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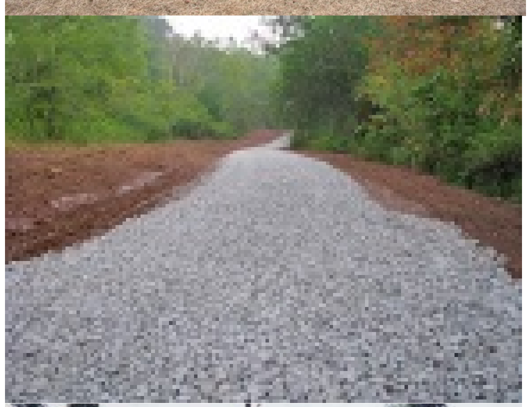
Earth and Aggregate Surfacing Design Guide



Acknowledgments

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Earth and Aggregate Surfacing Design Guide

Introduction

This document provides technical design guidance for aggregate surfacing on existing soils (subgrade) and applies to the conservation practices (CP) listed below. The code refers to the NRCS Conservation Practice Standard (CPS).

- Access Road (Code 560)
- Heavy-Use Area Protection (Code 561)
- Trails and Walkways (Code 575)
- Stream Crossing (Code 578)

This document will cover the following topics related to aggregate surfacing of existing soils (subgrade):

- Literature Review
- Aggregate and Similar Surface Materials
- Aggregate Components
- Aggregate Surfaced CP Planning and Field Investigation
- Design of Unpaved-Aggregate Access Roads
- Design of Heavy-Use Area Protection (HUAP)
- Design of Animal Trails and Walkways
- Design of Stream Crossings
- Subgrade Stabilization

The focus of the design methodologies is a stable foundation (existing subgrade) for aggregate surfacing, assuming the design load is applied at the top of the aggregate (surface course). The importance of the applied load position is covered under the *Literature Review* section. The chief failure mode of an aggregate surface on existing subgrade is bearing capacity. The failure is commonly seen as a punching, or rutting failure. Bearing failures normally occur by rupture, or failure along the shear surface in the soils under and adjacent to the load, shown as bulges next to the wheel load in figure 1. This failure mode occurs when loose or soft subgrade soils are present, or the aggregate layer is too thin, and the induced stress exceeds the subgrade's allowable strength.

Although this document is intended as a guide, it does not supplant the need for coordination between the designer and a qualified geotechnical engineer.

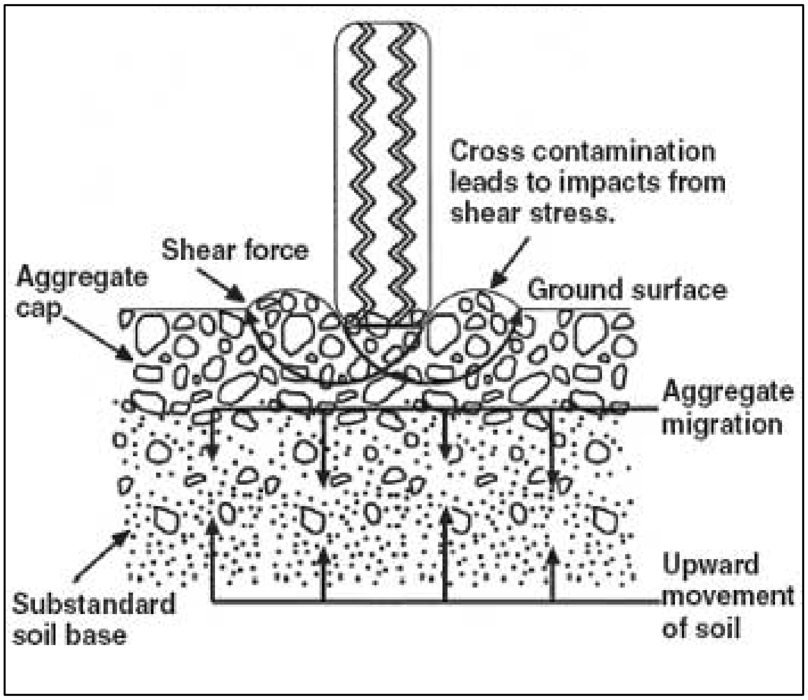

Figure 1 – Failure Mode of Aggregate Surfaced Road (U.S. Forest Service, 2008)

The methods are based upon theoretical analysis, empirical design procedures, observed performance, and field and laboratory tests. The theoretical analysis is a function of the ultimate bearing capacity of the existing soils and the load applied to the compacted base material.

Literature Review

A literature review was completed to describe the existing design procedures for low-volume, unpaved roads and the use of geotextiles in these systems. Low-volume, unpaved roads are often built on poor subgrades. Much of the criteria developed to date originated with the construction of footings over soft subgrades. For very soft and soft cohesive soil conditions, saturation is often assumed, and the bearing capacity of the soil is defined by a localized shear equation—

(1) $$q_{ult} = (\gamma B/2)N_\gamma + CN_c + q_{ob}N_{ob}$$

Where, γ is the unit weight of the soil, B is the footing width, C is the soil's cohesion parameter, q_{ob} is the vertical overburden pressure on the footing. N_γ, N_c, and N_{ob} are bearing capacity factors that are dependent upon the angle of internal friction of the soil, ϕ. For a rapidly loaded footing on the surface of a soil, the conditions are approximately undrained, and ϕ is approximately zero. Since the load is applied to the surface, q_{ob} is also zero. Thus, for these conditions, the bearing capacity of the footing depends upon the cohesion of the material or C.

For rapid cyclic loading conditions in pavements, the allowable subgrade stress is defined by the simplified ultimate bearing capacity described in Terzaghi et al. (1996), as—

(2) $$q_{ult} = CN_c$$

Where q_{ult} is the ultimate bearing capacity of the soil, C is the shear strength of the soil or cohesion for saturated clays, and N_c is the bearing capacity factor.

Summarizing the ultimate bearing capacity theory in terms of the Mohr-Coulomb failure criteria for soils. The Mohr-Coulomb soil shear strength is—

(3) $$S_u = C + \sigma_n \mathrm{Tan}\phi$$

Where S_u is the undrained shear strength of the soil, C is the cohesion, σ_n is the effective normal stress, and ϕ is the soil's angle of internal friction. For soft saturated clay and subgrades, ϕ is approximately zero indicating the soil shear strength is approximately equal to its cohesion.

In 1975, Barenberg et al. (1975), conducted two-dimensional cyclic load tests on laboratory specimens composed of a high-quality crushed rock over a saturated clay subgrade with a geotextile placed at the aggregate-subgrade interface. Barenberg compared the theoretical subgrade stress using a Boussinesq solution to the measured subgrade strength under various loading conditions. Barenberg concluded that the allowable subgrade stress without the geotextile was approximately 3.3 times the subgrade shear strength, C. For the specimens prepared with the geotextile, the allowable subgrade stress was approximately 6.0 times the shear strength of the soil. The increase in allowable stress for the geotextile-reinforced section was attributed to a change in the mode of shear failure from a localized failure to a general shear failure. Barenberg used these findings to develop a set of design curves for geotextile reinforced aggregate low-volume roads at a traffic level of approximately 100 vehicle passes. The change in the failure surface is illustrated in figure 2 below. The failure surface without a geotextile present in the section is shown as a dashed line, while the solid line represents the failure surface with a geotextile.

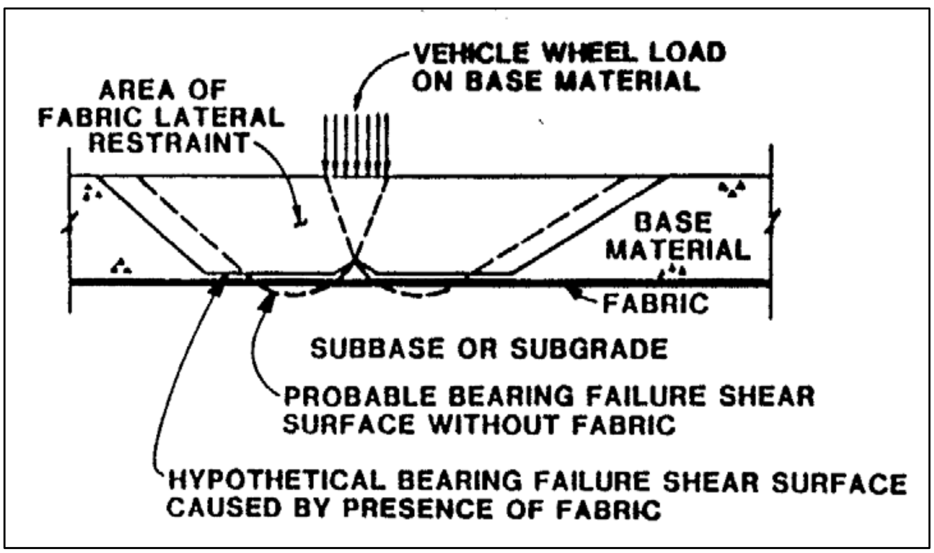

Figure 2 – Shear Failure Mechanism With and Without Geotextile

In 1977, Steward et al., modified the approach of Barenberg et al., to develop a design procedure for using geotextiles in low-volume unpaved roads for the U.S. Forest Service. Steward et al., noted that the net bearing capacity of an area for constant volume and undrained loading is approximately CNc, the same relationship used by Barenberg and cited in Terzaghi et al. Steward et al. proposed bearing capacity factors of 2.8 and 5.0 for the unreinforced and geotextile reinforced cases. These values were proposed for the design of low-volume roads to produce less than 2 inches of rutting in 1,000 equivalent 18-kip single axle loads (ESALs). Steward used a Boussinesq solution for calculating the vertical stress below a uniform circularly loaded area and the modified bearing capacity factors to construct design curves for single, dual, and dual tandem axle loadings. The resulting design procedure uses the subgrade bearing capacity (CNc) and the wheel loading to estimate the required aggregate thickness necessary to reduce the vertical subgrade stress below the theoretical limits for shear failure.

Aggregate and Similar Surface Materials

The term "aggregate" generally refers to materials that started out as bedrock. Aggregate is commonly used for subbase, base and surface courses for unpaved access roads, heavy-use area protection sites, stream crossings, trails and other projects that require subgrade stabilization. Components of an aggregate surfaced section are discussed further under the *Aggregate Components* section.

Aggregate includes combinations of crushed rock (stone), gravel, crushed gravel, sand, or other mineral materials. Aggregate is produced by crushing, screening, pit-run, or grid-rolling methods. Crushing and screening are the most commonly used methods. Pit-run and grid-rolling methods generally produce lower quality aggregate.

- *Crushing* breaks stone and gravel into smaller particles. Crushing equipment also blends the various sizes together for the proper gradation.
- *Grid-rolling* means crushing rock in place. Rock sources include native materials or aggregate hauled from pits. A heavy steel roller with a waffle pattern rolls the material, crushing and compacting it at the same time.
- *Processing* can include screening and washing. Screening separates raw material or crushed material into uniform sizes. The material is moved or shaken on sorting screens. Washing cleans the aggregate such that an aggregate with little to no fines is produced.

Aggregate can be graded for different applications (i.e., subbase, base, and surface courses for subgrade stability projects). Gradation refers to aggregate particle sizes and the relative distribution of those particle sizes in the material.

For aggregate-surface practices, well-graded aggregate are desirable. Well-graded means that there is a thorough distribution of particle sizes such that the aggregate, along with water as a lubricant, can be compacted to form a tight, dense mass. The suitable thickness of the aggregate surface varies, depending on soil conditions.

In order to achieve job specific gradation requirements or improve other characteristics, fillers, binders and chemical additives are sometimes added. Fillers are mineral materials, such as crushed limestone, that improve the gradation of the aggregate. Binders increase the cohesiveness or binding quality of the aggregate, with clay being a common binder. For example, a mix of sand and clay is often used in areas with abundant sand. The sand alone is too loose to form a well-compacted stable material. Adding small amounts of clay to aggregate may improve resistance to erosional processes as well as improve its compaction. Fillers and binders generally are not used alone but are blended uniformly with the aggregate. Added materials should be blended at the plant when the aggregate is processed.

Crushed Gravel and Crushed Stone

There are two types of crushed aggregate: crushed gravel and stone. Crushed gravel is produced by crushing natural gravel material. The number of fractured faces depends on the original gradation of the natural gravel. The coarser the gradation, the higher the percentage of fractured faces. Crushed stone is produced by crushing bedrock. Nearly all the faces of the fragments are fractured. Examples of materials used for crushed stone include limestone and granite. Many people refer to crushed gravel and crushed stone, either separately or in combination, as crushed rock. Crushed rock, with its angular faces, compacts relatively well into a densely uniform mass or unit. Crushed rock is suitable for sites that require subgrade or foundation stability. It is also suitable for road subbase, parking areas, parking pads, and trails. Crushed rock may be used in livestock areas and as surface courses on roads, heavy-use areas, and stream crossings. Small rocks 3⁄8 in. (about 9.5 mm) or smaller are less likely to get caught in rakes during manure cleanup. Larger rocks can lodge in an animal's hoofs, causing pain or injury. Crushed rock is suitable near water, for example on wearing surfaces around water hydrants, water troughs, and wash racks.

Crushed rock, when combined with fines and well compacted, generally is preferred for surface courses on trails, roads, and heavy-use areas. This material fits together tightly, offering a stable surface for pedestrians, stock, and vehicles. Compacted crushed rock with fines withstands high use and requires little maintenance. The material provides good traction and drainage. If it is well compacted and the surface hardens well, it is not dusty. The standard size for crushed material is ¾-inch-minus (less than about 19.1 mm), which includes rocks about ¾ inch in diameter and smaller. Some agencies prefer crushed materials that are ½-inch-minus (about 12.7 mm or less) for trail building, but this material may be more expensive.

Gravel

Gravel is a coarse, granular material produced by the natural weathering and erosion of rock. The USCS distinguishes gravel as particles that pass through a 3-in. (76.2-mm) sieve, but retained on a No. 4, 0.187-in. (4.750 mm) sieve. Particles larger than 3 in. (76.2 mm) are considered cobbles and boulders. Round gravel usually comes from alluvial deposits. Sometimes round gravel is used in wilderness settings or areas with low development where it is readily available. Round gravel consisting of a small gradation (1/8 to 3/8 in.) is sometimes called pea gravel. Pea gravel is appropriate for surfaces in animal watering areas and around hydrants, water troughs, and wash racks. Round or pea gravels are poor choices for trails, roads, parking areas, and parking pads because they do not compact well, nor do the particles interlock like crushed rock. The gravel roll against each other (due to their rounded shape), making it difficult for people and stock to walk. Vehicles pulling a trailer also have difficulty getting traction, especially if the gravel is deep. As the gravel particles roll, the vehicle sinks and may become stuck.

Sand

Sand is fine granular material produced by the natural disintegration of rock. The USCS gradation for sand is material that passes a No. 4 (4.750 mm) sieve, but is retained on a No. 200 (0.075 mm) sieve. Sand drains well and creates a soft trail tread for livestock. When used alone, sand is easily eroded or replaced by other materials and can be dusty. Often, sand is combined with clay and gravel or other materials to improve its drainage or to improve compaction. If more than 3 inches (76.2 mm) of sand is applied as a surface course, it can strain an animal's tendons and ligaments. Over time, animals that eat or breathe sand can contract sand colic, a serious illness. Sand should not be used in areas where animals eat or where they spend a lot of time.

Aggregate Components

The previous section covered the different types of aggregate. This section will describe the terms utilized in describing the components of an aggregate surfaced conservation practice. Typically, an aggregate surface conservation practice will consist of a layered system as shown in figure 3. Many sites may not need each component layer, depending on the type of structure, subgrade condition, and anticipated stresses. However, each component should be addressed during the design phase of all aggregate surfaced conservation practices.

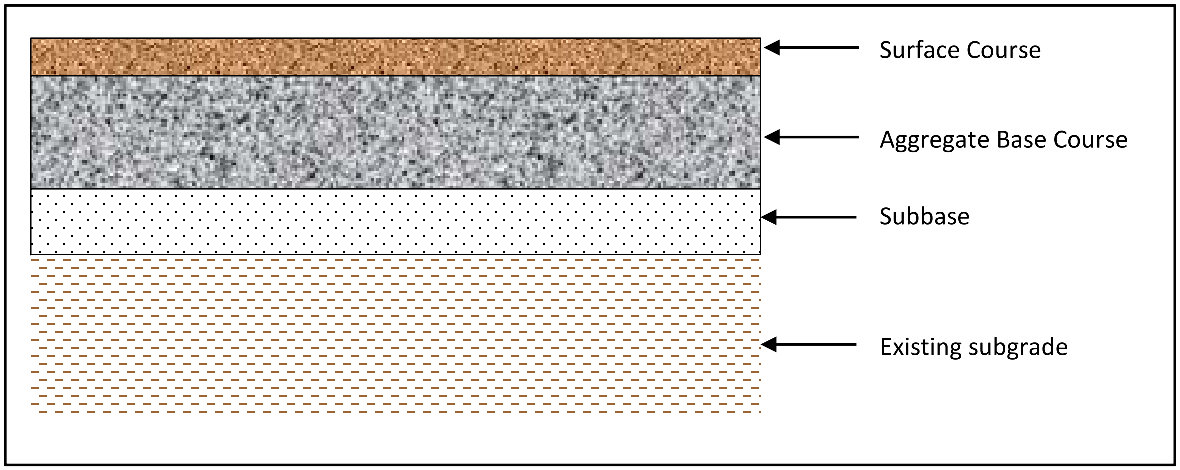

Figure 3 – Aggregate Layer System Components

- Surface Course.—The top layer of applied materials. The surface course carries the traffic load, provides a finished surface for traffic and livestock comfort. The surface should be dust-free and resists erosion from wind or water. Typical surface course material would be well-graded fine rock with fines. Surface course aggregate materials should be well compacted. Table 1 provides guidance on selection of surface materials for attended use.

Table 1: Suitability of Common Surface Materials Depending on Use

	Surface Material	**Access Roads**	**HUAP**	**Stream Crossing**	**Trails and Walkways**
Natural Materials	Native Soil				X
	Wood Chips				X
Aggregate	Crushed Rock with fines	X	X	X	X
	Crushed Rock without fines		X	X	
	Rounded Gravel			X	
	Sand				X
Soil Additives	Soil Additives	X	X		X

- Aggregate Base Course.—A support or stabilizing layer of applied materials. The base course provides the immediate support for the surface course. The design thickness of this layer is dependent on applied stress and bearing capacity of the subgrade. The gradation of aggregate base is filter compatible with the surface course and subgrade.
- Subbase.—A foundation layer placed over the subgrade and below the aggregate base course layer. The subbase typically consists of a compacted granular material that helps transition the aggregate base course to subgrade. The subbase can also be designed as an impervious barrier such as a geomembrane or compacted low permeability soil liner if placing the aggregate pad on porous or highly permeable subgrades. As with aggregate base, subbase is necessary on many aggregate layered systems. The subbase course should be filter compatible with the subgrade. Therefore, the material selection should be based on the intended functions.

