# Appendix A: Gravel Road Thickness Design Methods

Although this manual was developed with emphasis on the maintenance and operation of gravel roads, this Appendix is provided to discuss some aspects of design. Once the design is understood by a local official, estimating the amount of materials required to construct a section of road can be accomplished with ease, as can budgeting and prioritization. This section is provided to offer a taste, for those who are interested, of how thickness design is determined.

Theories of thickness design of unpaved roads can be rather complicated and cumbersome, but this guide has selected some simple and user-friendly approaches to illustrate how the thickness of a gravel mat can be determined.It is highly recommended that local governments seek the services of professional engineering consultants before a final decision is made concerning thickness.

Several factors are known to affect road surface performance during its life span.Some of these factors are: axle load, which is referred to as the 18-kip equivalent single axle load (ESAL); cover aggregate characteristics; surface/subsurface drainage; freeze/thaw; subgrade properties; resilient modulus; and moisture change, to name a few. The ESAL factor is considered vital to gravel road thickness design and must be calculated. Private automobiles and light weight trucks do not seem to have any influence in thickness determination. The American Association of State Highway and Transportation Officials (AASHTO) recommends the use of a maximum of 100,000 ESAL applications, while the practical minimum level (during a single performance period) is 10,000 ESAL (39).

The following two approaches will illustrate the proper procedure for the determination of gravel thickness. The first approach is based on theories and relies on charts and nomographs, while the second approach is based on design catalogs.

## I. Design Chart Procedure

To completely understand this method of design it is imperative that the user be familiar with the following terms. Their values must be determined before the design procedure is pursued.

### A. Predicted Future Traffic ($W_{18}$)

Any pavement must be designed to accommodate accumulated traffic for several years into the future. Due to the presence of mixed traffic on the road, i.e. passenger cars, semi-trailers, busses, etc., accumulated traffic volume must be presented in terms of a standard Equivalent Single Axle Load (ESAL).AASHTO defines ESAL as 18,000 lbs.; it is denoted in the literature by the symbol ($W_{18}$). Conversion factors are available to express axle loads other than 18,000 lbs. in terms of ESAL and are presented in Appendix D of AASHTO Guide for Design of Pavement Structures. (39)

### B. Roadbed Soil Resilient Modulus ($M_R$) in PSI

All material exhibits some deformation (strain) when subjected to loads per unit area (stress).As long as the stress is less than the strength,no failure is likely to occur. The relationship between the stress and strain can be expressed as resilient modulus ($M_R$). It is well known that most paving materials experience some permanent deformation after each load application. This might lead to rutting of asphalt pavements or cracking of concrete pavements. Therefore the value of resilient modulus of different materials and supporting soils is desired,as well as that of the pavement mixture itself. (40)

### C. Length of Season

One of the factors that affects pavement performance is length of season. Figure 1 shows how the United States is divided into six different climatic regions and the environmental characteristics associated with each region. Based on these different climatic characteristics, Table 2 is used to determine the season lengths for measuring the effective roadbed soil resilient modulus. Table 3 is used to find the roadbed soil resilient modulus values for aggregate surfaced road (41).

### D. Elastic Modulus of Aggregate Sub-Base Layer ($E_{SB}$) and Aggregate Base Layer ($E_{BS}$) in PSI

For materials subjected to significant permanent deformation under loads, elastic modulus is a fundamental property that must be considered. Resilient modulus defines the material's stress-strain behavior under normal pavement loading conditions. Here the notation $M_R$ is used only for roadbed resilient modulus while other notations such as ($E_{BS}$) and ($E_{SB}$) are used for modulus of base and sub-base respectively (40).

## E. Design Serviceability Loss (ΔPSI)

Serviceability is the ability of a specific section of pavement to serve traffic in its existing conditions. The present serviceability index (PSI) is the primary measure of serviceability. PSI ranges from 0 to 5 where 0 means the existing road condition is impossible for driving, and 5 means the road is in perfect condition for driving. The lowest serviceability motorists can tolerate, before rehabilitation, resurfacing or reconstruction,is called terminal serviceability ($P_t$). Common values for terminal serviceability index are $P_t$=2.5 or higher when used for the design of major highways and $P_t$=2.0 when used for low volume roads. The minimum level of serviceability is mostly dependent on people's acceptance. There are some minimum levels of $P_t$, which are obtained from AASHTO road tests, and which are given below:

| | | | |
|---|---|---|---|
| Terminal serviceability level ($P_t$) | 3.0 | 2.5 | 2.0 |
| Percent of people stating unacceptable | 12% | 55% | 85% |

For minor highways like aggregate surfaced roads where funds or economy is the main factor, the design is done by reducing the traffic or design life rather than reducing the terminal serviceability to a number lower than 2.00. In designing new roads the terminal serviceability is set up based on original or initial serviceability $P_o$. It is observed that the difference between $P_t$ and $P_o$, (= DPSI) has a great influence in the design of aggregate surfaced road and therefore must be determined as part of the design.(39)

