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16. Abstract

In the past decades, USDA Forest Service engineers have attempted to better clarify the design and construction of surfacing for low volume native and aggregate-surfaced roads. For the most part, this effort had been a trial-and-error process.

The Earth and Aggregate Surfacing Design Guide for Low Volume Roads is the result of decades of work aimed at better defining design mechanisms for aggregate surfacing and developing a model for use in native surfacing design while including the effects of maintenance and road management. The guide redefines the surfacing design process and performance criteria. And, for the first time, recognition is given to the importance of road maintenance in long-term road performance and that road surface design and management play a major role in erosion and sediment control.

This guide is a major step in the direction of realistic surfacing design for low-volume roads and provides a set of procedures, along with discussion and examples, which can be an aid to understanding the functions, selection, design, and maintenance of an earth or aggregate-surfaced road.

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Foreword

This study was funded as part of the Coordinated Federal Lands Highway Technology Implementation Program. It is intended to serve the immediate needs of those who design and construct Federal Lands Highways, but is also made available to all other interested parties.

This report redefines the surfacing design process and performance criteria for low volume roads and also recognizes the importance of road maintenance in long-term road performance and that road surface design and management play a major role in erosion and sediment control.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
	AREA			
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
	VOLUME			
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: Volumes greater than 1000 l shall be shown in m^3.				
	MASS			
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
	ILLUMINATION			
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
	FORCE and PRESSURE or STRESS			
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
	AREA			
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
	VOLUME			
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
	MASS			
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
	TEMPERATURE (exact)			
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
	ILLUMINATION			
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
	FORCE and PRESSURE or STRESS			
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

(Revised September 1993)

Preface

In the past decades, USDA Forest Service engineers have attempted to better clarify the design and construction of surfacing for low volume native and aggregate-surfaced roads. For the most part, this effort had been a trial-and-error process, leading us in many directions as we have attempted to better refine the design models and ultimately the road's performance.

Initially, we used models that had been developed for use in the design of asphalt pavements, modifying them to take into account basic material characteristics of aggregate surfaces. These models were generally overly conservative, which resulted in a high degree of design reliability, high costs, and few failures. Engineering personnel adapted to the conservative design process and modified the design method using "engineering judgment" and "local experience." In the case of native-surfaced roads, of which there are many miles in the Forest Service, engineers generally ignored improvements in the evaluation and maintenance altogether. A few farsighted engineering personnel took this on as a challenge, realizing that even though existing models worked, a change was necessary to better reflect the mechanics of aggregate surfacing.

The *Earth and Aggregate Surfacing Design Guide for Low Volume Roads* is the result of decades of work aimed at better defining design mechanisms for aggregate surfacing and developing a model for use in native surfacing design while including the effects of maintenance and road management. The guide redefines the surfacing design process and performance criteria. And, for the first time, recognition is given to the importance of road maintenance in long-term road performance and that road surface design and management play a major role in erosion and sediment control.

An important concept for the user of this guide to understand is that the object of the design method is to design a structurally sound foundation for the anticipated traffic ***to the first blading.*** To the road manager, this means that as long as a sound structural foundation is constructed, operational losses are replaced, and road maintenance activities are timely and appropriate, the life of the structure is indefinite—an observation made by many Forest Service field personnel.

The authors believe this guide is a major step in the direction of realistic surfacing design for low-volume roads. We would like to offer our appreciation to those individuals who contributed and took the time to provide extensive editorial and technical reviews. We would also like to recognize the work done by ARE, Inc., in preparing the *Aggregate Surfacing Design Guide*, August 1991, from which considerable text and information was "borrowed."

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Chapter 1
Introduction

The most costly construction and maintenance element of low volume forest roads is the surfacing. These roads are typically unpaved (either native (earth) or aggregate-surfaced (untreated)), with a small percentage of asphalt-treated or other type of bound surfacing material.

Recently, low volume forest roads have been identified as a major factor influencing the health of local ecosystems. The major concern is the sediment from the road cuts, fills, unpaved road surfaces, and road-associated slope failures being transported to adjacent fish bearing streams. Once in the streams, the sediment can degrade local spawning habitat.

These and other factors have highlighted the need to improve our understanding of the road surface structure, its design, and maintenance. The road surface structure is the combination of native material and any material placed on it necessary to support the traffic loads while meeting the road's objectives. Understanding the road surface structure includes knowing its intended function and how it is performed. Understanding surfacing design and maintenance includes knowing the factors that control the design and those that optimize maintenance.

1.1 Purpose

The *Earth and Aggregate Surfacing Design Guide for Low Volume Roads* (herein called the *Surfacing Design Guide*) provides a set of procedures, along with discussion and examples, which can be an aid to understanding the functions, selection, design, and maintenance of an earth or aggregate-surfaced road. The *Surfacing Design Guide* was developed to address earth, aggregate, bituminous surface treatments (BST's), and non-traditional surfaced roads. The guide will use the term "surfacing design" when referring to designing the pavement structure. Remember the road surface structure is a combination of the native material and any material placed on the native material necessary to support the traffic loads while meeting the road's objectives.

Road planners can use this *Surfacing Design Guide* to assist in evaluating various surfacing alternatives as well as selecting the type of road surface, be it earth, aggregate, or a non-traditional surfacing material. Road designers with limited surfacing design experience can use the guide to understand the basic concepts of surfacing design and learn the design process as they follow the discussion and examples for construction, reconstruction, and maintenance of earth, aggregate, or

non-traditional surfaced roads. The experienced road designer can use the *Surfacing Design Guide* as a reference when designing more complex surfacing projects.

This *Surfacing Design Guide* is intended to compliment the USDA Forest Service Handbook - 7709.56, Chapter 4.72 "Pavement Structure." The most current information available has been used in the development of this guide. Appendix 6.10 lists various agencies and organizations to contact for the most current publications, design methods, and associated computer programs referenced throughout this *Surfacing Design Guide.*

1.2 History

Since the mid-1960's, the USDA Forest Service has adapted three surfacing design methods. From the mid-1960's to 1972 the *D-11 Forest Service Design Guide* was used to design asphalt and aggregate surfaces. Its methodology was based on the 1950's AASHO Road Test. From 1973 to the mid-1980's the Forest Service's *Chapter 50 Design Guide* (1) addressed asphalt as well as aggregate surfacing design. Chapter 50 was based upon the 1950's AASHO Road Test and the 1970 U.S. Army Corps of Engineers aggregate design equation (2). In using the *Chapter 50 Design Guide* users felt that the design was conservative because more traffic was able to use the road before it was considered in need of complete resurfacing by Chapter 50 standards.

A project to improve and develop a comprehensive design system for aggregate, asphalt, and earth surfaced roads was conducted at the University of Texas from 1972 to 1987. This led to the development of the Surfacing Design and Management System (SDMS). The companion computer program proved too complex for most users, no matter their level of surfacing design experience. The basic SDMS design equation was computerized by the Southern Region of the Forest Service and is now called Analysis of Road Materials Systems (ARMS).

In 1988, the Forest Service evaluated all the available design algorithms for surfacing design in conjunction with ARE Engineering Consultants, Inc. The joint venture proposed the adoption of two guides (3):

1. the most current *AASHTO Guide for Design of Pavement Structures* (4) for asphalt and other traditional stabilized pavement structures, and

2. the *Aggregate Surfacing Design Guide* (5) and its companion computer program "STP" for aggregate and native-surfaced roads. The *Aggregate Surfacing Design Guide* was written by ARE Engineering Consultants, Inc. as part of the evaluation. Its methodology is based on the 1978 U.S. Army Corps of Engineers design equation (6).

Since 1989, the "STP" methodology has been enhanced and validated by field test tracks at the Waterways Experiment Station in Vicksburg, Mississippi, and by the Willamette National Forest in Lowell, Oregon.

This current *Surfacing Design Guide* includes the enhancements made to the *Aggregate Surfacing Design Guide* and its companion computer program "STP" between 1989 and 1993 using version 2.01 (1993).

1.3 Scope of the Design Guide

The *Surfacing Design Guide* has six chapters.

Chapter 1.0, "Introduction," contains the introduction, purpose, and scope of the *Surfacing Design Guide.*

Chapter 2.0, "From Management Plans to Design Elements," discusses issues transportation planners and road designers need to consider when evaluating surfacing types and the design and maintenance criteria.

Chapter 3.0, "Surfacing Design Considerations," addresses the information necessary for road designers to perform a surfacing design. This includes how to combine and analyze different types of traffic for use in a surface design; what performance criteria to consider during the design; tips on selecting the type and size of aggregate in the surfacing design; how to consider different probabilities of success in the design; the characteristics and engineering properties of the materials needed for design; and the economics during the life of the road.

Chapter 4.0, "Design," may be used by the road designer to determine the necessary material layer thicknesses for various surfacing alternatives. Either native, aggregate, BST's, non-traditional materials, or geotextile reinforced materials can be used with this *Surfacing Design Guide.*

Chapter 5.0, "Road Surface Design Guide Examples," includes examples that address resource protection needs (non-structural design), and traffic management needs (structural design) for native, aggregate, BST's, or geotextile reinforced designs. Road designers with or without surfacing design experience can use this chapter for self study by working the examples that have various degrees of complexity. The road manager can also use the earth and aggregate design examples to optimize and predict blading operations for both types of road surfaces.

Chapter 6.0, the appendix, contains documentation referred to in chapters 2 through 5, including the Dynamic Cone Penetrometer Operators Guide (appendix 6.4), design with geotextiles (appendix 6.5), the use of chunkwood and wood waste materials (appendix 6.6), the use of non-traditional materials (appendix 6.7), and a summary of road surface sediment reports and studies (appendix 6.8).

Chapter 2
From Management Plans to Design Elements

Forest Service Manual (FSM) and Handbook (FSH) guidance identifies the planning and design process, issues, and concerns that need to be considered when planning and designing any road related project, including any pavement design. This chapter summarizes some of the above information pertaining to pavement design and provides additional insight and guidance.

2.0.1 Manual and Handbook Direction

FSM 7710, *Transportation Planning*; FSH 7709.55, *Transportation Planning Handbook*; and FSH 7709.56, *Road Preconstruction Handbook*, contain guidelines, objectives, policies, responsibilities, and requirements for transportation planners and road designers and for the documentation of the transportation system. Included is direction pertaining to:

1. the need for area transportation and project analysis and the requirement that such analyses be tied to the Forest Plan;

2. the establishment of Road Management Objectives (RMO's) and defining the intended purpose of the facility. The intended purpose governs the development, design, operation, and maintenance of that facility; and

3. the planning effort and the need to consider cost efficiency along with physical and biological factors when selecting alternatives. The planning effort should include, but not be limited to, development and documentation of:

   a. design criteria, including mitigation measures for resource protection;
   b. operation and maintenance criteria; and
   c. preconstruction decisions leading to a final design.

Figure 2.0-1 illustrates the flow and relationship of the decisions from land and resource management plans to design standards.

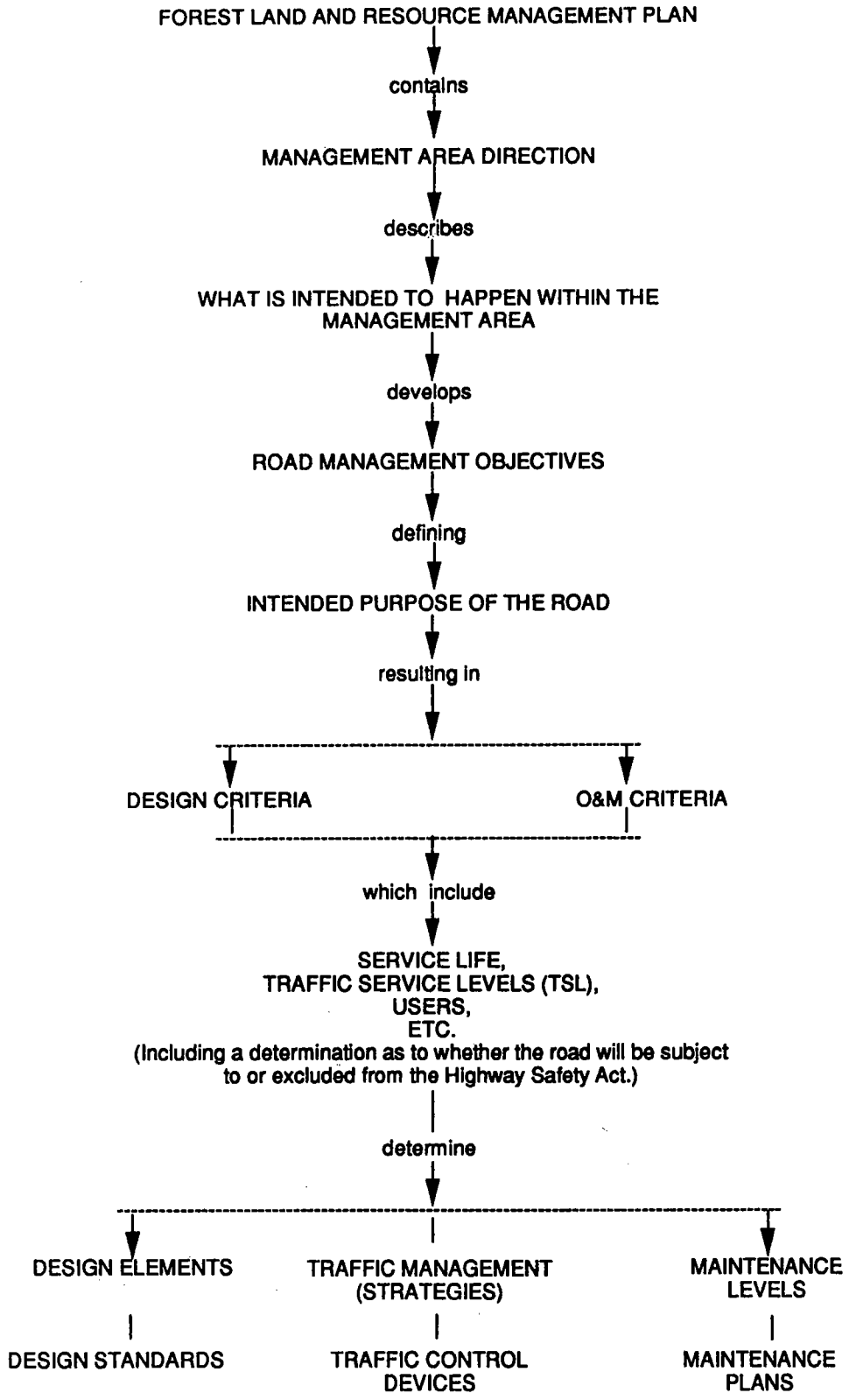


Figure 2.0-1.— Decision-making flowchart.

2.1 Environmental and Resource Considerations

Any project activity can have an effect on the ecosystem in a positive or negative manner. The expected environmental consequences associated with those activities play an important role in the development and selection of alternatives. Roads must be consistent with Forest Plan objectives and the desired future condition. Road sediment production is one of the most important environmental concerns.

2.1.1 Sediment Production

Sediment from all parts of the road prism has come under close scrutiny recently due to the impact transported sediment has on water quality and fish habitat. Road designs should minimize sediment yield from the road surface and reduce the delivery of sediment to streams and rivers. This is a multi-disciplined task, so the road designer should seek assistance in determining how best to mitigate sediment yield.

Generally, the travelway of unsurfaced roads contributes about one-third of all road related sediment (9,10). The remainder of the sediment comes from the cut and fill slopes and the ditch line. Road-generated landslide sediment is not considered in the above proportions. It can be substantially reduced depending on the type of surfacing used, as well as the access and operational management practices implemented. Traffic volume, traffic mix, moisture conditions during traffic, rainfall during and after traffic, season of use, rut depth, and maintenance frequency affect sediment production. Road-related sediment production becomes more important in areas where the risk of off-site sediment movement is the greatest.

Table 2.1.1-1 summarizes actions that have effectively reduced road surface-related sediment. Table 2.1.1-2 lists other activities that will help minimize sediment production, but their quantifiable benefits have not been established at this time. Other actions and activities that typically reduce the potential for sediment production from the road surface include:

- blading only when necessary, spot grading, and utilizing good blading methods;
- allowing use only when the surface course is dry;
- using a crowned road surface or in-slope/out-slope template rather than a flat section;
- using drainage dips;
- compacting the surface;
- use of frequent ditch outlets;
- use of flatter grades; and
- having hauling and heavy vehicles off-track.

Some sections of road probably contribute more sediment than others, and therefore require different analyses and treatment techniques.

There has been considerable research aimed at quantifying and developing measures to reduce and contain road-generated sediment. Included

Table 2.1.1-1.—Management activity and its potential reduction on sediment yield.*

Surface Treatment	Potential Results
2–6" aggregate	Potential reduction in sediment yield up to 80% compared to unsurfaced, depending on site-specific conditions, surfacing thickness and surfacing material. (9,10,17)
Dust oil	Potential reduction in sediment yield up to 85% compared to unsurfaced (9,10)
Asphalt surface	Potential reduction in sediment yield up to 97% compared to unsurfaced (9,10)
Use of high quality aggregate	Potential reduction in sediment yield about 80% compared to aggregate surface of marginal quality (17)
Reduced tire pressures on heavy vehicles	Potential reduction in sediment yield about 80% compared to using typical highway tire pressures (7)

* Note: The results of the various research efforts should be reviewed prior to selection of mitigating measures to determine if the conditions leading to conclusions apply to the specific situation.

Table 2.1.1-2.—Management activity and its potential reduction on sediment yield.

Activity	Potential Results
Design aggregate for minimal rut depth	Goes hand-in-hand with some of the recommendations shown in table 2.1.1-1, i.e. reduced rut depth yields a reduction in sediment yield
Blade road only when needed	Blading road surface only when ruts have developed to the point that they can channel surface water
Use of larger sized aggregate	May provide additional armoring of the running surface
Stabilization of existing surface	The potential reduction due to stabilization would be on the order of a dust oil or asphalt surface activity. Section 4.2 addresses some traditionally available materials and stabilizers that can be used in the stabilization of native or aggregate surfaces.

in appendix 6.8 is a list with summaries of some of the research used to assess the relationship of sediment, the road, and road use.

2.1.2 Seasonal Restrictions

Seasonal restrictions can provide the planner with mitigation for a number of resource issues. These include limiting traffic to reduce potential sediment produced by traffic during wet periods or limiting traffic to reduce road damage during wet or spring thaw conditions.

2.2 Maintenance and Operational Issues

Access and operation management affect selection of design alternatives. Some of the management activities that could have an effect include tire pressure management on hauling vehicles, expected frequency and quality of maintenance operations, and season of use. Following is a discussion of how each of these management practices can affect the selection of alternatives and the project design parameters.

2.2.1 Tire Pressure Management

Management of tire pressure during timber or other hauling operations has a major effect on not only the thickness of the surfacing, but also on the need for and frequency of road maintenance, sediment generated by the hauling vehicles (7,8), and mobility on steep grades. Reduced tire pressures create a situation where anticipated wheel loads are spread over a larger tire contact area. On aggregate-surfaced roads this has reduced the necessary aggregate thickness to support traffic and increased the time between necessary road maintenance, possibly extending the season of use. This may also be true for light vehicles, but little research has been done to determine the effects.

2.2.2 Road Maintenance

Road maintenance plays a major role in project design life and overall life-cycle costs. Poor or infrequent maintenance can decrease the project life expectancy and increase overall life-cycle costs. Problems associated with an inability to perform frequent road maintenance may be overcome by modifying the way the road surface is maintained. For example, the use of scarifying bits on a motor grader can rejuvenate an existing aggregate surface by removing potholes and wash-boarding or by bringing aggregate to the surface that has been contaminated by prior ditch cleaning. A crowned surface may improve surface drainage, thereby reducing the need for frequent grading operations. Dust abatement and compaction can reduce the frequency of blading significantly.

2.2.3 Seasonal Use

During wet conditions, subgrade soils and aggregate within the road surface structure may be saturated and at their lowest strength. By limiting the season of haul to drier conditions, the surfacing thickness can be substantially reduced.

There may be frost and/or spring thaw conditions at the project site. Historically, weight restrictions have been used to prevent or minimize damage to the surface structure. Section 4.4.5 discusses the design of an aggregate-surfaced road when considering frost or spring thaw conditions.

2.3 Design Considerations

This section summarizes considerations that are neither resource or operational in nature, but are more related to road use and the road user. Two of the most important design considerations are road use, which includes traffic volume and mix, and the overall safety of the facility. Following is a discussion of each of these considerations as they relate to surfacing selection and design.

2.3.1 Road Use

Current and projected traffic for the road is a major issue for the planner and designer. Traffic includes anticipated traffic mix (trucks, RV's, passenger cars, or even bicycles and ATV's); current and projected traffic volumes; and type of use ("high clearance" vehicles vs. passenger cars). For example, heavy traffic mixed with recreational traffic not only has an effect on geometric design and surfacing type, but also on the thickness of the surfacing material selected to meet the identified RMO's. Traffic design information is addressed in section 3.2.

Surfacing type can also have an effect on road use and is covered in detail in section 3.4. Usually an upgrade in surfacing type will result in a corresponding change (typically an increase) in use and vehicle speed. If traffic volume or vehicle mix changes and there is a corresponding change in speed, then the incidence of traffic-related conflicts and accidents can possibly increase. This can be especially true when commercial hauling operations start on a road that historically is known for recreational use.

2.3.2 Safety

User safety is an important consideration in project development. Some important safety questions that should be answered during the planning and design phase of project alternative development include:

- Does the Highway Safety Act govern the design and operation of the road (FSM 1535.11, Amendment 1)?
- Is the existing road safe for present and projected future traffic volumes, vehicle mix, and road use?
- If the road surface and/or alignment is upgraded, will the road be safe for projected future traffic volumes, vehicle mix, and road use?

A review of past accidents or near misses can help the designer identify particularly hazardous locations. Regular local users sometimes provide additional information on past close calls or near misses.

The designer must consider the effect any changes in alignment and/or surfacing type will have on road safety. Changes in surfacing type with little regard to road design speed may actually create a potential safety problem. This may be especially true if the road surface is upgraded from native to aggregate or from aggregate to paved with no corresponding upgrade in horizontal or vertical alignment. At the same time, some

safety issues can be resolved by a change in the surfacing type, such as increased skid resistance on a paved surface.

2.4 Economic Considerations

Project development should always include an economic comparison of alternatives, but this is only one factor in the decision-making process. Other issues, such as the role of the road in the ecosystem, may actually drive the selection of the alternative. Detailed information on economics can be found in section 3.5.

2.5 Surfacing Decision Tree

A logic flowchart similar to figure 2.5-1 can help address the issues associated with whether to surface or not. Table 2.5.1 can be used as a checklist of some traffic management and resource protection issues that will be helpful when using figure 2.5-1. The planner should define and document the results of any decision and the expected consequences of that decision.

Table 2.5.1.—Traffic management considerations and resource protection issues.

Traffic Management

- Current and projected road use
- Current and projected traffic volume and mix
- Season of use desired
- User safety
  - Past accidents and near misses
  - Current and proposed design speed and alignment
- Available resources to construct and maintain facility at desired traffic service level
- Tire pressure management
- Access management

Resource Protection

- Water quality restriction during periods of use and non-use
- Visual restrictions and user expectations
- Effect on wildlife during periods of use and non-use

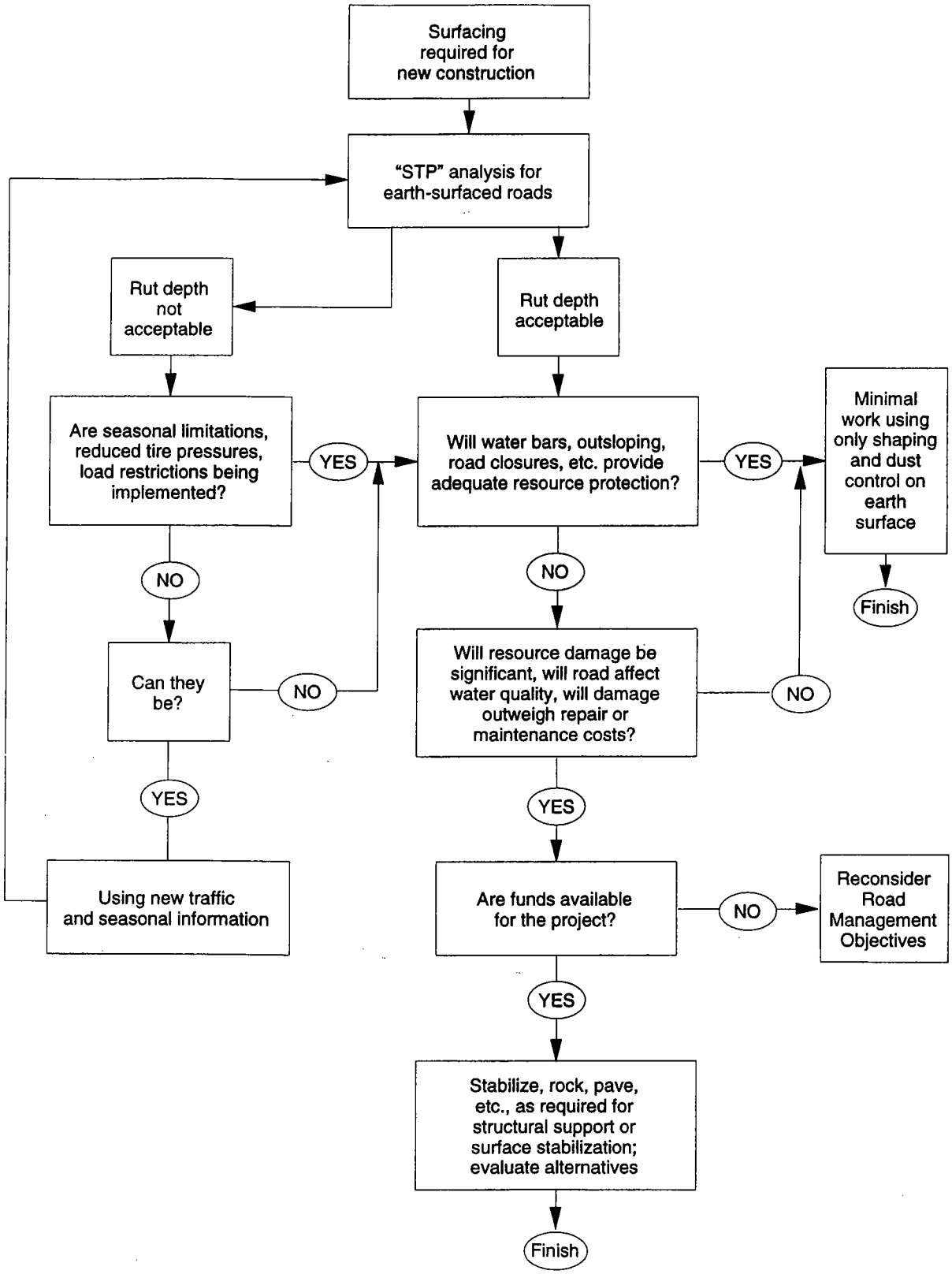


Figure 2.5-1.—Surfacing decision flowchart.

Chapter 3
Surfacing Design Considerations

This chapter covers much of the information needed to perform a pavement design. This includes;

- the design algorithm;
- how to model traffic;
- the design performance criteria;
- how to model earth and aggregate materials; and
- how to utilize life-cycle costs in the design.

3.1 Design Algorithm for "STP"

3.1.1 Design Equation

The algorithm selected for use in "STP" was developed by the U.S. Army Corps of Engineers in 1978.[6] Existing rutting data at the Waterways Experiment Station for gravel-surfaced, earth, and flexible pavements were utilized to develop deterioration and reliability models. A model was developed for aggregate-surfaced roads and was selected for use by the Forest Service, as discussed in chapter 1. The equation is based upon three factors. These are: traffic (expressed as equivalent single wheel load (ESWL)), tire pressure, number of repetitions, performance (expressed as rut depth and reliability), and strength of the subgrade and surface material (expressed as their respective CBR value). The equation is shown below:

$$RD = 0.1741 \frac{P_k^{0.4704} \; t_p^{0.5695} \; R^{0.2476}}{(\log t)^{2.002} \; C_1^{0.9335} \; C_2^{0.2848}} \qquad \text{(Eq. 3.1.1-1)}$$

where:

RD = rut depth, inches
P_k = equivalent single-wheel load (ESWL), kips
t_p = tire pressure, psi
t = thickness of top layer, inches
R = repetitions of load or passes
C_1 = CBR of top layer
C_2 = CBR of subgrade layer

Since the standard axle is an 18-kip ESAL (ESWL = 8.64 kips, appendix 6.2.5) with tire pressures of 80 psi, equation 3.1.1-1 may be further simplified to:

$$RD = 0.1741 \frac{(8.64^k)^{0.4704} \ (80 \text{ psi})^{0.5695} \ R^{0.2476}}{(\log t)^{2.002} \ C_1^{0.9335} \ C_2^{0.2848}}$$

(aggregate roads only)

$$RD = 5.8230 \frac{R^{0.2476}}{(\log t)^{2.002} \ C_1^{0.9335} \ C_2^{0.2848}} \qquad \text{(Eq. 3.1.1-2)}$$

Rut depth was selected as the failure criterion and is expressed as a function of load, tire pressure, number of passes or repetitions of axle loads, surface thickness, and layer material strengths. This is consistent with most other design procedures for aggregate-surfaced and earth roads.[5] Different combinations of aggregate layer thicknesses, soil strengths, and number of passes may be used to calculate rut depths.