- Subgrade. —The in-place material (usually the natural soil). Note that the subgrade is typically scarified to a depth of at least 6 to 12 inches to remove any organic or deleterious materials. The subgrade is the most important part of the aggregated layer system because—
  - *It is the layer on which the remainder of the structure is supported and helps resist the destructive effects of traffic and weather.*
  - *It acts as a construction platform for building subsequent layers.*
  - *If there are any subgrade performance issues due to lack of strength or uniformity, the entire section will have to be removed and replaced to correct the problems* (Minnesota Department of Transportation, 2003).
  - *The subgrade soil type, undrained shear strength and the water table's location within the subgrade will determine the design of the succeeding component layers of aggregate materials.*

Aggregate Surfaced CP Planning and Field Investigation

The following section is presented as a guidance for all aggregate-surfaced conservation practices within NRCS. Some of the information may not apply, depending on the type of project, but the section does provide the designer with information for consideration prior to and during the design. In advance of a site reconnaissance and investigation, preliminary project planning may consist of, but is not limited to, the following:

- Review of subsurface investigations (historical data) at or near the project site
- Review of construction and records of structural performance problems at nearby projects
- Review of U.S. Geological Survey (USGS) maps, reports, publications, and Web sites (https://www.usgs.gov/)
- Review of State geological survey maps, reports, and publications
- Review of the NRCS Web Soil Survey or soil maps (http://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm)

These resources can provide the designer with an indication of the project site conditions. The preliminary information is then enhanced by the subsurface investigation and laboratory testing.

The reconnaissance and investigation should be sufficiently detailed to provide documentation and photographs that reveal issues that will impact the construction and long-term performance of the structure. Although more applicable to dam rehabilitation, Title 210, National Engineering Handbook, Part 631, Sections 631.0203 through 631.0206, does provide a framework for site reconnaissance and investigation. Below are some factors related to aggregate-surfaced CP that that should be considered during the reconnaissance:

- Design and construction plans
    - Project purpose
    - Construction materials
    - Access restrictions for equipment
    - Location of underground and overhead utilities
    - Obstructions
    - Right-of-way constraints
    - Environmental issues
- General site conditions
    - Geologic setting
    - Drainage
    - Precipitation
    - Escarpments, outcrops, erosion features, and surface settlement
    - Flood levels

Any other unusual or unexpected conditions encountered during the investigation should be communicated to the designer as well.

Subsurface Investigation

All CPs covered by this AEN should have some level of subsurface investigation. The designer should also possess a basic understanding of the depth to which the subsurface conditions will influence the design, construction, and performance of the structure. For example, as previously mentioned under *Aggregate Components*, prior to placement of an aggregate surface, the subgrade is typically stripped to a depth of at least 6 to 12 inches to remove any organic or deleterious materials. Consequently, obtaining soil samples and strength measurements within the upper 12 inches may not provide the necessary data for design.

The subgrade investigation should include adequate sampling (disturbed and undisturbed) for the purpose of laboratory classification, determination of natural moisture content and laboratory shear strength testing, if desired.

Subgrade Classification

At a minimum, the subgrade soils should be classified per ASTM D 2488, *Description and Identification of Soils (Visual-Manual Procedure).* Soil samples sent to the NRCS Soil Mechanics Laboratories will also be classified per ASTM D 2487, *Classification of Soils for Engineering Purposes (Unified Soil Classification System*), based upon testing.

If the project is an access road, classifying the subgrade per the American Association of State Highway and Transportation Officials (AASHTO) soil classification system (M145) may also be desirable. Within the AASHTO system, soils with the same general load-carrying capacity and service characteristics are grouped together. Soils are grouped into seven basic groups (A-1 through A-7), as seen in figure 4 below. In general, the best highway subgrade soils are in group A-1 and the poorest in A-7.

General Classification	Granular Materials 35 percent or less of total sample passing No. 200 (75 µm)								Silt-Clay Materials More than 35 percent of total sample passing No. 200 (75 µm)						
Group Classification	A-1		A-3 [1]		A-2				A-4		A-5	A-6		A-7	
	A-1-a	A-1-b	A-3	A-3a	A-2-4	A-2-5	A-2-6	A-2-7	A-4a	A-4b		A-6a	A-6b	A-7-5	A-7-6
Sieve analysis, percent passing:						*				**	*			*	
No. 10 (2 mm)	50 max														
No. 40 (425 µm)	30 max	50 max	51 min	[2]					[3]	[4]					
No. 200 (75 µm)	15 max	25 max	10 max	35 max	35 max	35 max	35 max	35 max	36 min	50 min	36 min	36 min		36 min	
Characteristics of fraction passing No. 40															
Liquid limit	—	—	Non-	—	40 max	41 min	40 max	41 min	40 max		41 min	40 max		41 min	
Plasticity index	6 max	6 max	Plastic	6 max	10 max	10 max	11 min	11 min	10 max		10 max	11 – 15	16 min	$\le$LL-30	>LL-30
Group Index	0						4 max		8 max		12 max	10 max	16 max	20 max	
Usual types of significant constituent materials	Stone fragments, gravel and sand		Fine sand	Sand	Silty or clayey gravel and sand				Silty soils			Clayey soils			
General rating as subgrade	Excellent to good								Good to fair						

Notes

With the test data available, the classification of a soil is found by proceeding from left to right on the chart. The first classification that the test data fits is the correct classification.

* A-2-5 is not allowed under 703.16.B. A-5 and A-7-5 is not allowed under 703.16.A. See "Natural Soil and Natural Granular Soils" (203.02.H) in this manual

** A-4b is not allowed in the top 3 feet (1.0 m) of the embankment under 203.03.A.

[1] The placing of A-3 before A-2 is necessary in the "left to right" process, and does not indicate superiority of A-3 over A-2.

[2] A-3a must contain a minimum 50 percent combined coarse and find sand sizes (passing No. 10 but retained on No. 200, between 2 mm and 75 µm).

[3] A-4a must contain less than 50 percent silt size material (between 75 µm and 5 µm).

[4] A-4b must contain 50 percent or more silt size material (between 75 µm and 5 µm).

Figure 4 – AASHTO Classification System

Subgrade Strengths

Field Tests. —The subgrade shear strength can be obtained in the field using a variety of methods as listed below. The selected method will depend on the subgrade soils' classification and the complexity of the project. Field-derived strength values are also influenced by seasonal changes. That is, the results will vary depending on whether the site is dry or there has been an extended rainy period. Additionally, some of the tools only provide a rough estimation of an earth material's strength; consequently, based upon these factors, a qualified geotechnical engineer should be consulted prior to commencing the site reconnaissance or field investigation.

- Pocket penetrometer or miniature torvane – ASTM D4648
    - Can be used on Shelby tube and density drive cylinder ends as well as on the sides of test pits.
- Corps of Engineers (COE) Static Cone Penetrometer – ASAE S313.3
- COE Dual Mass Dynamic Cone Penetrometer (DCP) – ASTM D6951
- Field Vane Shear (FVS) – ASTM D2573
- Field California Bearing Ratio (CBR) – ASTM D4429
- Standard Penetration Test (SPT) – ASTM D1586
- Cone Penetrometer Test (CPT)ASTM D5778

The SPT will require the use of a drill rig and the CPT and Field CBR test will require specialized equipment in order to perform the tests.

Based upon the field test method utilized, the subgrade's strength can be obtained as indicated below:

- The pocket penetrometer provides a crude estimate of the unconfined compressive strength of the soil in tons per square foot (tsf) for cohesive soils.
- The miniature torvane reads undrained shear strength directly on fully saturated, fine-grained soils, with consistencies from soft to stiff.
- The COE static cone penetrometer provides a cone index (CI) that is related to CBR by the following equation: $\mathrm{CBR} = \frac{\mathrm{CI}}{40}$, or figure 5 can be used to correlate CI to CBR and shear strength.

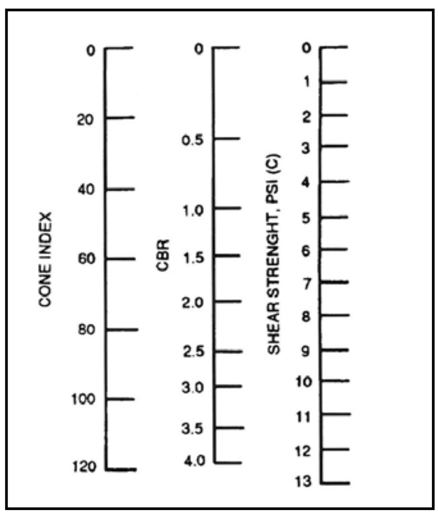

Figure 5 – Relationship Between Shear Strength CBR and Cone Index (U.S. Army, 1995)

- The DCP produces a DCP Index (mm/blow or in./blow) that is correlated to a field CBR by the equations (ASTM D6951) in table 2.

Table 2: DCP Index Relationship to CBR

All soils, except for CL soils below CBR 10 and CH soils	CBR = $292/DCP^{1.12}$ for DCP in mm/blow	CBR = $292/(DCP \times 25.4)^{1.12}$ for DCP in in./blow
CL soils with CBR < 10	CBR = $1/(0.017019 \times DCP)^2$ for DCP in mm/blow	CBR = $1/(0.432283 \times DCP)^2$ for DCP in in./blow
CH soils	CBR = (1/0.002871 X DCP) for DCP in mm/blow	CBR = (1/0.0729233 X DCP) in in./blow

  - The DCP measures a field CBR that does not correlate to the laboratory CBR and is highly influence by the subgrade condition at the time of testing.
- The FVS measures c directly.
  - Applicable to soft to stiff clays, not applicable for sandy or gravelly soils.
  - The device is more precise and measures the in situ strength of the soils versus the miniature torvane.
- The Field CBR measured field CBR directly.
- The SPT measures n values, which then are correlated to friction angle for cohesionless soils and unconfined compressive strength (q_u) for cohesive soils.
  - Note that there is considerable scatter in the data of N_{60} and the corresponding values of q_u such that the average is very large (Terzaghi et al., 1996).
  - Table 3 provides estimates of undrained shear strengths corresponding to N_{60} values.

Table 3: Undrained Shear Strength Estimates

Consistency	Identification Procedure	Undrained Shear Strength (C), Psf	N_{60} (SPT) Blows/Ft.
Very Soft	Thumb penetrates > 1 inch, extruded between fingers	< 250	< 2
Soft	Thumb penetrates 1 inch, molded by light finger pressure	250-500	2-4
Medium	Thumb penetrates 1/4 inch, molded be strong finger pressure	500-1,000	4-8
Stiff	Indented by thumb but not penetrated	1,000-2,000	8-15
Very Stiff	Not Indented by thumb, but indented by thumbnail	2,000-4,000	15-30
Hard	Not Indented by thumbnail, Indented with knife	> 4,000	> 30

- The CPT produces a cone index (c), which when divided by 17 or 18 unless a local correlation has been developed.

Laboratory Testing. —Tests may be performed on undisturbed or remolded samples and can consist of Unconsolidated Undrained (UU) or Unconfined Compressive Strength (UCS) tests to obtain the subgrade shear strength. The UU and UCS samples are obtained from undisturbed sampling methods.

A laboratory CBR test is performed on samples remolded to a specified compactive effort and moisture content. The samples are typically soaked, prior to testing, to provide the most conservative assessment of the materials. Unlike the triaxial shear tests above, the CBR involves applying a circular piston to penetrate material compacted into a mold. The CBR is expressed as the ratio of the unit load on the piston required to penetrate the tests soil at 0.1 in. and 0.2 in. to the unit load required to penetrate a standard material of well-graded crushed stone. Consequently, the CBR test mimics a punching shear failure.

Subgrade Strength Correlations

Strength correlations, based upon soil classification, are available such as that provided as figure 6. It can be seen that the correlated CBR values have a wide range for different soil classification designations. Accordingly, if used for design, the most conservative value should be chosen. The figure also stresses the need for adequate sampling and proper classification of the subgrade. Figures 5 and 6 can also be used as a check for field and laboratory measurements.

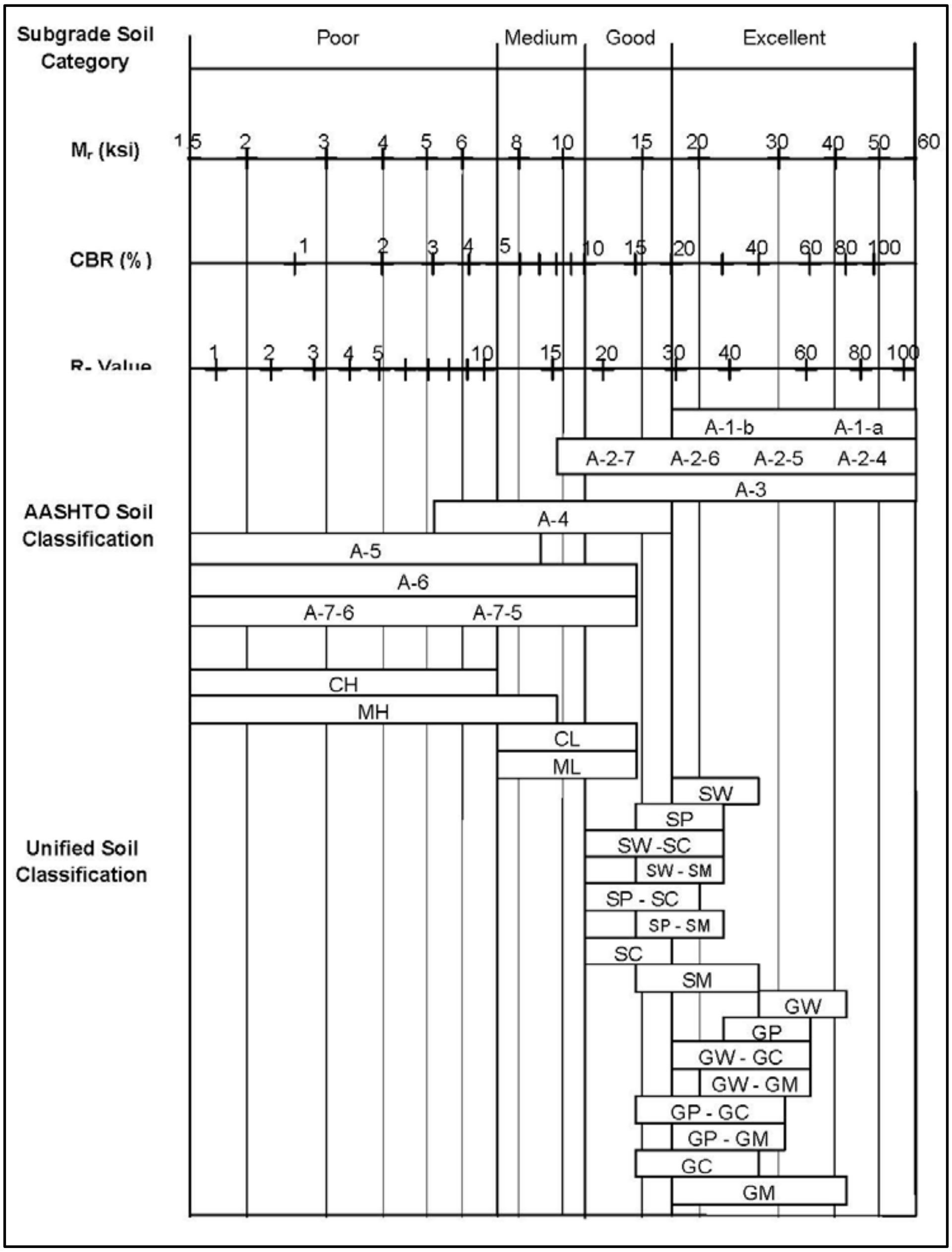

Figure 6 – Correlation of CBR Values With Soil Index (NCHRP, 2001)

Figure 7 is a graph developed by developed by O. James Porter (1942). The CBR values are in terms of percentages since the bearing value is divided by 1,000 psi (0.1 in. penetration) or 1,500 psi (0.2 in. penetration), which represents the bearing value of a crushed rock material. The figure is another quick reference to determine whether materials or the subgrade, based upon classification, are a good or poor base.

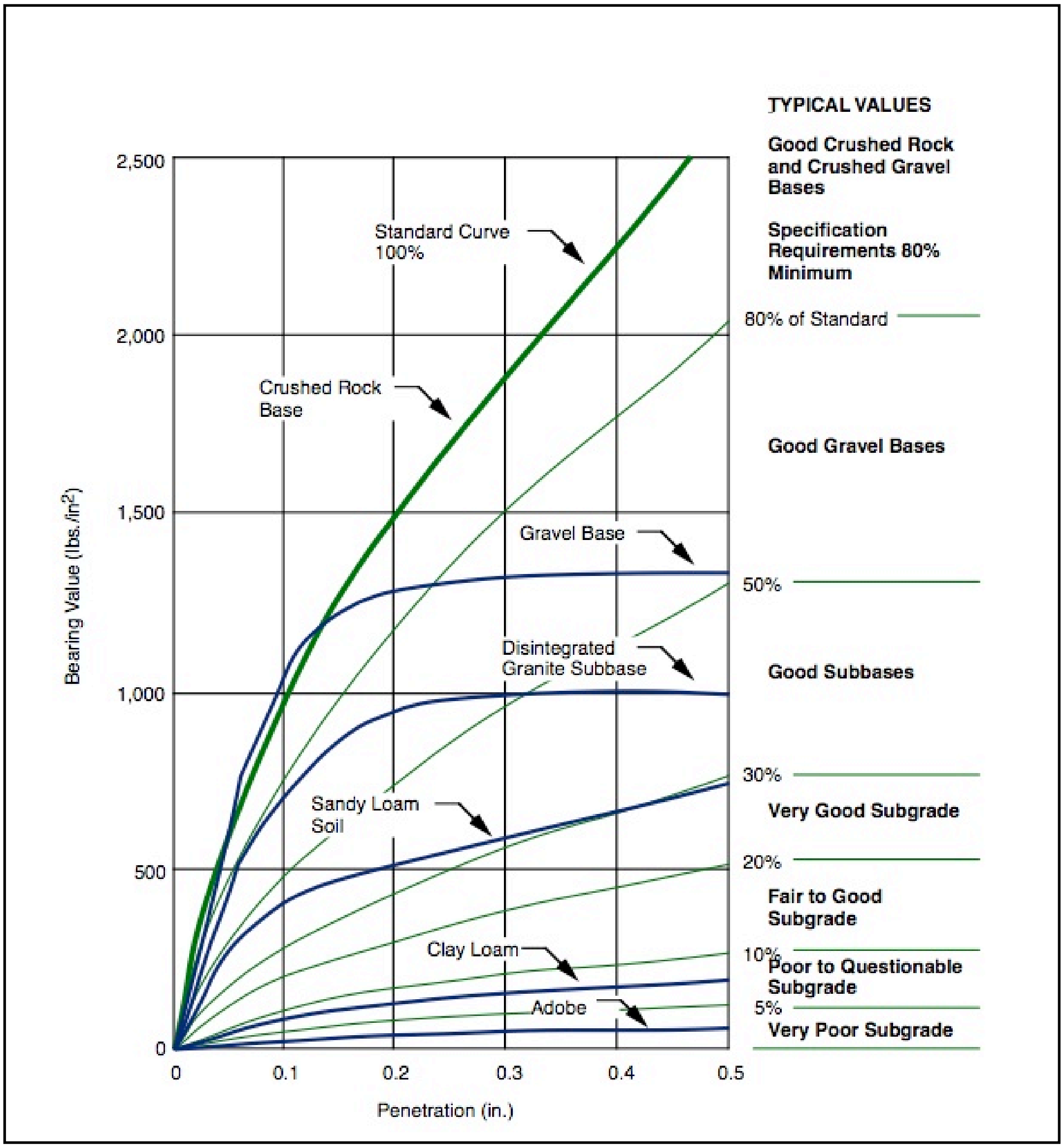

Figure 7 – Typical Bearing Values (psi) Versus Penetration (in.) for Various Materials

Design of Unpaved – Aggregate Access Roads

This section of this design note covers the aggregate thickness and layer design for unpaved access roads.

