>0.0-5.5</td>
<td>2.4</td>
<td>1.90</td>
<td>1.2</td>
<td>1.0</td>
<td>0.85</td>
</tr>
</tbody>
</table>

*Open graded shot rock base material has been assigned an equivalency value of 1.2:1. For untreated aggregate base with an R-value less than 75, but greater than 70, reduce the substitution ratio to 0.90:1.

**For Subbase with an R-value of less than 60 reduce the substitution ratio to that of granular borrow, (0.75:1).

Granular borrow is material designated as improved subgrade and should have an R-value greater than the natural subgrade to be improved. Granular borrow may include cinder aggregate and selected granular excavation if quality is satisfactory.
510.07 Minimum Thickness of Pavement Elements. In any design procedure, it is also necessary to consider construction and maintenance operations in order to avoid the possibility of producing an impractical design. Based on these considerations, it is generally impractical to place surface, base, or subbase layers less than some minimum thickness. For purposes of this design procedure, the following are considered to be minimum practical thicknesses that are to be applied to each pavement layer:

- **Surface**: 45 mm (0.15 foot)
- **Base**: 100mm (0.35 foot) (ATB, ATPB, UTB)
- **Subbase**: 100mm (0.35 foot) (If used) or a minimum of 2 times the maximum particle size.

The minimum thickness of asphalt pavement placed upon asphalt treated permeable base (ATPB) shall be 75 mm (0.25 foot), regardless of Traffic Index.

The minimum lift thickness of asphalt pavement constructed with coarse graded aggregate should be at least 3 times the nominal maximum aggregate size.

The minimum thickness of open graded shot rock base (rock cap) shall be 180 mm (0.6 foot).

Establish the minimum thicknesses with the following stipulations:

- **Design Traffic Index** shall not be less than 6.0 for routes on the state highway system.

- Where traffic including construction traffic will run on exposed base prior to placing the surface, the gravel equivalent of the base and subbase shall support a Traffic Index of at least 7.0 on Interstate and NHS routes.

- **Design thicknesses** shall not be less than 150 mm (0.50 foot) actual depth for off-system routes, nor less than 250 mm (0.80 foot) actual depth for on-system routes.

- Treat base course aggregates with an R-value less than 80 to a depth that will satisfy the ballast requirements of the underlying base and/or subbase courses, keeping in mind the minimum thicknesses stated above.

- In lieu of treating base course aggregates, increase the surface course thickness to satisfy the ballast requirements of the underlying base and/or subbase course, if more economical to do so.

- **Design base course thickness** for the actual subbase R-value where possible.

- The overall thickness design must satisfy the ballast requirements of the subgrade soil.

- Granular borrow, placed as improved subgrade, must be thick enough to protect the native subgrade.

- **Structural elements of a flexible pavement** are illustrated in Figure 510.07-1.
NOTE: When selective placement of excavation or granular borrow is used, in groundwater or when permeable bases are used, special drainage design may be needed.
510.08 Reduced Design Period Thickness Design for Flexible Pavement. It is the policy of the Department to build projects with completed pavements. However, there are circumstances where a reduced design period will permit increased benefits to the public or provide a higher type pavement. Prior approval will be required to use a design period less than 20 years.

In many cases, a reduced design period cannot be effectively provided, i.e., in sections with curb and gutter or where several bridges are included within the project boundaries. Large traffic volumes may also pose difficulties. Make a detailed economic analysis before a reduced design period is selected.

For projects where a reduced design period is feasible and desirable, design the pavement structural cross section according to the following criteria:

- Step 1: Determine the pavement structural cross section required for a 20-year design, as if a reduced design period was not to be considered.

- Step 2: Determine the Traffic Index for a reduced design period by using the design traffic loading for at least the first 8 years of the 20-year design period used in Step 1 above (use ESALs for on-system routes, CADT for off-system routes).

- Step 3: Determine the surface course thickness for a reduced design period using the Traffic Index computed in Step 2 above. Complete the pavement structural cross section for the reduced design period by using the base and subbase thicknesses computed in Step 1 above.

- Step 4: The addition of the desired future wearing surface to the pavement structural cross section determined in Step 3 above fulfills the requirements for the 20-year design.

- Step 5: The pavement structural cross section for a reduced design period shall not be less than the minimum standards specified in Section 510.07.