The same equation (3.1.1-1) is used for the design of earth-surfaced roads with one modification. Although an unsurfaced model was also developed by the Corps of Engineers, it used the assumption that the top layer was actually weaker than the bottom layer. The rationale was that the upper portion may be adversely affected by moisture and organic materials in a military situation. However, for Forest Service conditions, it is expected that compaction from construction traffic and trucks would offset these effects. Therefore, the Corps of Engineers model was not selected. The modification to equation 3.1.1-2 assumes the thickness (t) of an earth road is 6 inches. This is estimated to be the depth of compaction that would occur during construction. Therefore, the design algorithm may be further simplified for earth roads to:

$$RD = 5.8230 \frac{R^{0.2476}}{(\log 6")^{2.002} \ C_1^{0.9335} \ C_2^{0.2848}}$$

(earth roads only)

$$RD = 9.6213 \frac{R^{0.2476}}{C_1^{0.9335} \ C_2^{0.2848}} \qquad \text{(Eq. 3.1.1-3)}$$

where: C_1 = CBR of compacted subgrade.
C_2 = CBR of uncompacted subgrade.

Typically, C_1 will be the value of a soil that has been compacted to 90 percent of AASHTO T-99, while that for C_2 will be 85 percent of AASHTO T-99.

The remainder of this chapter discusses obtaining the above variables in much greater detail.

3.1.2 Practical Range of Input Values

Due to the algorithm used, the design method presented in the *Surfacing Design Guide* has some limitations on the acceptable range for input variables. Use of values outside the indicated acceptable ranges may lead to design errors. Following are some input value ranges that should yield acceptable results:

Timber volume:	0.03 to 89 MMBF*
% Non-truck traffic:	0 to 100
Total 18 kip ESAL's:	20 to 70,000*
Surface CBR (C_1):	20 to 100
Subgrade CBR (C_2):	3 to 30
C_1/C_2 ratio:	1 to 7
Allowable rut depth:	Maximum of 1/2 the structural thickness

** Note: The algorithm used for the design method presented was based on a maximum of 70,000 total 18-kip ESAL's (equates to approximately 89 MMBF assuming a single-lane road, tire pressures at 80 psi, 0.005 MMBF per log truck, equivalency factor for loaded log truck of 3.17, and an unloaded log truck of 0.76). With traffic greater than this amount, variables other than rut depth may dictate structural thickness. These variables could be the timing and method of road maintenance or aggregate material properties. See example 5.4.2 for designing for a situation where there is greater than 70,000 18 kip ESAL's.*

3.2 Traffic

The most important factor to be evaluated in the selection of surfacing material and material thickness of any roadway is the effect of vehicle loads. The vehicle type, traffic volume, and mode of operation all affect the road condition. A wheel load from any vehicle causes pressure in the vertical and horizontal directions. Vertical pressures are due to the weight of the vehicle and the nature of the vehicle bounce. The horizontal pressures are due to the horizontal alignment in conjunction with the vehicles speed, braking, tire traction, tire slip, and the vehicle bounce. Tire and axle loads, wheel configuration, and tire pressures also contribute to the vertical and horizontal pressures exerted on the road surface. The effect of all traffic loading is cumulative on the road surface.

3.2.1 Traffic Analysis Parameters

The following information is necessary to determine the design traffic:

- Anticipated traffic mix and vehicle types. This should include any traffic that might be associated with Forest Service management: range allotments, mining or oil and gas, logging, construction, recreation, etc. Each class of vehicle needs to be identified and expected traffic volumes determined in the analysis.

- Special, unique/large vehicles need to be identified. If large yarders are going to be moved over the road, then exact vehicle information needs to be gathered. This would include the make and model of the vehicle. From this information, axle configuration and loading can be determined for use in the analysis. Note: unless special rules dictate, all vehicles should comply with state legal load, axle, and tire requirements.

- The expected dates (season) for traffic and special vehicles.

- Number of traffic lanes. For most Forest Service roads, traffic occurs on a single-lane road, so traffic actually occurs twice over the road. With commercial traffic the vehicles may travel once empty and once loaded. On double-lane roads the traffic only occurs once per lane. The analysis lane should be the lane that includes the loaded commercial vehicles.

3.2.2 Tire Pressure Management

Research has shown that the reduction of hauling vehicle tire pressures can have a major effect in reducing the required depth of surfacing, on the frequency of road maintenance blading, and the amount of sediment produced on aggregate surfaces (7, 8, 14). Figures 3.2-5 through 3.2-10 will assist the designer in obtaining equivalency factors when using different tire pressures.

Typical reduced tire pressure scenarios include: (1) 70 psi on all tires; and (2) for western style log trucks, 64 psi for the steering axle tires and 52 psi for all other tires when the truck is loaded and when unloaded; 64 psi for the steering axle tires and 25 psi for the drive axle tires. There have been projects where pressures have been 25 psi for the steering axle tire pressures. Tire and Rim manufacturers' recommendations for tire pressure and travel speed should be followed when considering reduced tire pressures.

3.2.3 Traffic Analysis

Most traffic analysis procedures used in the United States for highway pavements employ a standard axle type to account for the cumulative nature of the above factors. In this *Surfacing Design Guide*, the 18-kip equivalent single-axle load (ESAL) with a tire pressure of 80 psi has been selected as the standard axle type. This is compatible with the design procedures of many State and Federal agencies in the United States. Based on these standards, all vehicle types can be converted to ESAL's and totaled to provide a cumulative impact produced by the different vehicle types anticipated.

Figures 3.2-1 through 3.2-5 present the equivalency factors for various axle loads and wheel configurations (5). The figures are for tire pressures of 25, 50, 70, 80, and 100 psi respectively. An axle may be single or tandem. Each axle may have single or dual tires. Tandem axles, where two axles are separated by more than 96 inches, are generally classified as two single axles. Figure 3.2-7 summarizes various vehicles

and their equivalency compared to a passenger car when using the above figures.

Appendix 6.2.5 describes the procedure to calculate these vehicle equivalencies when unusual axle loads are present. A standard log truck with two tandem axles of 35 kips each, a steering axle of 10 kips, (single axle, single wheel) all at a tire pressure of 80 psi (see figure 3.2-4) would have an equivalency factor of:

$$2(1.36) + 0.45 = 3.17$$

Chapters 4 and 5 contain examples using these equivalency factors for design. Typically, 800 18-kip single-axle loads (18k SAL's) are generated per million board feet (MMBF) of timber using western-style log trucks at 80 psi. In using the *Surfacing Design Guide*, generally a conversion factor of 5,000 board feet (MBF) to one standard log truck is used. In addition, on single-lane roads a 25 percent non-log truck factor is used to account for empty log truck traffic and non-log truck traffic such as recreational and administrative traffic. When known, the actual traffic mix percentages should be used.

Figure 3.2-6 is included for information on trucks with triple axles. This figure is from the AASHTO Guide (4). The equivalencies were developed for *flexible* pavements and a terminal serviceability index of 2.0. The U.S. Army Corps of Engineers did not develop any curves for triple-axle trucks.

Final outcome of the traffic analysis would include the total 18-kip ESAL's per season. The following form may be an aid in the development of the total number of 18-kip ESAL's.

Road Number: _____
Station or Mile Post Location: _____ to _____
Single or Double Lane: _____

Season Dates	Vehicle Type	Vehicle ESAL	Number of Vehicle Reps	Sum of ESAL's per vehicle
_____	_____	_____	_____	_____
_____	_____	_____	_____	_____
_____	_____	_____	_____	_____
_____	_____	_____	_____	_____
	Total ESAL for Season =			_____

Season Dates	Vehicle Type	Vehicle ESAL	Number of Vehicle Reps	Sum of ESAL's per vehicle
_____	_____	_____	_____	_____
_____	_____	_____	_____	_____
_____	_____	_____	_____	_____
_____	_____	_____	_____	_____
	Total ESAL for Season =			_____

Total ESAL for all Seasons = _____

Single Axle Single Wheel (kips)	Equivalency Factor	Tandem Axle Dual Wheels (kips)	Equivalency Factor	Tandem Axle Dual Wheels (kips)	Equivalency Factor	Tandem Axle Dual Wheels (kips)	Equivalency Factor
2	0.00	10	0.01	50	0.18	90	0.56
4	0.01	11	0.01	51	0.19	91	0.57
6	0.01	12	0.01	52	0.20	92	0.59
8	0.02	13	0.01	53	0.21	93	0.60
10	0.03	14	0.02	54	0.21	94	0.61
12	0.04	15	0.02	55	0.22	95	0.62
14	0.06	16	0.02	56	0.23	96	0.64
16	0.08	17	0.02	57	0.24	97	0.65
18	0.10	18	0.03	58	0.24	98	0.66
20	0.12	19	0.03	59	0.25	99	0.67
22	0.14	20	0.03	60	0.26	100	0.69
24	0.16	21	0.04	61	0.27	101	0.70
26	0.19	22	0.04	62	0.28	102	0.71
28	0.22	23	0.04	63	0.29	103	0.73
30	0.25	24	0.05	64	0.29	104	0.74
32	0.28	25	0.05	65	0.30	105	0.75
34	0.32	26	0.05	66	0.31	106	0.77
36	0.36	27	0.06	67	0.32	107	0.78
38	0.39	28	0.06	68	0.33	108	0.80
40	0.44	29	0.07	69	0.34	109	0.81
Single Axle Dual Wheels (kips)	Equivalency Factor	30	0.07	70	0.35	110	0.82
		31	0.07	71	0.36	111	0.84
		32	0.08	72	0.37	112	0.85
		33	0.08	73	0.38	113	0.87
		34	0.09	74	0.39	114	0.88
1	0.00	35	0.09	75	0.40	115	0.90
2	0.00	36	0.10	76	0.41	116	0.91
5	0.01	37	0.10	77	0.42	117	0.93
8	0.01	38	0.11	78	0.43	118	0.94
10	0.02	39	0.11	79	0.44	119	0.96
15	0.05	40	0.12	80	0.45	120	0.97
20	0.08	41	0.13	81	0.46	121	0.99
25	0.13	42	0.13	82	0-.47	122	1.00
30	0.18	43	0.14	83	0.48	123	10.2
35	0.24	44	0.14	84	0.49	124	1.03
40	0.31	45	0.15	85	0.50	125	1.05
45	0.39	46	0.16	86	0.52	126	1.07
50	0.48	47	0.16	87	0.53	127	1.08
55	0.58	48	0.17	88	0.54	128	1.10
60	0.68	49	0.18	89	0.55	129	1.12

Figure 3.2-1.—Equivalency factors for the pressures of 25 psi.

Single Axle Single Wheel (kips)	Equivalency Factor	Tandem Axle Dual Wheels (kips)	Equivalency Factor	Tandem Axle Dual Wheels (kips)	Equivalency Factor	Tandem Axle Dual Wheels (kips)	Equivalency Factor
2	0.01	10	0.04	50	0.91	90	2.77
4	0.03	11	0.05	51	0.94	91	2.83
6	0.06	12	0.06	52	0.98	92	2.89
8	0.10	13	0.07	53	1.01	93	2.95
10	0.15	14	0.08	54	1.05	94	3.01
12	0.22	15	0.09	55	1.09	95	3.07
14	0.29	16	0.10	56	1.13	96	3.13
16	0.38	17	0.12	57	1.16	97	3.20
18	0.47	18	0.13	58	1.20	98	3.26
20	0.57	19	0.14	59	1.24	99	3.32
22	0.69	20	0.16	60	1.28	100	3.39
24	0.81	21	0.17	61	1.32	101	3.45
26	0.95	22	0.19	62	1.37	102	3.52
28	1.09	23	0.21	63	1.41	103	3.58
30	1.24	24	0.22	64	1.45	104	3.65
32	1.40	25	0.24	65	1.49	105	3.71
34	1.57	26	0.26	66	1.54	106	3.78
36	1.75	27	0.28	67	1.58	107	3.85
38	1.94	28	0.30	68	1.63	108	3.92
40	2.14	29	0.32	69	1.67	109	3.99
Single Axle Dual Wheels (kips)	Equivalency Factor	30	0.34	70	1.72	110	4.06
		31	0.37	71	1.77	111	4.13
		32	0.39	72	1.81	112	4.20
		33	0.41	73	1.86	113	4.27
		34	0.44	74	1.91	114	4.34
1	0.00	35	0.46	75	1.96	115	4.41
2	0.01	36	0.49	76	2.01	116	4.49
5	0.03	37	0.51	77	2.06	117	4.56
8	0.07	38	0.54	78	2.11	118	4.64
10	0.11	39	0.57	79	2.16	119	4.71
15	0.24	40	0.59	80	2.22	120	4.79
20	0.41	41	0.62	81	2.27	121	4.86
25	0.63	42	0.65	82	2.32	122	4.94
30	0.90	43	0.68	83	2.38	123	5.02
35	1.20	44	0.71	84	2.43	124	5.09
40	1.55	45	0.74	85	2.49	125	5.17
45	1.93	46	0.77	86	2.54	126	5.25
50	2.36	47	0.81	87	2.60	127	5.33
55	2.83	48	0.84	88	2.66	128	5.41
60	3.34	49	0.87	89	2.71	129	5.49

Figure 3.2-2.—Equivalency factors for the pressures of 50 psi.

Single Axle Single Wheel (kips)	Equivalency Factor	Tandem Axle Dual Wheels (kips)	Equivalency Factor	Tandem Axle Dual Wheels (kips)	Equivalency Factor	Tandem Axle Dual Wheels (kips)	Equivalency Factor
2	0.02	10	0.09	50	1.97	90	6.01
4	0.06	11	0.11	51	2.04	91	6.14
6	0.13	12	0.13	52	2.12	92	6.26
8	0.22	13	0.15	53	2.20	93	6.39
10	0.33	14	0.18	54	2.28	94	6.53
12	0.47	15	0.20	55	2.36	95	6.66
14	0.63	16	0.23	56	2.44	96	6.79
16	0.82	17	0.25	57	2.52	97	6.93
18	1.02	18	0.28	58	2.61	98	7.06
20	1.25	19	0.31	59	2.69	99	7.20
22	1.49	20	0.34	60	2.78	100	7.34
24	1.76	21	0.38	61	2.87	101	7.48
26	2.05	22	0.41	62	2.96	102	7.62
28	2.36	23	0.45	63	3.05	103	7.76
30	2.69	24	0.49	64	3.14	104	7.91
32	3.04	25	0.53	65	3.24	105	8.05
34	3.41	26	0.57	66	3.33	106	8.20
36	3.80	27	0.61	67	3.43	107	8.35
38	4.22	28	0.65	68	3.53	108	8.50
40	4.65	29	0.70	69	3.63	109	8.65
Single Axle Dual Wheels (kips)	Equivalency Factor	30	0.75	70	3.73	110	8.80
		31	0.79	71	3.83	111	8.95
		32	0.84	72	3.93	112	9.10
		33	0.89	73	4.04	113	9.26
		34	0.95	74	4.14	114	9.41
1	0.00	35	1.00	75	4.25	115	9.57
2	0.01	36	1.05	76	4.36	116	9.73
5	0.06	37	1.11	77	4.47	117	9.89
8	0.16	38	1.17	78	4.58	118	10.05
10	0.24	39	1.23	79	4.69	119	10.21
15	0.52	40	1.29	80	4.80	120	10.38
20	0.90	41	1.35	81	4.92	121	10.54
25	1.37	42	1.41	82	5.03	122	10.71
30	1.94	43	1.48	83	5.15	123	10.88
35	2.60	44	1.54	84	5.27	124	11.05
40	3.35	45	1.61	85	5.39	125	11.22
45	4.19	46	1.68	86	5.51	126	11.39
50	5.12	47	1.75	87	5.63	127	11.56
55	6.14	48	1.82	88	5.76	128	11.73
60	7.24	49	1.89	89	5.88	129	11.91

Figure 3.2-3.—Equivalency factors for the pressures of 70 psi.

Single Axle Single Wheel (kips)	Equivalency Factor
2	0.02
4	0.08
6	0.17
8	0.30
10	0.45
12	0.64
14	0.86
16	1.11
18	1.39
20	1.69
22	2.03
24	2.39
26	2.79
28	3.21
30	3.66
32	4.14
34	4.64
36	5.17
38	5.73
40	6.32

Single Axle Dual Wheels (kips)	Equivalency Factor
1	0.00
2	0.02
5	0.09
8	0.21
10	0.33
15	0.71
20	1.22
25	1.87
30	2.64
35	3.54
40	4.56
45	5.70
50	6.97
55	8.35
60	9.85

Tandem Axle Dual Wheels (kips)	Equivalency Factor	Tandem Axle Dual Wheels (kips)	Equivalency Factor	Tandem Axle Dual Wheels (kips)	Equivalency Factor
10	0.13	50	2.67	90	8.17
11	0.15	51	2.78	91	8.34
12	0.18	52	2.88	92	8.52
13	0.21	53	2.99	93	8.69
14	0.24	54	3.10	94	8.87
15	0.27	55	3.20	95	9.05
16	0.31	56	3.32	96	9.23
17	0.34	57	3.43	97	9.42
18	0.38	58	3.55	98	9.60
19	0.43	59	3.66	99	9.79
20	0.47	60	3.78	100	9.98
21	0.51	61	3.90	101	10.17
22	0.56	62	4.02	102	10.36
23	0.61	63	4.15	103	10.56
24	0.66	64	4.27	104	10.75
25	0.72	65	4.40	105	10.95
26	0.77	66	4.53	106	11.15
27	0.83	67	4.66	107	11.35
28	0.89	68	4.80	108	11.55
29	0.95	69	4.93	109	11.75
30	1.01	70	5.07	110	11.96
31	1.08	71	5.21	111	12.17
32	1.15	72	5.35	112	12.38
33	1.21	73	5.49	113	12.59
34	1.29	74	5.63	114	12.80
35	1.36	75	5.78	115	13.01
36	1.43	76	5.92	116	13.23
37	1.51	77	6.07	117	13.45
38	1.59	78	6.22	118	13.67
39	1.67	79	6.38	119	13.89
40	1.75	80	6.53	120	14.11
41	1.83	81	6.69	121	14.33
42	1.92	82	6.84	122	14.56
43	2.01	83	7.00	123	14.79
44	2.10	84	7.17	124	15.02
45	2.19	85	7.33	125	15.25
46	2.28	86	7.49	126	15.48
47	2.38	87	7.66	127	15.72
48	2.47	88	7.83	128	15.95
49	2.57	89	8.00	129	16.19

Figure 3.2-4.—Equivalency factors for the pressures of 80 psi.

Single Axle Single Wheel (kips)	Equivalency Factor
2	0.04
4	0.13
6	0.29
8	0.50
10	0.76
12	1.07
14	1.44
16	1.85
18	2.32
20	2.83
22	3.39
24	4.00
26	4.66
28	5.36
30	6.11
32	6.91
34	7.75
36	8.64
38	9.58
40	10.56

Single Axle Dual Wheels (kips)	Equivalency Factor
1	0.01
2	0.03
5	0.15
8	0.36
10	0.55
15	1.18
20	2.04
25	3.12
30	4.41
35	5.91
40	7.62
45	9.53
50	11.64
55	13.95
60	16.45

Tandem Axle Dual Wheels (kips)	Equivalency Factor
10	0.21
11	0.25
12	0.30
13	0.35
14	0.40
15	0.45
16	0.51
17	0.58
18	0.64
19	0.71
20	0.78
21	0.86
22	0.94
23	1.02
24	1.11
25	1.20
26	1.29
27	1.39
28	1.48
29	1.59
30	1.69
31	1.80
32	1.91
33	2.03
34	2.15
35	2.27
36	2.39
37	2.52
38	2.65
39	2.79
40	2.92
41	3.06
42	3.21
43	3.35
44	3.50
45	3.66
46	3.81
47	3.97
48	4.13
49	4.30

Tandem Axle Dual Wheels (kips)	Equivalency Factor
50	4.47
51	4.64
52	4.81
53	4.99
54	5.17
55	5.35
56	5.54
57	5.73
58	5.92
59	6.12
60	6.32
61	6.52
62	6.72
63	6.93
64	7.14
65	7.35
66	7.57
67	7.79
68	8.01
69	8.24
70	8.47
71	8.70
72	8.93
73	9.17
74	9.41
75	9.65
76	9.90
77	10.15
78	10.40
79	10.65
80	10.91
81	11.17
82	11.44
83	11.70
84	11.97
85	12.24
86	12.52
87	12.80
88	13.08
89	13.36

Tandem Axle Dual Wheels (kips)	Equivalency Factor
90	13.65
91	13.94
92	14.23
93	14.53
94	14.82
95	15.12
96	15.43
97	15.73
98	16.04
99	16.36
100	16.67
101	16.99
102	17.31
103	17.64
104	17.96
105	18.29
106	18.62
107	18.96
108	19.30
109	19.64
110	19.98
111	20.33
112	20.68
113	21.03
114	21.38
115	21.74
116	22.10
117	22.47
118	22.83
119	23.20
120	23.57
121	23.95
122	24.33
123	24.71
124	25.09
125	25.47
126	25.86
127	26.25
128	26.65
129	27.05

Figure 3.2-5.—Equivalency factors for the pressures of 100 psi.

Axle Load (kips)	Pavement Structural Number					
	1	2	3	4	5	6
2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
4	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
6	0.0004	0.0004	0.0003	0.0003	0.0003	0.0003
8	0.0009	0.0010	0.0009	0.0008	0.0007	0.0007
10	0.002	0.002	0.002	0.002	0.002	0.001
12	0.004	0.004	0.004	0.003	0.003	0.003
14	0.006	0.007	0.007	0.006	0.006	0.005
16	0.010	0.012	0.012	0.010	0.009	0.009
18	0.016	0.019	0.019	0.017	0.015	0.015
20	0.024	0.029	0.029	0.026	0.024	0.023
22	0.034	0.042	0.042	0.038	0.035	0.034
24	0.049	0.058	0.060	0.055	0.051	0.048
26	0.068	0.080	0.083	0.077	0.071	0.068
28	0.093	0.107	0.113	0.105	0.098	0.094
30	0.125	0.140	0.149	0.140	0.131	0.126
32	0.164	0.182	0.194	0.184	0.173	0.167
34	0.213	0.233	0.248	0.238	0.225	0.217
35	0.273	0.294	0.313	0.303	0.288	0.279
38	0.346	0.368	0.390	0.381	0.364	0.353
40	0.434	0.456	0.481	0.473	0.454	0.443
42	0.538	0.560	0.587	0.580	0.561	0.548
44	0.662	0.682	0.710	0.705	0.686	0.673
46	0.807	0.825	0.852	0.849	0.831	0.818
48	0.976	0.992	1.015	1.014	0.999	0.987
50	1.17	1.18	1.20	1.20	1.19	1.18
52	1.40	1.40	1.42	1.42	1.41	1.40
54	1.66	1.66	1.66	1.66	1.66	1.66
56	1.95	1.95	1.93	1.93	1.94	1.94
58	2.29	2.27	2.24	2.23	2.25	2.27
60	2.67	2.64	2.59	2.57	2.60	2.63
62	3.10	3.06	2.98	2.95	2.99	3.04
64	3.59	3.53	3.41	3.37	3.42	3.49
66	4.13	4.05	3.89	3.83	3.90	3.99
68	4.73	4.63	4.43	4.34	4.42	4.54
70	5.40	5.28	5.03	4.90	5.00	5.15
72	6.15	6.00	5.68	5.52	5.63	5.82
74	6.97	6.79	6.41	6.20	6.33	6.56
76	7.88	7.67	7.21	6.94	7.08	7.36
78	8.88	8.63	8.09	7.75	7.90	8.23
80	9.98	9.69	9.05	8.63	8.79	9.18
82	11.2	10.8	10.1	9.6	9.8	10.2
84	12.5	12.1	11.2	10.6	10.8	11.3
86	13.9	13.5	12.5	11.8	11.9	12.5
88	15.5	15.0	13.8	13.0	13.2	13.8
90	17.2	16.6	15.3	14.3	14.5	15.2

Figure 3.2-6.—Axel load equivalency factors pavements, triple axles and pt of 2.0.

Type of Vehicle	Equivalency to* passenger car	Tire pressure	Notes
Passenger vehicle 4K	1	30	
Passenger vehicle 4K	3	50	
Pickup 8K	20	70	
Service vehicle 10K	32	70	
Dump truck empty 26K	127	80	10/16 wt distr
Dump truck loaded 45K	195	80	10/35 wt distr
Empty log truck 26K	127	80	
Empty log truck	167	90	
Empty log truck	48	64,25	CTI 10/16
Standard log truck 80K	213	64,52,52	CTI 10/35/35
Standard log truck	178	50	
Standard log truck	325	70	
Standard log truck	528	80	
Standard log truck	693	90	
Standard log truck	883	100	
Off highway log truck 108K	317	50	
Off highway log truck	572	70	
Off highway log truck	930	80	
Off highway log truck	1555	100	

Source of Equivalencies: "Aggregate Surfacing Design Guide," Feb. 1990.

*Note: 'Equivalency to passenger car' is a structural equivalency and is not related to surfacing loss due to traffic.

Figure 3.2-7.—Relative equivalencies for gravel-surfaced and earth-surfaced single-lane roads.

3.3 Surfacing Design Performance Criteria

3.3.1 Performance

The performance of a road surface is generally thought of in terms of deterioration over time due to traffic volumes and loadings, weathering, and the type, quality, and frequency of road maintenance. This degradation is noticed by most as changes in the characteristics of the road's surface. Road users consider smoothness (potholes and wash-boarding) and the resulting vehicle speed as indicators of performance. Those who maintain the road judge performance in terms of surface wear loss rates, rutting/structural failure, amount of dusting, gradeability, and surface defects such as wash-boarding and potholing. Yet those who design the structural thickness necessary to carry the traffic do so according to a "serviceability index."

3.3.2 Serviceability

First, in all surfacing design methods there is a limit (terminal condition) after which reconstruction or maintenance is necessary. This point is the lowest serviceability that the manager or designer is willing to accept (called terminal serviceability). For aggregate and native-surfaced roads, rut depth has been selected as the defining criteria for serviceability index. For native-surfaced roads, terminal serviceability is assumed to be reached when the rut depth reaches 6 inches, unless resource considerations dictate otherwise. *For aggregate-surfaced roads, terminal serviceability occurs when the rut depth reaches 2 inches or when the rut depth exceeds one-half the aggregate thickness, unless resource considerations dictate otherwise.* These conditions may or may not indicate failure of the surfacing material. For certain situations, the manager or designer may accept a terminal serviceability rut depth greater than 2 inches and at other times a 2-inch rut may be unacceptable.

3.3.3 Rut Depth

Rut depth criteria is used as a determination of surface serviceability and as such should be selected with care. It is assumed that terminal serviceability occurs in an aggregate-surfaced road with a 2-inch rut. Rut depth is determined by measuring from the bottom of rut, in the wheel track, with the bottom of a straight edge placed across the "upheaval" or material displaced in the formation of the rut. The maximum depth should be held to less than one-half the structural thickness. Following are some items that should be kept in mind when selecting an allowable rut depth.

For the designer to understand the use of rut depth criteria, the process of rut development needs to be understood. Traffic over an aggregate-surfaced road will create ruts. First the ruts occur in the surfacing material, the material placed over the subgrade necessary for structural support. If road maintenance is not frequent or timely, the ruts collect water. This reduces surface drainage, leading to surface saturation and lower strength, which further exacerbates the problem. Eventually the remaining structural thickness at the bottom of the rut is insufficient to

handle the traffic loads and still keep the subgrade from rutting. If the situation is not corrected, the surface will fail prematurely with deformation of the subgrade.

Recent studies have shown that very little rutting takes place in the subgrade, with aggregate surfacing, if care is taken to ensure surface rutting is not allowed to progress to a critical depth (8). Though this is true for high strength subgrades for roads constructed with aggregate surfacing over low strength subgrades, it has been shown that there is a high probability that surface rutting will reflect significantly into the subgrade with less than 6 inches of aggregate. Once significant deformation of subgrade soils takes place, there is a corresponding drop in soil strength and subsequent loss in the ability of the subgrade to support traffic. Therefore, for lower strength subgrades, the greater the aggregate thickness, the less the deformation is likely to take place at the aggregate/subaggregate interface.

There are some road maintenance implications associated with rut development. As noted above, frequent road maintenance can eliminate surface ruts, thus preventing the collection of water and further rut development that can lead to premature failure.

Road surface rutting plays a big role in road surface erosion and sediment production. The ruts act like ditches, gathering and transporting water. This collected water creates other problems. It saturates the aggregate surfacing, lowering strength and increasing the chance of aggregate degradation while "floating" existing aggregate fines from the road surface. If the ruts are deep enough to contribute to saturation of the subgrade, then the potential for potholes, subgrade failure, and the pumping of soil to the surface is increased, thereby increasing road related sediment. The concentration of water also aggravates the potential for surface erosion due to higher surface water runoff velocities. When the water finally finds somewhere to leave the road, additional embankment erosion is highly probable.

3.3.4 Reliability

Pavement design reliability is defined as the probability that the project will perform as anticipated over the selected design period, given the variability of the design input variables. For example, if a 50 percent reliability level is selected, it means that the manager or designer is willing to accept rut depth greater than the design value over 50 percent of the project length before reaching the desired design life. This may be acceptable for low standard, local, service level D roads, but most likely would not be acceptable for service level B roads. Figure 3.3.4-1 provides guidelines in the selection of an appropriate reliability factor.

Reliability Level, percent	Traffic Service Level	Reliability Factor, F_r
50	D	1.00
70	C	1.44
90	B	2.32

Note: The default value in "STP" is 50 percent reliability which has a reliability factor of 1.00.

Figure 3.3.4-1.—Reliability factors for aggregate surfaced roads.

Note: Reliability is used in aggregate design, but not in earth surface design.

The reliability factor, F_r, is used to increase estimated traffic over the design life of the project. The effect this has on the analysis is to increase the required structural thickness to meet allowable rut depth criteria. Increasing the structural thickness for a given traffic volume and design life increases the probability of the project achieving the anticipated performance. Appendix 6.2.6 addresses the development of the reliability factor in detail.