U.S. Forest Service Low Volume Access Road Design Procedure

The procedure is limited to low-volume, unpaved roads on soft cohesive subgrades and saturated undrained conditions. The aggregate depths should be expected to sustain up to 1,000 equivalent single axle load (ESAL) with less than 2 inches of rutting. One further consideration is that of the aggregate surface material.

The design procedure consists of the following steps:

1. Determine the design loading, typically the maximum axle loading.
2. Determine the subgrade soil strength and convert to an equivalent value of cohesion, C.
3. Select an appropriate value for the bearing capacity factor, Nc. A value of 2.8 is used for unreinforced roads and 5.0 is used for geotextile-reinforced roads. For temporary roads expecting less than 100 vehicle passes, 3.3 and 6.0 may be used for the unreinforced and geotextile-reinforced roads, respectively.
4. Compute the permissible stress (CNc).

   The amount of loading that can be applied without causing the subgrade soil to fail is referred to as permissible stress, (S). For the rapid cyclic loading, the permissible stress is equal to the allowable stress and is defined by its simplified ultimate bearing capacity as described as—

   $$S=q_{ult} = CN_c$$

   Permissible subgrade stress **without a geotextile** is—

   $$S=C(2.8)$$

   Permissible subgrade stress **with a geotextile** is—

   $$S=C(5.0)$$

5. Enter the appropriate design curve (single, dual, or dual tandem load configuration), with design load and permissible stress and determine the required aggregate depth with and without a geotextile.
6. Choose the best alternative, either an aggregate depth with geotextile or an increased aggregate depth without geotextile.

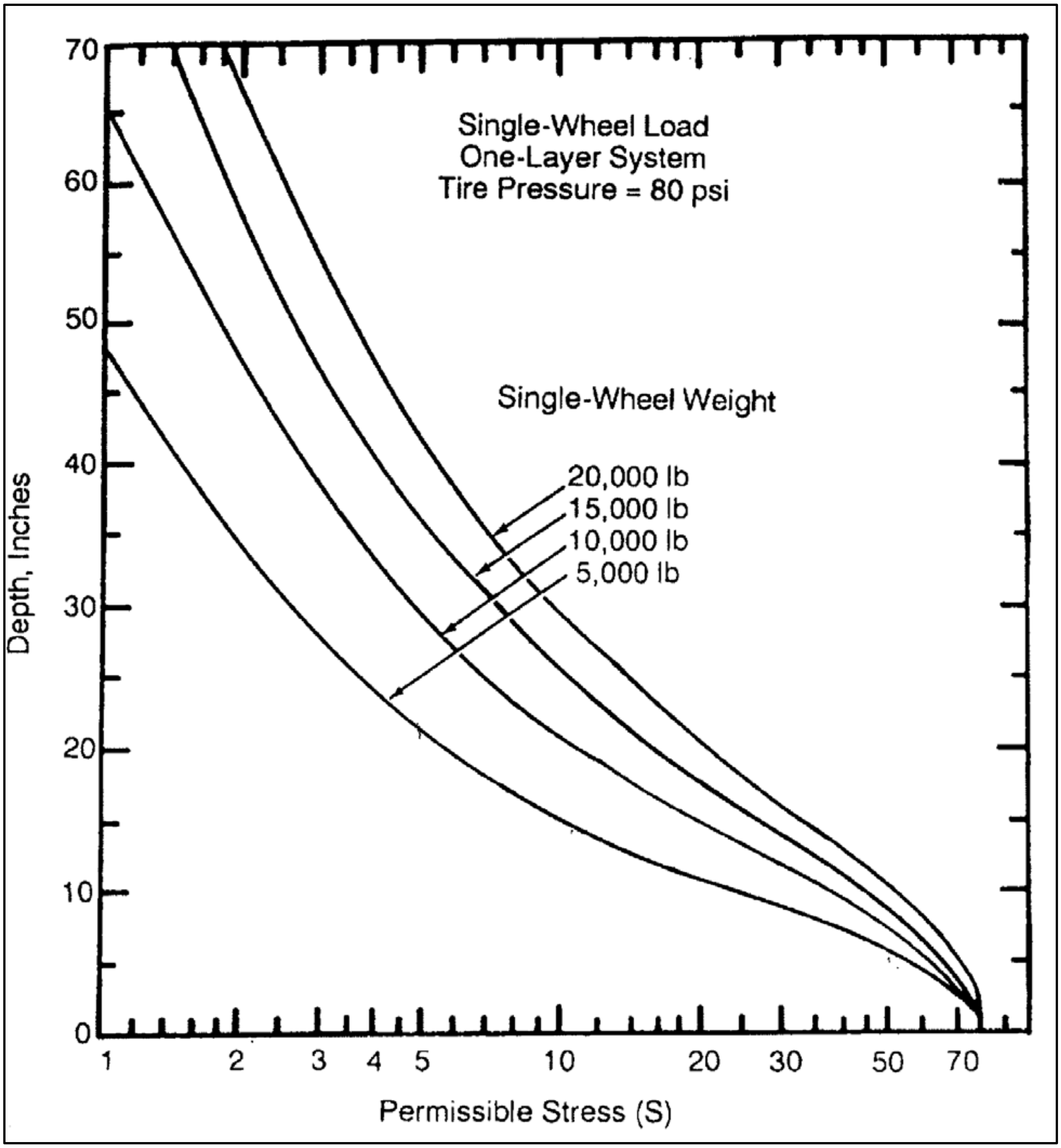

Figure 8 – Single Wheel Load One-Layer System (Stewart et al., 1977)

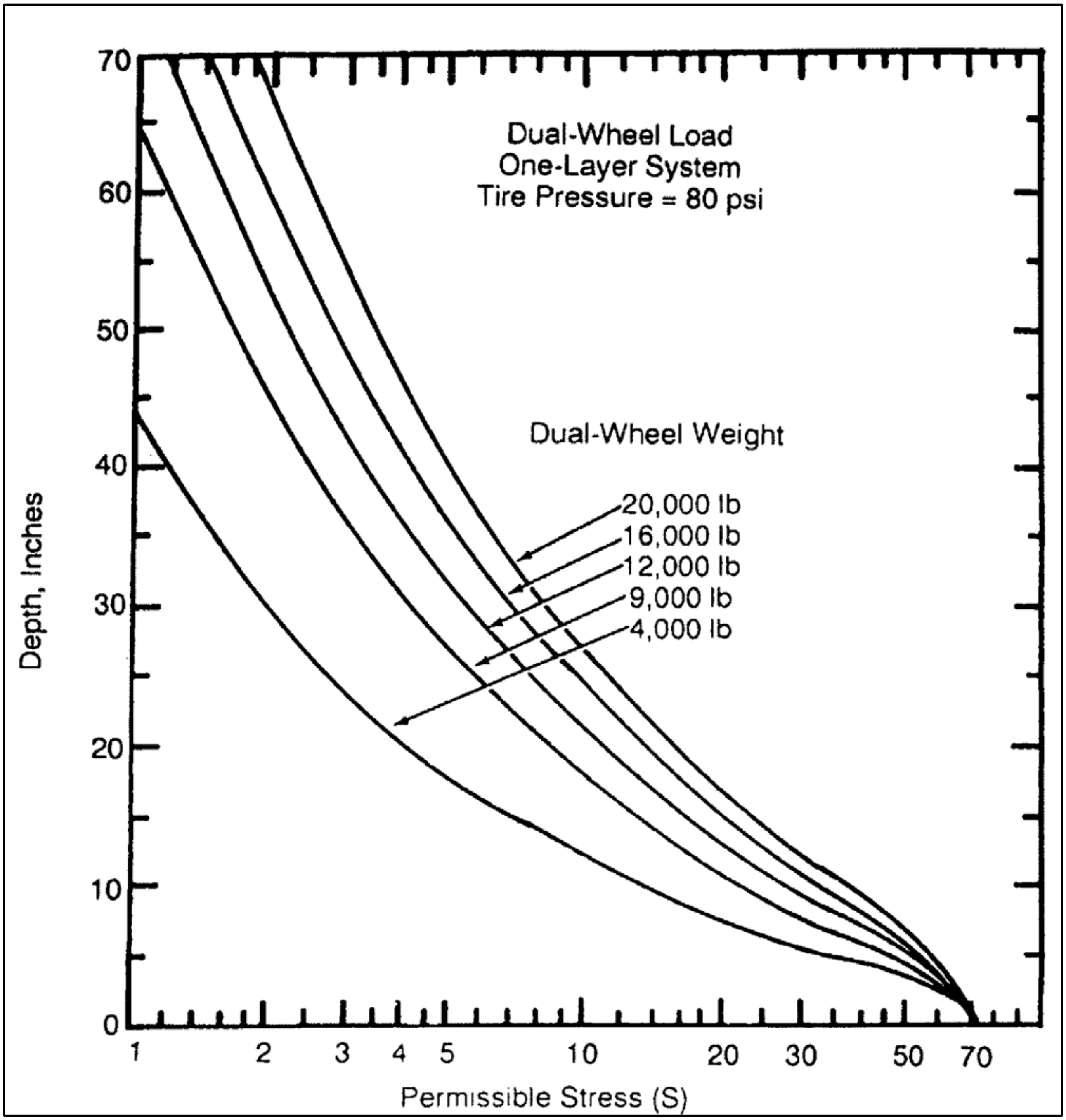

Figure 9 – Dual Wheel Load One-Layer System (Stewart et al., 1977)

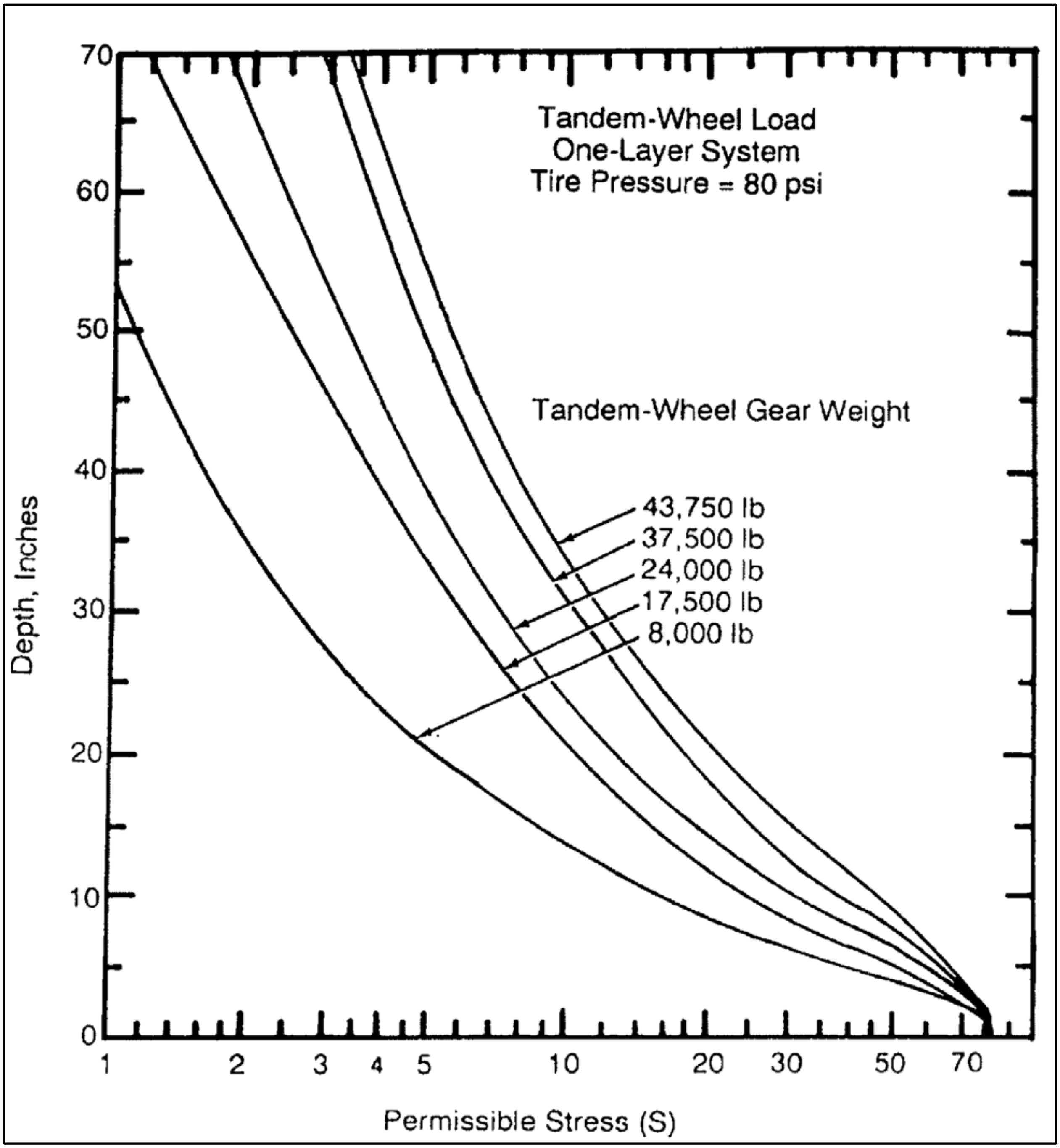

Figure 10 – Tandem Wheel Load One-Layer System (Stewart et al., 1977)

7. Adjust Aggregate-Section Thickness for Aggregate Quality

   The design procedure is based on the assumption that a good quality aggregate (CBR value of 80) is used. If lower-quality aggregate is used, the aggregate section thickness must be adjusted. Table 4 contains typical compacted strength properties of common aggregates. These values are approximations; use more specific data if it is available. Extract the appropriate thickness equivalent factor from table 4 and then divide depth by the factor to determine the adjusted aggregate section thickness.

The values listed in table 4 are general guidelines. More exact thickness equivalency factors can be determined by comparing the CBR of the available aggregate to the design CBR of 80. For example, assume a well-graded aggregate with a CBR of 55 would have an approximate thickness equivalency factor of 55/80=0.69.

Table 4: Typical Compacted Strength Properties of Common Structural Materials

Material	CBR Range	Thickness Equivalency Factor
Crushed hard rock	80-100	1.00
Crushed medium-hard rock	60-80	0.85
Soft rock	20-40	0.45
Shell	40-60	0.75
Well-graded gravel	40-70	0.80
Sand-gravel mixtures	20-50	0.50
Clean Sand	10-30	0.40
Asphalt, concrete plant mix, high stability	>100	3.00
Lime-treated base[1]	>100	1.00-2.00
Cement-treated base[1,2]		
650 psi or higher	>100	1.60
400 psi to 650 psi	>100	1.40
400 or less	>100	1.05

[1] The strength of lime-treated and cement-treated bases depends on soil properties and construction procedures. Treated bases are also subject to long-term failure due to continuing chemical reactions over time.
[2] Compressive strength at 7 days.

8. Adjust Aggregate-Base Thickness for Service Life

   The design method assumes that the pavement will be subjected to 1,000 passes of the maximum design axle load. If the traffic is greater than 1,000 passes, increase H (aggregate thickness) by the following percentages:

   2,000 passes 8%
   5000 passes 19%
   10,000 passes 27%

   If more than 10,000 passes, you need to increase the design thickness by 30 percent and monitor the performance of the road.

Alternative Access Road Design Approach

A more rigorous design approach is available to determine the minimum required aggregate base thickness above the subgrade for wheeled vehicles. The approach utilizes the Boussinesq theory of load distribution. The determination of the soil subgrade strength and estimation of the permissible stress.

1. Determine Wheel Loads, Contact Pressure, and Contact Area
   Estimate wheel loads, contact pressure, and contact-area dimensions from table 5. For geotextile design, single and dual wheels are represented as single wheel loads (L) equal to one-half the axle load. The wheel

load exerted by a single wheel is applied at a surface contact pressure (P) equal to the tire inflation pressure. Dual wheel loads apply a P equal to 75 percent of the tire inflation pressure. Tandem axles exert 20 percent more than their actual weight to the subgrade soil due to overlapping stress from the adjacent axle in the tandem set.