## F. Allowable Rutting (RD) in Surface Layer

Rutting is bound to occur in aggregate surfaced road, and is considered as performance criteria. If the rut is too high, then it is very difficult to drive on the road surface due to the creation of channels along wheel paths. This rutting will ultimately lead the road into permanent deterioration. A certain amount of rutting, however, can be tolerated without causing any hazards. The designer should decide upon an allowable rut depth before applying the design procedures. The typical value of allowable rut depth for designing an aggregate surfaced road falls between 1.00 and 2.00 inches. (39)

## G. Aggregate Loss of Surface Layer

It is inevitable that gravel roads will lose some of the surface aggregate due to several factors like the action of traffic loads, erosion, precipitation,etc.As a result,the load carrying capacity is reduced and the road becomes thinner;this leads to surface deterioration. This aggregate loss must be accounted for during the design of the aggregate surfaced roads. It is important to estimate the total thickness that will be lost during the design period and the minimum thickness of aggregate which will keep a maintainable working surface for the roads. (33)

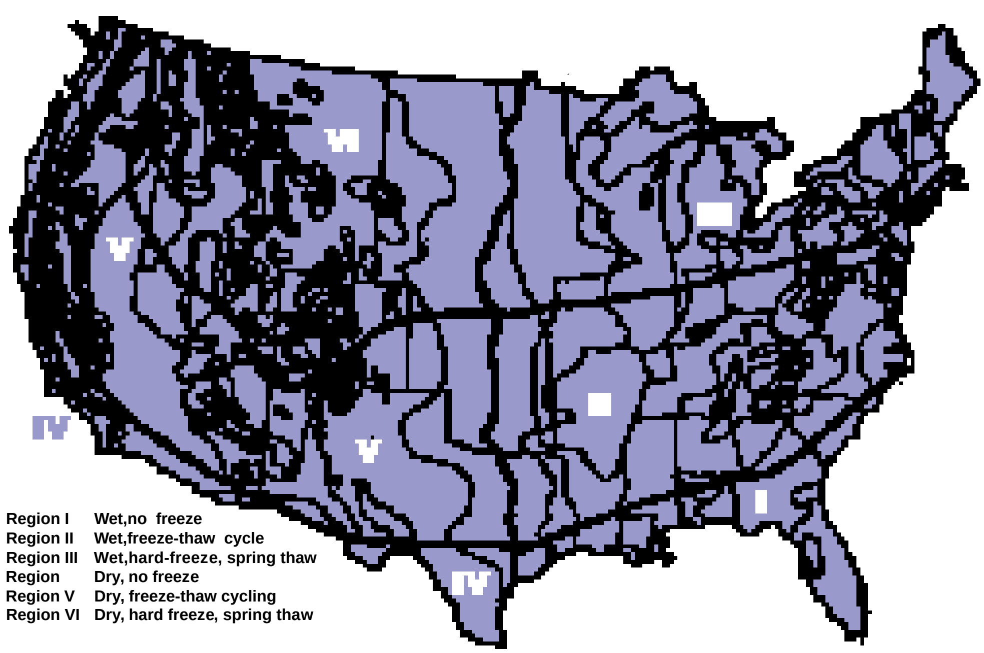


**Figure 10: The Six Climatic Regions in the United States. (39)**

**Table 2: Suggested Seasons Length (Months) for Six U.S.Climatic Regions. (39)**

| | Season (Roadbed Soil Moisture Condition) | | | |
|---|---|---|---|---|
| **U.S.CLIMATIC REGION** | Winter (Roadbed Frozen) | Spring/Thaw (Roadbed Saturated) | Spring/Fall (Roadbed Wet) | Summer (Roadbed Dry) |
| I | 0.0[1] | 0.0 | 7.5 | 4.5 |
| II | 1.0 | 0.5 | 7.0 | 3.5 |
| III | 2.5 | 1.5 | 4.0 | 4.0 |
| IV | 0.0 | 0.0 | 4.0 | 8.0 |
| V | 1.0 | 0.5 | 3.0 | 7.5 |
| VI | 3.0 | 1.5 | 3.0 | 4.5 |

[1] Number of month for the season

**Table 3: Suggested Seasonal Roadbed Soil Resilient Moduli, $M_R$ (psi), as a Function of the Relative Quality of the Roadbed Material. (39)**

| | Season (Roadbed Soil Moisture Condition) | | | |
|---|---|---|---|---|
| **RELATIVE QUALITY OF ROADBED MATERIAL** | Winter (Roadbed Frozen) | Spring/Thaw (Roadbed Saturated) | Spring/Fall (Roadbed Wet) | Summer (Roadbed Dry) |
| Very Good | 20,000[1] | 2,500 | 8,000 | 20,000 |
| Good | 20,000 | 2,000 | 6,000 | 10,000 |
| Fair | 20,000 | 2,000 | 4,500 | 6,500 |
| Poor | 20,000 | 1,500 | 3,300 | 4,900 |
| Very Poor | 20,000 | 1,500 | 2,500 | 4,000 |

[1] Values shown are Resilient Modulus in psi

## Steps in Thickness Design of Gravel Roads

According to the AASHTO design method, ten steps are followed to calculate the thickness of aggregate surfaced road. (39) The method is based on a trial-and-error approach. It assumes a thickness; then the expected damage due to serviceability and rutting criterion is calculated. The thickness that yields a damage of 100% is the one selected as the design thickness. Details of the procedure are listed below:

Step 1: Select trial base thickness. Normally four trial thicknesses are assumed ($D_{BS}$) although additional trials might be needed. These thicknesses are recorded in the upper left-hand corner of Table 4 (work sheet), which is used for this purpose. Several additional types of data are also recorded and used in subsequent calculations.