3.3.5 Maintenance

The purpose of road maintenance is to keep the road surface at a predetermined condition (service level) during the life of the road. This includes maintaining the template necessary for adequate surface drainage. Timely road maintenance can greatly affect road surface performance over the anticipated design life. It can also remove the ruts, washboarding, and potholes, thereby returning the road surface to approximately pre-rutting condition. It must be noted that improper road maintenance can also shorten the surfacing life by removing or loosening the aggregate rather than reshaping the road surface. The exact relationship between road maintenance, timing, and surfacing life has not been studied in the United States. The World Bank Organization has a recently developed model, but it has not been incorporated into the aggregate or native surface design algorithm.

Road management considerations, in terms of operation and maintenance, should be consistent from design through operation of the facility. For example, if the road was designed for "dry" season conditions and the road was left open for all season use, then the actual surfacing performance may not match expected surfacing performance. Therefore, it is extremely important to establish RMO's, operational procedures, and design variables that are consistent with those chosen objectives and operational procedures.

It is important to note that proper blading to eliminate ruts should increase the traffic volume at which the design rut will develop and, as such, provide a higher reliability level at the end of the design traffic.

3.3.6 Operational Loss

Operational loss can be defined as the aggregate thickness expected to be lost or damaged during the operation of the road (in the past this loss was called wear rate, surfacing loss before replacement, or aggregate loss; see FSH 7709.58 and old Chapter 50, FSH 7709.55). This thickness is added to the structural thickness determined by "STP" to determine the total thickness of aggregate necessary to met the road's objectives. Structural thickness is the thickness of surfacing necessary to support anticipated traffic during the anticipated analysis period.

Considerable judgment is required to select the operational loss for site-specific conditions in that there have not been any well-controlled studies. Historically, predicted operational losses were based on local experience over a wide range of conditions. Blading frequency, surface gradation, vehicle type and mix, snow plowing frequency, travel speed, and road alignment and grade need to be considered when making this judgment.

Historically, the operational thickness (surfacing loss) was estimated either 1 inch per 10 million board feet (MBF) of equivalent timber haul or was based upon equations from various references. Some specific factors influencing operational thickness and its relative effects are shown in table 3.3.6-1. These could be used to further refine the estimated 1-inch loss per equivalent 10 MMBF of timber haul, or locally determined operational loss. The table can be used as a checklist to guide the designer in determining an adjusted operational loss for site-specific conditions. Since road characteristics and conditions vary from site to site, there may be variations in the relative importance of each of the factors listed in table 3.3.6-1. They should be taken into account when determining the appropriate operational loss.

3.3.7 Reconstruction

A road *is not* expected to be "failed" or in a totally unserviceable condition after carrying the design traffic, but, rather, in an unacceptable condition. The surfacing material may be "worn" and/or the road template may be in a condition that would not meet future traffic needs.

The structural capacity and condition of the road should be evaluated near the end of the design traffic (design period). Based on this evaluation, the structural and operational aggregate requirements for the next design period can be determined. "STP" can be used to assist in this evaluation. Section 4.3.6 discusses the reconstruction design process in detail.

3.4 Specific Materials Characterization

General descriptions of the materials encountered in road construction are discussed in section 6.3. This section provides detailed information on the strength and drainage characteristics of those materials as they relate to pavement design.

Subgrade and aggregate strength may be measured using the California Bearing Ratio (CBR), soil resistance value (R-value), or resilient modulus (M_R) tests. The *Surfacing Design Guide* method used here adopts the CBR as the input to the design equation since the data supporting the

Table 3.3.6-1.—Variables having a relative effect on operational thickness.

VARIABLE	RELATIVE EFFECT ON OPERATIONAL THICKNESS		
	Reduction	Slight - None	Increase
Blading frequency	High	Medium	Low
Blading practices	Good	Moderate	Poor
Road moisture conditions during blading	Moist	Damp	Dry
Dust abatement	More than once/year	Once/year or water as needed	None
Surfacing gradation	Very dense (tight ban)	Surfacing gradation	Base gradation
Surfacing PI	6–9	3–5	0–2, > 9
Past surfacing wear rate	Low	Normal	High
Tire pressure	Low CTI	Reduced 65–79 psi	High 80–110 psi
Travel speed	< 10mph	11–24 mph	> 24 mph
Snow plowing	None	Once/year	More than once/year
Grade	< 8%	8–12%	> 12%
Percent truck traffic	< 25%	25–75%	> 75%
Typical alignment	Straight	Moderate to long radius curves	Short radius curves
Other	_____	_____	_____

chosen design algorithm is based upon CBR measurements. Correlation of CBR to other measurements of strength can be found in figure 3.4-5 and its associated reference.

3.4.1 Subgrade Soils

Subgrade soils and their expected moisture conditions can vary considerably along the project length. How the type of soil and moisture impact the strength and characteristics of the subgrade is addressed below. Due to these influences, it is important that the designer evaluate the soil conditions along the length of the project.

- Strength: Subgrade strength is dependent on the gradation, compaction, moisture content, and plasticity of the material. Typically an excellent subgrade can have a CBR approaching 30, while that of very soft subgrade material can be 2 or less. An excellent aggregate material can have a CBR approaching 100. Several methods may be employed to determine the CBR of subgrade materials:

  - field CBR's (includes field CBR or other field measuring devices correlated to field CBR);
  - laboratory CBR's (AASHTO T-193-92) (either soaked or unsoaked);
  - CBR correlations to soil classification (either local CBR values with similar soil origin, chemistry, or non-local CBR values obtained from soils of different origin).

The preferred method is to use field-obtained CBR values that equate to the time of year traffic will be using the road and to the corresponding density. Field CBR values can be obtained by a vehicle adapted to perform field CBR tests or by various field measuring devices correlated to field CBR measurements. The dynamic cone penetrometer (DCP) and the Clegg hammer (13) are two such devices. Appendix 6.4 addresses the use of the DCP in detail. The DCP has been used by various forests nationwide with good success. Its advantages are that it is portable, quick, and easy to use. Other uses of the DCP include locating relative weaker or stronger subgrade segments or evaluating changes in material strength through the year.

On roads yet to be built, the above field methods will not provide values that can be used for design since the subgrade is yet to be constructed. Another method to obtain CBR's is to sample materials and perform laboratory testing to obtain values for use in the surfacing thickness program. The laboratory CBR test should be performed according to AASHTO T-193. Again the laboratory tests should correspond to the expected field density. The DCP and Clegg hammer could be used to obtain expected minimum design values from nearby existing roads and help profile existing subsurface conditions.

If laboratory tests are not possible, the designer should look at past projects in the same area for historical CBR information. For example, Figure 3.4-1 presents a summary of historical laboratory-determined CBR data from the Willamette National Forest in the Pacific Northwest. The data presented here is applicable only to the Willamette's roads. It is strongly recommended that individual forests perform field studies to evaluate simple tools, such as the DCP, for estimating subgrade strength and summarizing for easy use by planners and road designers.

When past project information is not available, CBR values given in various engineering tables may be used. These values are generally for samples compacted to 100 percent of either AASHTO T-99 or T-180.

Figure 3.4-2 presents some guidelines that may be useful for the designer. These relationships were derived from Forest Service studies (1). However, the required or expected compaction may be considerably less, making adjustments necessary. If the DCP or the Clegg hammer is not used for existing roads, then the designer will have to make some judgment on the compaction level in the subgrade when using the above-mentioned tables. It is common to find subgrades compacted anywhere from 95 to 100 percent of AASHTO T-99 on existing roads that do not have seasonal frost penetration into the subgrade.

- Compaction. CBR values generally vary in a predictable manner with compaction or density. Values in figures 3.4-1 and 3.4-2 are based on various compaction efforts. Figure 3.4-1 is based on 90–95 percent compaction (AASHTO T-99), and Figure 3.4-2 is based on 85–100 percent compaction (T-99). For design purposes, it is necessary to use a CBR value that considers the variations in density and moisture that occur during and after construction. Forest Service specifications allow densities less than the laboratory maximum density (Forest Service Specifications [April 1985] Section 203.15(b)). They are estimated to be as follows:

Method 1.	Side Casting and End Dumping	80–85% AASHTO T-99
Method 2.	Layer Placement	85–90% AASHTO T-99
Method 3.	Layer Placement (Roller Compaction)	90–95% AASHTO T-99
Method 4.	Controlled Compaction	≥ 95% AASHTO T-99
Method 5.	Controlled Compaction Using Density Control Strips	90–95% AASHTO T-99
Method 6.	Special Project Controlled Compaction	≥ 95% AASHTO T-180 (for top foot) > 90% AASHTO T-180 (remaining layers)

Since the CBR test procedure (AASHTO T-193) requires a plot of CBR versus density, the designer has information with which to evaluate the effect of compaction on the design CBR. It should be noted that the standard CBR test is performed after a 96-hour soak. The CBR test procedure should be modified to match the expected/observed compaction and moisture conditions at the time of vehicle traffic. Note that these laboratory test values may not duplicate field-obtained CBR values, therefore engineering judgment and experience is necessary in these situations.

To efficiently compact a soil with the least construction equipment effort, one must use the proper equipment, have the soil at the optimum moisture content, and compact in limited lift thicknesses. For granular soils vibratory compactors are the most effective. Sheepsfoot rollers are best used on clayey soils. With these rollers, the ideal lift thickness is around 6 inches. Smooth drum rollers have limited effective depth and should be used where only thin layers or surface zones need to be compacted.

In some instances granular soils have a tendency to break down, creating fines when compacted with a steel wheel roller and lowering the

Unified Soil Classification System Classification	CBR (% of T – 99, soaked)			
	90%		95%	
	Range	Average	Range	Average
CH	1 – 4	2	2 – 5	3
CL	1 – 5	3	2 – 9	6
GC	–	6	–	13
GMd	1 – 16	5	5 – 54	14
GM – GC	–	1	–	8
GMu	1 – 22	5	2 – 40	11
GP	8 – 10	9	17 – 57	38
GP – GM	4 – 20	10	10 – 35	22
GW – GM	2 – 19	11	9 – 56	25
MH	1 – 8	3	1 – 14	6
ML	1 – 10	4	1 – 16	8
OL	–	2	–	5
SC	1 – 16	4	2 – 28	8
SMd	1 – 26	5	2 – 38	13
SM – SC	–	1	–	4
SMu	1 – 31	4	2 – 62	9
SP	–	9	–	11
SP – SM	1 – 9	5	13 – 19	16
SW – SM	1 – 17	8	3 – 31	14

Note: Data comes from Willamette National Forest and is site specific.

Figure 3.4-1.—Summary of historical laboratory CBR data from the Willamette National Forest.

Soil Classification	CBR Range[1]			
Cohesive Soils	85% T-99	90% T-99	95% T-99	100% T-99
GM_u	2.5 – 4	5 – 8	10 – 16	20 – 32
SM_u	1.0 – 2.5	2 – 5	4 – 10	8 – 20
ML	0.5 – 2.0	1 – 4	2 – 8	4 – 16
CL	0.5 – 2.0	1 – 4	2 – 8	4 – 16
OL	0.3 – 0.6	0.6 – 1.2	1.2 – 2.4	2.4 – 4.8
MH	0.5 – 2.0	1 – 4	2 – 8	4 – 16
CH	0.5 – 2.0	1 – 4	2 – 8	4 – 16
OH	0.3 – 0.6	0.6 – 1.2	1.2 – 2.4	2.4 – 4.8
Granular Soils				
GW	17 – 33	22 – 43	29 – 56	37 – 73
GP	13 – 25	17 – 33	22 – 42	29 – 55
SP	4 – 17	5 – 22	7 – 29	9 – 37
Intermediate Soils				
GM	8 – 12	14 – 20	23 – 35	39 – 59
GC	4 – 8	7 – 14	12 – 23	20 – 39
SM	3 – 8	5 – 14	9 – 23	15 – 39
SC	1 – 4	2 – 7	3 – 12	5 – 20

[1] The mean CBR value is taken as middle of the range. The standard deviation is taken as 1/4 of the range.

Notes: Other useful relationships are available:

1. Cohesive Soils – Multiply CBR values by 2.0 for each 5% increase in T-99 compaction above 85%. 95% of AASHTO T-180 maximum density is approximately equal to 100% of AASHTO T-99.
2. Granular and Base Soils – Multiply CBR values by 1.3 for each 5% increase in T-99 compaction above 85%. 97.5% of AASHTO T-180 is approximately equal to 100% of AASHTO T-99.
3. Intermediate Soils – Multiply CBR values by 1.7 for each 5% increase in T-99 compaction above 85%.

Source: USDA Forest Service, "Interim guide for Thickness Design of Flexible Pavement Structures," FSH 7709.11, Chapter 50, Region 6 Supplement No. 20, Portland, OR, January 1974 (p. 4, Table B) (Revised by USFS-R6, Jan 1991).

Figure 3.4-2.—Anticipated soil CBR range by Unified Soil Classification System.

permeability of the soil. This may be acceptable in some situations in that it may "seal" the top of the subgrade. This seal will occur when compacted on the dry side of optimum and the subgrade is not deformed during construction or with use. If the subgrade is crowned or outsloped, this seal can potentially reduce the amount of water infiltrating into the subgrade from the aggregate.

- Moisture: As noted above, moisture conditions in the subgrade can affect the subgrade strength. Coarse-grained soil CBR's are less susceptible to changes in moisture content than fine-grained soils. Below are ratios of CBR values showing the above mentioned trend based upon 95 percent compaction of AASHTO T-99, soaked for 96 hours and not soaked, both initially compacted at optimum moisture content.

Soil Type (USCS)	Average Unsoaked CBR/Soaked CBR
GW & GP	< 1.0
GM	1.2
SM	1.1
SMu & SC	1.4
ML & CL	1.1
MH & CH	1.8

  This information is from site-specific locations on the Willamette National Forest in the Pacific Northwest and is based on 150 CBR test comparisons. The above ratios could be even greater for the fine-grained soils if the comparison was made on unsoaked CBR's that had been initially compacted below or above optimum moisture.

- Seasonal Strength Variation: Aggregate thickness can be reduced by diverting most heavy traffic to drier seasons during the year. In addition, procedures have been developed in an attempt to refine aggregate thickness requirements by designing for seasonal traffic. To design accordingly, it is first necessary to develop relationships demonstrating the variation of percent saturation (relative proportion of water in the voids of the soil) in the subgrade through the year and the variation of CBR with respect to percent saturation. Once this has been performed, it is then possible to use this information to modify subgrade strength conditions at various times of the year.

  The number of seasons involves judgment and would be a function of the traffic pattern expected throughout the year and the variation in subgrade strength (subgrade saturation) during traffic. Typically the traffic pattern expected throughout the year is known and is based on the project needs and the RMO's. Subgrade saturation can vary throughout the year and depends on the road alignment, soil type, type and depth of surfacing, and most

importantly, the weather. FHWA studies are currently underway to determine the seasonal moisture variation of the subgrade and base under asphalt surfaced roads, but none address aggregate or earth surfaced roads. Variation in subgrade saturation should therefore be based on observation of local subgrade conditions or seasonal use of the DCP.

To design a road for which seasonal effects are a factor, Miner's Hypothesis is used. This is also known as the "linear summation of cycle ratios cumulative damage hypothesis," and permits an estimate of the damage to be made. It is expressed as:

$$\sum_{j=1}^{x} \frac{n_j}{N_j} \leq 1$$

where:

n_j = actual number of repetitions.
N_j = allowable number of repetitions.
j = number of seasons.

If the damage ratio is less than or equal to 1.0, this indicates that the road is adequate as designed. If the ratio exceeds 1.0, then a stronger structural section is required.

It is important to recognize that if this level of sophistication in the design is needed, laboratory or field determination of subgrade strength values is strongly recommended. Correlations with soil type or information gathered from other forests is not recommended.

3.4.2 Aggregates

- Strength: Base and surfacing aggregate strength is dependent on the gradation, particle shape, and to a lesser degree, the plasticity, compaction, and moisture content of the material. Laboratory determination of the CBR of aggregate materials is somewhat difficult because of the size of the aggregate particles. However, the strength of this surfacing layer is an important factor in determining the structural thicknesses required.

Several of the same methods used to obtain subgrade CBR's can be used to determine aggregate material CBR's. If laboratory or historical data is unavailable, figures 3.4-3, 3.4-4, and 3.4-5 may be used as guidelines regarding CBR values for use in the design algorithm. Figure 3.4-3 is reproduced from FSH 7709.11 Chapter 50, January 1974 and offers guidelines for the selection of an appropriate layer coefficient (a-value). The a-value expresses the relative ability of a material to function as a structural component of the pavement. Figure 3.4-3 has some guidelines for suitable a-values for different aggregate materials, such as 0.06 for cinders or 0.08 for fractured rock. Additional coefficients may be

AGGREGATE BASE (a_2) AND SURFACING (a_1) (UNTREATED)

Use Base Coefficient 0.06 for Cinders; 0.07 for S & G; 0.08 for Fractured Rock

Additional Coefficient	Plasticity			Quality	Grading			
					Pass 200		Pass 4	Pass 1.5"
	S.E.	P.I.					Base and	Base and
	Base Only	Base	Surfacing		Base	Surfacing	Surfacing	Surfacing
+.01	>35	<6	2.9					
.00 .01 .02				Marginal Good Excellent				
.01					0-8	3-15		
.01							30-65	
.01								100

Note: 1. Coefficients based on compaction at 100% of AASHTO T-99.
2. Coefficients may be adjusted to other compaction levels by using the density and CBR relationships provided in figure 3.4-2, note 2.
3. Refer to Forest Service Specifications (April 85) section 304.10 for relationships of compaction level versus percent of AASHTO T-99.

Source: USDA Forest Service, "Interim Guide for Thickness Design of Flexible Pavement Structures," FSH 7709.11, Chapter 50, Region 6 Supplement No. 20, Portland, Oregon, January 1974.

Figure 3.4-3.—Guidelines for determining a-values for aggregate surfacing.

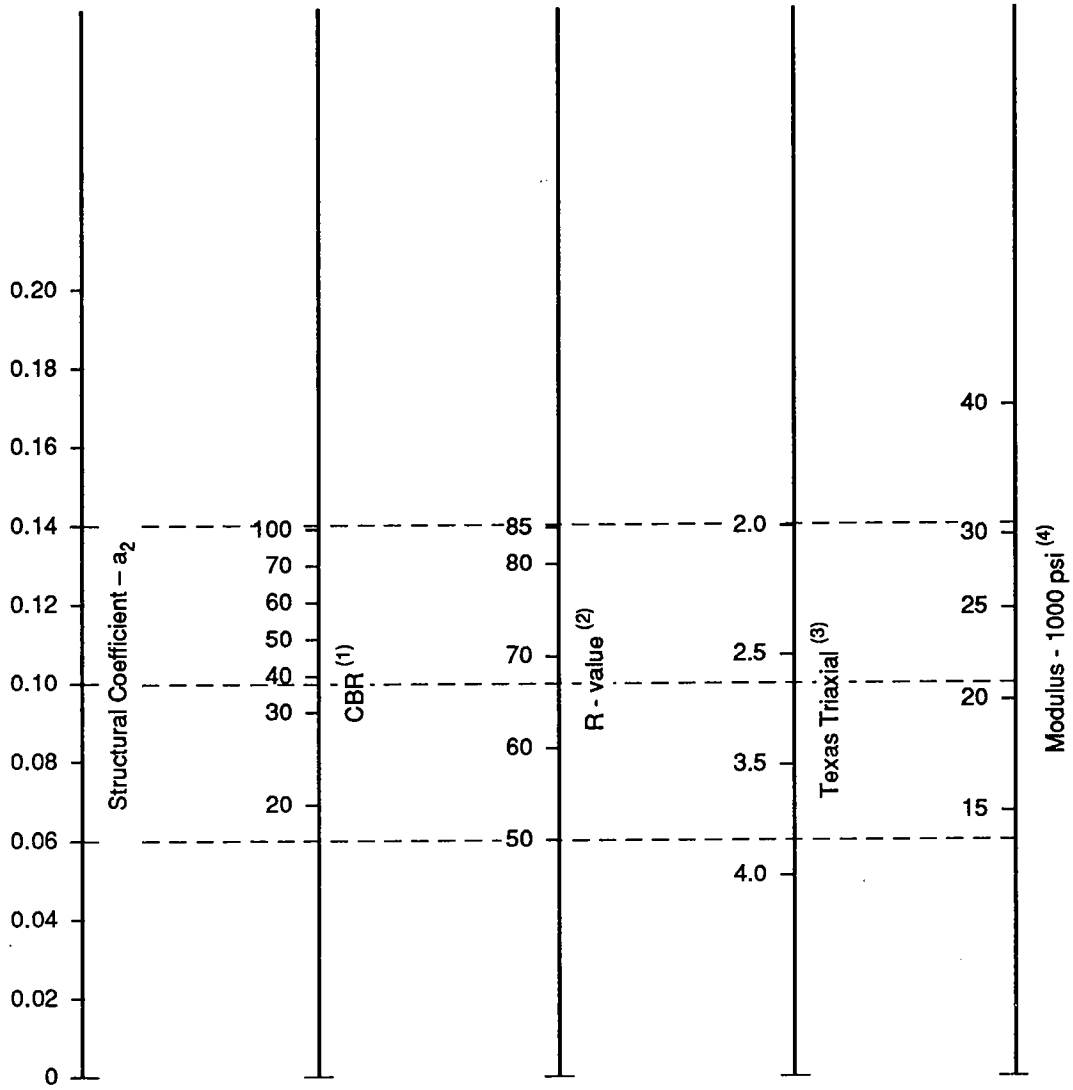
Percent of Time Pavement Structure is Exposed to Moisture Levels Approaching Saturation

Quality of Drainage[1]	Less than 1%	1-5%	5-25%	Greater than 25%
Excellent	1.40 – 1.35	1.35 – 1.30	1.30 – 1.20	1.20
Good	1.35 – 1.25	1.25 – 1.15	1.15 – 1.00	1.00
Fair	1.25 – 1.15	1.15 – 1.05	1.00 – 0.80	0.80
Poor	1.15 – 1.05	1.05 – 0.80	0.80 – 0.60	0.60
Very Poor	1.05 – 0.95	0.95 – 0.75	0.75 – 0.40	0.40

[1] The quality of drainage is expressed in terms of the time required to drain the base layer to 50% saturation. Excellent (2 hours), Good (1 day), Fair (7 days), Poor (1 month), Very Poor (does not drain).

Source: American Association of State Highway and Transportation Officials, "AASHTO Guide for Design Pavement Structures," Washington, D.C., 1986.

Figure 3.4-4.—Recommended moisture (m_1) factors for modifying structural layer coefficients of untreated base and subbase materials in flexible pavements.



(1) Scale derived by averaging correlations obtained from Illinois. Specimens were molded using T-180.
(2) Scale derived by averaging correlations obtained from California, New Mexico and Wyoming.
(3) Scale derived by averaging correlations obtained from Texas.
(4) Scale derived by NCHRP project.

Source: American Association of State Highway and Transportation Officials, "AASHTO Guide for Design of Pavement Structures," Washington, DC, 1986.

Figure 3.4-5.—Correlations of a-values (a_2) with other strength measures recommended for crushed aggregate.

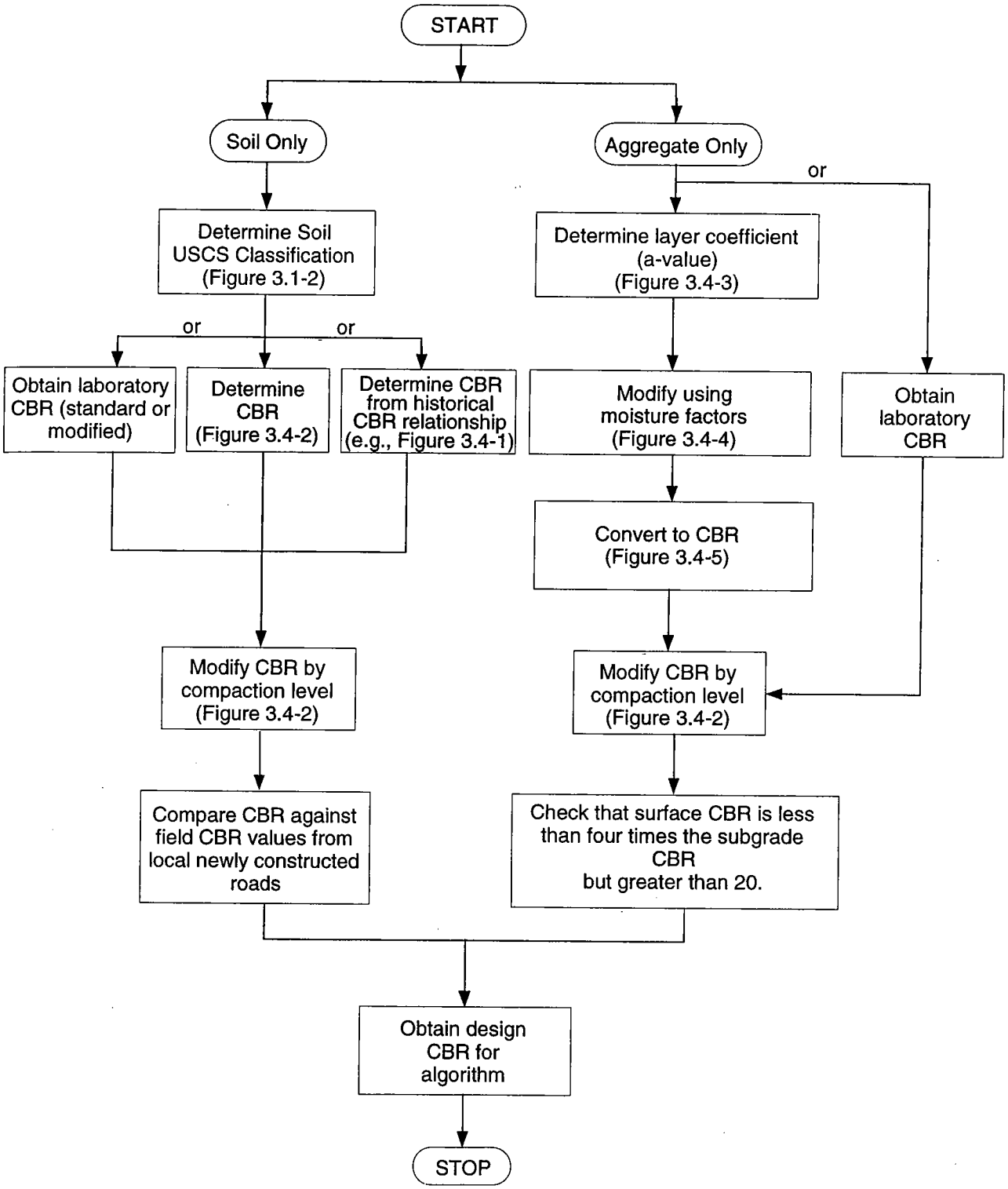


Figure 3.4-6.—Flowchart to determine design CBR's (new construction).

added if the material meets the criteria in the figure. An example for using the above figures can be found in chapter 5.

The presence of moisture can affect the relative strength of aggregate, hence the development of figure 3.4-4. Moisture (m_i) values are suggested to modify the layer coefficients depending on the quality of drainage. Once an appropriate a-value has been selected, it can be correlated to a CBR based on the information in figure 3.4-5.

It should be recognized that aggregate strength depends partially on the underlying subgrade strength, especially for newly constructed roads. The development of the design algorithm was derived from data which indicated an average ratio of surface CBR to subgrade CBR of 4.5 with a median value 2.9. Therefore it is recommended, unless local experience dictates otherwise, that for design, the CBR of the aggregate not exceed four times the value of the subgrade CBR.

The above surface-to-subgrade CBR ratio recommendation is realistic on roads that have not previously had high amounts of traffic. As the traffic and the road ages, especially in wet/dry climates, it appears that the average CBR ratio can be greater than 4. Not enough data has been reviewed at this time to determine a suitable ratio, but it is suggested for reconstruction design that the aggregate CBR should be the lower of:

- the field CBR or
- the CBR associated with 100 percent compaction from using figures 3.4-3 through 3.4-5 (not recommended in areas where the frost may penetrate completely into the base).

However, a lower limit of 20 is recommended for an aggregate CBR. Typically where weak subgrades are present, aggregate thicknesses may be such that more than one layer of differing aggregates will be more economical. In such cases, an "effective" CBR (which may be greater than the 4:1 ratio) should be used in the "STP" program to represent all the aggregate layers.

Figure 3.4-6 is a flowchart illustrating the procedure for obtaining a design CBR for either subgrade or aggregate material for new construction projects.

3.4.3 Aggregate Gradation Selection

A wide range of aggregate gradations may be used for aggregate surfacing. Selection of the aggregate gradation for a road should consider the following questions:

- Who are the users and what type of vehicles they will be using?
- What aggregate materials are available and what is the cost to place these materials?
- What grades are planned for the road?

- What is the expected season of use?
- What is the expected maintenance?
- What environmental considerations associated with the roadway must be addressed?

Once these questions are answered, the appropriate aggregate gradations can be established for the project.

As discussed in section 6.3.2, ideally one typically finds two layers in an aggregate pavement structure—a base course with an overlying surface course. The function of the base course is to provide a means to distribute the tire loads to the subgrade without producing undesirable surface deformations. Ideally it should consist of durable fractured aggregate that is insensitive to changes in moisture (low amount of fines) and free draining. Typically Grading F through H in the *U.S. Forest Service Specifications for Construction of Roads and Bridges* (Engineering Manual-7720-100LL) meets these criteria. The function of the surface course is to protect the base course from surface water infiltration and act as the wearing surface for the expected traffic. Ideally the surface course will be a durable fractured aggregate that is well-graded and impermeable to water. Typically Grading C through E in the Forest Service specifications meet these criteria.

<u>Realistically</u>

An aggregate source meeting the above requirements may not be found within an economical haul distance of most Forest Service projects. Therefore, many road surfaces consisting of one layer have been constructed, with a majority of these surfaces having served their intended purpose. These work if consideration is given to the following;

1. When does traffic use the road?
   (Wet or dry times of the year? During wet conditions a more impermeable surface is needed, whereas during the drier time of the year, moisture infiltration may not be a major concern. Therefore, aggregate meeting the base requirements and used as a surface layer may not function well if used during wet weather.)