Estimate the area being loaded (B^2) is—

$$B^2=L/P$$

Where B = Length of one side of the square contact area

Table 5: Vehicle Loading Parameters

Vehicle Type (Choose Category Nearest the Actual Design Vehicles)	Axles S - Single T - Tandem	Wheels S - Single D - Dual	Axle Loads (lb)	Wheel Loads[1] (lb)	Typical[2] Tire Inflation Pressure (psi)	Contact Pressure[3] (psi)	Wheel Contact Area B^2 (in^2)	One Side of Square Contact Area B (in)
Highway Legal Vehicles								
Haul trucks[4] - F Axle (stone, concrete)	S	S	18,000	9,000	110	110	82	9
R Axle	T	D	18,000	10,800	110	3	130	11.4
Tractor trailer - F Axle	S	S	18,000	9,000	120	120	75	8.7
(18 wheeler) - R Axle	T	D	18,000	10,800	120	90	120	11
Off Highway Legal Vehicles[5]								
35-ton trucks - F Axle	S	S	48,000	24,000	90	90	267	16.3
(CAT 769C) - R Axle	S	D	89,200	44,600	90	68	656	25.6
Wheel Loader - F Axle	S	S	24,000	12,000	50	50	240	15.5
(CAT 910) - R Axle	S	S	10,000	5,000	50	50	100	10
Wheel Loader - F Axle	S	S	37,000	18,500	60	60	308	17.6
(CAT 930) - R Axle	S	S	14,000	7,000	60	60	117	10.8
Wheel Loader - F Axle	S	S	65,000	32,000	60	60	542	23.3
(CAT 966C) - R Axle	S	S	25,000	12,500	60	60	208	14.4
Wheel Loader - F Axle	S	S	136,000	68,000	85	85	800	28.3
(CAT 988B) - R Axle	S	S	55,000	27,500	85	85	324	18
Wheel Loader - F Axle	S	S	290,000	145,000	70	70	2071	45.5
(CAT 992) - R Axle	S	S	120,000	60,000	60	60	1000	31.6
Scraper - F Axle	S	S	88,600	44,300	80	80	554	23.5
(CAT 31D) - R Axle	S	S	75,400	37,700	75	75	503	22.4
Scraper - F Axle	S	S	120,000	60,000	85	85	706	26.6
(CAT 651B) - R Axle	S	S	110,800	55,400	80	80	692	26.3

NOTES:
1. Wheel load is one-half the axle load and increased by 20% if the wheel is on a tandem axle.
2. Maximum tire inflation pressure is given for each class vehicle. Using tires with low2er inflation pressures would lower the contact pressures and allow for less thickness of the aggregate structural section.
3. Same as tire inflation pressure except that a factor of 0.75 times the inflation pressure must be used for all dual wheels.
4. Trucks used on and off-highway generally use lower inflation pressure tires requiring only 75 to 90 psi.
5. Manufactures' specifications should be consulted for off-highway vehicles. Wide ranges of different inflation pressure tires are available for these vehicles.

2. Determine Aggregate-Base Thickness
Assuming that wheel loads will be applied over a square area, we can use the Boussinesq theory of load distribution to determine the aggregate-section thickness required to support the design load. Boussinesq theory coefficients are found in table 6.

Table 6: Boussinesq Theory Coefficients

If X =	Then M =		If X =	Then M =
0.005	0.10		0.169	0.95
0.011	0.15		0.175	1.00
0.018	0.20		0.186	1.10
0.026	0.25		0.196	1.20
0.037	0.30		0.207	1.35
0.048	0.35		0.215	1.50
0.060	0.40		0.224	1.75
0.072	0.45		0.232	2.00
0.084	0.50		0.237	2.25
0.096	0.55		0.240	2.50
0.107	0.60		0.242	2.75
0.118	0.65		0.244	3.00
0.128	0.70		0.247	4.00
0.138	0.75		0.249	5.00
0.146	0.80		0.249+	7.50
0.155	0.85		0.250	10.00
0.162	0.90		0.250+	oo

a. First, solve for X
   Without a geotextile: X=C(2.8)/(4)P

   With a geotextile: $X_{geotextile}$ = C(5.0)/(4)P

b. Using the calculated values of X and Xgeotextile, find the corresponding value of M and Mgeotextile from table 6.

c. Then solve for aggregate-based thickness (H) without geotextile and (H) with geotextile.

   Without a geotextile: H = B(inches)/(2)M

   With a geotextile: $H_{geotextile}$ = B(inches)/(2)$M_{geotextile}$

1993 AASHTO Low Volume Road Design

The AASHTO's 1993 *Design of Pavement Structures* provides two empirical methods for designing low-volume aggregate-surfaced roads. The first method (appendix A, section 4.1) utilizes the selection of design inputs and nomographs to determine aggregate thickness. The second method (appendix A, section 4.2) utilizes the AASHTO design catalogs to determine aggregate thickness, when more detailed project information is not available.

Note that these methods were developed for a maximum traffic level of 100,000 18-kip ESAL application, with a practical minimum level (during a single performance period) of 10,000. That is to say the AASHTO methods may be overly conservative for many applications within NRCS; however, unlike the preceding methods, the methods accounts for climate, as indicated by appendix A, figure 4.1. The 1993 AASHTO low-volume road design procedure is provided in its entirety as appendix A, along with figures for relative roadbed quality and soil strength.

Design of Heavy-Use Area Protection (HUAP)

This section of this design note covers the stabilization of areas frequently and intensively used by livestock, people and light-weight vehicles or machinery by constructing layers of aggregate materials over subgrade. Aggregate design for access roads and travel lanes planned for heavy equipment should follow procedures under the *Access Roads* section.

HUAP Aggregate Pad Design Procedure

The design of any heavy-use area protection involves an analysis of each of the components of the system, which include the surface course, base course, and subgrade. The system must perform well under anticipated loads under various loading and climate conditions. All heavy-use systems derive their support from the underlying subgrade.

The design procedure is based on both theoretical analysis and empirical (laboratory and field) tests. A certain amount of rutting (< 2 inches) will occur under all traffic conditions, both with and without a geotextile separator.

1. Determine the sites loading conditions including animal type and the type of vehicles.
2. Perform a site reconnaissance and soils investigation, see *Aggregate Surfaced CP Planning and Field Investigation*.
3. Determine subgrade soil strength, see *Aggregate Surfaced CP Planning and Field Investigation*.

   Strength should be evaluated at a depth of 0 to 9 inches and from 9 to 18 inches below the proposed stripping depth. It is recommended that 6 to 10 strength measurements be made at each location to obtain a good average for the design. The subgrade soil strength determinations should be made at several locations where the soils appear to be the weakest. Another approach is to make strength determinations at each of the corners and at every 50-100 feet along the parameter and cross-section of the proposed area to be stabilized for heavy use. This can easily be done with test pits.

4. Stress on the Subgrade Soil

   The amount of loading that can be applied without causing subgrade failure is referred to as permissible stress (S). For the rapid cyclic loading, the permissible stress is a function of the ultimate bearing capacity.

   $$S=q_{ult} = CN_c$$

   - Permissible subgrade stress **without a geotextile** is—

   $$S=C(2.8)$$

   - Permissible subgrade stress **with a geotextile** is—

   $$S=C(5.0)$$

   Permissible stress (S) can also be obtained based upon the subgrade's undrained shear strength as provided in table 7.

Table 7: Permissible Subgrade Stress

Undrained Shear Strength (C), PSF	Permissible Stress (Ult. Bearing Capacity) Without geotextile	Permissible Stress (Ult. Bearing Capacity) With a Geotextile
150	420	750
250	700	1,250
500	1,400	2,500
750	2,100	3,750
1000	2,800	5,000
1500	4,200	7,500
2000	5,600	10,000
3000	8,400	15,000
4000	11,200	20,000

5. Determine aggregate base thickness.

The aggregate base is the support or stabilizing layer of applied materials. The base course provides the immediate support for the surface course. The design thickness of this layer is dependent on applied stress and bearing capacity of the subgrade. The gradation of aggregate base must be compatible with the surface course and subgrade.

The design thickness of aggregate for heavy-use protection can be determined using table 8. This table may be used to compare the cost of aggregate material with and without geotextile. The applied contact pressures for livestock and light vehicles were estimated based on hoof sizes and tire patches. Induced ground pressures from animals were obtained based on walking.

The table was developed based on the assumption the base course material is hard crushed angular rock. Crushed rock, with its angular faces, compacts relatively well. Coarse hard rock used for the aggregate base course should be well-graded with particle size between 2½ to ¾ inches. The base course should be compacted to a CBR of 80 or to about 125 to 135 pcf. This can be accomplished with three or four passes of a crawler tracker or vibratory roller.

Table 8: Aggregate Base Thickness (D) for Heavy-Use Protection Design (HUAP)

		Permissible Stress						
Load Description	**Ground pressure (psi)**	**CNc= 150-250 psf D(in)**	**CNc= 250-400 psf D(in)**	**CNc= 400-575 psf D(in)**	**CNc=575-720 psf D(in)**	**CNc=720-1,300 psf D(in)**	**CNc= 1,300-2,000 psf D(in)**	**CNc >2000 psf D(in)**
Horses/dairy cattle 1,400lbs	50	25	18	15	12	10	8	6
Beef cattle 1200lbs	37.5	20	16	12	10	8	6	6
Swine	25	15	12	10	8	6	6	6
Sheep/goats	14.5	8	6	6	6	6	6	6
Light trucks or farm machinery	GVW<10, 000 lbs	30	24	18	15	12	8	6

HUAP Details

HUAP Components

Coarse aggregate must be well-graded 2½ inches to ¾ inches in size. Fine aggregate can range from ¾-inch to No. 200 sieve size with 10-percent fines or 10 percent passing the #200 sieve. Use a woven or nonwoven needle-punched geotextile fabric with a minimum tensile strength of 180 lbs. and minimum weight of 8 ounces per square yard.

Two-Layer System

HUAPs typically consist of a two layer aggregate pad with a geotextile between the aggregate base course and subgrade, for subgrades with undrained shear strength less than 720 psf. The geotextile will improve the permissible stress or ultimate bearing capacity of the subgrade. Figure 11 provides a detail of a two-layer pad.

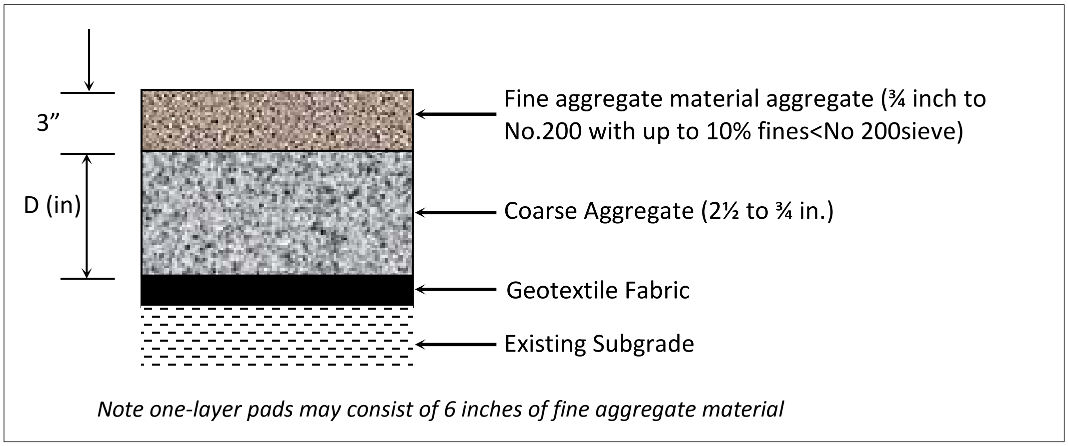

Figure 11 – Details for an Aggregate Pad

Subbase.—In the case of HUAPs, the subbase typically consists of a geotextile or compacted granular material that helps transition the aggregate base course to subgrade. The subbase can also be designed as an impervious barrier such as a geomembrane or compacted low-permeability soil liner if placing the aggregate pad on porous or highly permeable subgrades (see Geosynthetics Under Subgrade Stabilization).

Geotextile placed between the surface course and the subgrade acts as a separator to prevent the subgrade and aggregate base course from mixing and therefore ensure and maintain the desired design required thickness. In addition, geotextiles can provide the additional possible cost and performance increases the ultimate bearing capacity of the systems subgrade by interfering with the incipient bearing capacity failure surface, which forces the failure surface along an alternate surface. This is particular apparent on soft or poor (weak) subgrades with undrained shear strength less than 720 psf for these HUAP systems.

Cover Layer.—The surface course carries the traffic load, provides a finished surface for animal comfort (slip-resistant), and resists water damage. For HUAPs, materials should compact to a firm, slip-resistant surface that can withstand the impact load from animals and farm machinery. Paved surfaces provide little traction for livestock and are expensive.

Fine crushed rock aggregate can be used as a surface course for livestock, vehicle use, and travel lanes. Livestock are more comfortable lying down on crushed rock than on harder surfaces. The standard size for fine crushed rock is 3⁄4-inch-minus.

Crushed rock, when combined with fines and well compacted, generally is preferred for surface courses on heavy-use and livestock areas. This material fits together tightly, offering a stable surface for pedestrians, livestock, and vehicles. Compacted crushed rock with 10 percent fines withstands high use and requires little maintenance. The material provides good traction and dust control if it is well-compacted and the surface hardens well.

One-Layer System

Geotextiles are not required for subgrade reinforcement or separation when the undrained strength, (C), is greater than 720 pcf, which is equivalent to permissible stress or allowable ultimate bearing capacity (S=qult = CNc) of 2,000 psf without geotextile reinforcement. For these stronger subgrades, where the minimum aggregate thickness of 6 inches from table 8 is required, the total thickness can be replaced by one layer, with 6 inches of fine aggregate. Sufficient fines present in the aggregate will promote bonding of the material when compacted.

Design of Trails and Walkways for Animals

This section of this design note covers the stabilization of established lanes for trails or walkways that facilitate animal movement. Surfaces must be considered when developing trails and walkways for animals. Selection of trail surface depends on how well animals walk on a surface, degree of slope and traction, animal foot pressures, wearing ability, comfort, safety, and the distance the animals must travel.

When selecting surface materials, also consider the classification and consistency of the subgrade soils and how well the material will stand up to the major forces that affect the surface life. The subgrade should be analyzed for localized bearing failure under stresses exerted by repeated pressures from livestock and wheel loads or the need for subgrade stabilization. This will prevent deep rutting of the trail surface and supplicate erosion from concentrated runoff. See the *Design of Heavy-Use Area Protection (HUAP)* section to determine the need for base course and geotextile components for stabilization of the subgrade.

When cut and fill operations are performed within the corridor of the tail or walkway. The subgrade consistency, including undrained strength, should be determined at the depth below the elevation of the proposed cut. If the trail surface is to be placed on compacted fill, then the design can be analyze based on the consistency of the compacted fill if it is 2 feet or more. Increases in the degree of compaction of the soil can improve the undrained strength.

All surface materials have advantages and disadvantages. For example, many materials present slipping hazards, especially when they are wet, snowy, or icy. Surface materials selected should be appropriate for the regional climate and the level of development. For animal use, materials should be slip-resistant and able to withstand the impact of animal foot traffic. Table 9 lists the characteristics of common surface materials.

Table 9: Relative Characteristics of Common Surface Materials

	Surface Material	Traction or Slip-Resistance	Durability	Dust Free	Animal Comfort	Maintenance	Displacement
Natural Materials	Native Soil	Variable	Variable	Variable	Good to Excellent	Variable	Variable
	Wood Chips	Fair to good	Poor	Good	Excellent	Moderate	High
Aggregate	Crushed Rock with fines	Excellent	Excellent	Good to Excellent	Good	Low	Low
	Crushed Rock without fines	Good	Excellent	Good	Fair	Low to Moderate	Moderate
	Rounded Gravel	Poor	Excellent	Good	Poor	Moderate	High
	Sand	Good	Good	Poor	Good	Moderate	High
Additives	Soil Additives	Good	Good	Good to Excellent	Good	Low	Moderate

Natural Materials

As with all surface options, natural materials have advantages and disadvantages. Livestock-friendly natural surfaces are attractive and well received by users. On the other hand, these surfaces may be damaged by rain or snow. Some surfaces, such as loose shale, round tree needles, damp moss, or moist vegetation, offer poor traction, posing slipping hazards for all stock animals.

Native Soils

Native soils may vary, particularly if the trail or walkway is relatively long. Soils that are coarsely textured with high percentages of gravel and sand can be very good surface materials for trails and walkways. Fine-grained textured soils, those with a higher percentage of organic matter, silt, and clay tend to be poor surface materials. Trails and walkways and any other type of traffic areas surfaced with native soils are generally difficult to maintain and can become muddy. Hoofs, boots, and tires can damage the trail in wet or boggy areas. When these areas dry out, the ruts may make the area difficult to use. Some native soils also produce a lot of dust, an issue of special concern in urban areas and near residences. Unhealthy dust conditions may require abatement measures. Native Soils may be economical, but they may require frequent maintenance, reducing their overall cost effectiveness. Another option would be to stabilize native soils through mechanical compaction with or without a soil additive (stabilizer) utilizing construction equipment.

Wood Chips

Wood chips cushion the impact of hoofs on soils, and most stock are comfortable walking or lying on them. Consider using wood chips about 2 by 2 by 1⁄2 inches (51 by 51 by 13 millimeters) on animal trails. Wood chips from hardwood will last longer than chips from softwood trees. Wood chips will require more maintenance than other materials. They absorb water and eventually decompose and become embedded in the soil subgrade. Heavy rainfall can wash the chips away unless they are contained with edging. Wet wood chips can be slick, making them less desirable in regions that have steep grades or heavy use. Wood chips easily erode, harbor insects, retain unwanted moisture, and reduce accessibility. Chips with protruding knots can very uncomfortable and possibly cause injury to animals. Don’t use chips from trees that are toxic to animals.

Crushed Gravel and Crushed Stone

Crushed rock, when combined with fines and well compacted, generally is preferred for surface courses on trails, roads, and heavy-use areas. This material fits together tightly, offering a stable surface for pedestrians, stock, and vehicles. Compacted crushed rock with fines withstands high use and requires little maintenance. The material provides good traction and drainage. If it is well compacted and the surface hardens well, it is not dusty. The standard size for crushed material is 3⁄4-inch-minus (less than about 19.1 millimeters), which includes rocks about ¾ inch in diameter and smaller.

Design of Stream Crossings

This section of this design note covers the aggregate thickness, component layering, and rock size design for the stabilization of streambeds or waterways for access and crossings. This section is for typical stream access (ford) crossings and approaches for stock animals, people and light-weight vehicles and machinery. Aggregate design for access roads and travel lanes planned for heavy equipment should follow procedures under the *Design of Unpaved-Aggregate Access Roads* section. CPS Stream Crossing (Code 578) provides criteria on the side slopes, width and stream approaches for the design.

A major concern with aggregate layered stream crossings is the contamination of the aggregate with the underlying soft fine-grained or loose sandy subgrade soils within the stream bed and the entrance and exit approaches. Contamination can occur due to the following processes:

- Penetration of the aggregate into the weak subgrade due to localized bearing capacity failure under stresses exerted by repeated stresses by animals and wheel loads
- Intrusion of fine-grained soils into the aggregate because of pumping or subgrade weakening due to excess pore water pressure buildup

Geotextiles can provide cost and performance benefits for most soils. Geotextile fabric may be omitted from the streambed and the entrance and exit approaches only if stable gravel or cobble is present.