- Step 6: In all cases, fulfill expansion pressure thickness requirements during a reduced design period.

510.09 Design Examples. The following examples are offered to illustrate the design method described previously.

510.09.01 Example. Assume a four-lane interstate highway with the following design data.

<table>
<thead>
<tr>
<th></th>
<th>1987</th>
<th>2007</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accumulated ESALs (design lane)</td>
<td>545,000</td>
<td>21,392,000</td>
</tr>
<tr>
<td>R-value</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>Subgrade expansion pressure in kPa (psi)</td>
<td>4.13 (0.60)</td>
<td></td>
</tr>
<tr>
<td>Unit weight base and surface in kg/m³ (pcf)</td>
<td>2,080 (130)</td>
<td></td>
</tr>
<tr>
<td>Climatic region</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>
FACTORS FOR CLIMATIC & ENVIRONMENTAL EFFECTS

REGION OR ZONE | REGIONAL FACTOR
--- | ---
1 | 1.00
2 | 1.05
3 | 1.10
4 | 1.15

FIGURE 510.08-1
Assume that the available crushed aggregate base material has an R-value of 80+, and that a granular subbase source is also available with an R-value of 60.

Begin by making a sketch of the pavement cross section to be designed.

![Pavement Cross Section](image)

Calculate the design ESALs.

ESALs = 21,392,000 - 545,000 = 20,847,000

TI = 9.0(20,847,000/10^6)^0.119

TI = 12.92, use 12.9

Calculate the ballast requirement for the plant mix surface, including climatic adjustment.

GE = 0.975(TI)(100 - R)(CF)

GE = 0.975(12.9)(100 - 80)(1.05) = 265 mm

GE = 0.0032(TI)(100 - R)(CF)

GE = 0.0032(12.9)(100 - 80)(1.05) = 0.87 ft.

Calculate the layer thickness by applying the substitution ratio for plant mix pavement.

T = 265 / 1.5 = 177 mm, use 180 mm

GE 1 (actual) = 180 × 1.5 = 270 mm

T = 0.87 / 1.5 = 0.58 ft., use 0.60 ft.

GE 1 (actual) = 0.60 × 1.5 = 0.90 ft.

Calculate the ballast requirement for the crushed aggregate base course.

GE = 0.975(12.9)(100 - 60)(1.05) = 528 mm

GE = 0.0032(12.9)(100 - 60)(1.05) = 1.73 ft.
Calculate the layer thickness by applying the substitution ratio for aggregate base.

\[ T = \frac{(528 \text{ mm} - 270 \text{ mm})}{1.00} = 258 \text{ mm}, \text{ use 270 mm} \]

\[ \text{GE 2 (actual)} = (270 \text{ mm} \times 1.00) + 270 \text{ mm} = 540 \text{ mm} \]

\[ T = \frac{(1.73 \text{ ft.} - 0.90 \text{ ft.})}{1.00} = 0.83 \text{ ft.}, \text{ use 0.85 ft.} \]

\[ \text{GE 2 (actual)} = (0.85 \text{ ft.} \times 1.00) + 0.90 \text{ ft.} = 1.75 \text{ ft.} \]

Calculate the ballast requirement for the granular subbase.

\[ \text{GE} = 0.975 (12.9)(100 - 30)(1.05) = 925 \text{ mm} \]

\[ \text{GE} = 0.0032 (12.9(100 – 30)(1.05) = 3.03 \text{ ft.}} \]

Calculate the layer thickness by applying the substitution ratio for granular subbase.

\[ T = \frac{(925 \text{ mm} - 540 \text{ mm})}{0.85} = 453 \text{ mm}, \text{ use 465 mm} \]

\[ \text{GE 3 (actual)} = (465 \text{ mm} \times 0.85) + 540 \text{ mm} = 935 \text{ mm} \]

\[ T = \frac{(3.03 \text{ ft.} - 1.73 \text{ ft.})}{0.85} = 1.53 \text{ ft.}, \text{ use 1.55 ft.} \]

\[ \text{GE 3 (actual)} = (1.55 \text{ ft.} \times 0.85) + 1.75 \text{ ft.} = 3.06 \text{ ft.} \]

Check the actual pavement thickness provided by R-value design against the actual thickness requirement by expansion pressure.