2. What is the subgrade soil type?
   (Tied to the above question, fine-grained soils lose their support capacity with increasing moisture content. A saturated subgrade also tends to migrate into an open-graded aggregate with traffic. Again, aggregate meeting the base requirements and used as a surface layer may not function well if used during wet weather, especially with a fine-grained subgrade.)

Table 3.4.3-1.—Typical design situations with helpful design hints.

Situation	Helpful Hint
Wet weather commercial haul	1. Use the maximum economically feasible size aggregate (i.e., 3-inch or greater). Note: Larger rock gradations, if good quality and openly graded, may have a tendency to ravel and shove, especially on curves or steep grades. Large rock may also increase tire damage and wear.
Predominately low clearance	1. Use 3/4 to 1-inch maximum size aggregate that meets the surfacing recreation traffic requirements.
Year round "wet area"	1. Design wet area as a separate design segment. 2. Consider using 3-inch or greater maximum size aggregate or geotextiles which give strength and separation.
Grades between 12 and 18%	1. Minimize sharp radius curves. 2. For adverse grades with commercial haul, use grading D or E. 3. For favorable grades with commercial haul, use grading D or E and tighten gradation band. 4. Use low tire pressures on commercial vehicles (section 3.2.2). 5. Follow tips under raveling aggregate. 6. Pave or stabilize surface (consider consequences of black ice conditions on paved surfaces).
Grades greater than 18%	Most states require the use of an assist vehicle with commercial haul. To help gain traction: 1. See "Grades 12 to 18%". 2. If there is dry weather with fine-grained subgrade, an earth surface should suffice.
Marginal aggregate that degrades	1. Use larger maximum size open-graded aggregate and adjust the gradation to account for the amount that the aggregate degrades; for example grading M or N and require less passing the No. 4. 2. Stabilize by adding portland cement. 3. If the fine aggregate degrades more readily than coarse consider scalping prior to crushing. 4. Use low tire pressures on commercial vehicles (section 3.2.2).
Marginal aggregate that ravels (no binder)	1. Provide tighter control on the gradation requirements, either by a) using grading A through E (surfacing), or b) narrowing the allowable gradation band. 2. Add natural fines (silt or clay), manufactured fines, or a clay additive. 3. Stabilize by adding either cement, flyash, lime, asphalt, dust abatement, or other product. 4. Apply a bituminous surface treatment (BST).
Need for alternative specs	Should write aggregate specifications for the intended use considering economically available materials and local experience; i.e., replacing PI requirements with a finer or denser gradation or incorporating blending, scalping, or washing.
Changes in subgrade strength	Adjust the aggregate thickness to correspond with changes in the subgrade along the road strength.
Placing additional aggregate on an existing "dirty" surface	Blade-mix a thin lift of open-graded aggregate with the existing aggregate. The size and thickness of the aggregate is a function of the existing gradation and necessary structural requirements.
River run gravel	These sources typically produce a loose surface. Options on mitigating include: 1. Options listed in "marginal aggregate that ravel". 2. Use an impact crusher (tends to increase the number of fractured faces). 3. Creating a special project specification that increases the percent of fractured faces, similar to what state agencies are requiring for hot mix asphalt.
Aggregate source with seams or pockets of low strength or quality	1. Scalp prior to crushing to remove low quality material. 2. Use a smaller maximum size gradation which could increase the amount of manufactured fines.

Table 3.4.3-2.—"Out of Spec" aggregate, consequences and potential resolution.

Scenario

"Just Out"

For example: out less than two percentage points on a particular sieve, out less than two on the PI, out less than four on the SE, or out less than five on the durability.

Aggregate quality requirements "just out" consequences: probably not much unless one uses a material that typically degrades with use; if so, use during wet periods may result in premature rut development and increased sediment production; use during dry periods may result in excessive dust.

Aggregate gradation requirements "just out" consequences: if just one or two sieves are "just out," then probably not much in terms of performance; if more than two sieves are "just out" then there is a potential of either a "bony"/loose surface if it is on the coarse side. If it is on the fine side, it may "slop" during wet use and dust during dry use.

Resolution: if test results are out less than the precision stated in the corresponding AASHTO tests, then it is best to accept the material; if the tests are out more than the precision stated above then accept at a reduced payment. Reduced payment can be based upon:

1. the corresponding reduction in strength value;
2. cost to mitigate increased sediment control (if applicable);
3. cost expected with increased maintenance;
4. cost associated with one of the mitigation measures in table 3.4.3-1, for degrading or raveling aggregate; or
5. for gradation, use the pay factor analysis routinely used by the Northern Region (R-1).

"Way Out"

For example: out more than five percentage points on a particular sieve, out more than three on the PI, out more than eight on the SE, or out more than 15 on the durability.

Aggregate quality requirements "way out" consequences: use during wet periods may result in premature rut development and increased potential for sediment production; use during dry periods may result in excessive dust.

Aggregate gradation requirements "way out" consequences: if on the coarse side, the material will act "bony"/loose and berm material outside of the wheel tracks and water will penetrate more readily into the aggregate; if on the fine side, the material will more readily dust during dry use and rut/"slop" during wet use.

Resolution: either

1. reject and replace with aggregate that meets the requirements;
2. cap the "out of spec" material with aggregate that meets the requirements; or
3. if the aggregate is stockpiled, look at scalping, with or without additional crushing, prior to laydown.

3. What are the expected grades on the road? Are they adverse or favorable?
   (Open-graded aggregate does not provide the traction needed on grades steeper than 12 percent, especially with short radius curves. It also tends to ravel and washboard independent of the grade. Therefore, aggregate meeting the base requirements and used as a surface layer may not function well if used on grades greater than 12 percent.)

4. What is the expected maintenance on the road?
   (Traffic on open-graded aggregate creates berms of loose aggregate between the wheel paths, requiring additional maintenance.)

Table 3.4.3-1 lists some other typical design situations and helpful hints for selecting the proper aggregate gradation.

Consequences and Resolution of "Out of Spec" Aggregate

Questions typically arise on the consequences of "out of spec" aggregate. To answer the concern, one needs to look first at what component is out of the specification requirements and then at the proposed use of the aggregate. Two "out of spec" scenarios that commonly occur are: the aggregate quality requirements are not within the allowable tolerances (either just out or way out), and the aggregate gradation is not within the allowable tolerances (again either just out or way out) which produces either "bony" or "dirty" aggregate. Table 3.4.3-2 lists these typical scenarios, the common consequences, and possible resolutions.

If the aggregate source is a Forest Service source that has a history of producing similar material and there is no problem with how it performs, then the specifications for that source should be modified to match what the source can produce. If there is a problem with the material's past performance, then start with the recommendations in table 3.4.3-1 when looking at design alternatives.

Balancing Plasticity Index or Sand Equivalent with the Percent Passing the No. 200 Sieve

The standard Forest Service specifications (1985) requirements for plasticity index (PI) and sand equivalent (SE) are independent of the percent passing the No. 200 sieve. Some agencies (Federal Highway Administration) tie their PI or SE requirements to the percent passing the No. 200 sieve. These requirements are typically derived from local experience and can be implemented only after careful observation of the local situation. Generally, as the PI approaches its upper specification limit and the SE approaches its lower specification limit, other agencies reduce the amount of material passing the No. 200 sieve.

3.4.4 Marginal Aggregate

Marginal aggregate is defined as aggregate that does not meet specifications or aggregate that changes strength or anticipated performance

characteristics during the expected life of the project. Aggregate availability or economics may drive the use of marginal aggregate. If the designer chooses to use marginal materials, allowances must be made for anticipated material performance. For example, if material strength characteristics deteriorate with time and traffic, then allowances need to be made in selecting design CBR's that correctly model terminal characteristics. Specifications can also be modified as noted in section 3.4.3 to mitigate marginal aggregate concerns.

3.5 Economics

The principles of engineering economics can be applied to surfacing design projects at two levels. The first level is concerned with the management decisions required to determine the feasibility of a project; the second requires that the selected project alternative be cost effective, and that the cost effectiveness be maximized. This second level is achieved by considering a variety of alternatives capable of satisfying the overall project requirements.

The major difference in economic evaluation between these two levels of projects concerns the amount of detail and information required. Otherwise, the basic principles involved are the same. This chapter considers the second level of economic analysis only. The information in this chapter is summarized from the 1986 *AASHTO Guide for Design of Pavement Structures* and Forest Service 1907.17 *Economic and Social Analysis Handbook*, chapter 10.

3.5.1 Life-Cycle Costs

The term "life-cycle costs" was coined around 1970 for use with pavements. Life-cycle costs refer to all costs (and, in the complete sense, all benefits) which are involved in the provision of a pavement or surfacing structure during its complete life cycle. These include construction costs, maintenance costs, and rehabilitation costs. An example of life-cycle costs used to compare the costs and value of two automobiles for purchase include: (1) purchase price; (2) gasoline and operating costs, such as buying tires; (3) repair (maintenance); and (4) trade-in value (salvage). The same kind of comparison should be recognized for pavements.

Also required is a consideration of the useful life of the car. An inexpensive car may last 4 years while an expensive one, carefully selected, may last 15 years. Since all these costs do not occur simultaneously, it is useful to determine the amount of money that could be invested at a fixed time (usually the beginning) and that would earn enough interest at a specific rate to permit payment of all costs when they occur. Thus, an interest rate or time value of money becomes important in the calculations.

"Life-cycle costs" then is a term coined to call special attention to the fact that a complete and current economic analysis is needed if alternatives are to be truly and correctly compared to each other. All comparisons

should include a "do-nothing" alternative that states the risks and associated consequences if that alternative is selected.

3.5.2 Factors Involved in Pavement Costs and Benefits

Economic analysis should "include all costs through that stage of processing at which the benefits are valued or the environmental effects are achieved" (FSH 1909.17, chapter 13.11). Costs to be considered should include initial or construction costs, operation and maintenance costs over the expected analysis period, and any user costs that can be accurately determined. Environmental costs are difficult to obtain and are not normally included in engineering analyses.

Include only those costs that may have an effect on the outcome of alternatives. For example, maintenance costs and timing that would not change between alternatives need not be included since they will not affect the outcome of the analysis. FSH 1909.17 provides guidance for conducting an economic analysis and what should be included in Forest Service economic analyses.

In any life-cycle economic analysis, all alternatives must be brought to a common denominator. This usually means some analysis variables are fixed from alternative to alternative. The discount rate and project design life are normally fixed.

The major initial and recurring factors that should be considered in the economic evaluation of alternative road design strategies include: agency costs, user costs, analysis period, and discount rate.

- Agency costs include:
  - initial construction costs;
  - maintenance costs recurring throughout the analysis period (i.e., blading);
  - salvage or residual value at the end of the analysis period (which may be a "negative cost");
  - engineering and administration costs;
  - traffic control costs if any are involved; and
  - profit and risk typically included in cost estimates.

- Initial construction costs. Computing the initial cost of construction involves the calculation of material quantities to be provided in each pavement structure and multiplication by their unit prices. Material quantities are generally directly obtained from their thicknesses in the structure and the width of pavement and shoulders. Engineering and administrative costs associated with the design should also be included. Each forest should have local cost estimating guides available to help the designer. Note that initial construction costs would equate to reconstruction costs when evaluating reconstruction alternatives.

- Maintenance cost. Maintenance is defined as "the preservation of the entire roadway, including surface, shoulders, roadside, structures, and such traffic control devices as are necessary for its safe and efficient utilization." Road maintenance then involves the preservation of the surface including shoulders and related drainage. The maintenance cost is the estimate of all costs essential to preserving the roadway at the desired level of service. This can include blading and reshaping of the road surface and shoulders. Each alternative could possibly have different maintenance costs. The designer is referred to the local cost estimating guide for guidelines on maintenance costs. When evaluating alternatives, only the costs that change between alternatives need to be considered, if timing of activities are the same. It is important to document the expected maintenance for the selected alternative and use periodic condition surveys to review the maintenance requirements.

- Salvage or residual value. Salvage or residual value is used by some agencies in economic evaluation. It can be significant in road surfaces because it involves the value of reusable materials at the end of the analysis period. With the depletion of resources, such materials can become increasingly important in the future, especially when used in a new pavement or surface structure by reworking or reprocessing. The salvage value of a material depends on several factors, such as volume and position of the material, contamination, age, durability, and anticipated use at the end of the design period. Typically, it is represented as a percentage of the original cost. It also might be considered the cost of the material if it was removed, "sold," or otherwise used on another road. Salvage value can be difficult to calculate; the choice of values to be assigned will pose a problem for the engineer. For example, what value should one assign to an aggregate that is 5 years old? The Willamette National Forest, for example, uses remaining life beyond the analysis period to salvage value (i.e., 5 years remaining life for a 20-year analysis period equates to a 25 percent salvage value).

- User costs. User costs are generally difficult to quantify and will not be included in this discussion. If interested, the designer may refer to the *AASHTO Guide for Design of Pavement Structures* or other references for more detailed discussions.

- Analysis period. Analysis period (also called the design life) plays a major role in presenting an accurate picture of long-term project costs that should include operational and maintenance costs. For example, Forest Service economic analyses for selection of the surface structure for log hauling operations on local roads normally only consider initial construction costs. This is done because normally road-related costs for logging operations are to be

"only that necessary to remove the logs." There is no problem as long as the road is closed at the end of log hauling operations.

Economic analyses that only include initial construction costs give weight to low capital investment while ignoring long-term user and maintenance costs. The longer the selected analysis period, the clearer the picture of actual operational and maintenance costs for any alternative. This is not to say that initial construction costs are not important. In limited funding situations, initial construction costs may determine the outcome of the economic analysis, but other considerations may have a greater weight in alternative selection.

A 20-year analysis period is normally used for collector and arterial roads. Analysis of the surface structure should consider the thickness necessary to carry the expected traffic mix and volumes over the analysis period and then include costs for wear or maintenance. Each alternative should be evaluated for the same analysis period. Some alternatives might need to allow for future reconstruction to equalize the design lives between alternatives.

- Discount rate. Discount rate (interest rate) also plays a role in the outcome of any economic life-cycle analysis. In Forest Service economic analyses, a discount rate of 4 percent is used (FSH 1909.17, 15.42, par. 1) and is not adjusted for inflation. One reason this is done is "because projecting defensible rates of inflation is extremely difficult, involving many assumptions about economic variables and events outside the economic analysis of the project" (FSH 1909.17, 15.43, par. 3). Adjustments in the discount rate are not recommended (FSH 1909.17, 15.42, par. 2).

3.5.3 Methods of Economic Evaluation

There are several methods of economic analyses that are applicable to the evaluation of alternative surfacing design strategies:

- equivalent uniform annual cost method, often simply termed the "annual cost method;"
- present worth method for benefits minus costs, usually termed the "net present worth" or "net present value method;"
- rate-of-return method;
- benefit-cost ratio method; and
- cost-effectiveness method.

Of these, only the first two have been selected for inclusion in the *Surfacing Design Guide*. They are also the two most widely accepted methods of economic analysis used in engineering design.

- Equivalent uniform annual cost (EUAC) method. The EUAC method combines all initial construction costs and all recurring future expenses into equal annual payments over the analysis period. The primary advantage of this method is that alternatives with different service lives can be compared. Figure 3.5-1a illustrates the equivalent cash flows. The basic equation is:

$$EUAC = I * crf + MO - S * ssf \qquad \text{(Eq. 3.5-1)}$$

where:

EUAC = equivalent uniform annual cost for an analysis period of n years.
I = initial cost of construction.
crf = capital recovery factor for discount rate i and n years.

$$= \frac{i\,(1 + i)^n}{(1 + i)^n - 1}$$

ssf = sinking fund factor for discount rate i and n years.

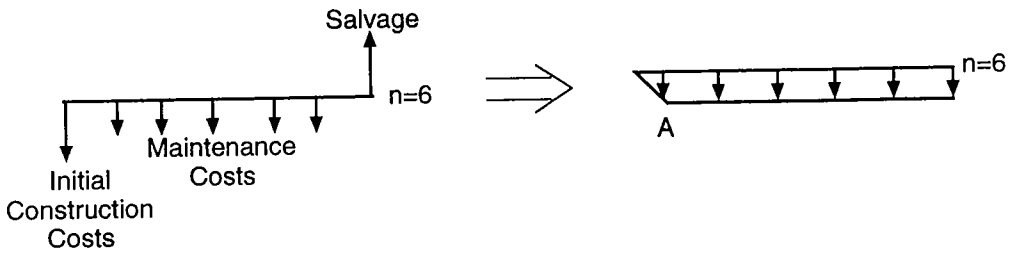
$$= \frac{i}{(1 + i)^n - 1}$$

MO = average annual maintenance plus operation costs.
S = salvage value, if any, at the end of n years.

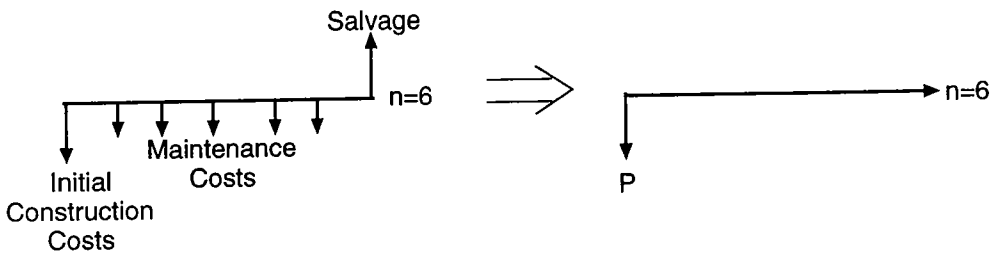
Figure 3.5-2 is a summary of the above equations calculated for various time periods at a discount rate of 4 percent.

- Net present worth (NPW) method. The NPW (figure 3.5-1b) is comparable to the EUAC method for comparable conditions (e.g., cost, discount rates, and analysis periods). It considers costs and benefits together and involves the discounting of all *future* sums to the *present*, using a discount factor. There are two discount factors available, one for a uniform series (i.e., yearly blading), and one for single future amounts (i.e., adding aggregate to replace aggregate loss). The present rate factor for *single* future amounts is:

$$pwf = \frac{1}{(1 + i)^n} \qquad \text{(Eq. 3.5-2a)}$$



a.) EUAC method. All costs are combined into equal annual amounts (A).



b.) Net present worth method. All costs and benefits are combined into one value (P) at a single instant of time.

Figure 3.5-1.—Illustrations of EUAC and NPW methods.

The present worth factor for a future *uniform* series is typically represented as pwf ' and is calculated as shown below:

$$pwf' = \frac{(1 + i)^n - 1}{i\,(1 + i)^n} \qquad \text{(Eq. 3.5-2b)}$$

where:

pwf = present worth factor for future amount.
pwf ' = present worth factor for future uniform series.
i = discount rate.
n = number of years to when the sum will be expended or saved.

Figure 3.5-2 is a summary of the above equations calculated for various time periods at a discount rate of 4 percent.

The NPW is the difference between the present worth of benefits and the present worth of costs. Benefits must exceed costs if a project is to be justified on economic grounds. The benefits include direct, indirect, and nonuser benefits accruing from the project. In cases where the Forest

n	Uniform series end-of-period amount *A* equivalent to			Present sum, *P* equivalent to			n	Future sum, *F* equivalent to			n
	future sum, F	present sum, P	gradient series, G	future sum, F	uniform series, A	gradient series, G		present sum, P	uniform series, A	gradient series, G	
	A/F	***A/P***	***A/G***	***P/F***	***P/A***	***P/G***		***F/P***	***F/A***	***F/G***	
1	1.00000	1.04000	0.000	0.9615	0.962	0.000	1	1.040	1.000	0.00	1
2	0.49020	0.53020	0.490	0.9246	1.886	0.925	2	1.082	1.040	1.00	2
3	0.32035	0.36035	0.974	0.8890	2.775	2.703	3	1.125	3.122	3.04	3
4	0.23549	0.27549	1.451	0.8548	3.630	5.267	4	1.170	4.246	6.16	4
5	0.18463	0.22463	1.922	0.8219	4.452	8.555	5	1.217	5.416	10.41	5
6	0.15076	0.19076	2.386	0.7903	5.242	12.506	6	1.265	6.633	15.82	6
7	0.12661	0.16661	2.843	0.7599	6.002	17.066	7	1.316	7.889	22.46	7
8	0.10853	0.14853	3.294	0.7307	6.733	22.181	8	1.369	9.214	30.36	8
9	0.09449	0.13449	3.739	0.7026	7.435	27.801	9	1.423	10.583	39.57	9
10	0.08329	0.12329	4.177	0.6756	8.111	33.881	10	1.480	12.006	50.15	10
11	0.07415	0.11415	4.609	0.6496	8.760	40.377	11	1.539	13.486	62.16	11
12	0.06655	0.10655	5.034	0.6246	9.385	47.248	12	1.601	15.026	75.65	12
13	0.06014	0.10014	5.453	0.6006	9.986	54.455	13	1.665	16.627	90.67	13
14	0.05467	0.09467	5.866	0.5775	10.563	61.962	14	1.732	18.292	107.30	14
15	0.04994	0.08994	6.272	0.5553	11.118	69.735	15	1.801	20.024	125.59	15
16	0.04582	0.04582	6.672	0.5339	11.652	77.744	16	1.873	21.825	145.61	16
17	0.04220	0.04220	7.066	0.5134	12.166	85.958	17	1.948	23.698	167.44	17
18	0.03899	0.03899	7.453	0.4936	12.659	94.350	18	2.026	25.645	191.14	18
19	0.03614	0.03614	7.834	0.4746	13.134	102.893	19	2.107	27.671	216.78	19
20	0.03358	0.03358	8.209	0.4564	13.590	111.565	20	2.191	29.778	244.45	20
21	0.03128	0.07128	8.578	0.4388	14.029	120.341	21	2.279	31.969	274.23	21
22	0.02920	0.06920	8.941	0.4220	14.451	129.202	22	2.370	34.248	306.20	22
23	0.02731	0.06731	9.297	0.4057	14.857	138.128	23	2.465	36.618	340.45	23
24	0.02559	0.06559	9.648	0.3901	15.247	147.101	24	2.563	39.083	377.07	24
25	0.02401	0.06401	9.993	0.3751	15.622	156.104	25	2.666	41.646	416.15	25
26	0.02257	0.06257	10.331	0.3607	15.983	165.121	26	2.772	44.312	457.79	26
27	0.02124	0.06124	10.664	0.3468	16.330	174.138	27	2.883	47.084	502.11	27
28	0.02001	0.06001	10.991	0.3335	16.663	183.142	28	2.999	49.968	549.19	28
29	0.01888	0.05888	11.312	0.3207	16.984	192.121	29	3.119	52.966	599.16	29
30	0.01783	0.05783	11.627	0.3083	17.292	201.062	30	3.243	56.085	652.12	30
35	0.01358	0.05358	13.120	0.2534	18.665	244.877	35	3.946	73.652	966.31	35
40	0.01052	0.05052	14.477	0.2083	19.793	286.530	40	4.801	95.026	1375.64	40
45	0.00826	0.04826	15.705	0.1712	20.720	325.403	45	5.841	121.029	1900.73	45
50	0.00655	0.04655	16.812	0.1407	21.482	361.164	50	7.107	152.667	2566.68	50
60	0.00420	0.04420	18.697	0.0951	22.623	422.997	60	10.520	237.991	4449.77	60
∞	0.00000	0.04000	25.000	0.0000	25.000	625.000	∞	∞	∞	∞	∞

Figure 3.5-2.—Discount rate at 4 percent.

Service cannot specifically quantify these benefits, the analysis will use costs only. Most agencies do not have available data to relate user costs to pavement factors. In this case, the project with the least present worth of costs should be selected. Only equation 3.5-5 is used in this case. The NPW equations can be represented as:

$$NPW = PW_B - PW_C \qquad \text{(Eq. 3.5-3)}$$

where:

NPW = net present worth.
PW_B = present worth of benefits.
PW_C = present worth of costs.

The present worth of benefits is expressed as:

$$PW_B = pwf' * [DU + IU + NU] \qquad \text{(Eq. 3.5-4)}$$

where:

DU = annual direct user benefits.
IU = annual indirect user benefits.
NU = annual nonuser benefits accruing from the project.

The present worth of costs is expressed as:

$$PW_C = IC + (pwf')[MO + UC] - (pwf) * [S] \qquad \text{(Eq. 3.5-5)}$$

where:

IC = initial capital cost of construction.
MO = annual maintenance plus operation costs.
UC = annual user costs, if any.
S = salvage value, if any, at end of design period.

There are several advantages inherent in the NPW method that make it, perhaps, the most feasible for the highway field in comparison to the "traditional" annual cost and benefit-cost methods. These advantages include the following:

1. The benefits and costs of a project are related and expressed as a single value.

2. All monetary costs and benefits are expressed in present-day terms.

3. The answer is given as a total payoff for the project.

Disadvantages to the NPW method include the following:

1. The results, in terms of a lump sum, may not be easily understandable to some people as a rate of return or annual cost. In fact, the summation of costs in this form can tend to act as a deterrent to investment in some cases.

2. Alternatives with different service lives cannot be easily compared.

3.5.4 Examples

Given the following conditions, calculate the NPW and EUAC.

- Initial cost of construction = $80,000.
- Analysis period (design life) = 10 years.
- Blading cost = $800/year.
- Spot rocking cost = $1,000/year.
- Engineering and administration costs = 10 percent of initial construction.
- Salvage value at end of analysis period = none.
- Discount rate = 4 percent.
- No benefits can be quantified.

Calculate EUAC:
Using equation 3.5-1,

$$EUAC = I * crf + MO - S * ssf$$

where:

$$crf = \frac{i(1 + i)^n}{(1 + i)^n -} = \frac{4\%(1 + 4\%)^{10}}{(1 + 4\%)^{10} - 1} = 0.1233$$

$$ssf = \frac{i}{(1 + i)^n - 1} = \frac{4\%}{(1 + 4\%)^{10} - 1} = 0.0833$$

I = construction + engineering + administrations costs
= $80,000 + 10% ($80,000) = $88,000.
MO = blading cost + spot rocking cost = $1,800/year.
S = salvage value = 0.

Substituting into equation 3.5-1:

∴ EUAC = ($88,000) (0.1233) + 1,800 - 0 (0.0833)
EUAC = $12,650/year

Calculate NPW:
Using equation 3.5-3,

$$NPW = PW_B - PW_C$$

but PW_B = 0, since there are no quantifiable benefits.

$$\therefore NPW = PW_C = IC + (pwf')[MO + UC] - (pwf)[S] \quad \text{(Eq. 3.5-5)}$$

where:

IC = initial construction costs = $88,000.
MO = $1,800/year as before.
UC = 0 as before.
S = 0 as before.

Therefore, the present worth discount factors are:

$$\therefore pwf = \frac{1}{(1+i)^n} = \frac{1}{(1+4\%)^n} = 0.6756$$

$$pwf' = \frac{(1+i)^n -}{i(1+i)^n} = \frac{(1+4\%)^{10} - 1}{4\%(1+4\%)^{10}} = 8.1109$$

Substituting into equation 3.5-5:

NPW = 88,000 + (8.1109) (1,800 + 0) - (0.6756)(0).
NPW = $102,600.

From the examples, the results for the same road design may be expressed in two ways:

- A cost of $12,650 a year for 10 years.
- A discounted total present cost of $102,600.

Note: The computer program "STP" allows one to analyze the life-cycle costs of a project.

Chapter 4
Design

4.1 Introduction

Most natural soils do not have the necessary bearing capacity (strength) to support traffic without excessive surface deformation. Therefore, a "pavement structure" is placed over the native materials to help distribute the load and obtain a sufficient surface for acceptable performance. A structural design procedure is necessary to determine the appropriate materials and associated thickness to meet expectations for the road. Consequences of not performing a design can be:

- shear failure in the subgrade soils, causing a reduction in the capacity of the road to carry the intended traffic;
- excessive surface deformations, leading to unacceptable performance, increased sediment loads from the road surface, or increased maintenance; or
- possibly increased construction costs associated with the construction of an overbuilt pavement structure.

This section is divided into two parts. The first portion discusses the design of road surfaces where it has been determined that surfacing material is not necessary to support traffic loads but necessary to either minimize erosion, control dust, provide traction, or for another nontraffic load supporting requirement. This has been classified as "nonstructural surfacing design," even though some limited structural support is provided. The second portion discusses the design of road surfaces where it has been determined that there are traffic load supporting requirements. This has been classified as "structural surfacing design." It is up to the designer to decide whether campgrounds, parking lots, or trailheads are considered nonstructural or structural. The following tips may help in the decision process:

1. If the traffic for the expected life of the facility consists of loaded pickup trucks and lighter vehicles, use nonstructural design procedure.
2. If the traffic for the expected life of the facility consists of RV's and lighter vehicles and traffic occurs during relatively drier times of the year, use the nonstructural design procedure and the fine-grain recommendations.
3. For all other campgrounds, parking lots, trailheads, heavy haul, or other traffic conditions, use structural design procedure.

4.1.1 Drainage

From maintenance personnel to designers, most know the answer to the question "What are the three most important factors in road design and performance?"

Drainage . . . Drainage . . . Drainage

Ensure during any surfacing design, be it structural or nonstructural, that drainage of the road surface and underlying materials is considered. A good surface design cannot make up for inadequate drainage. Consider specifying the following to help facilitate rapid removal of surface or subsurface water:

- Road Template
  - crown the subgrade (2 percent minimum).
  - crown the road surface for new construction roads and during road maintenance.

- Ditch
  - construct in the subgrade.

- Culverts
  - install all of the necessary cross-drainage structures.
  - install at springs, seeps, and wet areas.

- Other
  - use free draining base.
  - use a drainage cutoff lead off ditches.

These considerations are not necessary but recommended when traffic does not occur during times of year when water infiltrates into the surface or subsurface. Be aware of the environmental consequences if traffic does occur during those times of year and the road design does not incorporate adequate drainage.