- Prevents the subgrade fines from pumping into the base course aggregate
- Increases the ultimate bearing capacity of the subgrade by forcing the failure surface along an alternate surface

An additional concern is sizing the aggregate to prevent the aggregate materials from washing and being transported downstream during a bank full flood event. Therefore D_{50} aggregate size and gradation must be determined based on the stream channel bank full flow velocity.

Perform a Site Reconnaissance and Investigation

Site reconnaissance provides insight on potential construction and design problems. Stream crossings should be located in straight sections where the stream bed is stable or where grade control can be provided to create stability. Avoid locations such as bends, abrupt changes in channel grade, areas of excessive bank seepage, confluences of tributaries, or areas that are directly upstream or downstream of a bridge or culvert. Consideration should be made in locating the entrance and exit where banks are stable and where trees will not need to be removed.

All stream crossing structures foundations (subgrade) should be evaluated for soil moisture, plasticity, texture and undrained shear strength in combination with the design load and anticipated frequency of use. The subgrade underlying these structures will be saturated due to high water levels. Therefore, the saturated soil consistency parameters along with the undrained shear strength will be used to determine the bearing capacity of the subgrade and depth of aggregate needed along with the need for a subbase or geotextile.

Subgrade Soil Strength

See *Aggregate Surfaced CP Planning and Field Investigation* section for methods in determining subgrade strength. Undrained shear strength can be estimated from Table 3: Undrained Shear Strength Estimates. Strength should be evaluated at a depths of 0 to 18 inches below the proposed bottom elevation of the aggregate layered structure. It is recommended that 6 to 10 strength measurements be made at each location to obtain a good average for the design. The subgrade will likely be saturated and contain a high water table; therefore, digging test pits may be difficult with this practice.

Stream Crossing Design procedure

The design procedure consists of the following steps:

1. Perform a site reconnaissance and investigation and determine the design loading, typically including animal type and the type of vehicles.
2. Determine the subgrade soil undrained shear strength and convert to an equivalent value of cohesion, C, using soil consistency correlations from Table 3: Undrained Shear Strength Estimates or measure the undrained shear strength of the subgrade directly using field or laboratory tests.
3. Selecting an appropriate value for the bearing capacity factor, Nc. Saturated streambeds soils should include a geotextile as a separator. Therefore, use Nc =5.0 to compute the permissible stress (ultimate bearing capacity) of the subgrade.
4. Compute the permissible stress (CNc) as shown below or use Table 7: Permissible Subgrade Stress.

   The amount of loading that can be applied without causing subgrade failure is referred to as permissible stress (S). For the rapid cyclic loading, the permissible stress is a function of the ultimate bearing capacity.

   $$S = q_{ult} = CN_c$$

   Geotextiles are required on all steam bed soil subgrade and the entrance and exit approaches unless stable rock, gravel, or cobble is present. The permissible subgrade stress with a geotextile can be estimated with this equation or by table 7:

   $$S = C(5.0)$$

5. Enter the Table 8: Aggregate Base Thickness (D) for Heavy-Use Protection Design (HUAP) with design load and permissible stress and determine the required aggregate thickness.

   The table was developed based on the assumption the base course material is hard crushed angular rock. The applied contact pressures for livestock and light vehicles were estimated based on hoof sizes and tire patches. Induced ground pressures from livestock were obtained based on walking.

6. Obtain the aggregate D_{50} size from figure 12 to prevent the washing and movement of the aggregate. Median particle size (D_{50}) for stream crossing aggregate is based on bankfull slope and bankfull flow depth. The D_{50} indicates that 50 percent of the particles in the base layer are of specified size and larger. The minimum aggregate base course thickness for stream crossings is the greater of 6 inches or the thickness obtained in table 8 or twice the D_{50} rock size obtained from figure 12.

   The aggregate gradation should be well graded and well compacted. Well-graded aggregate fits together tightly, offering an erosion resistant and stable surface for pedestrians, stock, and vehicles. The base course should be compacted to a CBR of 80 or to about 125 to 135 pcf. This can be accomplished with 3-4 passes of a crawler tracker or vibratory roller.

Stream Crossing Notes

A geotextile must be placed between the base course and the subgrade acts as a separator to prevent the stream bed subgrade and aggregate base course from mixing and therefore ensure and maintain the desired design required thickness. In addition, geotextiles can increase the ultimate bearing capacity of the systems subgrade by interfering with the incipient bearing capacity failure surface, which forces the failure surface along an alternate surface. This is particularly apparent on soft or poor (weak) subgrades with low undrained shear strength. Geotextiles are required on all steam bed soil subgrade and the entrance and exit approaches unless stable rock, gravel, or cobble is present.

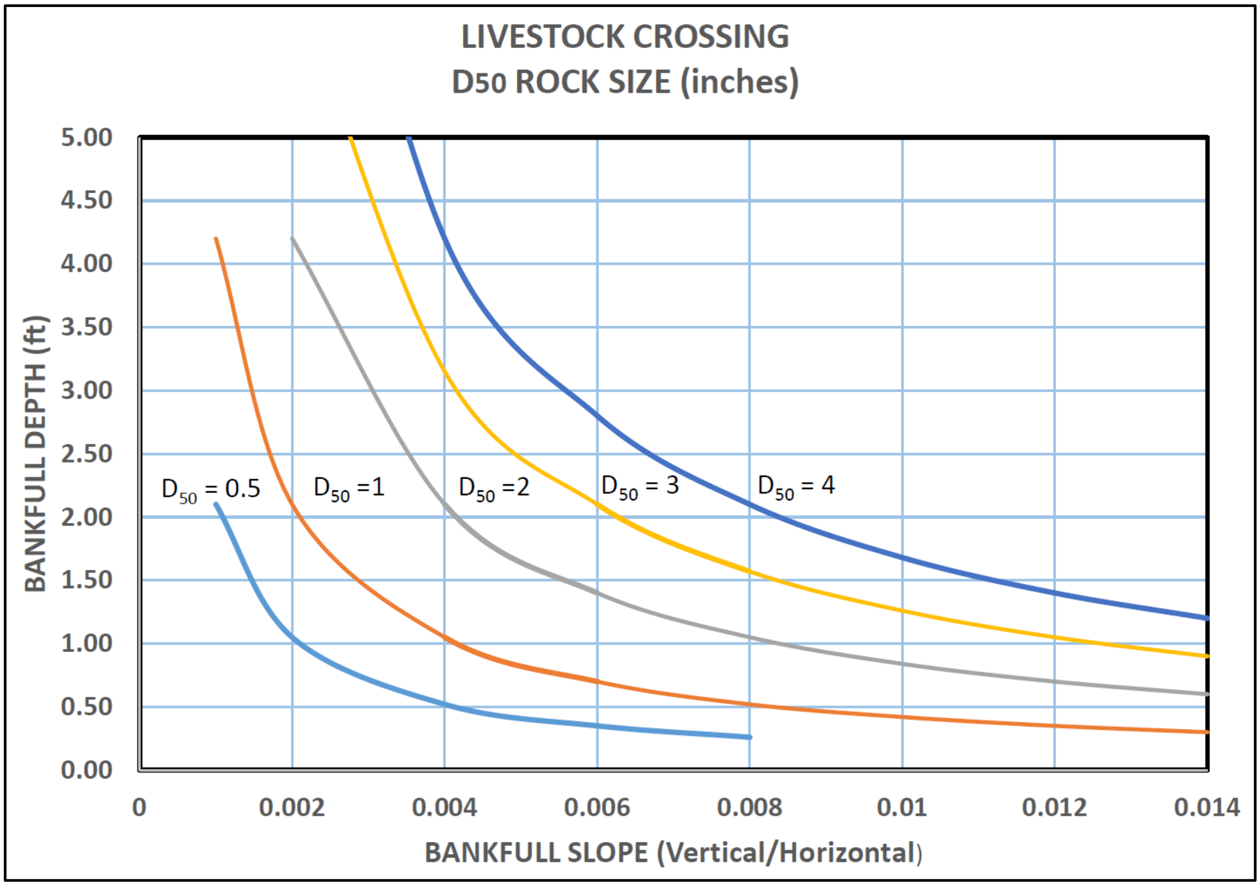

Figure 12 – D50 Rock Size

Subgrade Stabilization

The major concern with any of the aggregate surfaced CP is the contamination of the aggregate with underlying soft subgrade soils. Contamination can occur due to the following processes:

- Penetration of the aggregate into the weak subgrade due to localized bearing capacity failure under stresses exerted by repeated stresses.
- Intrusion of fine-grained soils into the aggregate because of pumping or subgrade weakening due to excess pore water pressure buildup.

The loss of aggregate thickness, from subgrade weakening, can result in inadequate performance and structural support of the structure. Subgrade stabilization problems most often occur at sites with fine-grained soils that have a low undrained shear strength due to a high water table or topography that yields low spots along the alignment (access road) or within the construction limits of other practices. Organic soils (OL, OH, and Peat) have very low undrained shear strength along with other concerns and should be avoided, if possible. If a conservation practice is needed over an organic soil subgrade, construction methods and each component of the design needs to be sufficiently addressed.

Once the subgrade has been scarified and prior to construction, proofrolling of the site might be considered. Proofrolling can be accomplished with a heavily loaded dump truck or similarly loaded vehicle. The entire area of proposed construction should is covered during the proofroll. The proofroll will densify the near-surface soils and help identify low-strength areas.

Remove and Replace

If low-strength soils are encountered along the alignment or within the construction limits and borrow materials are available, then removing the soils of concern and replacing them may be a viable alternative. Note that this is removal in addition to the recommended scarifying or stripping of the surface prior to construction.

Additives to be used as soil stabilizers can be mixed into the existing soil structure of the subgrade to improve the soil's engineering characteristics for stabilization and leave them looking natural. Traditional additives used to stabilize a subgrade or earthfill are lime, cement, and fly ash. When mixed into a soil, these additives generally rely on pozzolanic reactions and/or cation exchange to modify or stabilize the soil. Prior to selecting a stabilization method, work with a qualified soil mechanics laboratory to determine the most appropriate stabilization methods for the project site.

Geosynthetics

Installing a geotextile fabric can increase the bearing capacity of a soil by a factor of two or more. If installed correctly, the fabric can also minimize filter incompatibilities between the subgrade and base course. Geosynthetics can provide the cost and performance benefits below, particularly on soft subgrades with weak undrained shear strength. Geotextile fabrics can perform the following functions when used with aggregate-surfaced CPs:

- Acts as a filter to prevent fines from migrating into the aggregate due to high water pressures
- Prevents the subgrade fines from pumping into the base course aggregate
- Increases the ultimate bearing capacity of the subgrade by forcing the failure surface along an alternate surface

Designers should be aware that there are many types of geosynthetics: geotextile fabric, geogrids, geomembranes, etc. Each of these products has different characteristics. For example, although the geotextile fabric is a good filter medium between the base course and subgrade, in general it is relatively flexible compared to a geogrid. A geogrid is a rigid geosynthetic member that increases the strength of aggregate by providing confinement.

Although references to the use of geotextile fabric was provided under *Design of Unpaved-Aggregate Access Roads*, a comprehensive geosynthetic design is beyond the scope of this engineering note. The design and selection of geosynthetic materials is found in *NRCS Design Note 24, Guide for the Use of Geotextiles*. Another good reference for the selection of geosynthetics is the *Specifier's Guide* published annually by GeoSynthetics. The guide provides the physical properties of geotextiles, geomembranes, geogrids, GCLs, geocells, etc.

Lime Stabilization

Lime can be mixed into the soil to change index properties of the soil as well as improving the undrained shear strength of the soil. Lime has been found to react successfully with medium- and high-plastic, moderately fine and fine-gained soil, causing a decrease in plasticity and swell potential of expansive soils as well as an increase in their workability and strength properties. Research and experience has proven that lime may be an effective stabilizer in soils with clay content as low as 7 percent and in soils with plasticity indices (PI) greater than 10.

Cement Stabilization

Cement can be mixed into a soil or aggregate to harden and strengthen the surface layer. Cement stabilization is ideally suited for well-graded aggregates, gravels, and sands with a sufficient amount of fines to effectively fill the available void spaces and separate the coarse aggregate particles.

The general guidelines for identifying soils that are suitable for cement stabilization based on general classification and index properties are as follows:

- For stabilizing sandy soils with cement, the PI should be less than 30.
- For fine-grained soils with more than 50 percent by dry weight passing the #200 sieve, the general consistency guideline are the PI should be less than 20 and the liquid limit (LL) should be less than 40 in order to ensure proper mixing.
- A more specific general guideline based on the fines content is given in the equation below, which defines the upper limit of PI for selecting soil for cement stabilization for sandy and fine-grain soils.

$$\text{PI} \leq 20 + \frac{50-(\%\ smaller\ than\ \#200\ sieve)}{4}$$

- Cement is appropriate to stabilize gravel soils with not more than 45 percent retained on the #4 sieve. The Federal Highway Administration recommends the use of cement in materials with less than 35 percent passing #200 sieve and a PI of less than 20.

Fly Ash

A wide range of soils and aggregates can be suitably stabilized with addition of fly ash. Fly ash can be classified into two groups: class C and class F. Class C fly ash is a byproduct of burning lignite or sub-bituminous coal in power plants. Class C refers to as a self-cementing or cementitious fly ash that has enough available calcium to react with soil in the presence of water. Most of the calcium in class C fly ash is combined with the silica and/or alumina, so that when water is added, a hydration reaction similar to cement occurs. Free lime is produced in the hydration process, as it is in the hydration of cement. This free lime can participate in the pozzolanic reaction process between silica and/or alumina released from clay or silica and/or alumina from the fly ash, which are not combined with calcium.

Class-F fly ash or low-lime ash is a pure pozzolan and contains a low concentration of available calcium. Therefore, stabilization of soils with class-F fly ash requires the use of an activator like lime or cement to initiate the hardening processes. Low-lime ash or class-F fly ash is formed during burning of anthracite or bituminous coal.

Either class-C or class-F fly ash with activator (lime or cement) can be used to stabilize fine-grained, moderately plastic soils. The basis for stabilization is free lime that becomes available upon hydration of the ash, producing cementitious products that can react pozzolanically with the clay that stabilize the soil. This reaction reduces clay particle plasticity and improves the strength and workability of the soil.

Fly ash can be used effectively to stabilize coarse-grained soils with little or no fines. In coarser materials (sands, gravels, and crushed rock aggregates), fly ash generally acts as a pozzolan and/or filler to reduce the void spaces among larger-sized aggregate particles to separate and support the coarse aggregate particles. After the appropriate amount of fly ash is added to coarse-grained soils to fill the voids and optimize density, an activator can be used to maximize the pozzolanic reaction in the mixture.

Techniques for Additive Selection for Stabilization

The selection of soil additives or stabilizers for a given soil is generally based on the soil classification. A simple and accepted methodology by which to select the appropriate stabilizer is the Soil Stabilization Index System (SSIS). The method was developed by the U.S. Air Force and is based on soil index properties: PI and percent passing the No. 200 sieve. These laboratory tests can be easily performed and are necessary to correlate engineering properties of the soil, for example undrained shear strength, and to determine the most effective additive for use as a stabilizer. Figures 13 (for soils) and 14 (for base materials) use these two index properties, PI and percent passing the No. 200 sieve, to identify the appropriate stabilizer. These figures have been adjusted slightly based on experience and testing conducted by the NRCS soil mechanics laboratories. Once the stabilizer is selected, detailed laboratory tests to determine strength and performance characteristics of soils are required. Individual test methods required for mix designs for the three traditional stabilizers to determine percentage of the additive will also be required.