Step 2: Select an allowable serviceability loss ($\Delta$PSI), and allowable rutting depth (RD). These values need to be selected and recorded on the top of each of the four or more trial Tables.

Step 3: Select seasonal resilient modulus for roadbed ($M_R$) and elastic modulus of aggregate base material ($E_{BS}$). Once the approximate seasonal roadbed resilient modulus ($M_R$), from Table 3, and aggregate base resilient modulus ($E_{BS}$) are selected,they should be placed in columns 2 and 3 of Table 4 respectively. These same numbers are used in each of the four or more trial sheets (Table 4).

Step 4: Determine projected 18-kip. ESAL traffic. Seasonal 18-kip ESAL traffic is entered in column 4 of Table 4. The length of the season, from Table 2, should be used to determine the proportion of the total projected traffic for each season.

Step 5: Determine allowable 18-kip EASL traffic for serviceability criteria. Within each of the four or more tables, estimate the allowable 18-kip ESAL traffic for each of the four seasons using the serviceability-based nomograph in Figure 11 and enter in column 5 of Table 4. For values falling outside the nomograph assume a practical value of 500,000 18-kip ESAL.

Step 6: Determine allowable 18-kip EASL traffic for rutting criteria. Within each of the four tables, estimate the allowable 18-kip ESAL traffic for each of the four seasons using the rutting-based nomograph in Figure 12 and enter in column 7. For values falling outside the nomograph assume a practical value of 500,000 18-kip ESAL.

Step 7: Determine seasonal damage (serviceability and rutting criteria). Columns 6 and 8 carry values of seasonal damage under serviceability and rutting criterion respectively. Seasonal damage for the serviceability criteria is computed by dividing the projected seasonal traffic (column 4) by the allowable traffic in that season (column 5). Enter this seasonal damage value in column 6 of Table 4. Follow the same instructions for rutting criteria,i.e., divide column 4 by column 7 and enter in column 8.

Step 8: Determine average base thickness ($\bar{D}_{BS}$). Compute the total damage for both the serviceability and rutting criteria by adding the seasonal damages. Once this is accomplished for all four or more tables (corresponding to the four or more trial base thicknesses), a graph of total damage versus base layer thickness should be drawn. The average base layer thickness, DBS, required is determined by interpolating in this graph for a total damage equal to 1.0. Figure 14 provides an example, which will be explained later. Two values of $D_{BS}$ can be found, one for serviceability criteria and the other for rutting criteria. The design $\bar{D}_{BS}$ will be the greater of the two values.

**Table 4: Chart for Computing Total Pavement Damage (for Both Serviceability and Rutting Criteria).Based on a Trial Aggregate Base Thickness.(39)**

| TRIAL BASE THICKNESS, $D_{BS}$ = ______inches | | | | Serviceability Criteria $\Delta PSI$ = | | Rutting Criteria RD ( Inches) = | |
|---|---|---|---|---|---|---|---|
| **1** Season (Roadbed Moisture Condition) | **2** Roadbed Resilient Modulus $M_R$ (psi) | **3** Base Elastic Modulus $M_R$ (psi) | **4** Projected 18-kip ESAL Traffic, $W_{18}$ | **5** Allowable 18-kip ESAL Traffic $(W_{18})$PSI | **6** Seasonal Damage, $W_{18}/(W_{18})$ PSI | **7** Allowable 18-kip ESAL Traffic, $(W_{18})$ | RUT **8** Seasonal Damage, $W_{18}/(W_{18})$ |
| Winter (Frozen) | | | | | | | |
| Spring/Thaw (Saturated) | | | | | | | |
| Spring/Fall (Wet) | | | | | | | |
| Summer (Dry) | | | | | | | |
| | | **Total Traffic =** | | **Total Damage =** | | **Total Damage =** | |

Step 9: Correct average base aggregate thickness due to aggregate loss. This step is important for aggregate surface road. In this step, aggregate loss is calculated and determination of actual base thickness is accomplished by using the following formula:

$$D_{BS} = \bar{D}_{BS} + 0.5\ GL$$

Where GL = The total aggregate loss in inches.
$D_{BS}$ = Design Base Thickness in inches. Obtained in step 8 above.

Step 10: Convert base to equivalent sub-base thickness. This step helps to convert the aggregate base thickness to an equivalent thickness of sub-base. This step might be deemed necessary if base course material is very expensive compared to that used in the sub-base. This is done with help of Figure 4.