\[ T \text{ (actual)} = 180 \text{ mm} + 270 \text{ mm} + 465 \text{ mm} = 915 \text{ mm} \]

\[ B = \frac{(4.13 \text{ kPa} \times 102,000)}{2080 \text{ kg/m}^3} = 202 \text{ < 915 mm, OK} \]

\[ T \text{ (actual)} = 0.60 \text{ ft.} + .85 \text{ ft.} + 1.55 \text{ ft.} = 3.00 \text{ ft.} \]

\[ B = \frac{(0.60 \text{ psi} \times 144)}{130 \text{ pcf}} = 0.66 \text{ ft. < 3.00 ft., OK} \]

The typical section is then composed of:

180 mm (0.60 foot) plant mix pavement
270 mm (0.85 foot) crushed aggregate base
465 mm (1.55 feet) granular subbase

The section provides an actual total thickness of 915 mm (2.95 feet) and a gravel equivalent total thickness of 935 mm (3.06 feet)

NOTE: The conversion from English to metric units is not exact, hence the calculated thicknesses may not be the same.

NOTE: For convenience, R-value ballast requirements can be determined graphically using Figure 510.03-2 and expansion pressure requirements using Figure 510.04-2.
510.09.02 Example. Assume a four-lane interstate highway with the following design data:

<table>
<thead>
<tr>
<th></th>
<th>1987</th>
<th>2007</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accumulated ESALs (design lane)</td>
<td>30,000</td>
<td>1,070,000</td>
</tr>
<tr>
<td>R-value</td>
<td></td>
<td>54</td>
</tr>
<tr>
<td>Subgrade expansion pressure in kPa (psi)</td>
<td>9.38(1.36)</td>
<td></td>
</tr>
<tr>
<td>Unit weight base and surface in kg/m³ (pcf)</td>
<td>2,080 (130)</td>
<td></td>
</tr>
<tr>
<td>Climatic region</td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>

Assume that the available crushed aggregate base material has an R-value of 80+, and that a granular subbase source is also available with an R-value of 60.

Begin by making a sketch of the pavement cross section to be designed.

Calculate the design ESALs.

\[ \text{ESALs} = 1,070,000 - 30,000 = 1,040,000 \]

Calculate the Traffic Index.

\[ \text{TI} = 9.0 \left( \frac{1,040,000}{10^6} \right)^{0.119} \]
\[ \text{TI} = 9.04, \text{ use } 9.0 \]

Calculate the ballast requirement for the plant mix surface, including climatic adjustment.

\[ \text{GE} = 0.975 (9.0)(100 - 80)(1.00) = 176 \text{ mm} \]

\[ \text{GE} = 0.0032 (9.0)(100 - 80)(1.00) = 0.58 \text{ ft.} \]
Calculate the layer thickness by applying the substitution ratio for plant mix pavement.

\[
\begin{align*}
T &= \frac{176 \text{ mm}}{1.8} = 98 \text{ mm}, \text{ use } 105 \text{ mm} \\
GE_1 \text{ (actual)} &= 105 \text{ mm} \times 1.8 = 189 \text{ mm} \\
\end{align*}
\]

\[
\begin{align*}
T &= \frac{0.58 \text{ ft.}}{1.8} = 0.32 \text{ ft.}, \text{ use } 0.35 \text{ ft.} \\
GE_1 \text{ (actual)} &= 0.35 \text{ ft.} \times 1.8 = 0.63 \text{ ft.} \\
\end{align*}
\]

Calculate the ballast requirement for the plant mix and crushed aggregate base course, assuming granular subbase is not used.

\[
\begin{align*}
GE &= 0.975 (9.0)(100 - 54)(1.00) = 404 \text{ mm} \\
GE &= 0.0032 (9.0)(100 - 54)(1.00) = 1.32 \text{ ft.} \\
\end{align*}
\]

Calculate the layer thickness for aggregate base by applying the substitution ratio for aggregate base and subtracting the gravel equivalent for plant mix.