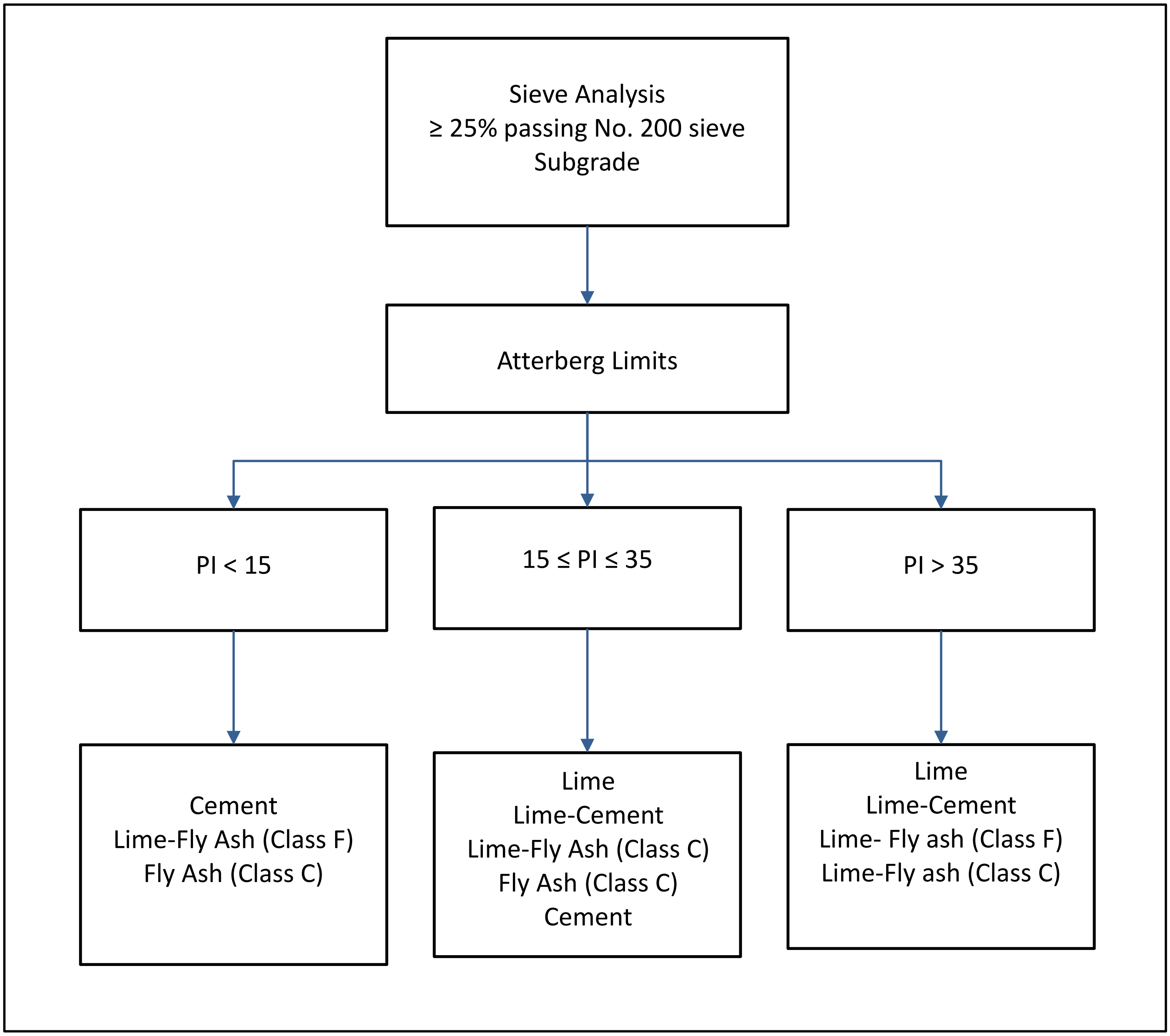

Figure 13 – Decision Tree for Additive Selection for Stabilization of Subgrade

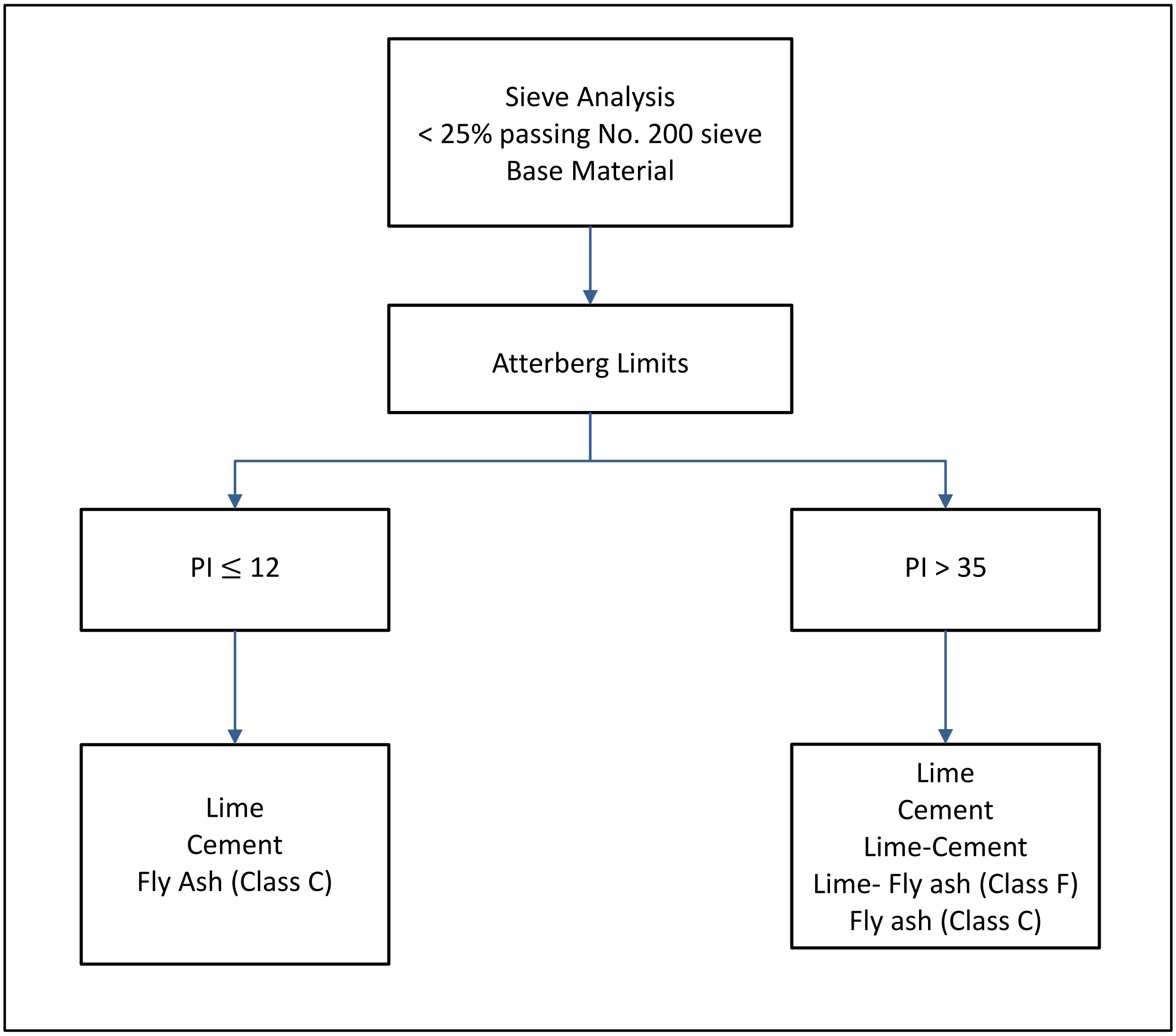

Figure 14 – Decision Tree for Additive Selection for Stabilization of Subgrade

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Appendix A

CHAPTER 4
LOW-VOLUME ROAD DESIGN

Pavement structural design for low-volume roads is divided into three categories:

(1) flexible pavements,
(2) rigid pavements, and
(3) aggregate-surfaced roads.

This chapter covers the design of low-volume roads for these three surface types using procedures based on design charts (nomographs) and design catalogs. These two procedures are covered in Sections 4.1 and 4.2, respectively. For surface treatment or chip seal pavement structures, the procedures for flexible pavements may be used.

Because the primary basis for all rational pavement performance prediction methods is cumulative heavy axle load applications, it is necessary in this Guide to use the 18-kip equivalent single axle load (ESAL) design approach for low-volume roads, regardless of how low the traffic level is or what the distribution is between automobiles and trucks.

Since many city streets and county roads that fall under the low-volume category may still carry significant levels of truck traffic, the maximum number of 18-kip ESAL applications considered for flexible and rigid pavement design is 700,000 to 1 million. The practical minimum traffic level that can be considered for any flexible or rigid pavement during a given performance period is about 50,000 18-kip ESAL applications. For the aggregate-surfaced (gravel) roads used for many county and forest roads, the maximum traffic level considered is 100,000 18-kip ESAL applications, while the practical minimum level (during a single performance period) is 10,000.

4.1 DESIGN CHART PROCEDURES

4.1.1 Flexible and Rigid Pavements

The low-volume road design chart procedures for flexible and rigid pavements are basically the same as those for highway pavement design. The low-volume road procedure basically relies on the set of design requirements (developed in Chapter 2) as well as the basic step-by-step procedures described in Chapter 3. The primary difference in the design for low-volume roads is the level of reliability that may be used. Because of their relative low usage and the associated low level of risk, the level of reliability recommended for low-volume road design is 50 percent. The user may, however, design for higher levels of 60 to 80 percent, depending on the actual projected level of traffic and the feasibility of rehabilitation, importance of corridor, etc.

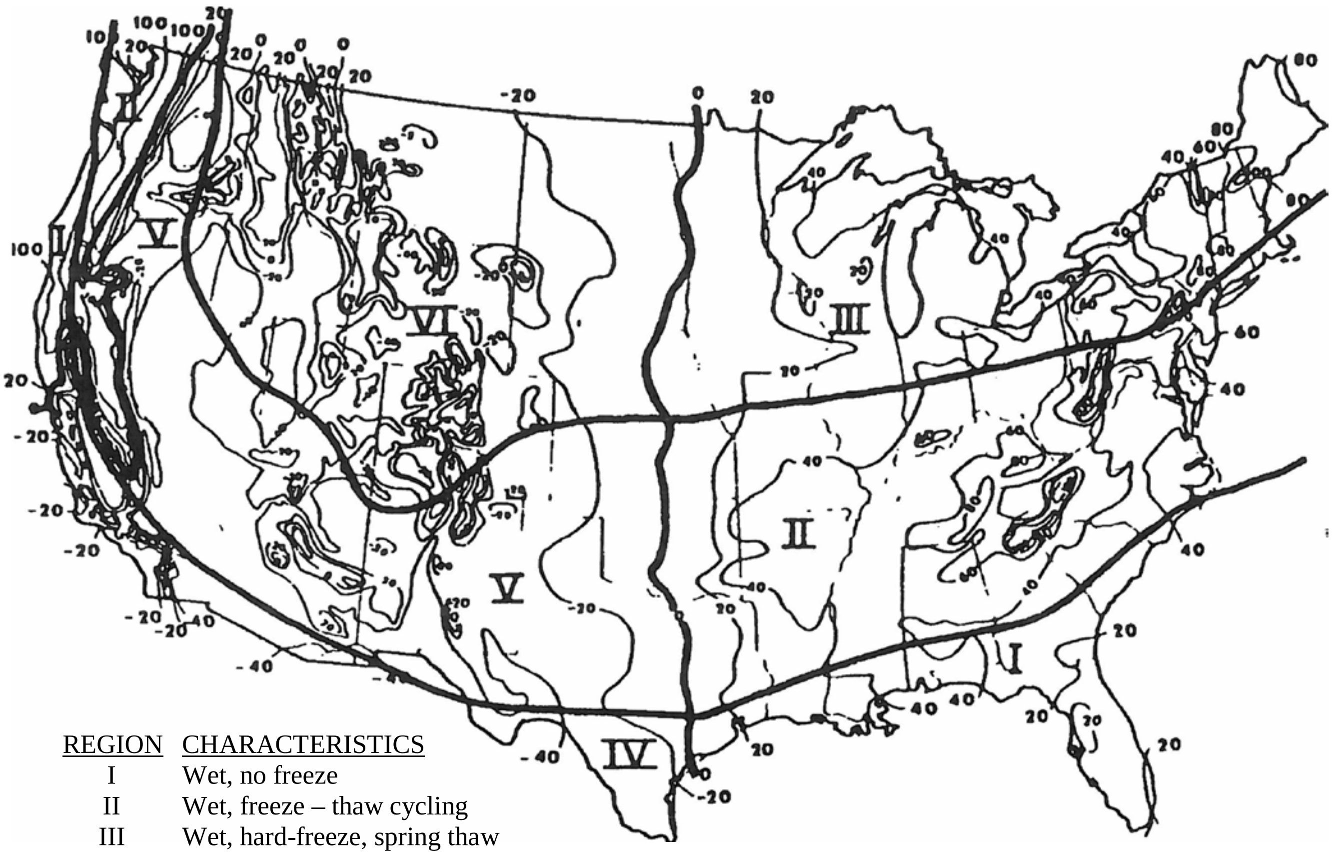
If, in estimating an effective resilient modulus of the roadbed material (M_R) or an effective modulus of subgrade reaction (k), it is not possible to determine the lengths of the seasons or even the seasonal roadbed soil resilient moduli, the following suggestions should be considered.

Season Lengths. Figure 4.1 provides a map showing six different climatic regions of the United States and the environmental characteristics associated with each. Based on these regional characteristics, Table 4.1 may be used to define the season lengths needed for determining the effective roadbed soil resilient modulus (Section 2.3.1) for flexible pavement design or the effective modulus of subgrade reaction (Section 3.2.1) for rigid pavement design.

Seasonal Roadbed Soil Resilient Moduli. Table 4. 2 provides roadbed soil resilient modulus values that may be used for low-volume road design if the user can classify the general quality of the roadbed material as a foundation for the pavement structure. If the suggested values in this table are combined with the suggested season lengths identified in the previous section, effective roadbed soil resilient modulus values (for flexible pavement design only) can be generated for each of the six U S climatic regions. These M_R values are presented in Table 4. 3.

4.1.2 Aggregate-Surfaced Roads

The basis for treating the effects of seasonal moisture changes on roadbed soil resilient modulus, M_R, is



REGION	CHARACTERISTICS
I	Wet, no freeze
II	Wet, freeze – thaw cycling
III	Wet, hard-freeze, spring thaw
IV	Dry, no freeze
V	Dry, freeze – thaw cycling
VI	Dry, hard-freeze, spring thaw

Figure 4.1. The Six Climatic Regions in the United States (12)

Table 4.1. Suggested Seasons Length (Months) for the Six U.S. Climatic Regions

U.S. Climate Region	Season (Roadbed Soil Moisture Condition)			
	Winter (Roadbed Frozen)	Spring-Thaw (Roadbed Saturated)	Spring/Fall (Roadbed Wet)	Summer (Roadbed Dry)
I	0.0*	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

*Number of months for the season

Table 4.2. Suggested Seasonal Roadbed Soil Resilient Moduli, MR (psi), as a Function of the Relative Quality of the Roadbed Material

Relative Quality of Roadbed Soil	Season (Roadbed Soil Moisture Condition)			
	Winter (Roadbed Frozen)	Spring-Thaw (Roadbed Saturated)	Spring/Fall (Roadbed Wet)	Summer (Roadbed Dry)
Very Good	20,000*	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

*Values shown are Resilient Modulus in psi

Table 4.3. Effective Roadbed Soil Resilient Modulus Values, M_R (psi), That May be Used in the Design of Flexible Pavements for Low-Volume Roads. Suggested values depend on the U.S. climatic region and the relative quality of the roadbed soil.

U.S. Climatic Region	Relative Quality of Roadbed Soil				
	Very Poor	Poor	Fair	Good	Very Good
I	2,800*	3,700	5,000	6,800	9,500
II	2,700	3,400	4,500	5,500	7,300
III	2,700	3,000	4,000	4,400	5,700
IV	3,200	4,100	5,600	7,900	11,700
V	3,100	3,700	5,000	6,000	8,200
VI	2,800	3,100	4,100	4,500	5,700

*Effective Resilient Modulus in psi

the same for aggregate-surfaced road design as it is for flexible or rigid pavement design. Unlike the flexible or rigid design procedures, however, the design chart-based procedure for aggregate-surfaced roads requires a graphical solution. It is important to note that the effective modulus of the roadbed soil developed for flexible pavement design should *not* be used in lieu of the procedure described here.

The primary design requirements for aggregate-surfaced roads *(17)* include

(1) the predicted future traffic, w_{18} (Section 2.1.2), for the period,
(2) the lengths of the seasons (Section 2.3.1; or criteria in Section 4.1.1 may be used if better information is not available),
(3) seasonal resilient moduli of the roadbed soil (Section 2.3.1 or general criteria in Section 4.1.1 may be used if better information is not available),
(4) elastic modulus, E_{BS} (psi), of aggregate base layer (Section 2.3.3),
(5) elastic modulus, E_{BS} (psi), of aggregate subbase layer (Section 2.3.3),
(6) design serviceability loss, Δ PSI (Section 2.2.1),
(7) allowable rutting, RD (inches), in surface layer (Section 2.2.2), and
(8) aggregate loss, GL (inches), of surface layer (Section 2.2.3)

These design requirements are used in conjunction with the computational chart in Table 4.4 and the design nomographs for serviceability (Figure 4.2) and rutting (Figure 4.3). An example of the application of certain steps of this procedure is presented in Table 4. 5.

Step 1. Select four levels of aggregate base thickness, D_{BS}, which should bound the probable solution. For this, four separate tables, identical to Table 4.4, should be prepared. Enter each of the four trial base thickness, D_{BS}, in the upper left-hand comer of each of the four tables (D_{BS} = 8 inches is used in the example).

Step 2. Enter the design serviceability loss as well as the allowable rutting in the appropriate boxes of each of the four tables.

Step 3. Enter the appropriate seasonal resilient (elastic) moduli of the roadbed (M_R) and the aggregate base material, E_{BS} (psi), in Columns 2 and 3, respectively, of Table 4.4. The base modulus values may be proportional to the resilient modulus of the roadbed soil during a given season. A constant value of 30,000 psi was used in the example, however, since a portion of the aggregate base material will be converted into an equivalent thickness of subbase material (which will provide some shield against the environmental moisture effects).

Step 4. Enter the seasonal 18-kip ESAL traffic in Column 4 of Table 4.4. Assuming that truck traffic is distributed evenly throughout the year, the lengths of the seasons should be used to proportion the total projected 18-kip ESAL traffic to each season. If the road is load-zoned (restricted) during certain critical periods, the total traffic may be distributed only among those seasons when truck traffic is allowed. (Total traffic of 21,000 18-kip ESAL applications and a seasonal pattern corresponding to U S Climatic Region III was used in the example in Table 4.5.)

Step 5. Within each of the four tables, estimate the allowable 18-kip ESAL traffic for each of the four seasons using the serviceability-based nomograph in Figure 4.2, and enter in Column 5. If the resilient modulus of the roadbed soil (during the frozen season) is such that the allowable traffic exceeds the upper limit of the nomograph, assume a practical value of 500,000 18-kip ESAL.

Step 6. 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 4.3, and enter in Column 7. Again, if the resilient modulus of the roadbed soil is such that the allowable traffic exceeds the upper limit of the nomograph, assume a practical value of 500,000 18-kip ESAL.

Step 7. Compute the seasonal damage values in each of the four tables for the serviceability criteria by dividing the projected seasonal traffic (Column 4) by the allowable traffic in that season (Column 5). Enter these seasonal damage values in Column 6 of Table 4.4 corresponding to serviceability criteria. Next, follow these same instructions for rutting criteria, i.e., divide Column 4 by Column 7 and enter in Column 8.