It is very important that the amount of sediment roads contribute to our stream systems is minimized. Road surfaces, cut slopes, and ditches have been identified as contributing approximately one-third of all the sediment produced from the total road prism (9, 10). Sediment from the road surface and ditch line can be minimized by requiring the use of lower tire pressures on commercial vehicles, applying dust abatement, surfacing the road, maintaining (blading and pulling the ditches) the road only when necessary, and armoring or vegetating the ditches. Additional information on road sediment is located in section 2.1.

If the road is located outside the riparian area one could consider, in addition to the above, the construction and maintenance of a sediment basin or silt fence. If planning to vegetate the ditch line, consider:

- deepening the ditch an extra 6 to 12 inches to accommodate the slower travel of water within the ditch;

- ensuring that the gradient is steep enough to keep water moving in the ditch, recommend a 2 percent minimum;
- keeping the vegetation from growing in the aggregate side slopes; and
- keeping aggregate berms from developing along the shoulders of the travelway.

Again, these recommendations would only apply to roads that have traffic during the time that surface and subsurface water infiltration would occur.

4.1.2 Minimum Aggregate Thickness

When designing an aggregate-surfaced road, certain construction/maintenance minimums are suggested. Briefly, the design aggregate thickness should be the greater of:

- 4 inches;
- twice the maximum particle size; or
- the structural thickness plus the aggregate loss (operational loss).

These suggestions were obtained from the Forest Service's *Chapter 50 Design Guide* (1). Thicknesses less than 4 inches are often chosen for nonstructural surfacing needs such as erosion control, traction, dust control, or armoring.

4.2 Nonstructural Use of Surfacing Materials

Several potential surfacing materials are available that could economically minimize erosion, control dust, or provide traction for the road user. These include the use of (1) traditional surfacing materials, (2) alternate stabilizing materials and products, or (3) alternative surfacing materials. This section discusses some of the materials and products available for both subgrade and aggregate and the recommended design considerations for use in nonstructural situations. Some of the materials and products will provide structural support but that is secondary to the above needs.

4.2.1 Traditional Materials

Traditional materials would include either aggregate, BST, hot or cold asphalt mix, or stabilization of the native material with asphalt cement, Portland cement, lime, or a combination of these additives. A brief description of some of these materials follows:

- Aggregate: discussed in chapter 3.
- Hot mix asphalt: a mix of paving grade asphalt cement and either dense-graded or open-graded aggregate (clean, hard, and durable; typical maximum size is 3/4 inch).

- Cold mix asphalt: a mix of emulsion or liquid asphalt and either dense-graded or open-graded aggregate (clean, hard, and durable; typical maximum size is 3/4 inch).

- Portland cement concrete: a mix of Portland cement and dense-graded aggregate, forming a relatively impermeable stabilized material with very high strength and durability.

- Cement treated base: a mix of Portland cement and aggregate forming a pervious stabilized material.

- Soil cement: a mix of Portland cement and soil, forming a stabilized material.

- BST: one or more repetitions of a sprayed asphalt cement (liquid or emulsified) layer followed by a layer of aggregate; typically each successive aggregate layer size becoming smaller; total thickness of BST less than 1 inch.

- Lime treatments: a mix of lime and soil, forming a material less sensitive in strength with moisture.

4.2.2 Stabilizers

Road performance can be greatly enhanced with the proper application of a stabilizer. For the *Surfacing Design Guide*, a stabilizer includes any chemical or additive that is designed to increase the stability of the treated material to improve its engineering properties. An effective stabilizer locks the aggregate particles in place, thus reducing aggregate loss and eliminating dust. For soil, effective stabilizers either lock the soil particles together or make the material less sensitive to changes in moisture. Traditional stabilizers such as hydrated lime, Portland cement, and bitumens have been laboratory tested; therefore field performance can be effectively predicted.

Alternative stabilizers rely on chemical reactions of the material and treatment product. Due to the lack of standard laboratory procedures, these treatments are only field verified. The designer needs to recognize that product performance can vary widely depending on the soil and aggregate properties. Alternative stabilizers are being developed currently because of a need for products that will be more economically feasible and still meet desired performance requirements. Current costs of alternative stabilizers are more than traditional stabilizers, but material costs are reducing with time.

Chemical stabilizers are primarily used on materials with enough clay constituents. A minimum PI of 17 or 5 percent passing the 0.002 mm is required. The chemicals in the stabilizers react with substances in the soil to form a binder. Electrolytes act in this manner. They include sulfonated oils and enzymes. These products are described briefly below. In addition, figure 6.2.1-1 lists where these products have been applied

in the Forest Service. For more detailed information, refer to the FHWA report *Non-Standard Stabilizers* (16).

- Sulfonated oils:
  - Sulfonated naphthalene (Condor SS)
    - comes from the manufacture of fabric dyes;
    - used for subgrade treatment;
    - must have 35 percent passing #200 sieve with clay fraction;
    - injection method is simplest;
    - minimal mixing required;
    - may require a drying period; and
    - some coarse material must be present to provide traction if not surfaced.

  - Sulfonated D-limonene (Roadbond EN-1)
    - by-product of citrus processing;
    - used to treat aggregate surface and base course with clay fines; and
    - must be intimately mixed at optimum moisture content and compacted.

- Ammonium chloride:
  - Consolid 444
    - used as an electrolyte for dry cells, sometimes occurs naturally in volcanic deposits;
    - used to treat subgrade soils to replace aggregate; and
    - must be intimately mixed, needs high degree of control during construction.

- Enzyme solutions:
  - Biocat, EMC Squared, PermaZyme, PSCS-320
    - a bacterial culture in an enzyme solution. When exposed to air the bacteria multiply and produce large organic molecules that attach to clay molecules, thereby preventing moisture absorption (acts as a waterproofer). Used in the cosmetic and cleaning industries. Soil enzymes can be manufactured by the fermenting process;
    - used to treat aggregate surface and base course with clay fines;
    - must be intimately mixed at optimum moisture content and compacted;
    - must be protected from freezing; and
    - contains wetting agents; difficult to dry back if too much water is added.

Pozzolan stabilizers are used to treat non-plastic aggregate surface and base courses. They include lime, kiln dust, cement kiln dust, class "C" fly ash, and class "F" fly ash mixed one part fly ash to one part hydrated lime. They are produced through the lime and cement manufacturing

process and from coal burning power plants. Percent of additive required varies from 1 to 10 percent and depends upon lime content, aggregate gradation, road grades, and local rainfall intensity. Additional moisture is required during mixing to hydrate the lime. All treatments should be compacted at optimum moisture.

Other alternative stabilizers can act as a binder, some the same way as asphalt cement. Some products are briefly described below.

- Mineral pitches:
  - Road Oyl
    - a stabilizer and dust palliative;
    - distilled from pulp waste; and
    - performs similarly to emulsified asphalt.

- Clay fillers:
  - Stabilite, Bentonite
    - marketed commercially as sodium/calcium montmorillonite; and
    - calcium may be more suited to wet climates.

- Acrylic Polymer:
  - Soil-Seal, Soil Sement, Soil Master
    - manufactured by chemical industry and marketed in an emulsion form; forms a weather resistant seal.

4.2.3 Alternative Surfacing Materials

Alternative surfacing types can include but are not limited to the use of wood products (chunkwood, woodchips), shredded rubber tires, spun polyester fibers mixed with the native surface, or geotextiles. Refer to appendices 6.6 and 6.7 for additional information and advice.

4.2.4 Design Procedures

Design for nonstructural needs should include the following procedure:

- Verification of the RMO's
  - includes documenting the use restrictions, surfacing needs, and seasonal closures;
  - defines the expected road maintenance and consequences of limited maintenance.

- Determination of material characteristics
  - includes the subgrade soil type and expected construction methods;
  - feasible aggregate gradation, if aggregate is used.

- Determination of feasible pavement alternatives
  - Possible alternatives include:
    - aggregate surface: 2-inch minimum compacted depth for coarse-grained subgrade or 4-inch minimum compacted depth for fine-grained subgrade. (Note: 3- to 4-inch open-graded aggregate compacted into a fine-grained surface that

has been used by forests in the past has mitigated sediment as well as 1-inch minus dense-graded aggregate. (FSH 7709.56 chapter 4.72))

- stabilized aggregate surface: use the same depths recommended above. (Aggregate gradation plays a vital role in the success or failure of a stabilizer; therefore, it is extremely important that the stabilizer chosen is appropriate for the aggregate to be treated. Aggregates containing 30–50 percent retained on #4 sieve have performed best when treated. Those aggregates with <20 percent retained developed excessive fines and rutted while those with >50 percent retained developed surface ravel and became abrasive.
- bituminous surface: use a double BST for a coarse-grained subgrade or 2-inch minimum asphalt concrete mat, with or without an aggregate base, for a fine-grained subgrade.
- stabilized native surface: typically use either cement or asphalt-treated subgrade; other stabilization techniques are mentioned above.
- alternative surfacing or nontraditional stabilized surface: see appendices 6.6 and 6.7 for additional information.

Note: As these scenarios are considered to be minimums, local experience may suggest additional material requirements. Future maintenance, the expected type of traffic, and the horizontal and vertical alignment may dictate the use of different materials or material thicknesses.

- Selection of the preferred surface materials
  - based on the combination of materials and thickness which provides the least life cycle cost while meeting the road's management and resource objectives.

4.3 Structural

4.3.1 Design Considerations

As discussed previously, there are many considerations in any surfacing design process. The following information must be considered in the design: RMO's and operational criteria, material characteristics, traffic, design rut depth, and special or unique project-specific considerations. Following is an introduction to the basic design process for aggregate-surfaced roads.

- RMO's and operational criteria: In any road related project the items one needs to confirm are:

  - Any use restrictions (i.e., seasonal closures).

- The expected road maintenance. Road maintenance schedules and frequency should be considered when developing design parameters. The designer should sit down with road maintenance personnel and define the desired purpose and expectations for road maintenance. If funding is limited and maintenance frequency is expected to be reduced, then this is the time to modify the process to make the road more maintenance free. This can be accomplished by adding more aggregate and/or drainage, changing aggregate gradations and road surface template, or a combination of all of these.

- The need for "operational" aggregate. There may be cases where it is desirable to forgo the operational aggregate (i.e., local timber haul roads that are to be closed after hauling operations are complete).

See section 2.0.1 for additional information concerning RMO's.

- Material characteristics: It is very important for the designer to obtain accurate material information. This should be done by actual sampling and testing of subgrade soils and, if applicable, aggregate base and surfacing materials where possible. Items to consider are:

  - Subgrade CBR. It is important to get information for characterization of subgrade soils through proper sampling and testing. Once soil characteristics have been identified, CBR's can be determined by testing or statistical analysis, if sufficient data is available. See section 3.4.1 for detailed information concerning subgrade CBR's.

  - Base or surfacing CBR. Since aggregate gradation and quality can be controlled it is usually sufficient to determine feasibility using economic and availability constraints. See sections 3.4.2 and 3.4.3 for detailed information concerning aggregate CBR's and gradations.

  - Erosion potential of the surfacing material. This would be especially important if the road was located next to a stream where water quality or fisheries concerns had been identified in the RMO's. If the material has a high potential for producing sediment then it might be necessary to change material sources, stabilize the surfacing, reduce commercial vehicle tire pressures, or take some other measures to prevent the offsite movement of sediment.

  - Seasonal considerations. If the specific RMO for the project has identified seasonal restrictions then this should be considered when determining material characteristics. If the traffic occurs

outside the design seasons of use the material characteristics might not be the same as those assumed during the design. This may lead to a road that does not perform according to expectations.

- Traffic estimation: Anticipated traffic is the next design parameter that must be ascertained. Existing and future traffic data must be gathered for the expected life of the project. It is important to include all traffic and project any growth in traffic volumes. See section 3.2 for detailed information concerning traffic analysis.

- Design rut depth: As discussed previously, allowable rut depth is used to determine surface serviceability and as such should be selected with care. For earth designs, the design equation calculates the expected rut depth. The rut depth can only vary due to a change in traffic (volume or season), or to a change in compaction effort. For aggregate surfacing design, it is assumed that terminal serviceability occurs with a 2-inch rut. This can be modified, but the maximum rut depth should be held to less than one-half the structural thickness. Section 3.3.3 discusses rut depth in more detail.

- Special or unique project specific considerations:
  Refer to section 4.4 for assistance and guidance for:
  - very weak subgrades (CBR<3);
  - excessive moisture; and
  - high wheel loads (non-standard highway legal loads).

4.3.2 Earth

Unsurfaced roads do not have layers of aggregate or other surfacing materials above the subgrade to help support traffic loads. They may be sufficient to carry the loads without failure as long as blading operations provide proper drainage and a smooth running surface. Subgrade failure is present if there are indications of surface pumping, excessive rutting, potholes or washboarding, erosion, slumps, or slides. Knowledge of the soil's strength properties aids in determining whether aggregate surfacing will be necessary.

Equation 4.3.2-1 is used for the design of earth-surfaced roads (see appendix 3.1.1 for additional discussion). Although an unsurfaced model was also developed by the U.S. Army Corps of Engineers (2), they assumed that the top layer was actually *weaker* than the bottom layer. The rationale was that the upper portion may be adversely affected by moisture and organic materials in a military situation. However, for Forest Service conditions it is expected that compaction from construction traffic and trucks would offset these effects. Therefore, equation 4.3.2-1 is used for earth and aggregate surfaces.

$$RD = 5.8230 \frac{R^{0.2476}}{(\log t)^{2.002}\, C_1^{0.9335}\, C_2^{0.2848}} \qquad \text{(Eq.4.3.2-1)}$$

where:
- RD = rut depth, inches.
- R = repetitions of load or passes of an 18,000-lb single-axle @ 80 psi; see section 3.2 for additional details.
- t = thickness of top layer, inches.
- C_1 = CBR of compacted subgrade; see section 3.4.1 for additional details.
- C_2 = CBR of uncompacted subgrade; see section 3.4.2 for additional details.

The modification to equation 4.3.2-2 assumes that the thickness (t) of an earth road will be 6 inches, the depth of compaction that occurs during construction.

$$RD = 5.8230 \frac{R^{0.2476}}{(\log 6'')^{2.002}\, C_1^{0.9335}\, C_2^{0.2848}}.$$

Simplifying:

$$RD = 9.6213 \frac{R^{0.2476}}{C_1^{0.9335}\, C_2^{0.2848}}. \qquad \text{(Eq. 4.3.2-2)}$$

Typically, C_1 will be the value for a soil compacted to 90 percent AASHTO T-99, while that for C_2 will be for 85 percent AASHTO T-99.

The "STP" design program uses the same information given here to calculate rut depth but the calculations are done by the computer. The program allows the designer to rapidly compare alternatives and conduct "what-if" analysis. See the Users Guide in appendix 6.2 for assistance with the "STP" computer program. Refer to section 4.3.7 for guidance with multiple design seasons and section 5.2 for an example using "STP." Note that the computer program allows only two design seasons. The *Aggregate Surfacing Design Guide* by ARE Engineering Consultants (5) has an example of an earth surface design calculated by hand in chapter 3.

4.3.3 Aggregate

Equation 4.3.3-1 is used to determine the structural pavement requirements for an aggregate-surfaced road. See appendix 3.1.1 for additional discussion on the development of the design equation.

$$RD = 5.8230 \frac{R^{0.2476}}{(\log t)^{2.002}\, C_1^{0.9335}\, C_2^{0.2848}} \qquad \text{(Eq. 4.3.3-1)}$$

where:
- RD = rut depth, inches.
- R = repetitions of load or passes of an 18,000-lb. single-axle @ 80 psi adjusted by the reliability factor (RF). See section 3.2 for details on traffic and section 3.3.4 for details on the reliability factor.

t = thickness of top layer, inches.
C_1 = CBR of aggregate; see section 3.4.2 for additional details.
C_2 = CBR of subgrade; see section 3.4.1 for additional details.

Equation 4.3.3-2 is modified to solve for the thickness of aggregate to limit the rut depth to 2 inches. Section 3.3.3 discusses the selection of the design rut depth.

$$RD = 5.8230 \frac{R^{0.2476}}{(\log t)^{2.002}\, C_1^{0.9335}\, C_2^{0.2848}} .$$

Simplifying:

$$\log t = 1.7054 \frac{R^{0.1237}}{C_1^{0.4663}\, C_2^{0.1423}} \qquad \text{(Eq. 4.3.3-2)}$$

The "STP" design program uses this same information to calculate the aggregate thickness necessary to meet the structural requirements, but the calculations are done by the computer. The program allows the designer to rapidly compare alternatives and conduct "what-if" analysis. See the Users Guide in Appendix 6.2 for assistance in the use of the "STP" computer program. Refer to section 4.3.7 for guidance with multiple design seasons and section 5.3 for an example using "STP." Note that the computer program allows only four design seasons. The *Aggregate Surfacing Design Guide* by ARE Engineering Consultants (5) has an example of an aggregate surface design calculated by hand in chapter 3.

4.3.4 Asphalt, Concrete, and Bituminous Surface Treatments

These surface types cover a large variety of surface types. Some of the most common and traditional of these are described in section 4.2.1.

This *Surfacing Design Guide* does not cover these in detail except the BST. The most current version of the AASHTO *Guide for Design of Pavement Structures* or the latest Portland Cement Association (PCA) design guides are recommended for these surface types. Much of the necessary design information needed for the AASHTO and PCA guides are the same for earth and aggregate pavement designs and are discussed in Chapter 3, "Surfacing Design Considerations."

Bituminous Surface Treatments. BST's differ from hot or cold mix asphalt in that the BST is a single or multiple layers of a sprayed asphalt emulsion (or liquid asphalt) layer followed by a layer of aggregate "chips," placed one aggregate thick. Typically the aggregate has quality requirements similar to those for a hot or cold mix asphalt. The maximum size of the aggregate can vary from three-fourths of an inch to one-fourth of an inch. Being a thin (less than three-fourths of an inch thick) layer, it is common for design not to assign any structural support capacity to the BST treatment. With that in mind, it is recommended to design the BST over unstabilized aggregate using the aggregate design algorithm

used in the *Surfacing Design Guide*. If the BST is placed on a stabilized material, then the most current version of the AASHTO *Guide for Design of Pavement Structures* should be used for a reference. Listed here are some design tips for using the BST aggregate design procedure:

- Use the reliability factor that corresponds to the road's traffic service level.
- The design rut depth should be 1 inch, not the default of 2 inches, which will increase the structural aggregate requirements.
- No operationial loss thickness should be required.

Limited design using "STP" with the above design tips has given reliable and reasonable pavement structures. An example using "STP" for the design of a BST can be found in section 5.5.

4.3.5 Alternative Surfacing Materials

Various alternatives to traditional surfacing materials exist. These include but are not limited to: (1) wood products (woodchips, bark, and chunkwood); (2) rubber tire products (shredded tires and sidewalls); (3) glass by-products; (4) mining waste products; (5) coal and cement manufacturing waste products; and (6) even crushed porcelain toilets! Appendices 6.6 and 6.7 contains information on wood and rubber products used as surfacing materials as well as background information on past Forest Service studies.

- Chunkwood. Chunkwood is of particular interest as an alternative surface material within forest environments. It can be made from wood waste such as small trees and limbs. The use of chunkwood was investigated initially by the North Central Forest Experiment Station in the early 1980's. In 1987, the Missoula Technology and Development Center developed a chunkwood machine similar to a whole tree chipper. The concept has been field tested on the Chequamegon, Superior, and Allegheny National Forests in Region 9; the Bienville and Kisatchie National Forests in Region 8; and the Winema National Forest in Region 6. Some advantages include the material's high water permeability, ability to provide structural integrity, biodegradability, elimination of dust, and lightweight fill characteristics for weak subgrade areas. It can be especially beneficial in permafrost areas. One disadvantage is its high compressibility which requires thick lifts of the material. Appendix 6.6 contains detailed design information and sample specifications.

4.3.6 Reconstruction Resurfacing

The resurfacing design procedure is included in the "STP" computer program and is applicable only to aggregate-surfaced roads. Figure 4.3.6-1 is a flowchart that illustrates the different steps in a resurfacing design. Basically, the approach assumes that there is an existing aggregate-surfaced road for which thickness and strength are known. This existing road may consist of a degraded or contaminated aggregate

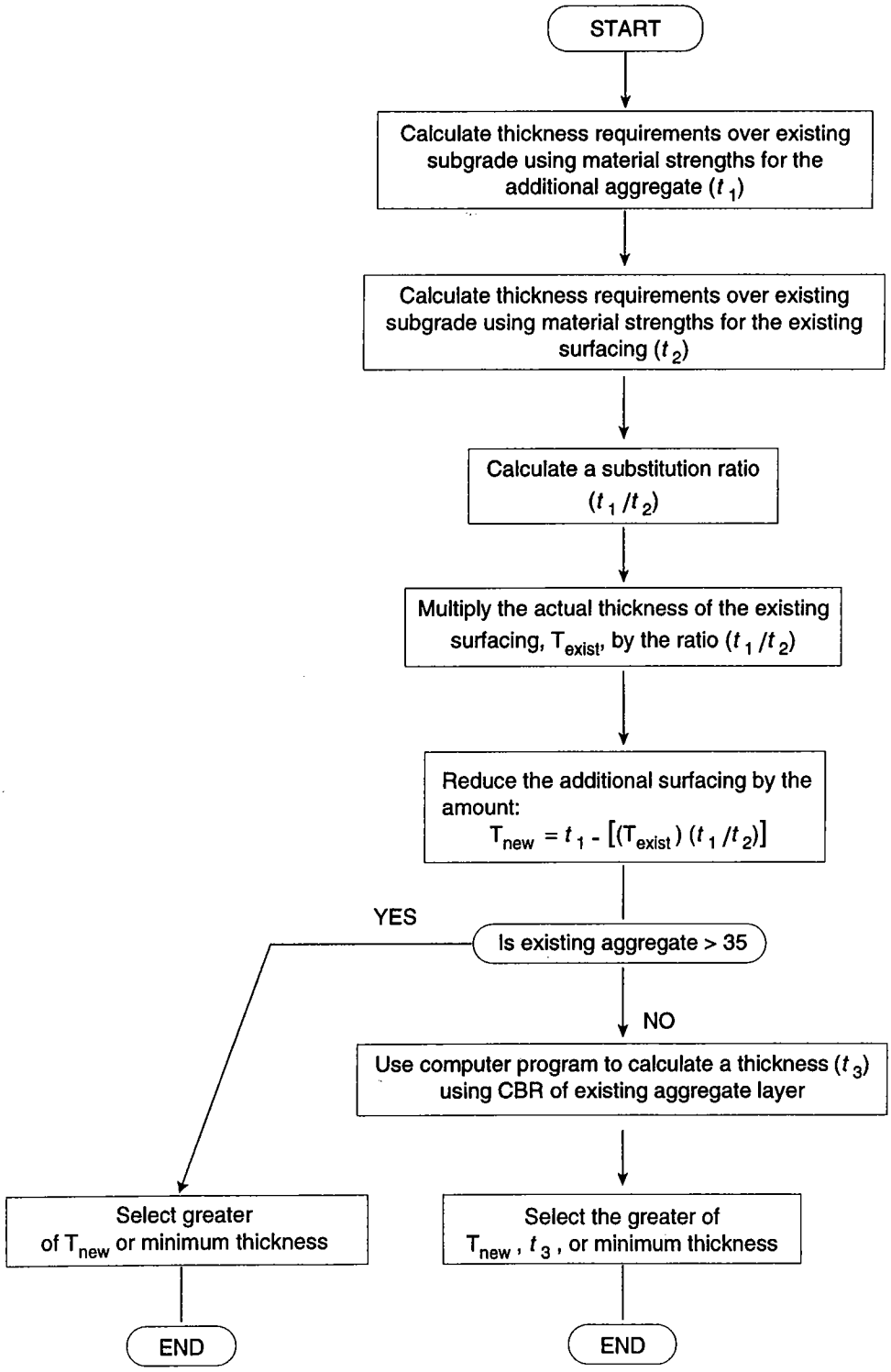


Figure 4.3.6-1.—Flowchart for resurfacing design.

surface, such that the CBR is lower than its original design and the roadway may no longer be able to fulfill its intended function. Therefore, a new surfacing is required to bring the roadway back up to standard.

The procedure obtains an equivalency between the old and new material so as to convert the existing material to an equivalent thickness of new material. These are the steps required in this procedure:

From equation 3.1.1-2, calculate a surfacing thickness (t_1) using new material as though no existing aggregate exists over the existing subgrade ($C_{subgrade}$). These are the needed variables:

RD_{allow}	=	allowable rut depth.
C_{new}	=	new material CBR; C_{new} can be greater than four times $C_{subgrade}$, but should be less than four times C_{old} unless special conditions exist; see section 3.4.2 for details.
R	=	number of EASL's; see section 3.2 for details.
$C_{subgrade}$	=	subgrade CBR; see section 3.4.1 for details.

Next, calculate a similar thickness (t_2) except that the CBR of the aggregate layer (C_{old}) will be that of the existing or old aggregate.

Calculate substitution ratio (t_1/t_2). If this ratio were 1/2, this would be interpreted to mean that 1 inch of the new material is equivalent to 2 inches of the old material.

Next, the existing thickness (t_{exist}) is converted to an equivalent thickness of new material using the substitution ratio.

$$t_{equiv} = (t_{exist})\ (t_1/t_2) \qquad \text{(Eq. 4.3.6-1)}$$

The new surfacing thickness is then the difference between t_1 and t_{equiv}

$$t_{new} = t_1 - t_{equiv} \qquad \text{(Eq. 4.3.6-2)}$$

If the existing aggregate CBR is less than 35, a check is made to ensure that the new thickness calculated is adequate to protect the old surface material. This is done by calculating a thickness (t_3) that uses the CBR of the new material (CBR_{new}) with the existing aggregate layer (C_{old}) as the subgrade CBR.

Select the aggregate resurfacing thickness.

If the existing aggregate is less than 35, select the greater of t_3, t_{new}, or the minimum aggregate thickness as the required resurfacing thickness.

If the existing aggregate is greater than 35, select the greater of t_{new} or the minimum aggregate thickness.

Realistically, if t_3 or t_{new} is less than 2 inches and the existing aggregate is not degraded or contaminated, one might consider adding only 2 inches of 1-inch minus material and processing that with the existing material or forgo the additional aggregate until a later time.

Example of a reconstruction resurfacing project can be found in section 5.4.

4.3.7 Multiple Season

In "STP," a maximum of two design seasons for earth roads, four for newly constructed aggregate-surfaced roads, and one for reconstructed aggregate-surfaced roads is possible. Miner's Hypothesis is used to sum up the damage ratios for each season. The following variables must be known:

i	=	number of seasons.
$R_{est,i}$	=	estimated traffic for each season. Note: sum of the traffic for each season must equal the total design traffic.
C_{1i}, C_{2i}	=	material CBR's for each season.
t	=	trial thickness.
RD_{allow}	=	maximum allowable rut depth.

Earth Road Design Procedure. The steps in this procedure are:

1. Calculate the allowable number of repetitions, R_{allow}, for the season in which the lowest soil strength is anticipated (given an allowable rut depth (RD_{allow}), 6 inches maximum) using equation 4.3.2-2.

$$RD = 9.6213 \frac{R^{0.2476}}{C_1^{0.9335}\, C_2^{0.2848}} \cdot \qquad \text{(Eq. 4.3.2-2)}$$

2. Calculate the damage ratio as noted in section 3.4.1. If the ratio is less than 1, the design is acceptable and proceed to step 3. If greater than 1, the actual traffic level must be reduced, the allowable rut depth (RD_{allow}) increased, or more aggregate is required. The CBR's of the subgrade (C_2) and compacted layer (C_1) may not be modified as this is the strength of in situ material, unless a greater compaction effort is used during construction.

3. Repeat steps 1 and 2 for the next season using the same allowable rut depth (RD_{allow}).

4. Sum up the damage ratios and check to see that they are less than or equal to 1 for an acceptable design. If the damage ratios are greater than 1, then the traffic level must be reduced or the engineer should consider an aggregate-surfaced road. Alternatively, a maintenance strategy is possible.

Aggregate-Surface Road Design Procedure. The steps in this procedure are:

1. For the first season, calculate R_{allow}, given that RD_{allow}, t, C_1, and C_2 are known using equation 4.3.3-2.

$$\log t = 1.7054 \frac{R^{0.1237}}{C_1^{0.4663} C_2^{0.1423}} \qquad \text{(Eq. 4.3.3-2)}$$

2. Calculate the damage ratio of estimated traffic ($R_{est,1}$) to allowable traffic ($R_{allow,1}$) for the first season. If this ratio is less than or equal to 1,

$$\text{damage ratio} = \frac{R_{est,1}}{R_{allow,1}} \leq 1 \qquad \text{(Eq. 4.3.6-1)}$$

This indicates that the road as designed is adequate for the first season. If the damage ratio is greater than 1, then the following variables may be modified and the process iterated until the ratio is less than 1.

C_2	=	aggregate CBR.
$R_{est,1}$	=	estimated traffic modified by either restricting traffic or using lower tire pressures on vehicles.
t	=	thickness modified by increasing.
RD_{allow}	=	allowable rut depth modified by allowing deeper ruts; need to ensure that this still meets expectations in the RMO.

However, the designer will typically only change the thickness before repeating the process.

3. Repeat steps 1 and 2 for as many seasons as required. The allowable rut depth (RD_{allow}) and trial thickness (t) *must* be constant for all seasons.

4. Sum up the damage ratios.

$$\Sigma \frac{R_{2est,i}}{R_{allow,i}} \leq 1 \qquad \text{(Eq. 4.3.6-2)}$$

If the sum is less than or equal to 1, then the design is acceptable. If not, modifications to the variables listed in step 2 are required and the whole process must be repeated. Equations 4.3.6-1 and 4.3.6-2 must be less than or equal to 1 for the design to be acceptable.

An example is provided in section 5.3.2 using the "STP" computer program.