\[
\begin{align*}
T &= \frac{(404 \text{ mm}) - (189 \text{ mm})}{1.00} = 215 \text{ mm}, \text{ use } 225 \text{ mm} \\
GE_2 \text{ (actual)} &= (225 \text{ mm} \times 1.00) + 189 \text{ mm} = 414 \text{ mm} \\
\end{align*}
\]

\[
\begin{align*}
T &= \frac{(1.32 \text{ ft.}) - (0.63 \text{ ft.})}{1.00} = 0.69 \text{ ft.}, \text{ use } 0.70 \text{ ft.} \\
GE_2 \text{ (actual)} &= (0.70 \text{ ft.} \times 1.00) + 0.63 \text{ ft.} = 1.33 \text{ ft.} \\
\end{align*}
\]

check the actual pavement thickness provided by R-value design against the actual thickness requirement by expansion pressure.

\[
\begin{align*}
T \text{ (actual)} &= 105 \text{ mm} + 225 \text{ mm} = 330 \text{ mm} \\
B &= \frac{(9.38 \text{ kPa} \times 102,000)}{2082 \text{ kg/m}^3} = 460 > 330 \text{ mm}, \text{ add subbase} \\
\end{align*}
\]

\[
\begin{align*}
T \text{ (actual)} &= 0.35 \text{ ft.} + 0.70 \text{ ft.} = 1.05 \text{ ft.} \\
B &= \frac{(1.36 \text{ psi} \times 144)}{130 \text{ pcf}} = 1.51 > 1.05 \text{ ft.}, \text{ add subbase} \\
\end{align*}
\]

In this case, expansion pressure governs and additional material is needed. Since the granular subbase has an R-value different than that of the subgrade soil, recalculate the ballast requirement for the aggregate base layer to include a layer of granular subbase.

\[
\begin{align*}
GE &= 0.975 (9.0)(100 - 60)(1.00) = 351 \text{ mm} \\
GE &= 0.0032 (9.0)(100 - 60)(1.00) = 1.15 \text{ ft.} \\
\end{align*}
\]
Recalculate the layer thickness by applying the substitution ratio for aggregate base.

\[
T = \frac{(351 \text{ mm} - 189 \text{ mm})}{1.00} = 162 \text{ mm}, \text{ use } 165 \text{ mm}
\]

GE 3 (actual) = \((165 \text{ mm} \times 1.00) + 189 \text{ mm} = 354 \text{ mm}\)

\[
\begin{align*}
T &= (1.15 \text{ ft.} - 0.63 \text{ ft.}) / 1.00 = 0.52 \text{ ft.}, \text{ use } 0.55 \text{ ft.} \\
\text{GE 3(actual)} &= (0.55 \text{ ft.} \times 1.00) + 0.63 \text{ ft.} = 1.18 \text{ ft.}
\end{align*}
\]

Recalculate the depth of granular subbase necessary to fulfill the ballast requirement from expansion pressure.

\[
T = 460 - (105 \text{ mm} + 165 \text{ mm}) = 190 \text{ mm}, \text{ use } 195 \text{ mm}
\]

GE 3 (actual) = \((195 \text{ mm} \times 0.85) + 354 \text{ mm} = 520 \text{ mm}\)

\[
\begin{align*}
T &= 1.15 \text{ ft.} - (0.35 \text{ ft.} + 0.55 \text{ ft.}) = 0.61 \text{ ft.}, \text{ use } 0.65 \text{ ft.}
\end{align*}
\]

Check the ballast provided against the ballast required by the subgrade soil.

GE = \(0.975 (9.0)(100 - 54)(1.00) = 404 \text{ mm}\)

GE (provided) = 520 mm > 404 mm, OK

\[
\begin{align*}
\text{GE} &= 0.0032 (9.0)(100 – 54)(1.00) = 1.32 \text{ ft.} \\
\text{GE (provided)} &= 1.73 \text{ ft.} > 1.32 \text{ ft.}, \text{ OK}
\end{align*}
\]

The typical section is then composed of:

- 105 mm (0.35 foot) plant mix pavement
- 165 mm (0.55 foot) crushed aggregate base
- 195 mm (0.65 foot) granular subbase

The section provides an actual total thickness of 465 mm (1.55 feet) and a gravel equivalent total thickness of 520 mm (1.73 feet).

**510.09.03 Example.** Assume a ramp on the interstate project shown in example 510.09.02 above. This example (510.09.03) is presented to illustrate the necessity to establish a new expansion pressure balance line when the traffic changes for a given soil. It will also show the alternate method of determining Traffic Index.