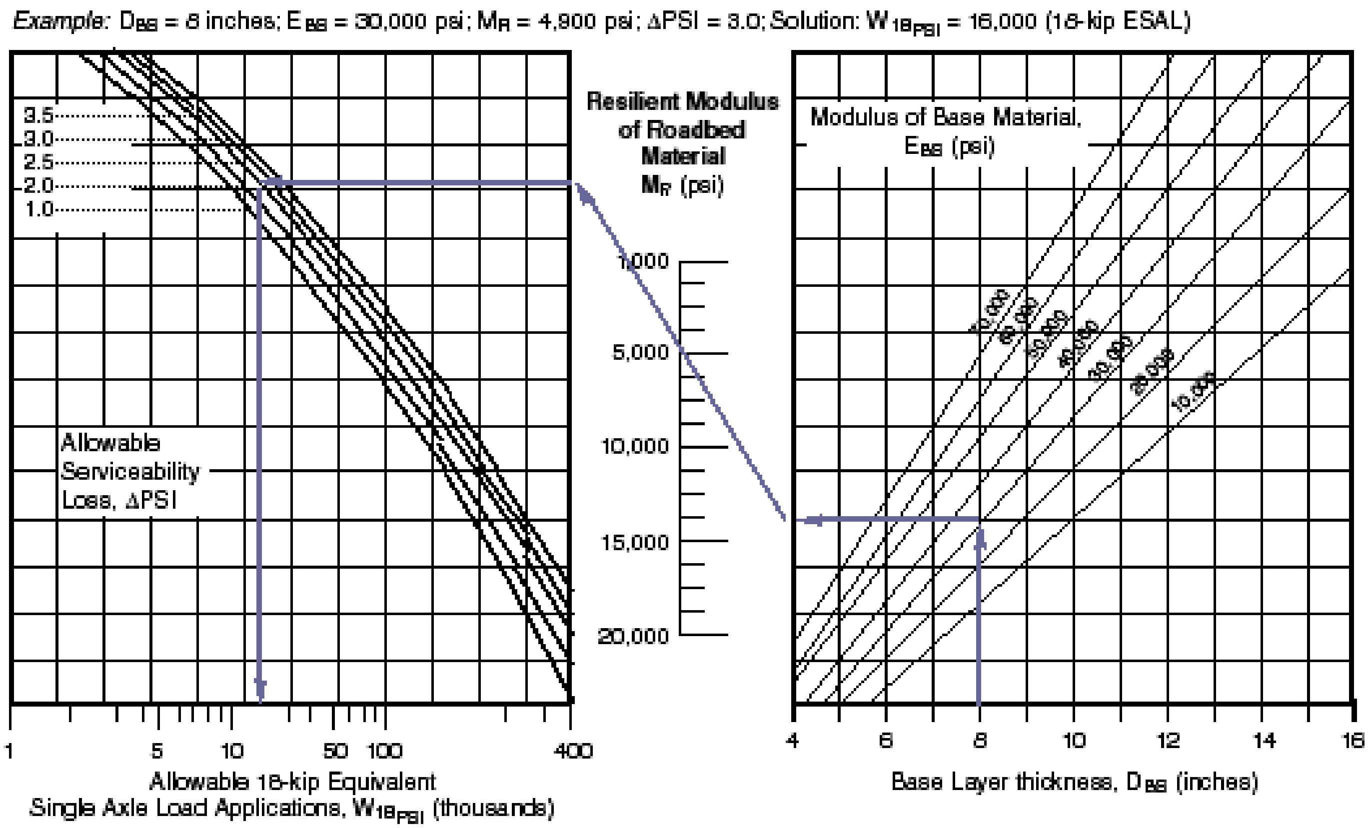


**Figure 11: Design Chart for Aggregate-Surfaced Roads Considering Allowable Serviceability Loss. (39)** From *AASHTO Guide for Design of Pavement Structures*. Copyright 1993, by the American Association of State Highway and Transportation Officials, Washington, D.C. Used by permission.

Example:
An aggregate surfaced road is to be designed using the following information:

| | | |
|---|---|---|
| 18-kip ESAL repetitions ($W_{18}$) | = | 35,000 |
| Gravel bed Resilient Modulus | = | Good |
| Base Elastic Modulus ($E_{BS}$) | = | 25,000 psi |
| Sub base Elastic Modulus ($E_{SB}$) | = | 15,000 psi |
| Climatic region | = | VI |

Solution:

Step 1: Select trial base thickness. This method of thickness design is based on trial and error and therefore several thickness trials are needed. Each trial will result in an answer point that can be plotted with other points to form a curve of total damage versus aggregate base thickness. Although the more trials (and therefore the more points on the curve), the better the curve fitting and therefore the more accurate the design, about four trials will be considered adequate in most designs. In this example, five trial base thicknesses were needed to determine the best probable solution. For this, five separate tables identical to Table 4 are completely filled. The assumed trial thicknesses are 10, 11, 12, 13, and 14 inches.

Step 2: Select an allowable serviceability loss and allowable rutting depth. Assume ΔPSI = 2psi and allowable rut depth RD = 2.0 inches.