4.3.8 Material Substitution

Typically, a forest may want to reduce costs by using a less expensive or lower quality aggregate in some combination with higher quality aggregate. Figure 4.3.8-1 is a flowchart that outlines this procedure, which is very similar to that of the resurfacing design process. The steps are as follows:

1. First, assume the CBR of aggregate A is higher than that for aggregate B (i.e., $CBR_B > CBR_B$).

2. Calculate the thickness (t_A) required if only aggregate A is used.

3. Next, calculate the thickness (t_B) required if only aggregate B is used.

4. A substitution ratio (t_B/t_A) is then obtained. This ratio is read as t_B inches of material B to be equivalent to t_A inches of material A.

5. Next, a portion of t_A is to be replaced with material B. This replacement thickness is t_{rep}. Therefore, the amount of material B (t_{sub}) required to substitute for t_{rep} will be:

$$t_{sub} = (t_{rep})\ (t_B/t_A) \qquad \text{(Eq. 4.3.8-1)}$$

6. "STP" is then used to perform the economic analysis on the costs and benefits of using a lower quality aggregate as a substitute.

An example of material substitution follows:

Assume the following:

R	=	30,000 ESAL's
C_A	=	40 (CBR of material A)
C_B	=	30 (CBR of material B)
C_2	=	10
RD_{allow}	=	2 inches

Note: the 4:1 ratio is still valid for both cases.

Calculate t_A using material A. From equation 3.1.1-2, we can solve for t:

$$t_A = 6.13 \text{ inches}$$

Calculate t_B using material B. From equation 3.1.1-2:

$$t_B = 7.95 \text{ inches}$$

Calculate substitution ratio:

$$t_B/t_A = 7.95/6.13 = 1.30 \text{ inches}$$

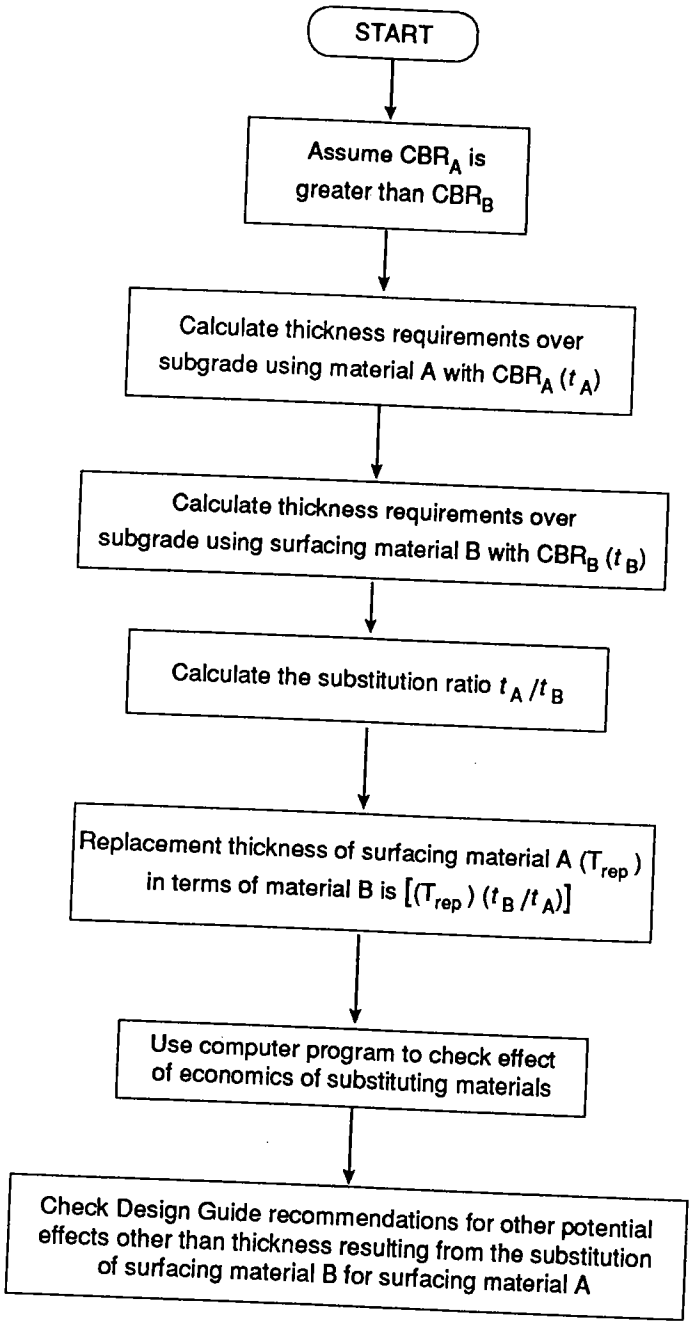


Figure 4.3.8-1.—Flowchart for substitution of different quality sources of surfacing.

This is interpreted to mean 1.30 inches of material B is equivalent to 1 inch of material A.

Assume that 4 inches (t_{rep}) of material A is to be replaced with material B. Calculate the substitution thickness (t_{sub}):

$$t_{sub} = (t_{rep})\,(t_B/t_{BA}) \qquad \text{(Eq. 4.3.8-2)}$$

$$= (4'')\,(1.30'')$$

t_{sub} = 5.2 inches, round to the nearest 0.5 inches, therefore 5 inches.

Therefore, if 4 inches of material A (the stronger material) is to be replaced, it requires 5 inches of material B (the weaker material).

4.3.9 Maintenance

It is necessary to determine how to use the "STP" design algorithm when the road will be bladed periodically.

As noted in section 3.3.5, if the aggregate surface is properly bladed prior to development of the design rut, reliability in the design can be increased. Blading could be included in the design by reducing the reliability factor, F_r. This decreases the structural aggregate requirements but with blading the design life of the aggregate road is the same. Since the design algorithm has not been validated with blading activities, this procedure should be used with caution. Until local experience shows otherwise, it is recommended to reduce the reliability factor by a maximum of 10 to 15 percent.

The design algorithm can also be used to calculate the traffic, in ESAL's that will generate an expected rut depth for a known subgrade CBR, known surfacing CBR, and thickness. This is called the rut depth analysis in the "STP" computer program. The process can be used to help set a blading program for a given section of road. Section 5.3.3 includes an example of this application.

4.4 Special Considerations

In some surfacing design situations there are conditions that need to be handled differently. Following are a few items that the designer needs to be aware of as needing special consideration during the design process.

4.4.1 Very Weak Subgrades

The "STP" design method presented in the *Surfacing Design Guide* is not appropriate for determining surfacing needs for very weak subgrades. If subgrade soils are shown to have design CBR's less than 3, then the designer should use appendix 6.5 for designing with geotextiles.

4.4.2 Excessive Moisture Conditions

A pavement structure can be designed and built to counter wet areas or the times of the year when saturated pavement conditions occur. However, the resulting pavement structure may not be the most economical

solution to the problem. Following are some alternatives that one can consider when designing for excessive moisture in the pavement structure.

Situation	Alternative
Periodic heavy rainfall, or spring thaw conditions	1. limit traffic during wet or thaw period. 2. use geotextiles. 3. stabilize the aggregate or subgrade. 4. ditch the road. 5. crown or outslope subgrade and/or surface.
Permanent spring, or ground water table within 3 ft. of subgrade	1. intercept spring and divert away from pavement structure. 2. use geotextile for separation between subgrade and aggregate. 3. relocate road away from problem. 4. install french drain with geotextile.
Seasonal spring	1. limit traffic during occurrence. 2. intercept spring and divert away from pavement structure. 3. use geotextile for separation between subgrade and aggregate. 4. relocate road away from problem.

4.4.3 Control During Construction

During the design process, the designer makes certain assumptions about what level of material quality and construction control will take place. It is important that construction control be consistent with the design assumptions. Those quality standards need to be incorporated into the project specifications and need to be followed if the anticipated performance is to be achieved. Some important items that must be carefully monitored during construction are:

- Compaction of subgrade and base or surfacing material. This would include control of moisture during the compaction effort. Care must be taken to ensure layers of material placed in fills is of proper depth to guarantee adequate compaction. Appropriate base and surface course compaction is critical to anticipated performance.

- Depth, gradation, and quality of the aggregate base or surfacing material.

4.4.4 High Wheel Loads

Occasionally there may be situations where very high wheel loads, such as large yarders, may be allowed on the road, particularly when subgrade soil strengths are very low. The design method presented does not allow for this situation. The involvement of a geotechnical specialist may be warranted since a bearing capacity solution may be more appropriate in these cases. Geotextile subgrade reinforcement may be required to support the load.

4.4.5 Frost/Spring Thaw Conditions

Frost heaving results from ice lenses growing through the soil. During the spring melt, the ice lenses in the subgrade will melt and result in excessive moisture or prevent moisture from above from moving downwards. These conditions can saturate the subgrade, thus lowering its load supporting capacity. The depth of frost penetration is dependent on many factors, mainly temperature conditions, soil type, traffic, rainfall history, ground water, drainage, and atmospheric humidity. Past studies (15) have identified soil's susceptibility to frost heave. A listing of soils follows.

Frost Susceptibility: Soil Description

LOW: Gravelly soils containing 3–20 percent finer than .02 mm by weight (GW, GP, GM, SW, SP, GW-GM, GP-GM, SW-SM, SP-SM).

MEDIUM: Sands containing 3–15 percent finer than .02 mm by weight (SM, SW-SM, SP-SM).

HIGH: Gravelly soils containing more than 20 percent finer than .02 mm by weight; sands, except very fine silty sands containing more than 15 percent finer than .02 mm by weight; clays with plasticity indexes of more than 12; varved clays existing with uniform subgrade conditions (GM, GC, SM, SC, CL, CH).

VERY HIGH: All silts including sandy silts; very fine silty sands containing more than 15 percent finer than .02 mm by weight; clays with plasticity indexes of less than 12; varved clays existing with nonuniform subgrade conditions (ML, MH, SM, CL, CH, CL-ML).

Frost-related problems also include possible loss of compaction, development of permanent roughness, potholes, restriction of drainage by the frozen strata, and excessive maintenance requirements. Generally, cold, wet climates are likely to have the most serious problem with frost penetration.

It has been common practice to set road and load restrictions during spring thaw. In most cases, the timing of restrictions is based on local experience and visual indication of damage or have coincided with state or county closures and restrictions. Some forests have used temperature monitors (thermistors) to predict when road conditions reach critical thaw-weakening conditions.

Another alternative is to design the road's surfacing type and increased surface structural thickness to resist frost heaving. The U.S. Army Corps of Engineers has developed a method for determining the thickness design of a surface that has adequate resistance to distortion by frost heave and cracking and distortion under traffic loads as affected by seasonal variation in subgrade support. This procedure is called the reduced subgrade strength method. The procedures to determine the

reduced subgrade moduli of the aggregates and the subgrade soils can be obtained from U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) (15).

Chapter 5
Road Surface Design Guide Examples

This section has several examples that the designer can use as guides for any of the design procedures. Each example builds on the other to minimize the complexity of each example. Where appropriate, the examples include the information obtained from a realistic RMO and forest plan. Wherever possible the computer program "STP" is used to demonstrate the examples. Hand calculations are not included in these examples.

5.1 Selection of Surface Type

Surface Selection—Example One—Local

From RMO's and forest plan:

- single-lane, local.
- .5 mile, new construction.
- traffic service level: C.
- maintenance level: 2 (during and after activity).
- traffic information:
  - 1 log truck per weekday, June 15 through September 30;
  - 10 pickups (firewood) per weekend day, August 15 through October 15.
- grades: 5 percent max.
- design vehicle and critical vehicle: log truck.
- allow for high clearance vehicle, and manage for use, 6-inch acceptable rut depth.
- Remarks:
  - first 500 feet of road traverses Class II stream;
  - road within Forest Service boundary;
  - not within scenic designation, or within view of scenic location;
  - no migrating wildlife;
  - not a share cost road; and
  - minimum maintenance dollars available.

Determine if earth surface is sufficient to meet road objectives using Figure 2.5-1, "Surfacing Decision Flowchart" for a 5-year design life:

Step 1: Will the rut depth be greater than 6 inches when unsurfaced and not maintained?

- Answer: No, calculated rut depth from "STP" is 4.1 inches, which is less that the acceptable rut depth. (See section 5.2.2 for an

example if the ruts will be bladed prior to the calculated rut depth.)

- Discussion: With 5-year design there will be 350 trips of a loaded and 350 trips of an unloaded log truck, and 800 trips of a loaded and 800 trips of an unloaded pickup truck; uncompacted CBR = 5.4, compacted CBR = 11; used "STP" to calculate rut depth (see 5.2.1 Earth Surface Design Example for details).

Step 2: Will water bars, outsloping, road closure, etc. provide adequate protection?

- Answer: Yes from M.P. 0.1 to 0.5 (since not adjacent to class II stream); no from M.P. 0.0 to 0.1 (since adjacent to class II stream).

Step 3: Will resource damage be significant (will road affect water quality and will damage outweigh repair/maintenance costs)?

- Answer: Yes from M.P. 0.0 to 0.1 and no from M.P. 0.1 to 0.5.

- Discussion: From M.P. 0.0 to 0.1 (native soils are silty sand, and the cost to surface with aggregate is $1,600 with 4 inches of 1.5-inch minus crushed and $500 with of 3 inches of 3-inch jaw run); (need only 3 inches since purpose will probably be for nonstructural; refer to design recommendations in section 4.2.4). The road will impact water quality to an undetermined amount, but estimate that the damage will be more than the $500 to minimize/mitigate the issue.

Step 4: Is there a better alternative route or method of access?

- Answer: No.

Step 5: Are funds available for the project?

- Answer: Yes.

- Discussion: $15,000 available to build the road; estimate $10,000 to build the road to subgrade; leaves $5,000 for surfacing.

Step 6: Results:

- M.P. 0.0 to 0.1: stabilize, rock, pave, etc., as required for structural support or surface stabilization; use "STP" to determine necessary aggregate depth; remember to evaluate various surfacing alternatives.

- M.P. 0.1 to 0.5: minimal work for erosion protection.

Surface Selection—Example Two—Collector

From RMO's and forest plan:

- single-lane, collector.
- 0.5 mile, new construction.
- traffic service level: B.
- maintenance level: 3 (during and after activity).
- traffic information:
  - 3 log trucks per weekday, June 15 through September 30;
  - 10 pickups (firewood) per weekend day, August 15 through November 15; and
  - administrative traffic from April 1 to November 30.
- grades: 5 percent max.
- design vehicle: log truck; critical vehicle: yarder.
- allow for high clearance vehicle and manage for use, 2-inch acceptable rut depth.
- Remarks:
  - first 500 feet of road traverses class II stream;
  - road within Forest Service boundary;
  - not within scenic designation, or within view of scenic location;
  - no migrating wildlife;
  - not a share cost road; and
  - minimal maintenance dollars available.

Determine if earth surface is sufficient to meet road objectives using Figure 2.5-1, "Surfacing Decision Flowchart" for a 15-year design life:

Step 1: Will the rut depth be greater than 2 inches when unsurfaced and not maintained?

- Answer: Yes, calculated rut depth = 5.3 inches, which is not acceptable. (See section 5.2.2 for an example if ruts will be bladed prior to the calculated rut depth.)

- Discussion: With 15-year design there will be 953 trips of a loaded and 953 trips of an unloaded log truck, estimated 14 trips of yarder; and 3,600 trips of a loaded and 3,600 trips of an unloaded pickup truck; uncompacted CBR = 5.5, compacted CBR = 11; used "STP" to calculate rut depth.

Step 2: Are seasonal limitations. reduced tire pressures, and load restrictions being implemented?

- Answer: No, and load restrictions or lower tire pressures are not feasible.

Step 3: Will water bars, outsloping, road closure, etc. provide adequate protection?

- Answer: Yes from M.P. 0.1 to 0.5 (since not adjacent to class II stream); no from M.P. 0.0 to 0.1 (since adjacent to class II stream).

Step 4: Will resource damage be significant (will road affect water quality and will damage outweigh repair/maintenance costs)?

- Answer: Yes, from M.P. 0.0 to 0.1 and no, from M.P. 0.1 to 0.5.

- Discussion: From M.P. 0.0 to 0.1 (native soils are silty sand, and the cost to surface with aggregate is $1,600 with 4 inches of 1.5-inch minus crushed and about $1,000 with 6 inches of 3-inch jaw run) (see section 5.3.1), and cost to maintain native surface when ruts are greater than 4 inches (blade once every 2 years) is about $200 per year; the road will impact water quality to an undetermined amount, but estimate that the damage will be more than $1,000 to minimize/mitigate the issue.

Step 5: Are funds available for the project?

- Answer: Yes.

- Discussion: $15,000 available to build the road; estimate $10,000 to build the road to subgrade; leaves $5,000 for surfacing.

Step 6: Results: Stabilize, rock, pave, etc., as required for structural support or surface stabilization; use "STP" to determine necessary aggregate depth; remember to evaluate various surfacing alternatives.

5.2 Earth Surface—New Construction Example

5.2.1 Single Season Design

From RMO's and forest plan: same as section 5.1, example one, local.

Step 1: Traffic.

a. Using 5-year design life for earth surface, determine the number of each vehicle type:

- No. of log trucks: 1 truck/day * 5 days/week * 4 weeks/month * 3.5 months/year * 5 years = 350 trips unloaded and 350 trips loaded.

- No. of pickups: 10 trucks/day * 2 days/week * 4 weeks/month * 2 months/year * 5 years = 800 trips empty and 800 trips loaded with firewood.

b. Determine the ESAL's for each vehicle:

- For an empty and loaded log truck @ 90 psi = 1.00 for empty + 4.16 for loaded = 5.16 (from a combination of figures 3.2-4 and 3.2-5 and the "STP" help menu).

- For loaded pickup trucks (assume negligible for empty) = 0.09 (from figure 3.2-2 and "STP" help menu).

c. Determine the total ESAL's for all the expected traffic:

= (350 log truck trips * 5.16 ESAL/trip) + (800 pickup trips * 0.09 ESAL/trip) = 1,878 total 18-kip ESAL's.

Step 2: Materials.

a. Determine the number of seasons with similar soil conditions:

- For given location, all the traffic occurs during similar weather conditions so assume that there will be only one set of material strength values; therefore have 100 percent of the traffic ESAL's in one season.

b. Determine the CBR of the compacted and uncompacted soil:

- From the soil resource inventory for that proposed road location, the soil is a silty sand (USCS = SM).

  From prior knowledge and forest CBR data bases, the following CBR's are obtained for a silty sand:

  CBR @ 85% AASHTO T-99 = 3,
  CBR @ 90% AASHTO T-99 = 6,
  CBR @ 95% AASHTO T-99 = 13.

- The above CBR's are based on saturated conditions. Since our road has traffic during the dry season, the above numbers need to be adjusted based upon past experience of soaked and unsoaked CBR's. You have observed an increase in silty sands by a factor of 1.8 in the past, so dry CBR's would be as follows for your silty sand (note that this factor is site specific):

  CBR @ 85% T-99 = 5.4,
  CBR @ 90% T-99 = 11,
  CBR @ 95% T-99 = 23.

- Your past experience has shown that native uncompacted soil is typically 85 percent of T-99. For earth-surfaced roads the

surface gets compacted to 90 percent of T-99, so use the following CBR's for design:

Compacted CBR = 11
Uncompacted CBR = 5.4

Step 3: Results using the computer program "STP," earth thickness design:

a. expected rut depth = 4.1 inches; see figure 5.2.1-1 for example input data sheet, and figure 5.2.1-2 for "STP" output file.

5.2.2 Maintenance

Using the same information from example 5.2.1, one now needs to determine when to blade the road since it has been determined to keep the rut depths to less than 2 inches.

RMO's and forest plan information is the same as example 5.2.1. Traffic and materials are the same as example 5.2.1.

- Solution One:

  Using the "STP" rut depth analysis module, 2-inch rut depth will occur when the traffic equates to 94 18-kip ESAL's. Note: In rut depth analysis, use the following:

  Compacted thickness = 6 inches
  Subgrade CBR = uncompacted CBR = 5.4
  Aggregate CBR = compacted CBR = 11

  Discussion: 94 18Kip ESAL equates to 18 log trucks which occurs in 3 to 4 weeks after haul starts, assuming 1 log truck per day (see RMO's); note 1 log truck (90 psi) in and out on the road equals 5.16 18-kip ESAL's. It would then be estimated that 20 gradings would be required over the 5-year period to keep the ruts less than 2 inches.

- Solution Two:

  Using figure 5.2.2-1: 2 inches represents 48 percent of the expected rut, which corresponds to approximately 5 percent of the expected traffic. Five percent equals 94 18-kip ESAL's.

  Note on figure 5.2.2-1: This graph represents a guide for equating the percentage of total rut to percentage of total traffic for earth-surfaced roads. Most all practical combinations of materials and traffic follow the trend shown in the figure. A quick check using "STP" rut depth analysis will confirm if the trend is valid for your given conditions.

Earth Surfacing Design - STP

Problem Name: EXAMPLE 5.2.1
Problem Number: _____
Project Designer: _____
Date: _____

Road Number: 20
Traffic Service Level: C
Problem Description: Used to calculate rut depth for Example 5.1 - Local

Traffic Information

1) Timber Volume:
   1a: Timber Volume (MBF): _____
   1b: Conversion Factor: 5 MBF/truck or _____
   1c: % Non-Log Truck Traffic: .25 or _____
   1d: ESALs = (_____) * ((_____) /(_____)) * (1 + (_____))

   = (Equivlency Factor of log truck)*((1a)/(1b))*(1c)

   = _____

2) Vehicle Type:

Vehicle	Tire Pressure	E.F.	No. of Passes	No. passes * Equivalency Factor
loaded log truck	90	4.16	350	1456
unloaded log truck	90	1.00	350	350
loaded pickup	50	0.09	800	72
			Sum =	1878

Refer to the Figures in Section 3.2 of the "Surfacing Design Guide" or the computer program STP for the selection of the Equivalency Factors (E.F.).

3) Total # ESALS:
   Total # ESALs = ESALs due to timber volume + ESALs due to vehicle type
   = — + 1878 = 1878

Seasonal Information

1) Number of Seasons:
   X A) One season
   _____B) More than one season
   Operating Season: _____
   No. of Months: _____ ESALs per Month: _____

Season No.	Dates of Season	# Months in Season	Timber ESAL per Season	Vehicle ESAL per Season	ESAL per Season	% Traffic
1					1878	100
2						
					1878 (Total)	

Figure 5.2.1-1.—Earth surfacing design.

2) Uncompacted CBR:

A) Soil Type: SM Obtained from: SRI

B) CBR per Season:

Season No.	Expected Moisture Conditions	CBR	Remarks
1	dry @ 85%	5.4	included historical CBR by 1.8
~~2~~			

CBRs obtained from:

___Figure 3.4-2 ____Best Estimate ____SRI ____Lab Tests

_X_Historical Data base ___Other: _____

3) Compacted CBR:

A) Season 1 Uncompacted CBR * 4 = 21.6
Season 2 Uncompacted CBR * 4 = ____

B) Expected subgrade conditions during construction:

____Wet _X_Moist ___Dry

C) Expected compaction during construction:

___Method 1 (80-85% T-99) _X_Method 2 (85-90% T-99)
___Method 3 (90-95% T-99) ___Method 4 (95-97% T-99)
___Method 5 (90-97% T-99) ___Method 6 (95% T-180)

D) Step C CBR For Season 1 11 (used 90% compaction level of native material
Season 2 ____ and increased by 1.8 since dry)

E) Design CBR per Season:

CBR	11	____
Season No.	1	2

(use minimum value from Step A or Step D)

Output

Calculated Rut Depth: 4.1 inches

Remarks

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Figure 5.2.1-1.—Earth surfacing design (cont'd.).

USFS SURFACING THICKNESS PROGRAM
Earth Design

Problem Number : 5.2.1
Problem Description : Earth Surface Example
Surfacing Design Guide
Date of Analysis : 7/29/1994
Filename : (null)

SUMMARY OF INPUT AND RESULTS

Timber Volume : 0 MMBF
Conversion Factor : 5000 BF for 1 Std Log Truck
Percent Non-Truck Traffic : 25

Timber Volume 18K ESALS : 0

Vehicle Type	Equivalency Factor	Actual Passes	No. Passes of 18K ESALS
9 Standard Log Truck	4.16	350	1456
4 Empty Log Truck	1.00	350	350
23 Pickup	0.09	800	72
	0.00	0	0
	0.00	0	0
	0.00	0	0
	0.00	0	0
	0.00	0	0
	0.00	0	0
	0.00	0	0
		Vehicle Type 18K ESALS =	1878
		TOTAL 18K ESALS =	1878

Reliability Factor : 1.00

	Estimated Traffic	Compacted CBR	Uncompacted CBR	Damage Ratios
Season 1	100.0	11	5	0.00
Season 2	0.0	0	0	0.00
TOTAL =	100.0 Percent			0.00

Compacted Thickness . . . . . 6.0 inches
Rut Depth . . . . . 4.1 inches

Figure 5.2.1-2.—Earth design example—"STP" output file.

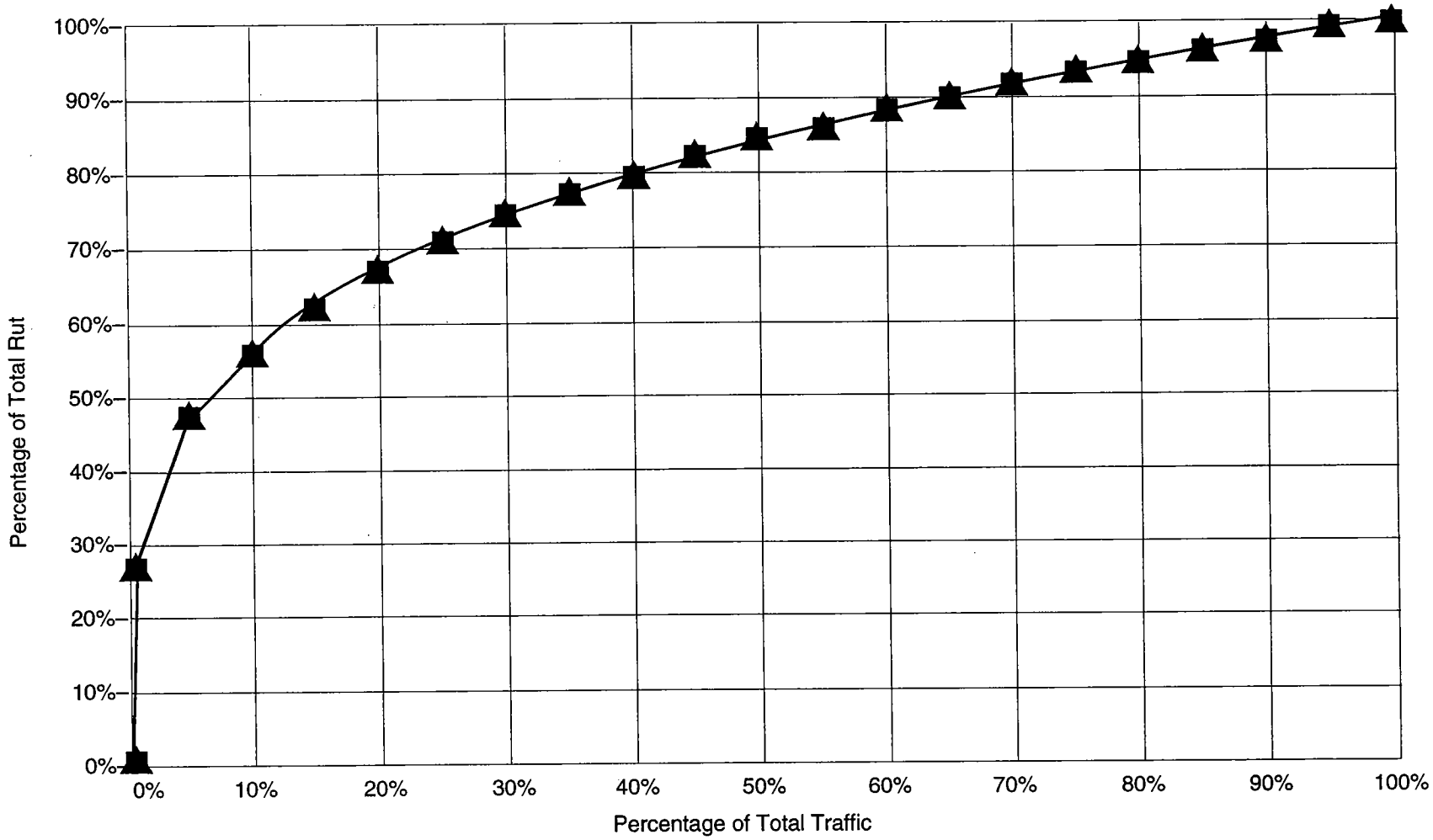

Figure 5.2.2-1.—Variation of rut depth with traffic for earth roads.

5.3 Aggregate Surface—New Construction Example

5.3.1 Single Season Design

From RMO's and forest plan: same as section 5.1, example two, collector.

Step 1: Traffic.

a. Using 15-year design life for aggregate surface, determine the number of each vehicle type:

- No. of log trucks: 3 trucks/day * 5 days/week * 4 weeks/month * 3.5 months/year * 15 years = 3,150 trips unloaded and 3,150 trips loaded.

- No. of pickups: 10 trucks/day * 2 days/week * 4 weeks/month * 3 months/year * 15 years = 3,600 trips empty and 3,600 trips loaded with firewood.

- No. of yarders: 1 yarder/year * 15 years = 15 trips in and 15 trips out.

b. Determine the ESAL's for each vehicle:

- For an empty and loaded log truck @ 90 psi = 1.00 for empty + 4.16 for loaded = 5.16 (from a combination of figures 3.2-4 and 3.2-5 and the "STP" help menu).

- For loaded pickup trucks (assume negligible for empty) = 0.09 (from figure 3.2-2 and "STP" help menu).