<table>
<thead>
<tr>
<th></th>
<th>1987</th>
<th>2007</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total ADT</td>
<td>83</td>
<td>250</td>
</tr>
<tr>
<td>% Commercial</td>
<td></td>
<td></td>
</tr>
<tr>
<td>volume</td>
<td></td>
<td>12</td>
</tr>
<tr>
<td>Commercial class</td>
<td></td>
<td>Medium</td>
</tr>
<tr>
<td>‘n</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subgrade R-value</td>
<td></td>
<td>54</td>
</tr>
<tr>
<td>Subgrade expansion pressure in kPa</td>
<td></td>
<td>9.38</td>
</tr>
<tr>
<td>(psi)</td>
<td></td>
<td>(1.36)</td>
</tr>
</tbody>
</table>
Traffic on the ramp is one-way. Calculate the design ADT.

ADT = \( \frac{83 + 250}{2} = 167 \)

Compute the commercial volume.

CADT = \( 167 \times 0.12 = 20 \)

Use Figure 510.02.02-1 with the CADT and commercial classification shown above to determine that the Traffic Index is 7.0.

Using Figure 510.03-2, a Traffic Index of 7.0, and R-value of 54, the total unadjusted thickness (gravel equivalent) is 314 mm (1.03 feet).

Determine the expansion pressure balance line from Figure 510.04-1 with the use of the test report (Figure 510.03-1). Select the expansion pressure value for the changed traffic conditions at the intersection of the expansion pressure curve and the expansion pressure balance line (Figure 510.09.03-1). This gives an expansion pressure of the subgrade soil equal to 7.86 kPa (1.14 psi).

Using Figure 510.04-2 with the 7.86 kPa (1.14 psi) expansion pressure and 2082 kg/m² (130 pcf) for weight of base and pavement materials results in a required thickness of 384 mm (1.26 feet).

The climatic factor for Region 1 is 1.00 (Figure 510.08-1), resulting in no increase for climate.

It should be noted at this point, that if a comparison is made with example 510.09.02 above, the change in Traffic Index from 9.0 to 7.0 has decreased the required thickness for the ramps from 402 mm (1.32 feet) to 314 mm (1.03 feet) gravel equivalent by R-value and from 460 mm (1.51 feet) to 384 mm (1.26 feet) actual thickness by expansion pressure.

Calculate the ballast requirement for the plant mix surface, including climatic adjustment.

GE = 0.975 (7.0)(100 - 80)(1.00) = 137 mm

\[
GE = 0.0032 (7.0)(100 – 80)(1.00) = 0.45 \text{ ft.}
\]

Calculate the layer thickness by applying the substitution ratio for plant mix pavement.

\[
T = \frac{137 \text{ mm}}{2.0} = 70 \text{ mm}, \text{ use } 75 \text{ mm}
\]

\[
\text{GE 1 (actual)} = 75 \text{ mm} \times 2.0 = 152 \text{ mm}
\]

\[
T = \frac{0.45 \text{ ft.}}{2.0} = 0.23 \text{ ft.}, \text{ use } 0.25 \text{ ft.}
\]

\[
\text{GE 1 (actual)} = 0.25 \text{ ft.} \times 2.0 = 0.50 \text{ ft.}
\]
Calculate the ballast requirement for the crushed aggregate base course.

GE = 0.975 (7.0)(100 - 54)(1.00) = 314 mm

GE = 0.0032 (7.0)(100 – 54)(1.00) = 1.03 ft.

Calculate the layer thickness by applying the substitution ratio for aggregate base.

T = (314 mm - 150 mm) / 1.00 = 164 mm, use 165 mm

GE 2 (actual) = (165 mm × 1.00) + 150 mm = 315 mm

T = (1.03 ft. – 0.50 ft.) / 1.00 = 0.53 ft. use 0.55 ft.

GE 2 (actual) = (0.55 ft. × 1.00) = 0.50 ft. = 1.05 ft.

Check the actual pavement thickness provided by R-value design against the actual thickness requirement by expansion pressure.

T (actual) = 75 mm + 165 mm = 240 mm

B = (801 kPa × 144) / 2082 kg/m³ = 384 mm > 240 mm, add subbase

B = (1.14 psi × 144) / 130 pcf = 1.26 ft. > 0.80 ft., add subbase

In this case, expansion pressure governs and additional material is needed. Since the granular subbase has an R-value different than that of the subgrade soil, recalculate the ballast requirement for the aggregate base layer to include a layer of granular subbase.