Step 3: Assume appropriate seasonal resilient moduli $M_R$ and base elastic modulus $E_{BS}$. The approximate seasonal roadbed resilient modulus and aggregate base resilient modulus $E_{BS}$ can be selected from Table 2 and Table 3.

| Season | Winter | Spring/Thaw | Spring/Fall | Summer |
|---|---|---|---|---|
| $M_R$ (psi) | 20,000 | 2,000 | 6,000 | 10,000 |

Step 4: Determine projected 18-kip ESAL traffic. Total traffic = 35,000 (given). Using Table 1,W18 can be calculated for each season.

| Item | Winter | Spring/Thaw | Spring/Fall | Summer |
|---|---|---|---|---|
| $W_{18}$ | 35,000 x (3/12) = 8,750 | 35,000 x (1.5/12) = 4,375 | 35,000 x (3/12) = 8,750 | 35,000 x (4.5/12) = 13,125 |

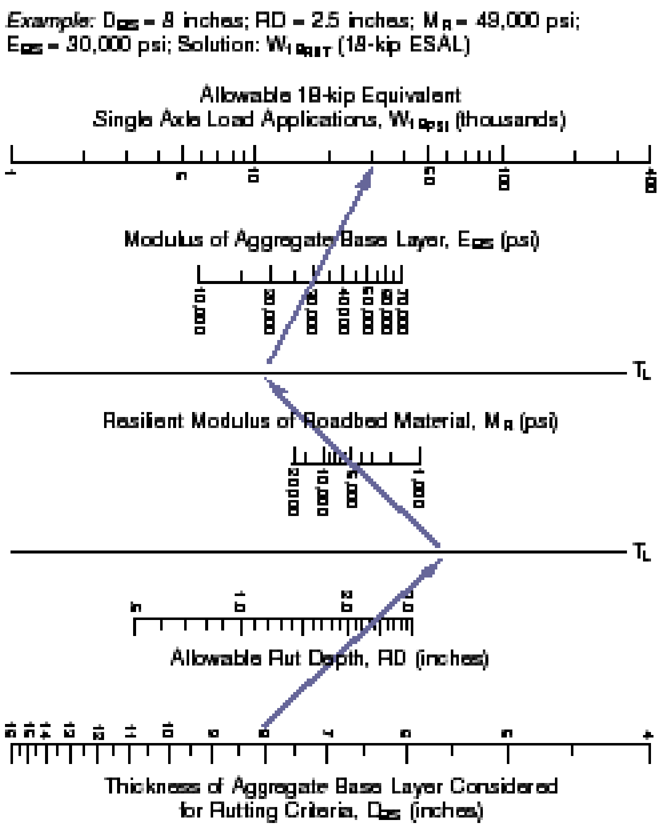


**Figure 12: Design Chart for Aggregate-Surfaced Roads Considering Allowable Rutting. (39)** From *AASHTO Guide for Design of Pavement Structures*. Copyright 1993, by the American Association of State Highway and Transportation Officials, Washington, D.C. Used by permission.

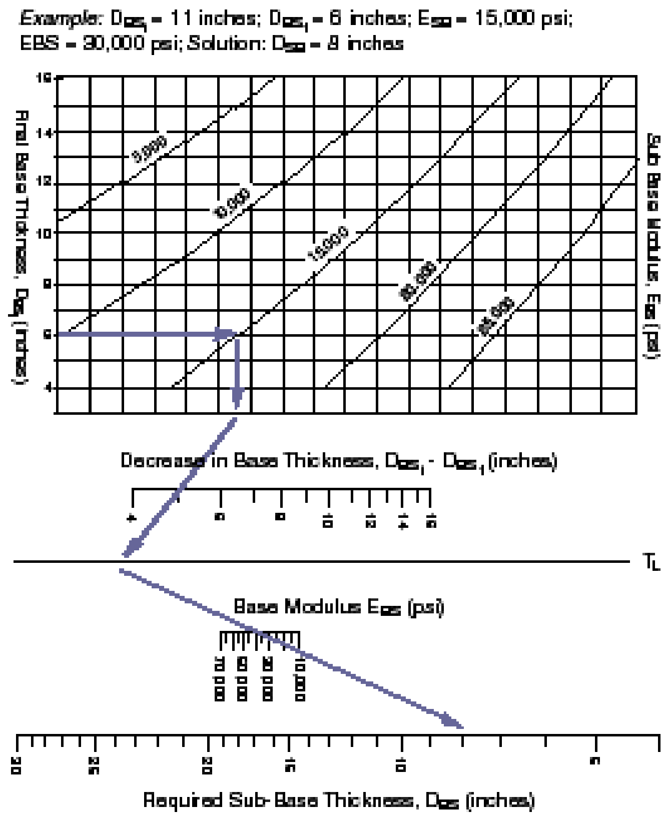


**Figure 13: Chart to Convert a Portion of the Aggregate Base Layer Thickness to an Equivalent Thickness of Sub-base. (39)** From *AASHTO Guide for Design of Pavement Structures*. Copyright 1993, by the American Association of State Highway and Transportation Officials, Washington, D.C. Used by permission.

Step 5: Determine allowable 18-kip EASL traffic for serviceability criteria. For each trial base thickness the allowable $W_{18}$ ESAL can be calculated from the serviceability base nomograph of Figure 11. For example, the 11-inch trial thickness yields the following allowable $W_{18}$ for the above stated criteria: $W_{18}$ = 400,000 for Winter season, 10,000 for Spring/Thaw season, 32,000 for Spring/Fall season, and 90,000 for Summer season as shown in the table of the 2nd trial. These values are recorded in column 5 of Table 4.