- For a yarder @ 80 psi = 16.97 (Washington 208 w/tower) (from a combination of figure 3.2-4 and "STP" help menu).

c. Determine the total ESAL's for all the expected traffic:

= (3150 log truck trips * 5.16 ESAL/trip) + (3,600 pickup trips * 0.09 ESAL/trip) + (30 yarder trips * 16.97 ESAL/trip) = 17,087 total 18-kip ESAL's.

d. Determine the reliability factor: for a collector use 90 percent reliability factor, F_r = 2.32 (from section 3.3.4).

e. Design ESAL's then:

= 17,087 * 2.32
= 39,642

Step 2: Materials.

a. Determine the number of seasons with similar soil conditions (section 3.4.1):

For a given location, all the traffic occurs during similar weather conditions so assume that there will be only one set of material strength values; therefore 100 percent of the traffic ESAL's will be in one season.

b. Determine the CBR of the subgrade and aggregate (sections 3.4.1 and 3.4.2):

- Subgrade: From the soil resource inventory for that proposed road location, the soil is a silty sand (USCS = SM). From laboratory CBR tests the following CBR's were obtained:

  CBR @ 85% AASHTO T-99 = 3,
  CBR @ 90% AASHTO T-99 = 6,
  CBR @ 95% AASHTO T-99 = 13.

- The above CBR's are based on saturated conditions. Since our road has traffic during the dry season, the above numbers need to be adjusted based upon past experience of soaked and unsoaked CBR's. You have observed an increase in silty sands, when dry, by a factor of 1.8, so dry CBR's would be as follows:

  CBR @ 85% T-99 = 5.4,
  CBR @ 90% T-99 = 11,
  CBR @ 95% T-99 = 23.

- You plan to call for the subgrade to be compacted using placement method 3 which, from your past experience in silty sands, 90 percent of T-99 is typically obtained which corresponds to a design subgrade CBR of 11.

- Aggregate: Since this is a traffic service level B road you have found a local source that economically provides crushed aggregate. You plan to use grading "F" (3-inch open-graded) as the base course and provide the necessary surfacing using grading "D" (1-inch dense-graded). You only count on the base to provide the necessary structural support. Your past experience has shown that the aggregate is typically compacted to 90 percent of T-99.

- Using figure 3.4-3, the layer coefficient for grading "F" compacted to 100 percent of T-99 is 0.12. Use figure 3.4-4 and increase the layer coefficient by 1.3 (base good drainage and saturated less than 1 percent of the time); therefore the layer coefficient is 0.12 * 1.3 = 0.16. Figure 5.3.1-1 outlines how the layer coefficient was obtained using figure 3.4-3.

- Using figure 3.4-5 to determine the aggregate CBR, which is much greater than 100 so use 100 for 100 percent of T-99. Divide by 1.7 to obtain the CBR at 90 percent of T-99, 100/1.7 = 59 (1.7 is obtained from note 2 in figure 3.4-2).

  *Note: this is greater than four times the subgrade CBR so use the lesser of the two numbers, design CBR = 4 * 11 = 44.*

- Materials summary: one season with the subgrade CBR = 11 and the surface CBR = 44.

Step 3: Results using the computer program "STP," aggregate—new construction design:

- Aggregate needed is 5.9 inches for structure; round up to 6 inches to meet the construction minimum of placing twice the maximum particle size or 4 inches minimum. Figure 5.3.1-1 is the data for this example, and figure 5.3.1-2 is the "STP" output file.

5.3.2 Multiple Season Design

From RMO's and forest plan: same as section 5.1 example two, collector, except for the traffic.

- Traffic information:
  - 2.3 MMBF per year, operating season: March 15 through November 30.
  - 10 pickups (firewood) per weekend day, August 15 through November 15.
  - administrative traffic from March 1 to November 30.

Step 1: Traffic.

a. Using 15-year design life for aggregate surface, determine the number of each vehicle type:

   - No. of log trucks: 2.3 MMBF/year * 15 yr / .005 MMBF per truck = 6,900 unloaded and 6,900 loaded trips.

   - No. of pickups: 10 trucks/day * 2 days/week * 4 weeks/month * 3 months/year * 15 years = 3,600 empty and 3,600 load trips with firewood.

   - No. of yarders: 1 yarder/year * 15 years = 15 trips in and 15 trips out.

b. Determine the ESAL's for each vehicle:

   - For a loaded log truck @ 90 psi = 4.16 (figures 3.2-4 and 3.2-5).

   - For an empty log truck @ 90 psi = 1.00

Aggregate Surfacing Design - STP

Problem Name: EXAMPLE 5.3.1
Problem Number: _____
Project Designer: _____
Date: _____

Road Number: 30
Traffic Service Level: B
Problem Description: used to calculate aggregate thickness for Example 5.1 - Collector

Traffic Information

1) Timber Volume:
   1a: Timber Volume (MBF): —
   1b: Conversion Factor: 5 MBF/truck or _____
   1c: % Non-Log Truck Traffic: .25 or _____
   1d: ESALs = (_____) * ((_____) /(_____)) * (1 + (_____))

   = (Equivlency Factor of log truck)*((1a)/(1b))*(1c)
   = _____

2) Vehicle Type:

Vehicle	Tire Pressure	E.F.	No. of Passes	No. passes * Equivalency Factor
loaded log truck	90	4.16	3150	13,104
unloaded log truck	90	1.00	3150	3,150
loaded pickup	50	0.09	3600	324
grader	80	16.97	30	509
				Sum = 17,087

Refer to the Figures in Section 3.2 of the "Surfacing Design Guide" or the computer program STP for the selection of the Equivalency Factors (E.F.).

3) Reliability:

Traffic Service Level:	D	C	B
Reliability Factor:	____1.00	____1.44	X 2.32
Reliability:	(50%)	(70%)	(90%)

4) Total # ESALs:
   Total # ESALs = (Timber ESALs + Vehicle ESALs) * Reliability Factor
   = (— + 17,087) * 2.32 = 39,642

Seasonal Information

1) Number of Seasons:
   X A) One season
   ____ B) More than one season
   Operating Season: _____
   No. of Months: _____ ESALs per Month: _____

Season No.	Dates of Season	# Months in Season	Timber ESAL per Season	Vehicle ESAL per Season	ESAL per Season	% Traffic
1					39,642	100
2						
3						
4						
					39,642 (Total)	

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Figure 5.3.1-1.—Aggregate surfacing design "STP."

2) Subgrade CBR:

A) Soil Type: SM Obtained from: Soil sample

B) Expected subgrade conditions during construction:
___Wet ___Moist X Dry

C) Expected compaction during construction:
___Method 1 (80-85% T-99) ___Method 2 (85-90% T-99)
X Method 3 (90-95% T-99) ___Method 4 (95-97% T-99)
___Method 5 (90-97% T-99) Method 6 (95% T-180)

D) CBR per Season:

Season No.	Expected Moisture Conditions	CBR	Remarks
1	dry @ 90%	11	increased lab by 1.8
2			
3			
4			

CBR's obtained from:
___Figure 3.4-2 ___Best Estimate ___SRI X Lab Tests
___Historical Data base ___Other: _____

3) Surface CBR:

A) Season 1 Subgrade CBR * 4 = 44
Season 2 Subgrade CBR * 4 = ____
Season 3 Subgrade CBR * 4 = ____
Season 4 Subgrade CBR * 4 = ____
Note: if result is < 20 use 20 and skip the remainder of Part 3.

B) Type of Aggregate
___Pit Run Maximum Size: _____
___Grid Rolled Maximum Size: _____
___Screened Aggregate
X Crushed, Grading: ___A ___B ___C ___D ___E
X F ___G ___H ___J ___K
___L ___M ___N ___O ___Other: _____
___Cinders ___Sand & Gravel X Fracture Rock

C) Aggregate Quality
___Marginal X Good ___Excellent
SE= >35 PI=___

D) "A" Value From Figure 3.4-3
= base value + additional coefficients
= 0.08 + 0.01 + 0.01 + 0.01 + 0.01 = 0.12
(Fractured rock, SE >35, good quality, grading)

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Figure 5.3.1-1.—Aggregate surfacing design "STP" (cont'd.).

E) Moisture Factor Correction

1) Quality of Drainage

___Excellent X Good ___Fair ___Poor ___Very Poor

2) % time road exposed to moisture levels approaching saturation

Season:	1	2	3	4
# months in season approaching saturation	0			
# months in season				
percent exposed	<1%			
moisture factor from Figure 3.4-4	1.3			

F) New "a" value = Step D * Step E	0.10			
G) CBR from Figure 3.4-5 Note: CBR at 100% of T-99	≥ 100			
H) Adjust CBR to match expected field density, = Step G/1.0 for 100% T-99 = Step G/1.3 for 95% T-99 = Step G/1.7 for 90% T-99	59			
I) Max of Step A, or 20	44			
J) Design CBR, lesser of Step H or Step I	44			

Aggregate Thickness

A) Structural Thickness: 5.9 (from "STP" @ 2 " rut depth))

B) Aggregate Loss: 0 since have surface course

C) Total: 5.9

D) Twice the maximum particle size: 6"

E) Recommended: 6"

(Maximum of Step C, Step D, or 4 inches, round to the nearest whole number)

Remarks

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Figure 5.3.1-1.—Aggregate surfacing design "STP" (cont'd.).

USFS SURFACING THICKNESS PROGRAM
Aggregate Design

Problem Number : 5.3.1
Problem Description : Aggregate Surface – New Construction
Single Season Design
Date of Analysis : 7/29/1994
Filename : (null)

SUMMARY OF INPUT AND RESULTS

Timber Volume : 0 MMBF
Conversion Factor : 5000 BF for 1 Std Log Truck
Percent Non-Truck Traffic : 25

Timber Volume 18K ESALS : 0

Vehicle Type	Equivalency Factor	Actual Passes	No. Passes of 18K ESALS
9 Standard Log Truck	4.16	3150	30401
4 Empty Log Truck	1.00	3150	7308
23 Pickup	0.09	3600	752
40 Washington 208 w/t	16.97	30	1181
	0.00	0	0
	0.00	0	0
	0.00	0	0
	0.00	0	0
	0.00	0	0
	0.00	0	0

Vehicle Type 18K ESALS = 39642

TOTAL 18K ESALS = 39642

Reliability Factor : 2.32

	Estimated Traffic	Surface CBR	Subgrade CBR	Damage Ratios
Season 1	100.0	44	11	0.98
Season 2	0.0	0	0	0.00
Season 3	0.0	0	0	0.00
Season 4	0.0	0	0	0.00
TOTAL =	100.0 Percent			0.98

Allowable Rut Depth : 2.0 inches

Aggregate Loss : 0.0 inches
Structural Thickness Required : 5.9 inches

Total Aggregate Thickness Req'd : 5.9 inches

Figure 5.3.1-2.—Aggregate new construction—single season example—"STP" output file.

- For loaded pickup trucks (assume negligible for empty) = 0.09 (figure 3.2-2).

- For yarder @ 80 psi = 16.97 (Washington 208 w/tower) (figure 3.2-4 and "STP" help menu).

c. Determine the total ESAL's for all the expected traffic:

= (6,900 log truck trips * 5.16 ESAL/trip * 1) + (3,600 pickup trips * 0.09 ESAL/trip) + (30 yarder trips * 16.97 ESAL/trip) = 36,437 total 18-kip ESAL's.

d. Determine the reliability factor: for a collector use 90 percent reliability factor, F_r = 2.32 (section 3.3.4).

e. Design ESAL's then:

= 36,437 * 2.32
= 84,534

Note: See section 5.4.2 for discussion of ESAL's greater than 70,000.

Step 2: Materials.

a. Determine the number of seasons with similar soil conditions (section 3.4.1):

- For a given location, the traffic occurs over months that the roadway materials are wet as well as dry. Break the traffic into three seasons; March 15 to June 15 (3 months); June 15 to October 15 (4 months); and October 15 to November 30 (1.5 months).

b. Determine the CBR of the subgrade and aggregate (sections 3.4.1 and 3.4.2):

- Subgrade: From the soil resource inventory for that proposed road location, the soil is a silty sand (USCS = SM). From laboratory CBR tests the following CBR's were obtained:

  CBR @ 85% AASHTO T-99 = 3,
  CBR @ 90% AASHTO T-99 = 6,
  CBR @ 95% AASHTO T-99 = 13.

- You plan to call for the subgrade to be compacted to placement method 3, which from your past experience in silty sands 90 percent of T-99 is typically obtained. The above CBR's are based on saturated conditions. Since our road has traffic during various moisture conditions, the above numbers need to be adjusted. Based upon your past experience of soaked and unsoaked CBR's, you have observed an increased CBR in silty

sands by a factor of 1.8, if the sample was considerably below optimum and 1.2 if the sample was at optimum. An assumption has to be made at this point based upon your experience. How does the moisture change in the subgrade throughout the year? Some forests have monitored these changes and have developed some guidelines based on their local conditions. Assume, for our example, that you have observed that during the dry times of the year (June to October) the subgrade is dry and at below optimum moisture conditions. You have also observed that during the fall (October to November) the subgrade is close to optimum. Combining your knowledge of the subgrade moisture conditions and changes in CBR with moisture content, you arrive at the following design CBR's:

CBR @ 90% T-99 (soaked) = 6.0,
CBR @ 90% T-99 (optimum)= 7.8,
CBR @ 90% T-99 (below optimum) = 11.

- Aggregate: Since this is a traffic service level B road you have found a local source that economically provides crushed aggregate. You plan to use grading "F" (3-inch open-graded) as the base course and provide the necessary surfacing using grading "D" (1-inch dense-graded). You only count on the base to provide the necessary structural support. Your past experience has shown that the aggregate is typically compacted to 90 percent of T-99.

- Using figure 3.4-3, the layer coefficient for grading "F" compacted to 100 percent of T-99 is 0.12. Use figure 3.4-4 and increase the layer coefficient by 1.3 for the dry (summer) months (base good drainage and saturated less than 1 percent of the time); 1.1 for the fall months (good drainage and saturated 5 to 25 percent of the time); and by 1.0 for the spring (base good drainage and saturated greater than 25 percent of the time). Therefore the corresponding layer coefficients are 0.16, 0.13, and 0.12. Figure 5.3.2-1 outlines how the layer coefficient was obtained. Use figure 3.4-5 to determine the aggregate CBR, which corresponds to 100, 70, and 55 for 100 percent of T-99. Divide by 1.7 to obtain the CBR at 90 percent of T-99, which corresponds to 59, 41, and 32 (1.7 is obtained from note 2 in figure 3.4-2). Now you need to determine if these CBR's are greater than four times the subgrade CBR. All the calculated CBR's are greater than four times their corresponding subgrade CBR, so that four times the subgrade CBR value is used for design.

- Materials summary:

	Subgrade CBR	Surface CBR
Summer Months:	11	44
Fall Months:	7	28
Spring Months:	6	24

Step 3: Traffic per season.

a. From step 2, the seasons are as follows:

March 15 to June 15 (3 months);
June 15 to October 15 (4 months); and
October 15 to November 30 (1.5 months),

for a total of 8.5 months. Break the traffic into seasons using the following assumptions: (1) log truck traffic is uniform throughout the year, and (2) the yarder goes in in the spring and out in the fall.

b. The following traffic percentages occur per season:

Summer = 47%
Fall = 18%
Spring = 35%

See figure 5.3.2-1 details in determining the percent of traffic per season.

Step 4: Results using the computer program "STP," aggregate new construction design.

- Aggregate needed is 12.9 inches for structure; round up to 13 inches to meet the construction minimum of placing twice the maximum particle size or 4 inches minimum. Figure 5.3.2-1 is the data form for this example and figure 5.3.2-2 is the "STP" output file.

- Note that the computer program performs the trial and error, choosing an aggregate thickness so that the damage ratio is less than or equal to 1. For this example the damage ratio was 0.99.

5.3.3 Maintenance

The design algorithm can be used to determine the necessary aggregate thickness for a desired rut depth and the expected rut depth for known material conditions and known traffic. Road managers can use the rut depth analysis module in "STP" to help program the expected blading on an aggregate-surfaced road. For example:

Aggregate Surfacing Design - STP

Problem Name: EXAMPLE 5.3.2
Problem Number: _____
Project Designer: _____
Date: _____

Road Number: 3200
Traffic Service Level: B
Problem Description: Example 5.3.2

Traffic Information

1) Timber Volume:
   1a: Timber Volume (MBF): _____
   1b: Conversion Factor: (5) MBF/truck or _____
   1c: % Non-Log Truck Traffic: .25 or _____
   1d: ESALs = (_____) * ((_____) /(_____)) * (1 + (_____))

   = (Equivlency Factor of log truck)*((1a)/(1b))*(1c)
   = _____

2) Vehicle Type:

Vehicle	Tire Pressure	E.F.	No. of Passes	No. passes * Equivalency Factor
loaded log trucks	90	4.16	6900	28,704
unloaded log trucks	90	1.00	6900	6,900
pickups	50	0.09	1200/mo X 3 mo	324
yarder	90	16.97	once in March + November for 15 yrs.	509
			Sum =	36,437

Refer to the Figures in Section 3.2 of the "Surfacing Design Guide For Low Volume Roads," or the computer program STP for the selection of the Equivalency Factors (E.F.).

3) Reliability:

Traffic Service Level:	D	C	B
Reliability Factor:	____1.00	____1.44	X 2.32
Reliability:	(50%)	(70%)	(90%)

4) Total # ESALs:
   Total # ESALs = (Timber ESALs + Vehicle ESALs) * Reliability Factor
   = (_____ + 36,437) * 2.32 = 84,534

Seasonal Information

1) Number of Seasons:
   ____A) One season
   X B) More than one season
   Operating Season: March 15 through November 30
   No. of Months: 8½ ESALs per Month: 35,604

Season No.	Dates of Season	# Months in Season	Timber ESAL per Season	Vehicle ESAL per Season	ESAL per Season	% Traffic
1	6/15 to 10/15	4	16,756	254	17,010	47
2	10/15 to 11/30	1.5	6,283	324	6,607	18
3	3/15 to 6/15	3	12,567	254	12,821	35
4						
					36,438 (Total)	

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Figure 5.3.2-1.—Aggregate surfacing design "STP."

2) Subgrade CBR:

A) Soil Type: SM Obtained from: Soil Sample

B) Expected subgrade conditions during construction:
____Wet ___Moist X Dry

C) Expected compaction during construction:
___Method 1 (80-85% T-99) ___Method 2 (85-90% T-99)
X Method 3 (90-95% T-99) ___Method 4 (95-97% T-99)
___Method 5 (90-97% T-99) Method 6 (95% T-180)

D) CBR per Season:

Season No.	Expected Moisture Conditions	CBR	Remarks
1	Summer dry	11	1.8 x Soaked CBR
2	Fall moist	7	1.2 x soaked CBR
3	winter wet	6	Soaked CBR @ 90%
4			

CBR's obtained from:
___Figure 3.4-2 ____Best Estimate ____SRI X Lab Tests
___Historical Data base ___Other: _____

3) Surface CBR:

A) Season 1 Subgrade CBR * 4 = 44
Season 2 Subgrade CBR * 4 = 28
Season 3 Subgrade CBR * 4 = 24
Season 4 Subgrade CBR * 4 = ____
Note: if result is < 20 use 20 and skip the remainder of Part 3.

B) Type of Aggregate
___Pit Run Maximum Size: _____
___Grid Rolled Maximum Size: _____
___Screened Aggregate
X Crushed, Grading: ___A ___B ___C ___D ___E
X F ___G ___H ___J ___K
___L ___M ___N ___O ___Other: _____
___Cinders ___Sand & Gravel X Fracture Rock

C) Aggregate Quality
___Marginal X Good ___Excellent
SE= >35 PI=___

D) "A" Value From Figure 3.4-3
= base value + additional coefficients
= 0.08 + 0.01 + 0.01 + 0.01 + 0.01 = 0.12
(fractured rock, SE > 35, good quality, grading)

Page 2 of 3

Figure 5.3.2-1.—Aggregate surfacing design "STP" (cont'd.).

E) Moisture Factor Correction

1) Quality of Drainage

___Excellent X Good ___Fair ___Poor ___Very Poor

2) % time road exposed to moisture levels approaching saturation

Season:	1	2	3	4
# months in season approaching saturation	0	.25	2	
# months in season	4	1.5	3	
percent exposed	0%	20%	50%	
moisture factor from Figure 3.4-4	1.3	1.1	1.0	
F) New "a" value = Step D * Step E	.16	.13	.12	
G) CBR from Figure 3.4-5 Note: CBR at 100% of T-99	100	70	55	
H) Adjust CBR to match expected field density, = Step G/1.0 for 100% T-99 = Step G/1.3 for 95% T-99 = Step G/1.7 for 90% T-99	59	41	32	
I) Max of Step A, or 20	44	28	24	
J) Design CBR, lesser of Step H or Step I	44	28	24	

Aggregate Thickness

A) Structural Thickness: 12.9 (from "STP" @ 2 " rut depth))

B) Aggregate Loss: 0 Since have surfacing course

C) Total: 12.9

D) Twice the maximum particle size: 6

E) Recommended: 13

(Maximum of Step C, Step D, or 4 inches, round to the nearest whole number)

Remarks

Page 3 of 3

Figure 5.3.2-1.—Aggregate surfacing design "STP" (cont'd.).

USFS SURFACING THICKNESS PROGRAM
Aggregate Design

Problem Number : 5.3.2
Problem Description : Aggregate Surface – New Construction
Multiple Season Design
Date of Analysis : 7/29/1994
Filename : (null)

SUMMARY OF INPUT AND RESULTS

Timber Volume : 0 MMBF
Conversion Factor : 5000 BF for 1 Std Log Truck
Percent Non-Truck Traffic : 25

Timber Volume 18K ESALS : 0

Vehicle Type	Equivalency Factor	Actual Passes	No. Passes of 18K ESALS
9 Standard Log Truck	4.16	6900	66593
4 Empty Log Truck	1.00	6900	16008
23 Pickup	0.09	3600	752
40 Washington 208 w/t	16.97	30	1181
	0.00	0	0
	0.00	0	0
	0.00	0	0
	0.00	0	0
	0.00	0	0
	0.00	0	0
		Vehicle Type 18K ESALS =	84534
		TOTAL 18K ESALS =	84534

Reliability Factor : 2.32

	Estimated Traffic	Surface CBR	Subgrade CBR	Damage Ratios
Season 1	47.0	44	11	0.05
Season 2	18.0	28	7	0.18
Season 3	35.0	24	6	0.76
Season 4	0.0	0	0	0.00
TOTAL =	100.0 Percent			0.99

Allowable Rut Depth : 2.0 inches

Aggregate Loss : 0.0 inches
Structural Thickness Required : 12.9 inches

Total Aggregate Thickness Req'd : 12.9 inches

Figure 5.3.2-2.—Aggregate new construction—multiple season example—"STP" output file.

- Situation:

  Existing aggregate depth = 5 inches;
  CBR of subgrade = 17;
  CBR of the existing aggregate = 50;
  Single lane road; and
  Predominately log truck traffic.

- Determine:

  At what point in traffic does a 1/2-inch, 3/4-inch, or a 1-inch rut occur?

- Solution:

  Using "STP" rut depth analysis module with the above data and reliability factor = 1.0, one obtains the following:

Rut Depth	18K ESAL	No. of Log Truck Trips @ 90psi	No. of Log Truck Trips @ 70psi
1/2 inch	181	35	72
3/4 inch	1206	234	480
1 inch	2971	576	1184

Figure 5.3.3-1 shows the associated "STP" output for a 1-inch rut depth analysis.

If one has an estimate of the number of daily or weekly log trucks, one can then then determine the time it takes traffic to achieve any desired rut depth. Observation of rut depth development after blading in two studies (7, 8, 14) has shown that the rut development rate increases after the blading on aggregate-surfaced roads. Local experience therefore should be used to adjust the results from the rut depth analysis.

5.3.4 Tire Pressure Management

To show the effect of changing the tire pressures on the structural thickness requirements, example 5.3.1 will be reanalyzed. Below is the traffic information associated with that example and the resulting aggregate thickness requirements:

Vehicle	No. of Passes	Tire Pressure	E.F.	No. passes * Equivalency Factor
loaded log truck	*3150*	*90*	*4.16*	*13,104*
unloaded log trk.	*3150*	*90*	*1.00*	*3,150*
pickup	*3600*	*50*	*0.09*	*324*
yarder	*30*	*80*	*16.97*	*509*
			Sum =	*17,089*

```
                    USFS SURFACING THICKNESS PROGRAM
                          Rut Depth Analysis

Problem Number       : 5.3.3
Problem Description  : Aggregate Surface - Maintenance
                       Surfacing Design Guide
Date of Analysis     : 7/29/1994
Filename             : (null)
-----------------------------------------------------------------------

                     SUMMARY OF INPUT AND RESULTS

Aggregate Thickness . . . . . . . . . . . . . . .      5.0 inches

Subgrade CBR. . . . . . . . . . . . . . . . . . .       17

Aggregate CBR . . . . . . . . . . . . . . . . . .       50

Allowable Rut Depth . . . . . . . . . . . . . . .      1.0 inches

Reliablity Factor . . . . . . . . . . . . . . . .      1.00

Allowable Traffic . . . . . . . . . . . . . . . .     2971 18K ESALS
```

Figure 5.3.3-1.—Aggregate rut depth analysis—"STP" output file.

Structural aggregate thickness required = 5.9 inches with 2-inch rut depth.

If the log trucks were required to use lower tire pressures than typically used on the highway (loaded = steer axle @ 64 psi, drive and tandem axle @ 52 psi, unloaded = steer @ 64 psi and drive @ 25 psi), one would have the following vehicle equivalency factors and aggregate thickness:

Vehicle	No. of Passes	Tire Pressure	E.F.	No. passes * Equivalency Factor
loaded log truck	*3150*	*64/52/52*	*1.28*	*4,032*
unloaded log trk.	*3150*	*64/25*	*0.29*	*914*
pickup	*3600*	*50*	*0.09*	*324*
yarder	*30*	*80*	*16.97*	*509*
			Sum =	*5,779*

Structural aggregate thickness = 4.8 inches with 2-inch rut depth.

There would be a reduction of 1 inch of aggregate in addition to reduced road maintenance (trucks tend to create wider wheel tracks), reduced spot rock needs, less vehicle wear, and less driver fatigue.

Figure 5.3.4-1 shows the associated "STP" output file for the lower tire pressures.

USFS SURFACING THICKNESS PROGRAM
Aggregate Design

Problem Number : 5.3.4
Problem Description : Aggregate Surface – New Construction
Single Season – Reduced Tire Pressures
Date of Analysis : 7/29/1994
Filename : (null)

SUMMARY OF INPUT AND RESULTS

Timber Volume : 0 MMBF
Conversion Factor : 5000 BF for 1 Std Log Truck
Percent Non-Truck Traffic : 25

Timber Volume 18K ESALS : 0

Vehicle Type	Equivalency Factor	Actual Passes	No. Passes of 18K ESALS
6 Standard Log Truck	1.28	3150	9354
2 Empty Log Truck	0.29	3150	2119
23 Pickup	0.09	3600	752
40 Washington 208 w/t	16.97	30	1181
	0.00	0	0
	0.00	0	0
	0.00	0	0
	0.00	0	0
	0.00	0	0
	0.00	0	0
		Vehicle Type 18K ESALS =	13406
		TOTAL 18K ESALS =	13406

Reliability Factor : 2.32

	Estimated Traffic	Surface CBR	Subgrade CBR	Damage Ratios
Season 1	100.0	44	11	0.90
Season 2	0.0	0	0	0.00
Season 3	0.0	0	0	0.00
Season 4	0.0	0	0	0.00
TOTAL =	100.0 Percent			0.90

Allowable Rut Depth : 2.0 inches

Aggregate Loss : 0.0 inches
Structural Thickness Required : 4.8 inches

Total Aggregate Thickness Req'd : 4.8 inches

Figure 5.3.4-1.—Aggregate new construction—single season—reduced tire pressure example—"STP" output file.

5.4 Aggregate Surface—Reconstruction Sample

5.4.1 Single Season by "Hand"

An existing aggregate-surfaced pavement with the following properties (see figure 5.4.1-1) requires resurfacing.

C_{old} = 20
$C_{subgrade}$ = 10
t_{exist} = 4 inches
R = 30,000 ESAL's
RD_{allow} = 2 inches

The new aggregate is fractured rock, with a PI of 5. The road will be exposed to wet conditions for 4 months of the year, when it may be expected that saturation levels will be reached. However, the aggregate has excellent drainage qualities.

Step 1. Calculate CBR's of new aggregate (C_{new}).

Since this is fractured rock, the layer coefficient (a-value) is 0.08 (see figure 3.4-3). The PI is 5. This is intended as a surfacing material, so we can add 0.01 to the layer coefficient.

$$a = 0.08 + 0.01 = 0.09$$

In addition, the road will be exposed to wet conditions for 4 months of the year (33 percent of time), but it has excellent drainage qualities (drains to 50 percent saturation in 2 hours). Therefore, the moisture (m_j) factor is 1.20 (Figure 3.4-4). The layer coefficient is now:

$$a = (0.09)\ (1.20) = 0.108$$

To convert this value to CBR, figure 3.4-5 is referenced. From this chart, for a = 0.108, the CBR is approximately 45 (i.e., C_{new} = 45). This assumes 100 percent of AASHTO T-180. Assume 95 percent of T-99 is achieved in the field. Therefore:

100 percent T-99 CBR = 45 x 0.975 = 44
95 percent T-99 CBR = 44 ÷ 1.3 = 34

Therefore, the user should select C_{new} = 34. Note that this does not violate the 4:1 criterion.