Step 8. Compute the total damage for both the serviceability and rutting criteria by adding the seasonal damages. When this is accomplished for all four tables (corresponding to the four trial base thicknesses), a graph of total damage versus base layer thickness should be prepared. The average base layer thickness, $\overline{D}_{BS}$, required is determined by interpolat-

Table 4.4. Chart for Computing Total Pavement Damage (for both Serviceability and Rutting Criteria) Based on a Trial Aggregate Base Thickness

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

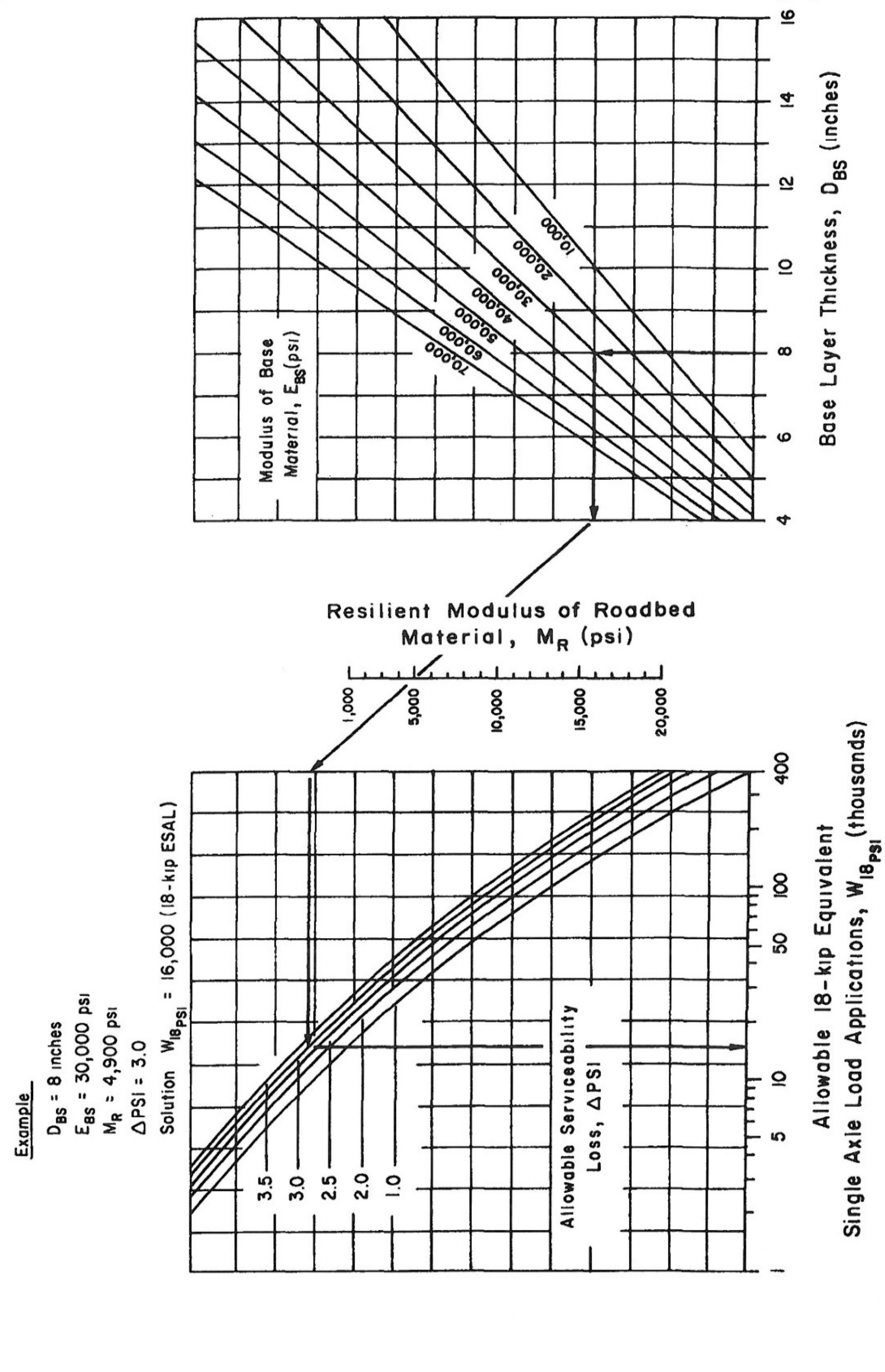


Figure 4.2. Design Chart for Aggregate-Surfaced Roads Considering Allowable Serviceability Loss

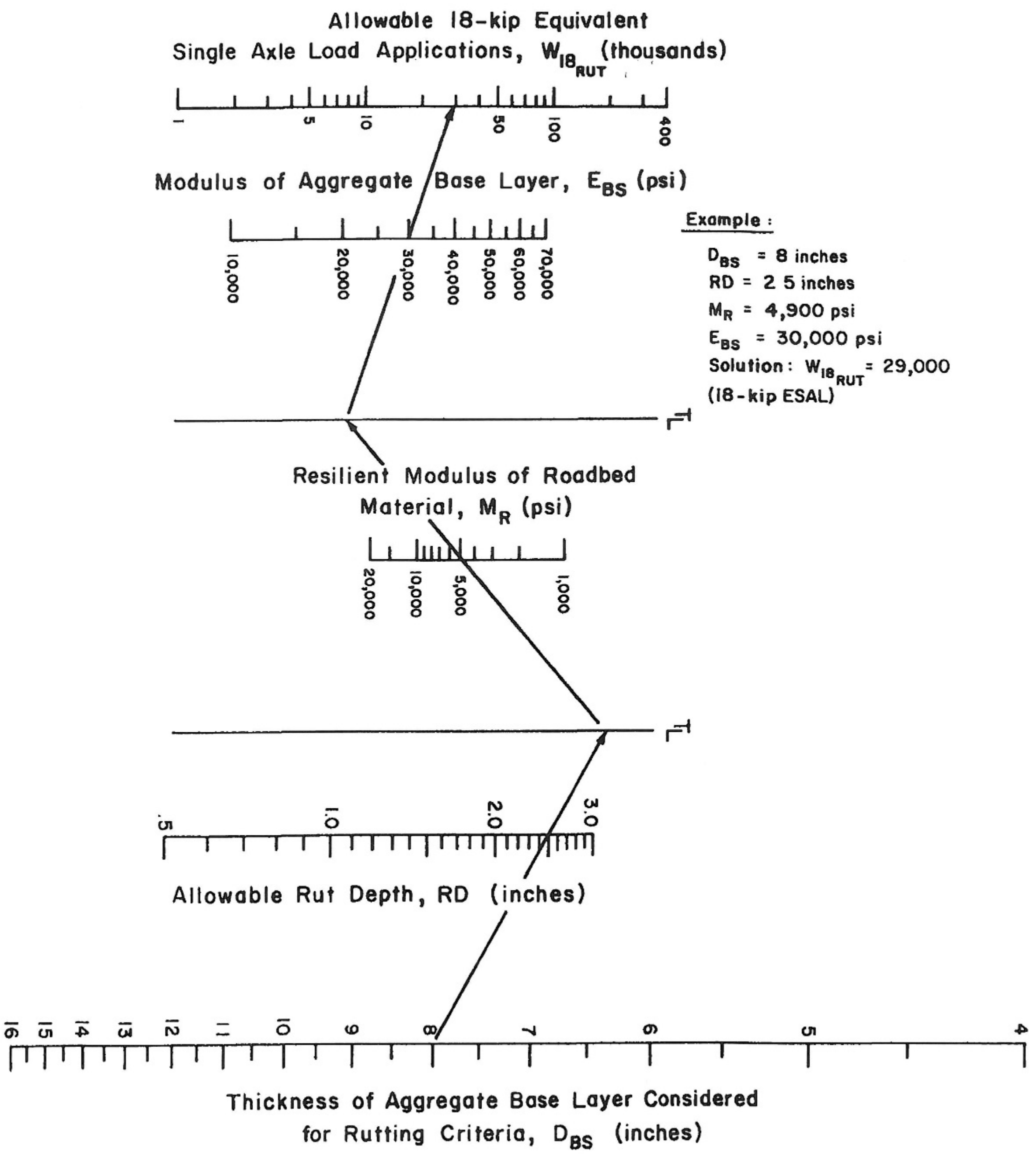


Figure 4.3. Design Chart for Aggregate-Surfaced Roads Considering Allowable Rutting

Table 4.5 Example Application of Chart for Computing Total Pavement Damage (for both Serviceability and Rutting Criteria) Based on a Trial Aggregate Base Thickness

TRIAL BASE THICKNESS, D_{BS} (inches) 8				Serviceability Criteria, PSI = 3.0		Rutting Criteria, RD (inches) = 2.5	
(1) Season (Roadbed Moisture Condition)	(2) Roadbed Resilient Modulus, M_R (psi)	(3) Base Elastic Modulus, E_{BS} (psi)	(4) Projected 18-kip ESAL Traffic, W_{18}	(5) Allowable 18-kip ESAL Traffic, $(W_{18})_{PSI}$	(6) Seasonal Damage, $\frac{W_{18}}{(W_{18})_{PSI}}$	(7) Allowable 18-kip ESAL Traffic, $(W_{18})_{RUT}$	(8) Seasonal Damage, $\frac{W_{18}}{(W_{18})_{RUT}}$
Wmter (Frozen)	20,000	30,000	4,400	400,000	0.01	130,000	0.03
Spring/Thaw (Saturated)	1,500	30,000	2,600	4,900	0.53	8,400	0.31
Spring/Fall (Wet)	3,300	30,000	7,000	8,400	0.83	20,000	0.35
Summer (Dry)	4,900	30,000	7,000	16,000	0.44	29,000	0.24
		Total Traffic =	21,000	Total Damage =	1.81	Total Damage =	0.93

ing in this graph for a total damage equal to 1.0. Figure 4.4 provides an example in which the design is controlled by the serviceability criteria: $\overline{D}_{BS}$ is equal to 10 inches.

Step 9. The base layer thickness determined in the last step should be used for design if the effects of aggregate loss are negligible If, however, aggregate loss is significant, then the design thickness is determined using the following equation:

$$D_{BS} = \overline{D}_{BS} + (0.5 \ X \ GL)$$

where

GL = total estimated aggregate (gravel) loss (in inches) over the performance period.

If, for example, the total estimated gravel loss was 2 inches and the average base thickness required was 10 inches, the design thickness of the aggregate base layer would be

$$D_{BS} = 10 + (0.5 \ x \ 2) = 11 \text{ inches}$$

Step 10. The final step of the design chart procedure for aggregate-surfaced roads is to convert a portion of the aggregate base layer thickness to an equivalent thickness of subbase material. This is accomplished with the aid of Figure 4.5. Select the final base thickness desired, $^{D}BS_{F}$ (6 inches is used in the example). Draw a line to the estimated modulus of the subbase material, E_{SB} (15,000 psi is used in the example). Go across and through the scale corresponding to the reduction in base thickness, ^{D}BSi - ^{D}BSf (11 minus 6 equal to 5 inches is used in the example). Then for the known modulus of the base material, E_{BS} (30,000 psi in the example), determine the required subbase thickness, D_{SB} (8 inches).

4.2 DESIGN CATALOG

The purpose of this Section is to provide the user with a means for identifying reasonable pavement structural designs suitable for low-volume roads. The catalog of designs presented here covers aggregate-surfaced roads as well as both flexible and rigid pavements. It is important to note, however, that although the structural designs presented represent precise solutions using the design procedure described in the previous section, they are based on a unique set of assumptions relative to design requirements and environmental conditions. The following specific assumptions apply to all three types of structural designs considered:

(1) All designs are based on the structural requirement for one performance period, regardless of the time interval. The range of traffic levels for the flexible and rigid pavement designs is between 50,000 and 1,000,000 18-kip ESAL applications. The allowable range of relative traffic for aggregate-surfaced road design is between 10,000 and 100,000 18-kip ESAL applications.

(2) All designs presented are based on either a *50*- or 75-percent level of reliability.

(3) The designs are for environmental conditions corresponding to all six of the US climatic regions. (See map in Figure 4. 1)

(4) The designs are for five qualitative levels of roadbed soil strength or support capability: Very Good, Good, Fair, Poor, and Very Poor. Table 4.2 indicates the levels of roadbed soil resilient modulus that were used for each soil classification. Table 4.1 indicates the actual lengths of the seasons used to quantify the effects of each of the six climatic regions on pavement performance.

(5) The terminal serviceability for the flexible and rigid pavement designs is 1.5 and the overall design serviceability loss used for aggregate-surfaced roads is 3.0. (Thus, if the initial serviceability of an aggregate-surfaced road was 3.5, the corresponding terminal serviceability inherent in the design solution is 0.5)

4.2.1 Flexible Pavement Design Catalog

Tables 4.6 and 4.7 present a catalog of flexible pavement SN values (structural numbers) that may be used for the design of low-volume roads when the more detailed design approach is not possible. Table 4.6 is based on the 50-percent reliability level and Table 4.7 is based on a 75-percent level. The range of SN values shown for each condition is based on a specific range of 18-kip ESAL applications at each traffic level:

High	700,000 to 1,000,000
Medium	400,000 to 600,000
Low	50,000 to 300,000

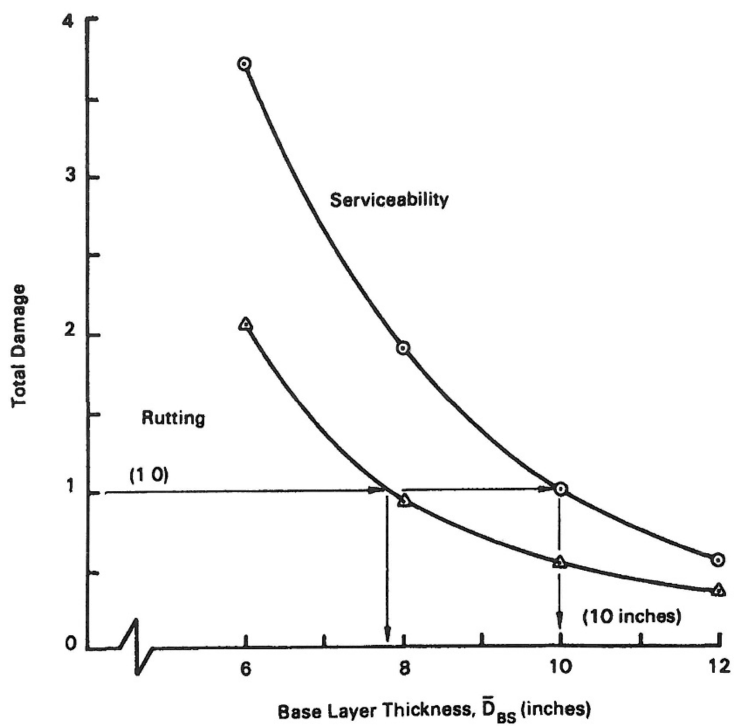


Figure 4.4. Example Growth of Total Damage Versus Base Layer Thickness for Both Serviceability and Rutting Criteria

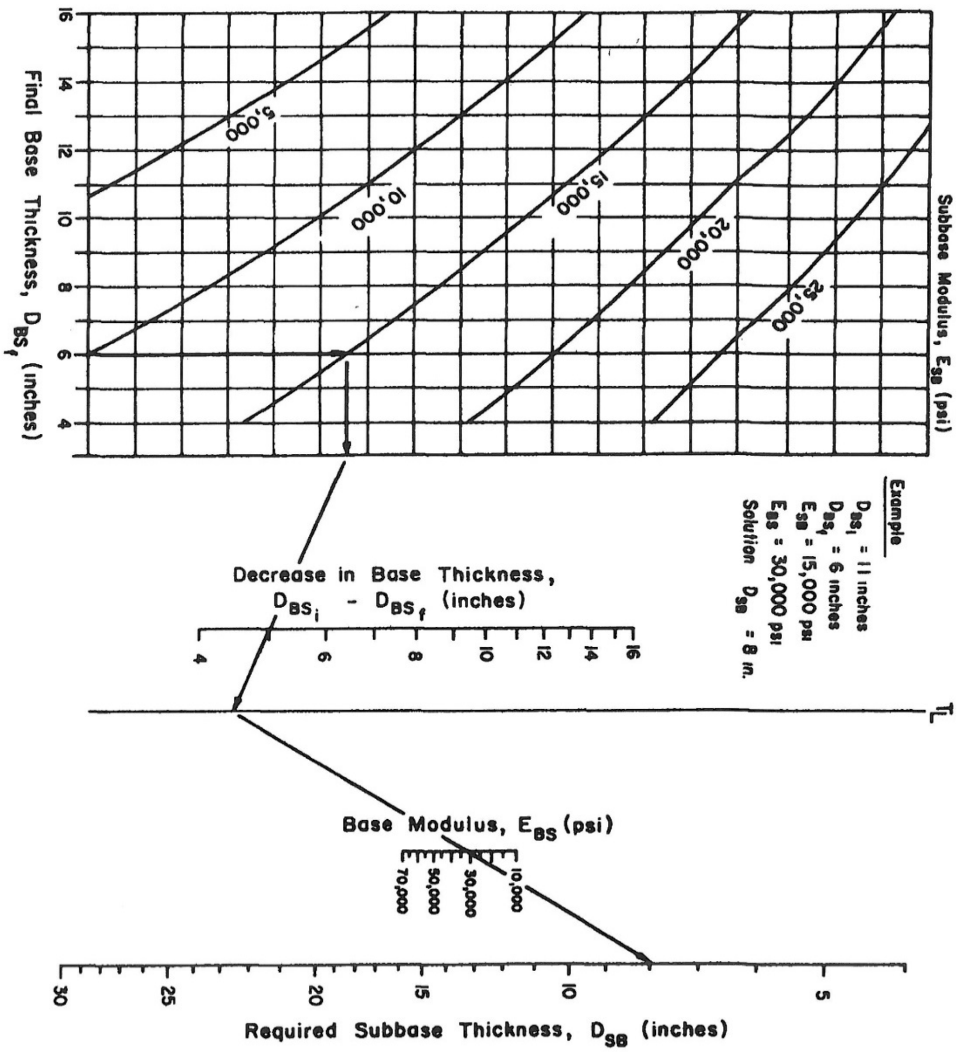


Figure 4.5. Chart to Convert a Portion of the Aggregate Base Layer Thickness To an Equivalent Thickness of Subbase

Table 4.6. Flexible Pavement Design Catalog for Low-Volume Roads: Recommended Ranges of Structural Number (SN) for the Six U.S. Climatic Regions, Three Levels of Axle Load Traffic and Five Levels of Roadbed Soil Quality-Inherent Reliability: 50 percent

Relative Quality of Roadbed Soil	Traffic Level	U.S. Climatic Region					
		I	II	III	IV	V	VI
Very good	High	2.3 - 2.5*	2.5 - 2.7	2.8 - 3.0	2.1 - 2.3	2.4 - 2.6	2.8 - 3.0
	Medium	2.1 - 2.3	2.3 - 2.5	2.5 - 2.7	1.9 - 2.1	2.2 - 2.4	2.5 - 2.7
	Low	1.5 - 2.0	1.7 - 2.2	1.9 - 2.4	1.4 - 1.8	1.6 - 2.1	1.9 - 2.4
Good	High	2.6 - 2.8	2.8 - 3.0	3.0 - 3.2	2.5 - 2.7	2.7 - 2.9	3.0 - 3.2
	Medium	2.4 - 2.6	2.6 - 2.8	2.8 - 3.0	2.2 - 2.4	2.5 - 2.7	2.7 - 2.9
	Low	1.7 - 2.3	1.9 - 2.4	2.0 - 2.7	1.6 - 2.1	1.8 - 2.4	2.0 - 2.6
Fair	High	2.9 - 3.1	3.0 - 3.2	3.1 - 3.3	2.8 - 3.0	2.9 - 3.1	3.1 - 3.3
	Medium	2.6 - 2.8	2.8 - 3.0	2.9 - 3.1	2.5 - 2.7	2.6 2.8	2.8 - 3.0
	Low	2.0 - 2.6	2.0 - 2.6	2.1 - 2.8	1.9 - 2.4	1.9 - 2.5	2.1 - 2.7
Poor	High	3.2 - 3.4	3.3 - 3.5	3.4 - 3.6	3.1 - 3.3	3.2 - 3.4	3.4 - 3.6
	Medium	3.0 - 3.2	3.0 - 3.2	3.1 - 3.4	2.8 - 3.0	2.9 - 3.2	3.1 - 3.3
	Low	2.2 - 2.8	2.2 - 2.9	2.3 - 3.0	2.1 - 2.7	2.2 - 2.8	2.3 - 3.0
Very poor	High	3.5 - 3.7	3.5 - 3.7	3.5 - 3.7	3.3 - 3.5	3.4 - 3.6	3.5 - 3.7
	Medium	3.2 - 3.4	3.3 - 3.5	3.3 - 3.5	3.1 - 3.0	3.1 - 3.3	3.2 - 3.4
	Low	2.4 - 3.1	2.4 - 3.1	2.4 - 3.1	2.3 - 3.0	2.3 - 3.0	2.4 - 3.1