Step 6: Determine allowable 18-kip EASL traffic for rutting criteria. For each trial base thickness the allowable W18 ESAL can be calculated from the rutting depth-base nomograph of Figure 12. From the nomograph, $W_{18}$ = 80,000 for Winter season, 7,300 for Spring/Thaw season, 23,000 for Spring/Fall season, and 38,000 for Summer season as shown in the table of the 1st trial. These values are recorded in column 7 of Table 4.

Step 7: Determine seasonal damage (serviceability and rutting criteria). The seasonal values of damages are calculated for serviceability criteria by dividing the projected seasonal traffic (column 4) by allowable traffic in that season (column 5). The corresponding damage for the serviceability criteria is then calculated as (Damage) = 8,750/400,000 = 0.022 and recorded in column 6 as shown in the table of the 1st trial. The same procedure is applied for rutting criteria where the seasonal damages are calculated by dividing column 4 by column 7 and recorded in column 8 as: [Damage = 8,750/80,000 = 0.109].

Step 8: Determine average base thickness. Once the total damages for both serviceability and rutting criteria are completed for the four trial thicknesses, two curves are developed as shown in Figure 14. The first curve represents the relationship between serviceability failure and base thickness ($D_{BS}$) and the other curve represent rutting failure and base thickness. Average base thickness for each damage criteria is determined by interpolating the corresponding base thickness value for a total damage of 1.0. From Figure 5 these values are $\overline{D}_{BS}$ = 12.9 inches for rutting criteria and $\overline{D}_{BS}$ = 10.6 inches for serviceability criteria. In this example rutting governs, so the design base thickness should be 13 inches.

**First Trial**

| TRIAL BASE THICKNESS, $D_{BS}$ (inches) = **10.00** | | | | Serviceability Criteria $\Delta PSI$ = **2.5** | | Rutting Criteria RD (Inches) = **2.00** | |
|---|---|---|---|---|---|---|---|
| **1** Season (Roadbed Moisture Condition) | **2** Roadbed Resilient Modulus $M_R$ (psi) | **3** Base Elastic Modulus $M_R$ (psi) | **4** Projected 18-kip ESAL Traffic, $W_{18}$ | **5** Allowable 18-kip ESAL Traffic ($W_{18}$) PSI | **6** Seasonal Damage, $W_{18}/(W_{18})$ PSI | **7** Allowable 18-kip ESAL Traffic, ($W_{18}$) | RUT **8** Seasonal Damage, $W_{18}/(W_{18})$ |
| Winter (Frozen) | 20,000 | 25,000 | 8,750 | 400,000 | 0.022 | 80,000 | 0.109 |
| Spring/Thaw (Saturated) | 2,000 | 25,000 | 4,375 | 18,500 | 0.643 | 5,800 | 0.754 |
| Spring/Fall (Wet) | 6,000 | 25,000 | 8,750 | 25,000 | 0.350 | 19,000 | 0.461 |
| Summer (Dry) | 10,000 | 25,000 | 13,125 | 67,000 | 0.196 | 31,500 | 0.417 |
| | | Total Traffic = | **35,000** | Total Damage = | **1.211** | Total Damage = | **1.741** |

**Second Trial**

| TRIAL BASE THICKNESS, $D_{BS}$ (inches) = **11.00** | | | | Serviceability Criteria $\Delta PSI$ = **2.5** | | Rutting Criteria RD (Inches) = **2.00** | |
|---|---|---|---|---|---|---|---|
| **1** Season (Roadbed Moisture Condition) | **2** Roadbed Resilient Modulus $M_R$ (psi) | **3** Base Elastic Modulus $M_R$ (psi) | **4** Projected 18-kip ESAL Traffic, $W_{18}$ | **5** Allowable 18-kip ESAL Traffic ($W_{18}$) PSI | **6** Seasonal Damage, $W_{18}/(W_{18})$ PSI | **7** Allowable 18-kip ESAL Traffic, ($W_{18}$) | RUT **8** Seasonal Damage, $W_{18}/(W_{18})$ |
| Winter (Frozen) | 20,000 | 25,000 | 8,750 | 400,000 | 0.022 | 80,000 | 0.109 |
| Spring/Thaw (Saturated) | 2,000 | 25,000 | 4,375 | 10,000 | 0.438 | 7,300 | 0.599 |
| Spring/Fall (Wet) | 6,000 | 25,000 | 8,750 | 32,000 | 0.273 | 23,000 | 0.380 |
| Summer (Dry) | 10,000 | 25,000 | 13,125 | 90,000 | 0.146 | 38,000 | 0.345 |
| | | Total Traffic = | **35,000** | Total Damage = | **0.879** | Total Damage = | **1.433** |