GE = 0.975 (7.0)(100 - 60)(1.00) = 273 mm

GE = 0.0032(7.0)(100 - 60)(1.00) = 0.90 ft.

Recalculate the layer thickness by applying the substitution ratio for aggregate base.

T = (273 mm - 152 mm) / 1.00 = 122 mm, use 120 mm

GE 2 (actual) = (120 mm × 1.00) + 152 mm = 272 mm

T = (0.90 ft. – 0.50 ft.) / 1.00 = 0.40 ft., use 0.40 ft.
Recalculate the depth of granular subbase necessary to fulfill the ballast requirement from expansion pressure.

\[ T = 384 - (75 \text{ mm} + 120 \text{ mm}) = 189 \text{ mm}, \text{ use } 195 \text{ mm} \]

\[ \text{GE } 3 \text{ (actual)} = (195 \text{ mm} \times 0.85) + 272 \text{ mm} = 437 \text{ mm} \]

| T = 1.26 - (0.25 ft + 0.40 ft.) = 0.61 ft., use 0.65 ft. |
| GE 3 (actual) = (0.65 ft. \times 0.85) + 0.90 ft. = 1.45 ft. |

Check the ballast provided against the ballast required by the subgrade soil.

\[ \text{GE} = 0.975 (7.0)(100 - 54)(1.00) = 314 \text{ mm} \]

\[ \text{GE (provided)} = 437 \text{ mm} > 314 \text{ mm}, \text{ OK} \]

\[ \text{GE} = 0.0032 (7.0)(100 - 54)(1.00) = 1.03 \text{ ft.} \]

\[ \text{GE (provided)} = 1.45 \text{ ft.} > 1.03 \text{ ft.}, \text{ OK} \]

The typical section is then composed of:

75 mm (0.25 foot) plant mix pavement
120 mm (0.40 foot) crushed aggregate base
195 mm (0.65 foot) granular subbase

This section provides an actual total thickness of 390 mm (1.30 feet) and a gravel equivalent total thickness of 437 mm (1.45 feet).

**510.09.04 Example.** Assume an Interstate or major NHS Highway with the following design data: This is a major route, carrying in excess of 1000 trucks per day. To achieve pavement drainage, Open-graded Shot Rock Base (Rock Cap) is selected for base.

<table>
<thead>
<tr>
<th>1995</th>
<th>2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accumulated ESALs</td>
<td></td>
</tr>
<tr>
<td>(Design Lane)</td>
<td>400,000</td>
</tr>
<tr>
<td></td>
<td>16,500,000</td>
</tr>
<tr>
<td>Subgrade R-value</td>
<td></td>
</tr>
<tr>
<td></td>
<td>48</td>
</tr>
<tr>
<td>Subgrade Expansion Pressure: kPa (psi)</td>
<td>2.75 (0.4)</td>
</tr>
<tr>
<td>Unit Weight - Surfacing: kg/m³ (pcf)</td>
<td>2,360 (147)</td>
</tr>
<tr>
<td>Unit Weight - Rock Cap: kg/m³ (pcf)</td>
<td>1,760 (110)</td>
</tr>
<tr>
<td>Unit Weight - Rock Cap: kg/m³ (pcf)</td>
<td>2,080 (130)</td>
</tr>
<tr>
<td>Climatic Region</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
</tr>
</tbody>
</table>
Assume Rock Cap has an R-value of at least 80, and that a source of granular subbase is available with an R-value of at least 60.

Begin by making a sketch of the pavement cross section to be designed.

1. A plantmix binder/leveling course is placed an average of 45mm (0.15 feet) thick over the rock cap before placing plantmix surface. This binder course is given no structural value. An overrun of 5 to 10% in plant mix binder should be expected due to penetration into the rock cap.

2. If aggregate base is used to level the surface of the rock cap, an overrun of up to 40% may occur depending on the gradation of the rock cap. Unless filter criteria is satisfied, this option is not recommended, since infiltration of the aggregate base may continue after paving. In certain conditions, where traffic must be routed over the Rock Cap before the plant mix binder can be placed, an aggregate base binder becomes necessary.