*Recommended range of structural number (SN)

Table 4.7. Flexible Pavement Design Catalog for Low-Volume Roads: Recommended Ranges of Structural Number (SN) for Six U.S. Climatic Regions, Three Levels of Axle Load Traffic and Five Levels of Roadbed Soil Quality- Inherent Reliability: 75 percent

Relative Quality of Roadbed Soil	Traffic Level	U.S. Climatic Region					
		I	II	III	IV	V	VI
Very good	High	2.6 - 2.7*	2.8 - 2.9	3.0 - 3.2	2.4 - 2.5	2.7 - 2.8	3.0 - 3.2
	Medium	2.3 - 2.5	2.5 - 2.7	2.7 - 3.0	2.1 - 2.3	2.4 - 2.6	2.7 - 3.0
	Low	1.6 - 2.1	1.8 - 2.3	2.0 - 2.6	1.5 - 2.0	1.7 - 2.2	2.0 - 2.6
Good	High	2.9 - 3.0	3.0 - 3.2	3.3 - 3.4	2.7 - 2.8	3.0 - 3.1	3.3 - 3.4
	Medium	2.6 - 2.8	2.7 - 3.0	3.0 - 3.2	2.4 - 2.6	2.6 - 2.9	2.9 - 3.2
	Low	1.9 - 2.4	2.0 - 2.6	2.2 - 2.8	2.4 - 2.6	2.0 - 2.5	2.2 - 2.8
Fair	High	3.2 - 3.3	3.3 - 3.4	3.4 - 3.5	1.8 - 2.3	3.2 - 3.3	3.4 - 3.5
	Medium	2.8 - 3.1	2.9 - 3.2	2.7 - 3.3	3.0 - 3.2	2.8 - 3.1	3.0 - 3.3
	Low	2.1 - 2.7	2.2 - 2.8	2.3 - 2.9	2.7 - 3.0	2.1 - 2.7	2.3 - 2.9
Poor	High	3.5 - 3.6	3.6 - 3.7	3.7 - 3.9	2.0 - 2.6	3.5 - 3.6	3.7 - 3.8
	Medium	3.1 - 3.4	3.2 - 3.5	3.4 - 3.6	3.4 - 3.3	3.1 - 3.4	3.3 - 3.6
	Low	2.4 - 3.0	2.4 - 3.0	2.5 - 3.2	2.3 - 2.8	2.3 - 2.9	2.5 - 3.2
Very poor	High	3.8 - 3.9	3.8 - 4.0	3.8 - 4.0	3.6 - 3.8	3.7 - 3.8	3.8 - 4.0
	Medium	3.4 - 3.7	3.5 - 3.8	3.5 - 3.7	3.3 - 3.6	3.3 - 3.6	3.4 - 3.7
	Low	2.6 - 3.2	2.5 - 3.3	2.6 - 3.3	2.5 - 3.1	2.5 - 3.1	2.6 - 3.3

*Recommended range of structural number (SN)

Once a design structural number is selected, it is up to the user to identify an appropriate combination of flexible pavement layer thicknesses which will provide the desired load-carrying capacity. This may be accomplished using the criteria for layer coefficients (a_i-values) presented in Section 2.3.5 and the general equation for structural number:

$$SN = a_1D_1 + a_2D_2 + a_3D_3$$

where

a_1, a_2, a_3 = layer coefficient for surface, base, and subbase course materials, respectively, and
D_1, D_2, D_3 = thickness (in inches) of surface, base, and subbase course, respectively.

4.2.2 Rigid Pavement Design Catalog

Tables 4.8a, 4.8b, 4.9a, and 4.9b present the catalog of portland cement pavement slab thicknesses that may be used for the design of low-volume roads when the more detailed design approach is not possible. Tables 4.8a and 4.8b are based on a 50-percent reliability level, without granular subbase and with granular subbase, respectively. Tables 4.9a and 4.9b are based on a 75-percent level, without granular subbase and with granular subbase, respectively. The assumptions inherent in these design catalogs are as follows:

(1) Slab thickness design recommendations apply to all six U S climatic regions
(2) If the option to use a subbase is chosen, it consists of 4 to 6 inches of high quality granular material
(3) Mean PCC modulus of rupture (S'_C) is 600 or 700 psi
(4) Mean PCC elastic modulus (E_C) is 5,000,000 psi
(5) Drainage (moisture) conditions are fair (C_d = 1 0).
(6) The 18-kip ESAL traffic levels are

High	700,000	to	1,000,000
Medium	400,000	to	600,000
Low	50,000	to	300,000

(7) The levels of roadbed soil quality and corresponding ranges of effective modulus of subgrade reaction (k-value) are

Very Good	Greater than *550* pci
Good	400 to *550* pci
Fair	250 to 350 pci
Poor	150 to 250 pci
Very Poor	Less than 150 pci

4.2.3 Aggregate-Surfaced Road Design Catalog

Table 4.10 presents a catalog of aggregate base layer thicknesses that may be used for the design of low-volume roads when the more detailed design approach is not possible. The thicknesses shown are based on specific ranges of 18-kip ESAL applications at traffic levels:

High	60,000	to	100,000
Medium	30,000	to	60,000
Low	10,000	to	30,000

One other assumption inherent in these base thickness recommendations is that the effective resilient modulus of the aggregate base material is 30,000 psi, regardless of the quality of the roadbed soil. This value should be used as input to the nomograph in Figure 4.5 to convert a portion of the aggregate base thickness to an equivalent thickness of subbase material with an intermediate modulus value between the base and roadbed soil.

Table 4.8(a). Rigid Design Catalog for Low-Volume Roads: Recommended Minimum PCC Slab Thickness (Inches) for Three Levels of Axle Load Traffic and Five Levels of Roadbed Soil Quality

Inherent reliability: 50 percent
Without Granular Subbase

Load Transfer Devices	**No**				**Yes**			
Edge Support	No		Yes		No		Yes	
S'_c (psi)	600	700	600	700	600	700	600	700
Relative Quality of Roadbed Soil				**Low Traffic**				
Very good & good	5.5	5	5	5	5.25	5	5	5
Fair	5.5	5	5.25	5	5.25	5	5	5
Poor & very poor	5.5	5.25	5.25	5	5.5	5	5	5
				Medium Traffic				
Very good & good	6.25	5.75	5.75	5.25	6	5.5	5.5	5
Fair	6.25	5.75	5.75	5.25	6	5.5	5.5	5
Poor & very poor	6.25	5.75	5.75	5.25	6	5.5	5.5	5
				High Traffic				
Very good & good	7	6.25	6.25	5.75	6.5	6	5.75	5.25
Fair	7	6.25	6.25	5.75	6.5	6	6	5.5
Poor & very poor	7	6.5	6.5	6	6.5	6	6	5.5

Table 4.8(b). Rigid Design Catalog for Low-Volume Roads: Recommended Minimum PCC Slab Thickness (Inches) For Three Levels of Axle Load Traffic and Five Levels of Roadbed Soil Quality

Inherent reliability: 50 percent
With Granular Subbase

Load Transfer Devices	**No**				**Yes**			
Edge Support	No		Yes		No		Yes	
S'_c (psi)	600	700	600	700	600	700	600	700
Relative Quality of Roadbed Soil				**Low Traffic**				
Very good & good	5	5	5	5	5	5	5	5
Fair	5.25	5	5	5	5	5	5	5
Poor & very poor	5.25	5	5	5	5	5	5	5
				Medium Traffic				
Very good & good	5.75	5.25	5.25	5	5.5	5	5	5
Fair	5.75	5.25	5.5	5	5.5	5	5	5
Poor & very poor	6	5.5	5.5	5	5.75	5.25	5	5
				High Traffic				
Very good & good	6.5	6	6	5.5	6	5.5	5.25	5
Fair	6.5	6	6	5.5	6	5.5	5.5	5
Poor & very poor	7	6	6	5.5	6.25	5.75	5.5	5

Table 4.9(a). Rigid Design Catalog for Low-Volume Roads: Recommended Minimum PCC Slab Thickness (Inches) for Three Levels of Axle Load Traffic and Five Levels of Roadbed Soil Quality

Inherent reliability: 75 percent
Without Granular Subbase

Load Transfer Devices	**No**				**Yes**			
Edge Support	No		Yes		No		Yes	
S'_c (psi)	600	700	600	700	600	700	600	700
Relative Quality of Roadbed Soil								
Low Traffic								
Very good & good	6	5.5	5.5	5	5.75	5.25	5.25	5
Fair	6	5.5	5.75	5.25	5.75	5.25	5.25	5
Poor & very poor	6	5.5	5.75	5.25	6	5.5	5.25	5
Medium Traffic								
Very good & good	6.75	6.25	6.25	5.75	6.5	6	6	5.5
Fair	6.75	6.25	6.25	5.75	6.5	6	6	5.5
Poor & very poor	6.75	6.25	6.25	5.75	6.5	6	6	5.5
High Traffic								
Very good & good	7.5	7	7	6.25	7	6.5	6.5	6
Fair	7.5	7	7	6.25	7	6.5	6.5	6
Poor & very poor	7.5	7	7	6.5	7.25	6.5	6.5	6

Table 4.9(b). Rigid Design Catalog for Low-Volume Roads: Recommended Minimum PCC Slab Thickness (Inches) for Three Levels of Axle Load Traffic and Five Levels of Roadbed Soil Quality

Inherent reliability: 75 percent
With Granular Subbase

Load Transfer Devices	**No**				**Yes**			
Edge Support	No		Yes		No		Yes	
S'_c (psi)	600	700	600	700	600	700	600	700
Relative Quality of Roadbed Soil								
Low Traffic								
Very good & good	5.5	5	5	5	5	5	5	5
Fair	5.75	5.25	5	5	5	5	5	5
Poor & very poor	5.75	5.25	5	5	5	5	5	5
Medium Traffic								
Very good & good	6.25	5.75	5.75	5.25	6	5.5	5.5	5
Fair	6.5	5.75	6	5.5	6.25	5.5	5.5	5
Poor & very poor	6.5	6	6	5.5	6.25	5.75	5.5	5.25
High Traffic								
Very good & good	7.25	6.5	6.5	6	6.75	6	6	5.5
Fair	7.25	6.5	6.5	6	6.75	6	6	5.5
Poor & very poor	7.25	6.75	6.75	6	6.75	6.25	6.25	5.5

Table 4.10. Aggregate Surfaced Road Design Catalog: Recommended Aggregate Base Thickness (in Inches) for the Six U.S. Climatic Regions, Five Relative Qualities of Roadbed Soil and Three Levels of Traffic

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

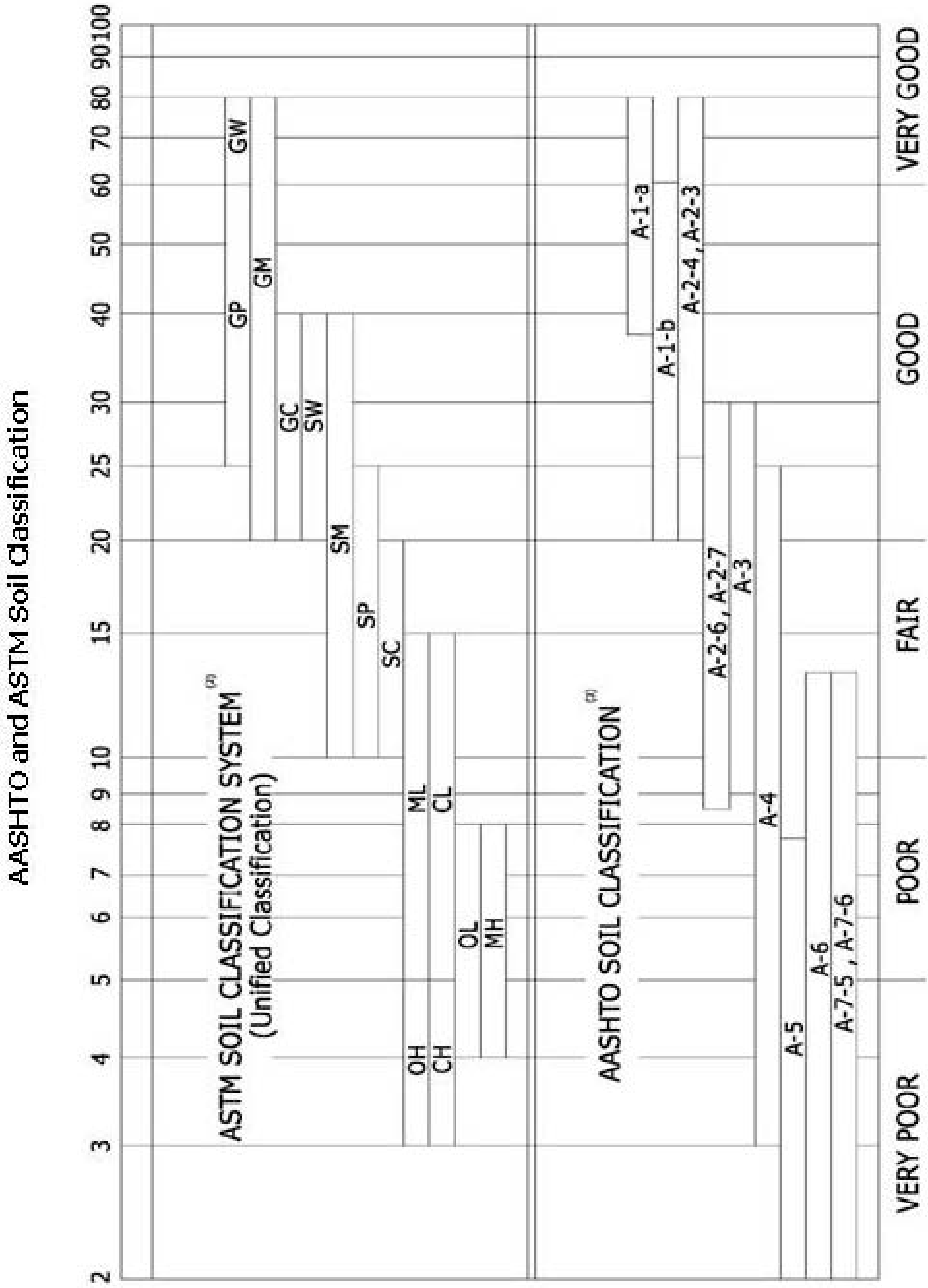


Figure 155 – Relative Quality of the Roadbed Soil

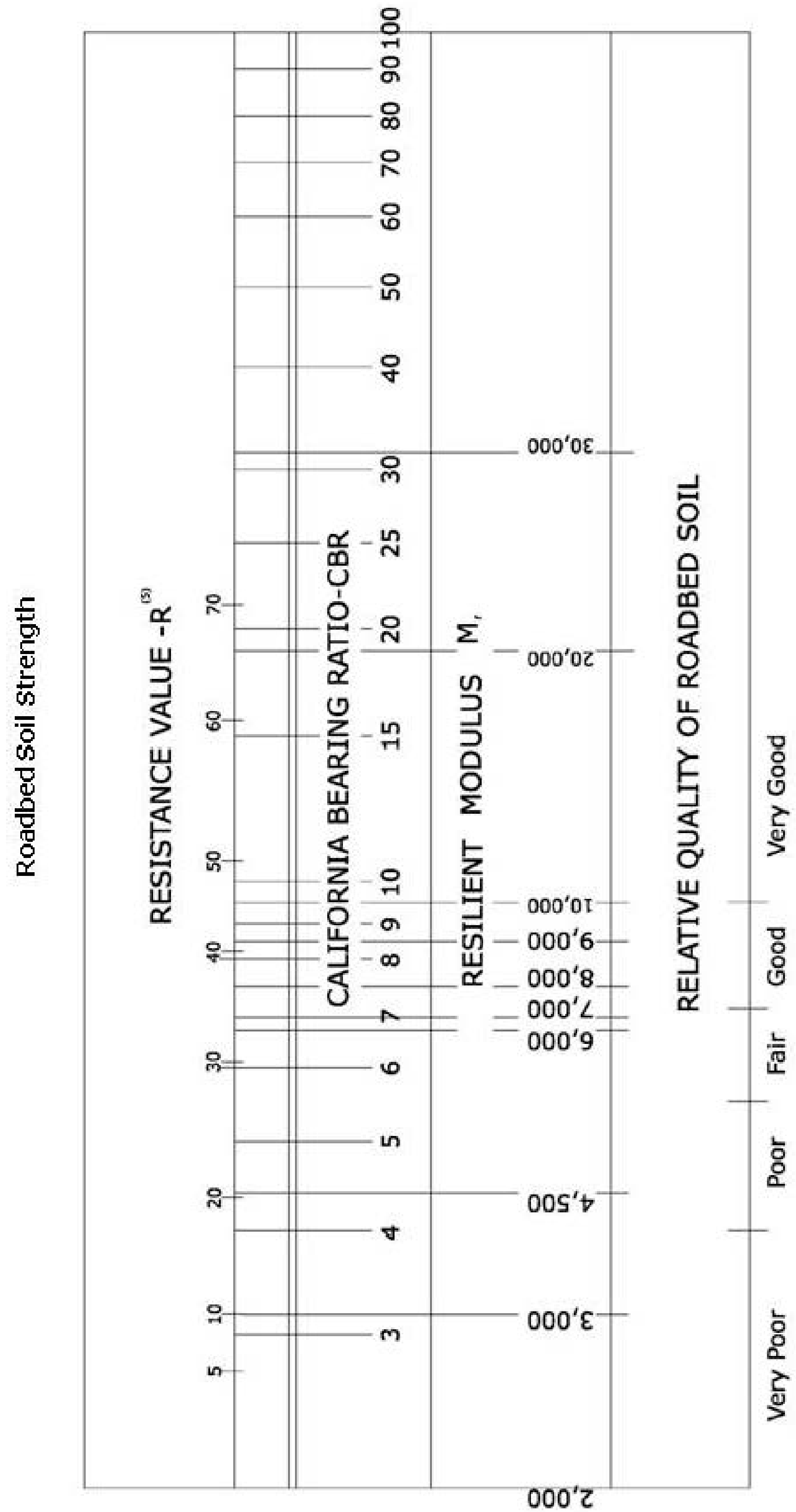


Figure 166 – Roadbed Soil Strength