**Third Trial**

| TRIAL BASE THICKNESS, $D_{BS}$ (inches) = **12.00** | | | | Serviceability Criteria $\Delta PSI$ = **2.5** | | Rutting Criteria RD (Inches) = **2.00** | |
|---|---|---|---|---|---|---|---|
| **1** Season (Roadbed Moisture Condition) | **2** Roadbed Resilient Modulus $M_R$ (psi) | **3** Base Elastic Modulus $M_R$ (psi) | **4** Projected 18-kip ESAL Traffic, $W_{18}$ | **5** Allowable 18-kip ESAL Traffic ($W_{18}$) PSI | **6** Seasonal Damage, $W_{18}/(W_{18})$ PSI | **7** Allowable 18-kip ESAL Traffic, ($W_{18}$) | RUT **8** Seasonal Damage, $W_{18}/(W_{18})$ |
| Winter (Frozen) | 20,000 | 25,000 | 8,750 | 400,000 | 0.022 | 100,000 | 0.088 |
| Spring/Thaw (Saturated) | 2,000 | 25,000 | 4,375 | 14,000 | 0.313 | 8,500 | 0.515 |
| Spring/Fall (Wet) | 6,000 | 25,000 | 8,750 | 40,000 | 0.219 | 29,000 | 0.302 |
| Summer (Dry) | 10,000 | 25,000 | 13,125 | 110,000 | 0.119 | 48,000 | 0.273 |
| | | Total Traffic = | **35,000** | Total Damage = | **0.673** | Total Damage = | **1.178** |

**Fourth Trial**

| TRIAL BASE THICKNESS, $D_{BS}$ (inches) = **13.00** | | | | Serviceability Criteria $\Delta PSI$ = **2.5** | | Rutting Criteria RD (Inches) = **2.00** | |
|---|---|---|---|---|---|---|---|
| **1** Season (Roadbed Moisture Condition) | **2** Roadbed Resilient Modulus $M_R$ (psi) | **3** Base Elastic Modulus $M_R$ (psi) | **4** Projected 18-kip ESAL Traffic, $W_{18}$ | **5** Allowable 18-kip ESAL Traffic ($W_{18}$) PSI | **6** Seasonal Damage, $W_{18}/(W_{18})$ PSI | **7** Allowable 18-kip ESAL Traffic, ($W_{18}$) | RUT **8** Seasonal Damage, $W_{18}/(W_{18})$ |
| Winter (Frozen) | 20,000 | 25,000 | 8,750 | 400,000 | 0.022 | 140,000 | 0.063 |
| Spring/Thaw (Saturated) | 2,000 | 25,000 | 4,375 | 18,500 | 0.236 | 11,000 | 0.398 |
| Spring/Fall (Wet) | 6,000 | 25,000 | 8,750 | 54,000 | 0.162 | 32,000 | 0.273 |
| Summer (Dry) | 10,000 | 25,000 | 13,125 | 130,000 | 0.101 | 50,000 | 0.263 |
| | | Total Traffic = | **35,000** | Total Damage = | **0.521** | Total Damage = | **0.997** |

**Fifth Trial**

| TRIAL BASE THICKNESS, $D_{BS}$ (inches) = **14.00** | | | | Serviceability Criteria $\Delta PSI$ = **2.5** | | Rutting Criteria RD (Inches) = **2.00** | |
|---|---|---|---|---|---|---|---|
| **1** Season (Roadbed Moisture Condition) | **2** Roadbed Resilient Modulus $M_R$ (psi) | **3** Base Elastic Modulus $M_R$ (psi) | **4** Projected 18-kip ESAL Traffic, $W_{18}$ | **5** Allowable 18-kip ESAL Traffic ($W_{18}$) PSI | **6** Seasonal Damage, $W_{18}$/($W_{18}$) PSI | **7** Allowable 18-kip ESAL Traffic, ($W_{18}$) | RUT **8** Seasonal Damage, $W_{18}$/($W_{18}$) |
| Winter (Frozen) | 20,000 | 25,000 | 8,750 | 400,000 | 0.022 | 170,000 | 0.051 |
| Spring/Thaw (Saturated) | 2,000 | 25,000 | 4,375 | 22,000 | 0.199 | 12,000 | 0.365 |
| Spring/Fall (Wet) | 6,000 | 25,000 | 8,750 | 66,000 | 0.133 | 40,000 | 0.219 |
| Summer (Dry) | 10,000 | 25,000 | 13,125 | 170,000 | 0.077 | 68,000 | 0.193 |
| | | Total Traffic = | **35,000** | Total Damage = | **0.431** | Total Damage = | **0.828** |

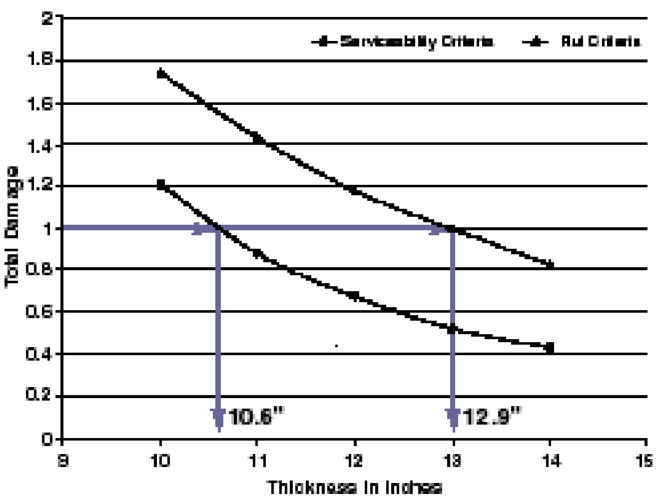


**Figure 14: Total Damage versus Thickness for Serviceability and Rutting Criteria.**

Step 9: Correction of average base aggregate thickness for aggregate loss. This step is important for aggregate surface road; in this step aggregate loss is calculated.Actual base thickness is then determined by using the following formula:

$D_{BS} = D_{BS} + 0.5$ GL;Where GL is allowable aggregate loss.
In this example, corrected thickness is:
$D_{BS} = 13.0 + 0.5 * 1 = 13.5$ inches

Step 10: Convert base to equivalent sub-base thickness. Occasionally the designer can place an inferior sub-base material under the good gravel layer. This will lead, most of the time, to savings in material cost. Therefore placing a sub-base can reduce the thickness of the more expensive gravel layer. To accomplish that,part of the good gravel layer can be converted to an equivalent thickness of sub-base layer. This is done with the help of Figure 13.Assuming that only 6 inches of good base material will be placed instead of the proposed 13.5 inches obtained by the complete analysis as shown in step 9 above. The reduction of base thickness = 13.5 - 6 = 7.5 inches. This 7.5 inches of good gravel base needs to be converted to an equivalent sub-base layer. This is accomplished by entering Figure 13 with 6 inches of good base thickness and moving up to the $E_{SB}$ curve of 15,000, then turning right. Connect with the decrease in base thickness of 7.5 inches and extend to the $T_L$ line. Connect the point on the $T_L$ line with the $E_{BS}$ of 25,000 and extend to the required sub-base thickness line. Therefore sub-base thickness = 11 inches. This approach yields a gravel thickness that consists of 6 inches of good base gravel and 11 inches of sub-base gravel.

If the quality of roadbed soil is not good enough,i.e. is of poor quality, then the roadbed resilient modulus will be smaller. Table 3 shows that if the quality of roadbed is lower, seasonal roadbed modulus will also be less. This will lead the road surface to accommodate less traffic. In that case the base thickness will be greater. So it is very clear that before designing aggregate surface roads, high quality roadbed soil should be given serious considerations.

# II. Design Catalogs

When not enough detailed information is available, the design catalog approach is recommended to design aggregate surface roads. Table 5 presents a catalog of aggregate base layer thickness that may be used for the design of low-volume roads. The thicknesses shown are based on specific ranges of 18-kip ESAL applications at traffic levels (39):

| Level | 18-kip ESAL Traffic Load |
|---|---|
| High | 60,000 - 100,000 |
| Medium | 30,000 - 60,000 |
| Low | 10,000 - 30,000 |

**Table 5: Aggregate Surfaced Road Design Catalog: Recommended Aggregate Base Thickness (in Inches) For Six U.S. Regions, Five Relative Qualities of Roadbed Soil, and Three Traffic Levels. (39)**

| Relative Quality of Roadbed Soil | Traffic Level | U.S. Climatic Region | | | | | |
|---|---|---|---|---|---|---|---|
| | | I | II | III | IV | V | VI |
| Very Good | High | 8* | 10 | 15 | 7 | 9 | 15 |
| | Medium | 6 | 8 | 11 | 5 | 7 | 11 |
| | Low | 4 | 4 | 6 | 4 | 4 | 6 |
| Good | High | 11 | 12 | 17 | 10 | 11 | 17 |
| | Medium | 8 | 9 | 12 | 7 | 9 | 12 |
| | Low | 4 | 5 | 7 | 4 | 5 | 7 |
| Fair | High | 13 | 14 | 17 | 12 | 13 | 17 |
| | Medium | 11 | 11 | 12 | 10 | 10 | 12 |
| | Low | 6 | 6 | 7 | 5 | 5 | 7 |
| Poor | High | ** | ** | ** | ** | ** | ** |
| | Medium | ** | ** | ** | 15 | 15 | ** |
| | Low | 9 | 10 | 9 | 8 | 8 | 9 |
| Very Poor | High | ** | ** | ** | ** | ** | ** |
| | Medium | ** | ** | ** | ** | ** | ** |
| | Low | 11 | 11 | 10 | 8 | 8 | 9 |

* Thickness of aggregate base required (in inches)  ** Higher type pavement design recommended

# The South Dakota Catalog Design Method

A similar approach to the above procedure is suggested for local and other agencies in the state of South Dakota to determine gravel layer thickness. The method is rather crude because it only relies on two parameters, heavy trucks and subgrade support condition. Table 6 represents suggested thicknesses. (3)

**Table 6: Suggested Gravel Layer Thickness for New Or Reconstructed Rural Roads.**

| Estimated Daily Number of Heavy Trucks | Subgrade Support Condition[1] | Suggested Minimum Gravel Layer Thickness,mm (in.) |
|---|---|---|
| | Low | 165 (6.5) |
| 0 to 5 | Medium | 140 (5.5) |
| | High | 115 (4.5) |
| | Low | 215 (8.5) |
| 5 to 10 | Medium | 180 (7.0) |
| | High | 140 (5.5) |
| | Low | 290 (11.5) |
| 10 to 25 | Medium | 230 (9.0) |
| | High | 180 (7.0) |
| | Low | 370 (14.5) |
| 25 to 50 | Medium | 290 (11.5) |
| | High | 215 (8.5) |

Notes: [1] Low Subgrade support: CBR ≤3 percent;
Medium Subgrade support: 3 < CBR ≤ 10 percent;
High Subgrade support: CBR >10 percent.