Calculate Traffic Index:

\[ TI = 9.0 \left( \frac{13,550,000}{10^6} \right)^{0.119} \]
\[ TI = 12.27 \text{ Use 12.3} \]

Calculate the ballast requirement for the plant mix surface, including climatic adjustment.

\[ GE = 0.975(TI)(100-R_B)(CF) \]
\[ GE = .0975(12.3)(20)(1.10) = 264\text{mm} \]

\[ GE = 0.0032 \left( TI \right)(100 - R_B)(CF) \]
\[ GE = 0.0032 (12.3)(20)(1.10) = 0.87\text{ ft.} \]

Calculate the layer thickness by applying the substitution ration for plant mix pavement.

\[ T = 264 \text{ mm} / 1.6 = 165\text{mm}, \text{ use 165} \]
\[ GE \ 1 \ (\text{actual}) = 165 \text{ mm} \times 1.6 = 264 \text{ mm} \]

\[ T = 0.87 \text{ ft} / 1.6 = 0.54 \text{ ft., use 0.55 ft.} \]
\[ GE \ 1 \ (\text{actual}) = 0.55 \text{ ft.} \times 1.6 = 0.88 \text{ ft.} \]
Calculate the ballast requirement over subgrade.

\[ GE = 0.0975(12.3)(100-48)(1.10) = 686mm \]

\[ GE = 0.0032 (12.9)(100 – 48)(1.10) = 2.25 \text{ ft.} \]

Calculate the layer thickness by applying the substitution ratio for Rock Cap and subtract out the plantmix surfacing.

\[ T = \frac{(686 \text{ mm} – 264 \text{ mm})}{1.2} = 352\text{ mm}, \text{ Use 360mm} \]

\[ \text{GE 2 (actual)} = (360 \text{ mm } \times 1.2) + 264 \text{ mm} = 696\text{ mm} \]

\[ T = \frac{(2.25 \text{ ft.} – 0.88 \text{ ft./ 1.2 = 1.14 ft.}, \text{ use 1.2 ft.}} \]

\[ \text{GE 2 (actual)} = (1.20 \text{ ft. } \times 1.2) + 0.88\text{ ft.} = 2.32 \text{ ft.} \]

NOTE: A subbase layer may be placed beneath the rock cap in some instances provided the filter criteria in Section 511 is satisfied or a geotextile is placed over the subbase.

Check the actual pavement thickness provided by R-value design against actual thickness required by expansion pressure.

\[ T (\text{actual}) = 165 \text{ mm} + 360 \text{ mm} = 525 \text{ mm} \]

\[ B = \frac{(2.75 \text{ kPa } \times 102)}{2080} = 135\text{ mm} < 525\text{ mm}, \text{ OK} \]

\[ T (\text{actual}) = 1.20 \text{ ft.} + 0.55 \text{ ft.} = 1.75 \text{ ft.} \]

\[ B = \frac{(0.4 \text{ psi } \times 144)}{130} = 0.44 \text{ ft.} < 1.75 \text{ ft.}, \text{ OK} \]

The above calculations were based on an averaged unit weight of 2,080 kg/m³ (130 pcf). Where pavement components have different unit weights, a weighted average may be used to calculate the equivalent thickness, or make the comparison based on vertical pressure.

Compute weighted average unit weight:

\[ (165 \text{ mm } \times 2360) + (360 \text{ mm } \times 1760)/(165 + 360) = 1956 \text{ kg/m}^3 \text{ (122 pcf)} \]

Recalculate thickness required by expansion pressure.

\[ T (\text{actual}) = 525 \text{ mm} \]

\[ B = \frac{(2.75 \text{ kPa } \times 102)}{1956} = 143 \text{ mm} \text{ (a 6\% increase)} \]

Calculate subgrade pressure exerted by pavement section.

\[ P = (2360 \text{ kg/m}^3 \times 165 \text{ mm}/1000) + (1760 \text{ kg/m}^3 \times 360 \text{ mm}/1000) = 1023 \text{ kg/m}^2 \]

\[ P = 1023 \text{ kg/m}^2 \times 0.00978 = 9.95 \text{ kPa} > 2.75 \text{ kPa} \quad \text{OK} \]
510.10 References.


Highway Research Record No. 13, "Thickness of Flexible Pavements by the California Formula Compared to AASHTO Road Test Data," F.N. Hveem and G.B. Sherman.