Step 2. Calculate t_1 using equation 6.2.2-2.

$$RD = 5.8230 \frac{(R)^{0.2476}}{(\log t)^{2.002}\ C_1^{0.9335}\ C_2^{0.2848}} \qquad \text{(Eq. 6.2.2-2)}$$

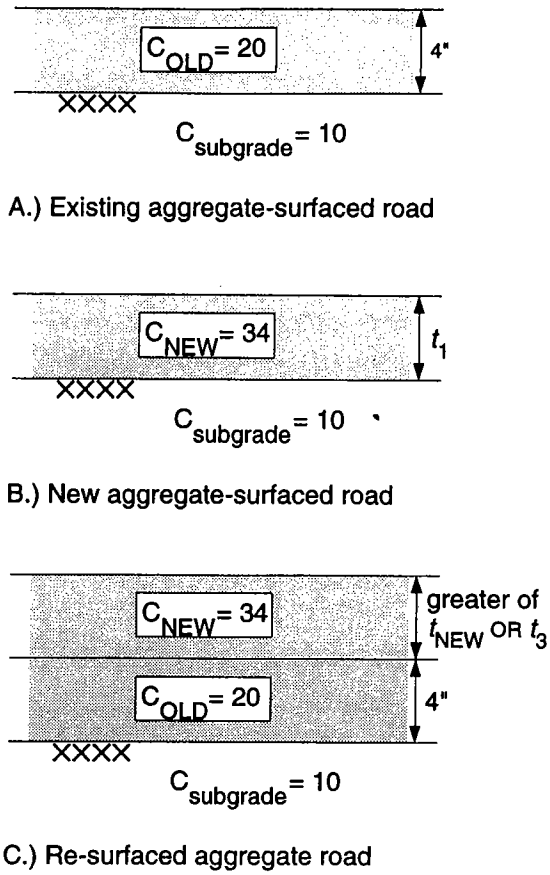

Figure 5.4.1-1.—Resurfacing design example.

Substituting:

$$2'' = 5.8230 \frac{(30{,}000)^{0.2476}}{(\log t_1)^{2.002}\,(34)^{0.9335}\,(10)^{0.2848}}$$

Solving for t_1:

$$\therefore \quad t_1 = 7.07''$$

Step 3. Calculate t_2.

$$2'' = 5.8230 \frac{(30{,}000)^{0.2476}}{(\log t_2)^{2.002}\,(20)^{0.9335}\,(10)^{0.2848}}$$

$$\therefore \quad t_2 = 12.25''$$

Step 4. Calculate t_1/t_2.

$$t_1/t_2 = 7.07''/12.25'' = 0.58''$$

In short, 1 inch of old or existing material is approximately equivalent to 0.58 inches of new material.

Step 5. Convert existing thickness.

$$t_{equiv} = (t_{exist})\ (t_1/t_2) \qquad \text{(Eq. 4.3.5-1)}$$

$$= (4'')\ (0.58)$$

$$t_{equiv} = 2.31 \text{ inches}$$

Step 6. Calculate t_{new}.

$$t_{new} = t_1 - t_{equiv} \qquad \text{(Eq. 4.3.5-2)}$$

$$= 7.07'' - 2.31''$$

$$= 4.76''$$

$$t_{new} = 4.8 \text{ inches (round up to nearest 0.1 inch)}$$

Step 7. Check t_3.

As a check, t_3 is calculated using the existing aggregate CBR as C_2. Note that C_2 is now 20, therefore the 4:1 ratio still holds.

$$2'' = 5.8230 \ \frac{(30{,}000)^{0.2476}}{(\log t_3)^{2.002}\ (34)^{0.9335}\ (20)^{0.2848}}$$

Solving for t_3:

$$t_3 = 5.9'' \text{ (round up to nearest 0.1 inch)}$$

Since t_{new} is less than t_3 (4.8" < 5.9"), use t_3 as the design thickness. If $t_3 < t_{new}$, then the design thickness used should be t_{new}. Resurfacing thickness for structural requirements would be 5.9, for construction rounded to the nearest 0.5 inches and use 6 inches. Operational thickness, as discussed in section 3.3.6, should be considered before selection of the final contract thickness.

5.4.2 Single Season by "STP"

Aggregate Surface—Reconstruction by "STP"

From RMO's and forest plan:

- double-lane, arterial.
- 10.5 miles, reconstruction.
- traffic service level: B.
- maintenance level: 2 (during and after activity).
- traffic Information:
  - 6 log trucks per weekday, May 15 through September 30;
  - 10 pickups (firewood) per weekend day, August 15 through November 15; and
  - administrative traffic from April 1 to November 30.
- grades: 5% max.
- design vehicle: log truck; critical vehicle: yarder.
- allow for high clearance vehicle and manage for use; 2-inch acceptable rut depth.

Step 1: Traffic.

a. Using 15-year design life for aggregate surface, determine the number of each vehicle type:

- No. of log trucks: 6 trucks/day * 5 days/week * 4 weeks/month * 4.5 months/year * 15 years = 8,100 unloaded and 8,100 loaded trips.

- No. of pickups: 10 trucks/day * 2 days/week * 4 weeks/month * 3 months/year * 15 years = 3,600 empty and 3,600 trips loaded with firewood.

- No. of yarders: 1 yarder/year * 15 years = 15 trips in and 15 trips out.

b. Determine the ESAL's for each vehicle:

- For a loaded log truck @ 90 psi = 4.16 for loaded (note: since double lane; need to design for the loaded lane only; figures 3.2-4 and 3.2-5 and "STP" help menu).

- For loaded pickup trucks = 0.09 (figure 3.2-2 and "STP" help menu).

- For a yarder @ 80 psi = 16.97 (Washington 208 w/tower, figure 3.2-4 and "STP" help menu).

c. Determine the total ESAL's for all the expected traffic:

= (8,100 log truck trips * 4.16 ESAL/trip) + (3,600 pickup trips * 0.09 ESAL/trip) + (15 yarder trips * 16.97 ESAL/trip) = 34, 275 total 18-kip ESAL's.

d. Determine the reliability factor:

- For an arterial, use 90% reliability factor, $F_r = 2.32$ (section 3.3.4).

The total design 18-kip ESAL's is then 79,517 (34,274 times 2.32). Note that this is greater than the recommended input maximum of 70,000. Similar situations will occur occasionally and need to be addressed. In considering whether to continue with the design, review the reliability used in the design and the consequences of any changes in the reliability. For this example, one could consider the following:

- Use the design traffic of 79,517 18-kips ESAL's; the actual traffic is 34,274 18-kip ESAL's, which is within the range of ESAL's used in the development of the design algorithm. Consequences of designing for traffic close to 10,000 18-kip ESAL's over the maximum recommended value should not be significant, especially if the calculated depth of aggregate is rounded up to the nearest whole number for construction.

- Use a reliability factor of 2.04 (which equates to a reliability level of 85 percent instead of 90 percent) representing a design traffic of 70,000 18-kip ESAL's; consequences of designing for 70,000 18-kip ESAL's is that there is an 85 percent confidence instead of a 90 percent confidence that the road will perform as expected.

For this example, it was chosen to proceed with a design ESAL of 79,517.

e. Design ESAL's then:

= 34,275 * 2.32
= 79,518

Step 2: Materials.

a. Determine the number of seasons with similar soil conditions (section 3.4.1).

- For a given location, most of the traffic occurs during the dry time of the year (July through September) and some when the ground is drying out (May and June). Some decision will have to be made since the reconstruction design allows for only one season of use. Note that there is another method to perform a reconstruction analysis, given various seasons. It involves using the aggregate new construction module in combination with material substitution. This procedure is not detailed in this *Surfacing Design Guide*.

b. Determine the CBR of the subgrade and aggregate:

- Subgrade: From test pit observations and field classification, the soil is a silty sand (USCS = SM) throughout the entire route. By using the DCP (see appendix 6.4) within the travelway at various locations along the route, you have determined the average field CBR in June is 17. This corresponds to CBR values greater than 95 percent of AASHTO T-99, which makes sense due to the age of the road and the traffic that this road has experienced in the past.

- Existing aggregate: Using the DCP at various locations along the route, the average CBR is 50. During the excavation of the test pits you found an average depth of 5 inches along the route.

- New aggregate: Since this is a traffic service level B road, you have found a local source that economically provides crushed aggregate. You plan to use grading "D" (1-inch dense-graded). Your past experience has shown that you typically get the aggregate compacted to 90 percent of T-99.

- Using figure 3.4-3, the layer coefficient for grading "D" compacted to 100 percent of T-99 is 0.14. Use Figure 3.4-4 and increase the layer coefficient by 1.3 (base good drainage and saturated less than 1 percent of the time); therefore the layer coefficient is 0.14 * 1.3 = 0.18. Figure 5.4.2-1 outlines how the layer coefficient was obtained using figure 3.4-3.

- Use figure 3.4-5 to determine the aggregate CBR. You estimate the CBR to be 120. Divide by 1.7 to obtain the CBR at 90 percent of T-99, 120/1.7 = 71. Note that this is not greater than four times the existing surface CBR, so use a design CBR of 71 (1.7 is obtained from note 2 in figure 3.4-2).

- Materials summary: One season with the subgrade CBR = 17, the existing surface CBR = 50, existing aggregate depth is 5 inches, and the new aggregate CBR = 71.

Step 3: Results using the computer program "STP" aggregate reconstruction design.

- Aggregate needed is 0.4 inches for structure; round up to 1 inch. This is not a practical minimum to place, given that we are using grading "D". One must make a decision at this point to either:

  - forgo the placement of any aggregate and increase the probability that greater than a 2-inch rut will occur (i.e. reliability factor less than 90 percent);

- add the minimum lift thickness of 4 inches; or

- add 2 inches of grading "D" and blade mix and compact with the existing aggregate (only practical if the existing aggregate has a maximum size of 1 inch and is not contaminated with fines or organic material).

Figure 5.4.2-1 is the data form for aggregate reconstruction and figure 5.4.2-2 is the "STP" output file.

5.5 Bituminous Surface Treatment Example

BST Surface—New Construction—One Season of Use

This example is similar to example 5.3.1 (aggregate, new construction). This example will show the designer how to use "STP" as a tool for determining the aggregate thickness necessary for a BST. The following example assumes a newly constructed road using a double BST.

Step 1: Traffic.

a. Use 15-year design life for aggregate surface, determine the number of each vehicle type (see example 5.3.1 for supporting information):

   - No. of log trucks: 3 trucks/day * 5 days/week * 4 weeks/month * 3.5 months/year * 15 years = 3,150 unloaded and 3,150 loaded trips.

   - No. of pickups: 10 trucks/day * 2 days/week * 4 weeks/month * 3 months/year * 15 years = 3,600 empty and 3,600 trips loaded with firewood.

   - No. of yarders; 1 yarder/year * 15 years = 15 trips in and 15 trips out.

b. Determine the ESAL's for each vehicle:

   - For an empty and loaded log truck @ 90 psi = 1.00 for empty + 4.16 for loaded = 5.16. (Figures 3.2-4, 3.2-5, and "STP" help menu).

   - For loaded pickup trucks (assume negligible for empty) = 0.09. (FIgure 3.2-2 and "STP" help menu).

   - For a yarder @ 80 psi = 16.97 (Washington 208 w/ tower). (Figure 3.2-4 and "STP" help menu).

Reconstruction Design - STP

(One Season Only)

Problem Name: EXAMPLE 5.4
Problem Number: _____
Project Designer: _____
Date: _____

Road Number: 50
Traffic Service Level: B
Problem Description: _____
Operating Season: _____

A. Existing Conditions

Layer	Thickness	Material Description	CBR
Existing	5 inches		50
Subgrade	N/A	SM	17

B. Traffic Information

1) Timber Volume:
   1a: Timber Volume (MBF): —
   1b: Conversion Factor: 5 MBF/truck or _____
   1c: % Non-Log Truck Traffic: .25 or _____
   1d: ESALs = (_____) * ((_____) /(_____)) * (1 + (_____))

   = (Equivlency Factor of log truck)*((1a)/(1b))*(1c)
   = _____

2) Vehicle Type:

Vehicle	Tire Pressure	E.F.	No. of Passes	No. passes * Equivalency Factor
loaded log trucks	90	4.16	8100	33,696
pickup	50	0.09	3600	324
yarder	80	16.97	15	255
			Sum =	34,275

3) Reliability:

Traffic Service Level:	D	C	B
Reliability Factor:	___1.00	___1.44	X 2.32
Reliability:	(50%)	(70%)	(90%)

4) Total # ESALs:
   Total # ESALs = (Timber ESALs + Vehicle ESALs) * Reliability Factor
   = (— + 34,275) * 2.32 = 79,578

C. Proposed New Aggregate Info and CBR

1) Type of Aggregate
   ___Pit Run Maximum Size: _____
   ___Grid Rolled Maximum Size: _____
   ___Screened Aggregate
   X Crushed, Grading: ___A ___B ___C X D ___E
   ___F ___G ___H ___J ___K
   ___L ___M ___N ___O ___Other: _____
   ___Cinders ___Sand & Gravel X Fracture Rock

Page 1 of 2

Figure 5.4.2-1.—Reconstruction design "STP."

2) Aggregate Quality
___Marginal X Good ___Excellent
SE=___ PI=___

3) "A" Value From Figure 3.4-3
= base value + additional coefficients
= 0.08 + 0.01+0.01+0.01+0.01+0.01+0.01 = 0.14

4) Moisture Factor Correction
a) Quality of Drainage
___Excellent X Good ___Fair ___Poor ___Very Poor
b) % time road exposed to moisture levels approaching saturation
Season: 1
months approaching saturation 0
percent exposed <1%
moisture factor from Figure 3.4-4 1.3

5) New "a" value
= Step 3 * Step 4 .18

6) CBR from Figure 3.4-59
Note: assume CBR at 100% of T-99 120

7) Adjusted CBR to match expected field density,
= Step 6/1.0 for 100% T-99 ___
= Step 6/1.3 for 95% T-99 71
= Step 6/1.7 for 90% T-99 ___

8) Design CBR.
Minimum of 4 times the subgrade CBR or step 7 4x17=68

D. Aggregate Thickness

A) Structural Thickness: 0.4 inches (from "STP", @ 2" Rut Depth)
B) Aggregate Loss: ___
C) Total: ___
D) Twice the maximum particle size: 2
E) Recommended: ___
(Maximum of Step C, Step D, or 4 inches, round to the nearest whole number)

E. Remarks

___

___

___

___

Page 2 of 2

Figure 5.4.2-1.—Reconstruction design "STP" (cont'd.).

USFS SURFACING THICKNESS PROGRAM
Aggregate Reconstruction Design

Problem Number : 5.4
Problem Description : Aggregate Surface - Reconstruction
Single Season Design
Date of Analysis : 7/29/1994
Filename : (null)

SUMMARY OF INPUT AND RESULTS

Timber Volume : 0 MMBF
Conversion Factor : 5000 BF for 1 Std Log Truck
Percent Non-Truck Traffic : 25

Timber Volume 18K ESALS : 0

Vehicle Type	Equivalency Factor	Actual Passes	No. Passes of 18K ESALS
9 Standard Log Truck	4.16	8100	78175
4 Empty Log Truck	1.00	0	0
23 Pickup	0.09	3600	752
40 Washington 208 w/t	16.97	15	591
	0.00	0	0
	0.00	0	0
	0.00	0	0
	0.00	0	0
	0.00	0	0
	0.00	0	0
		Vehicle Type 18K ESALS =	79517
		TOTAL 18K ESALS =	79517

Reliability Factor : 2.32

CBR (existing) 50.0

CBR (subgrade) 17.0

Existing aggregate thickness . . . . . 5.0 inches

CBR of new material. . . . . 68.0 inches

Allowable rut depth. . . . . 2.0 inches

Thickness of resurfacing material required . . 0.4 inches

Figure 5.4.2-2.—Aggregate reconstruction—single season example—"STP" output file.

c. Determine the total ESAL's for all the expected traffic:

= (3,150 log truck trips * 5.16 ESAL/trip) + (3,600 pickup trips * 0.09 ESAL/trip) + (30 yarder trips * 16.97 ESAL/trip) = 17,087 total 18-kip ESAL's.

d. Determine the reliability factor: for a collector use 90% reliability factor, F_r = 2.32 (section 3.3.4).

e. Design ESAL's then:

= 17,087 * 2.32
= 39,642

Step 2: Materials.

a. Determine the number of seasons with similar soil conditions (section 3.4.1):

- For a given location, all the traffic occurs during similar weather conditions so assume that there will be only one set of material strength values, therefore have 100 percent of the traffic ESAL's in one season.

b. Determine the CBR of the subgrade and aggregate (sections 3.4.1 and 3.4.2):

- Subgrade: From the soil resource inventory for that proposed road location, the soil is a silty sand (USCS = SM). From laboratory CBR tests, the following CBR's were obtained:

  CBR @ 85% AASHTO T-99 = 3,
  CBR @ 90% AASHTO T-99 = 6,
  CBR @ 95% AASHTO T-99 = 13.

  The above CBR's are based on saturated conditions. Since our road has traffic during the dry season, the above numbers need to be adjusted. Based upon your past experience of soaked and unsoaked CBR's, you have observed an increase in silty sands, when dry, by a factor of 1.8, so dry CBR's would be as follows:

  CBR @ 85% T-99 = 5.4,
  CBR @ 90% T-99 = 11,
  CBR @ 95% T-99 = 23.

- You plan to call for the subgrade to be compacted to placement method 3, which from your past experience in silty sands, 90 percent of T-99 is typically obtained which corresponds to a design subgrade CBR of 11.

- Aggregate: Since this is a traffic service level B road, you have found a local source that economically provides crushed aggregate. You plan to use grading "H" (1-1/2-inch open-graded) as the base course. You only count on the base to provide the necessary structural support. Your past experience has shown that the aggregate is typically compacted to 90 percent of T-99. Using figure 3.4-3, the layer coefficient for grading "H" compacted to 100% of T-99 is 0.13. Use figure 3.4-4 and increase the layer coefficient by 1.3 (base good drainage and saturated less than 1 percent of the time), therefore the layer coefficient is 0.13 * 1.3 = 0.17.

- Use figure 3.4-5 to determine the aggregate CBR. You estimate the CBR to be 120. Divide by 1.7 to obtain the CBR at 90 percent of T-99, 120/1.7 = 71 (1.7 is obtained from note 2 in figure 3.4-2).

  *Note that this is greater than four times the subgrade CBR, so use the lesser of the two numbers, design CBR = 4 * 11 = 44.*

- Materials summary: One season with the subgrade CBR = 11 and the surface CBR = 44. Note that since this is a BST-surfaced road (double) we are not going to assign any structural strength to the BST layer.

Step 3: Results using the computer program "STP," aggregate new construction design:

- Aggregate needed is 12.3 inches for structure; round to 13 inches to meet the construction minimum of placing twice the maximum particle size or 4 inches minimum. Note that since a BST is going to be placed there will be no aggregate loss added to the structural thickness.

  Figure 5.5-1 is the data form for this example and figure 5.5-2 shows the associated "STP" output file.

5.6 Geotextile Example

This example follows the procedure and tables outlined in appendix 6.5.

Given:

- Design vehicle = standard log truck, 90 psi, @ 80,000 GVW.

- Require less than 2-inch rut depth (expect more than 1,000 passes of an 18-kip ESAL).

- Subgrade strength values by DCP = 3.4, 3.3, 2.6, 2.2, 1.7, 1.5, 1.2. Average = 2.3.

Aggregate Surfacing Design - STP

Problem Name: EXAMPLE 5.5
Problem Number: _____
Project Designer: _____
Date: _____

Road Number: 40
Traffic Service Level: B
Problem Description: Example 5.5

Traffic Information

1) Timber Volume:
   1a: Timber Volume (MBF): _____
   1b: Conversion Factor: 5 MBF/truck or _____
   1c: % Non-Log Truck Traffic: .25 or _____
   1d: ESALs = (_____) * ((_____) /(_____)) * (1 + (_____))

   = (Equivlency Factor of log truck)*((1a)/(1b))*(1c)
   = _____

2) Vehicle Type:

Vehicle	Tire Pressure	E.F.	No. of Passes	No. passes * Equivalency Factor
loaded log truck	90	4.16	3150	13,104
unloaded log truck	90	1.0	3150	3,150
pickup	50	0.09	3600	324
yarder	30	16.97	30	509
			Sum =	17,087

Refer to the Figures in Section 3.2 of the "Surfacing Design Guide" or the computer program STP for the selection of the Equivalency Factors (E.F.).

3) Reliability:

Traffic Service Level:	D	C	B
Reliability Factor:	____1.00	____1.44	X 2.32
Reliability:	(50%)	(70%)	(90%)

4) Total # ESALs:
   Total # ESALs = (Timber ESALs + Vehicle ESALs) * Reliability Factor
   = (— + 17,087) * 2.32 = 39,642

Seasonal Information

1) Number of Seasons:
   X A) One season
   ____B) More than one season
   Operating Season: _____
   No. of Months: _____ ESALs per Month: _____

Season No.	Dates of Season	# Months in Season	Timber ESAL per Season	Vehicle ESAL per Season	ESAL per Season	% Traffic
1					39,642	100
2						
3						
4						
					39,642 (Total)	

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Figure 5.5-1.—Aggregate surfacing design "STP."

2) Subgrade CBR:

A) Soil Type: SM Obtained from: Soil Sample

B) Expected subgrade conditions during construction:
____Wet ___Moist _X_Dry

C) Expected compaction during construction:
___Method 1 (80-85% T-99) ___Method 2 (85-90% T-99)
_X_Method 3 (90-95% T-99) ___Method 4 (95-97% T-99)
___Method 5 (90-97% T-99) Method 6 (95% T-180)

D) CBR per Season:

Season No.	Expected Moisture Conditions	CBR	Remarks
1	dry	11	1.8 times soaked CBR
2			
3			
4			

CBR's obtained from:
___Figure 3.4-2 ____Best Estimate ____SRI _X_Lab Tests
___Historical Data base ___Other: _____

3) Surface CBR:

A) Season 1 Subgrade CBR * 4 = 44
Season 2 Subgrade CBR * 4 = ____
Season 3 Subgrade CBR * 4 = ____
Season 4 Subgrade CBR * 4 = ____
Note: if result is < 20 use 20 and skip the remainder of Part 3,

B) Type of Aggregate
___Pit Run Maximum Size: _____
___Grid Rolled Maximum Size: _____
___Screened Aggregate
_X_Crushed, Grading: ___A ___B ___C ___D ___E
___F ___G _X_H ___J ___K
___L ___M ___N ___O ___Other: _____
___Cinders ___Sand & Gravel _X_Fracture Rock

C) Aggregate Quality
___Marginal _X_Good ___Excellent
SE=>35 PI=___

D) "A" Value From Figure 3.4-3
= base value + additional coefficients
= 0.08 + 0.01+0.01+0.01+0.01+0.01 = 0.13
(Fractured rock, SE>35, good quality, grading)

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Figure 5.5-1.—Aggregate surfacing design "STP" (cont'd.).

E) Moisture Factor Correction

1) Quality of Drainage

___Excellent X Good ___Fair ___Poor ___Very Poor

2) % time road exposed to moisture levels approaching saturation

Season:	1	2	3	4
# months in season approaching saturation	0			
# months in season				
percent exposed	<1%			
moisture factor from Figure 3.4-4	1.3			

F) New "a" value = Step D * Step E	.17			
G) CBR from Figure 3.4-5 Note: CBR at 100% of T-99	120			
H) Adjust CBR to match expected field density, = Step G/1.0 for 100% T-99 = Step G/1.3 for 95% T-99 = Step G/1.7 for 90% T-99	71			
I) Max of Step A, or 20	44			
J) Design CBR, lesser of Step H or Step I	44			

Aggregate Thickness

A) Structural Thickness: 12.3 (from "STP" @ 1 " rut depth))

B) Aggregate Loss: 0 Since BST

C) Total: 12.3

D) Twice the maximum particle size: 3"

E) Recommended: 13"

(Maximum of Step C, Step D, or 4 inches, round to the nearest whole number)

Remarks

Page 3 of 3

Figure 5.5-1.—Aggregate surfacing design "STP" (cont'd.).

USFS SURFACING THICKNESS PROGRAM
Aggregate Design

Problem Number : 5.5
Problem Description : Bituminous Surface Treatment
New Construction - Single Season Design
Date of Analysis : 7/29/1994
Filename : (null)

SUMMARY OF INPUT AND RESULTS

Timber Volume : 0 MMBF
Conversion Factor : 5000 BF for 1 Std Log Truck
Percent Non-Truck Traffic : 25

Timber Volume 18K ESALS : 0

Vehicle Type	Equivalency Factor	Actual Passes	No. Passes of 18K ESALS
9 Standard Log Truck	4.16	3150	30401
4 Empty Log Truck	1.00	3150	7308
23 Pickup	0.09	3600	752
40 Washington 208 w/t	16.97	30	1181
	0.00	0	0
	0.00	0	0
	0.00	0	0
	0.00	0	0
	0.00	0	0
	0.00	0	0
		Vehicle Type 18K ESALS =	39642
		TOTAL 18K ESALS =	39642

Reliability Factor : 2.32

	Estimated Traffic	Surface CBR	Subgrade CBR	Damage Ratios
Season 1	100.0	44	11	0.98
Season 2	0.0	0	0	0.00
Season 3	0.0	0	0	0.00
Season 4	0.0	0	0	0.00
TOTAL =	100.0 Percent			0.98

Allowable Rut Depth : 1.0 inches

Aggregate Loss : 0.0 inches
Structural Thickness Required : 12.3 inches

Total Aggregate Thickness Req'd : 12.3 inches

Figure 5.5-2.—BST new construction—single season example—"STP" output file.

Solution:

- Determine undrained shear strength of soil:
  from table 5-1, c = 4 * CBR = 4 * 2.3 = 9.2

- Determine design gear loads:
  from given traffic, tandem axle = 35,000 lbs @ 90 psi
  single axle = 10,000 lbs @ 90 psi

- Determine bearing capacity factor:
  from table 5-1, w/o geotextile, $N_c = 2.8$
  w geotextile, $N_c = 5.0$

- Determine C * N_c values:
  w/o geotextile, 9.2 * 2.8 = 25.8
  w/ geotextile, 9.2 * 5.0 = 46.0

- Determine necessary aggregate thickness:
  from figure 5.16 (tandem @ 90psi, 35,000 lbs axle load),
  w/o geotextile, 10 inches
  w/ geotextile, 5 inches
  from figure 5.5 (single @ 90psi, 10,000 lbs axle load),
  w/o geotextile, 8 inches
  w/ geotextile, 5 inches

- Select design thickness:
  w/o geotextile, 10 inches
  w/ geotextile, 5 inches
  Note: some manufacturers of geotextile have minimum cover thickness requirements.

- Determine filtration requirements and check serviceability requirements: refer to section 5.8 and table 5-1 in appendix 6.5.

- Select geotextile specifications based on above requirements: refer to sections 5.10 and 5.11, and *Forest Service Specifications for Construction of Roads and Minor Drainage Structures* (EM-7720-100LL), section 720, for additional assistance and specifications.

5.7 Economic Alternative Example

Three surfacing alternatives are considered for this particular project. They are adapted from example 5.3.1 and provide the necessary aggregate thickness to support the traffic in that example. The alternatives include:

- Alternative A: 2 inches of grading "D" over 6 inches of grading "F." (Note: 2 inches used as the surface course.)

- Alternative B: 7 inches of grading "F." (Note: 1 inch of aggregate added for operational loss.)

- Alternative C: Double BST over 12 inches of grading "F." (Note: used "STP" to calculate the necessary structural thickness.)

Details on the road geometry include:

- single-lane road with turnouts,

- running surface of 12 feet with a 1.3 factor for turnouts,

- road length = 1 mile,

- aggregate and asphalt concrete side slopes at 2H to 1V, and

- analysis period = 15 years.

Details on grading "F":

- $12/CY to haul, place and compact;

- $1000/yr per mile to blade; and

- estimated salvage value is 10 percent of the construction costs.

Details on grading "D":

- $17/CY to haul, place, and compact;

- $1000/yr per mile to blade; and

- estimated salvage value is 10 percent of the construction costs.

USFS SURFACING THICKNESS PROGRAM
Economic Analysis

Problem Number : 5.7
Problem Description : 2 inches of Grading "D" over 6 inches of Grading "F"
Date of Analysis : 8/1/1994
Filename : (null)

SUMMARY OF INPUT AND RESULTS

Physical Geometry

Length (feet)	5280
Top Width (feet)	12.0
Turnout Factor / Curve Widening	1.3
Side Slopes	2: 1

Surfacing Construction Costs

	Layer #1	Layer #2
Thickness (inches)	2.0	6.0
Volume (CY)	522.6	1652.4
Unit cost ($/CY)	17.00	12.00
Total Surfacing Cost ($)	8884	19829

Subgrade Preparation Additional Cost ($)	0
Total Maintenance Cost ($/mi/yr)	1000
Total Operational Cost ($/mi/yr)	0
Discount Rate (percent)	4.00
Analysis Period (years)	15
Equivalent Uniform Annual Cost ($/year)	3438
Net Present Worth ($)	38221

Note: Salvage Value = $2,900

Figure 5.7-1.—Economic analysis by "STP" for alternative A.

USFS SURFACING THICKNESS PROGRAM
Economic Analysis

Problem Number : 5.7
Problem Description : 7 inches of Grading "F"

Date of Analysis : 8/1/1994
Filename : (null)

SUMMARY OF INPUT AND RESULTS

Physical Geometry

Length (feet)	5280
Top Width (feet)	12.0
Turnout Factor / Curve Widening	1.3
Side Slopes	2: 1

Surfacing Construction Costs

	Layer #1	Layer #2
Thickness (inches)	7.0	0.0
Volume (CY)	1952.6	0.0
Unit cost ($/CY)	17.00	0.00
Total Surfacing Cost ($)	33194	0

Subgrade Preparation Additional Cost ($)	0
Total Maintenance Cost ($/mi/yr)	1000
Total Operational Cost ($/mi/yr)	0
Discount Rate (percent)	4.00
Analysis Period (years)	15
Equivalent Uniform Annual Cost ($/year)	3821
Net Present Worth ($)	42480

Note: Salvage Value = $3,300

Figure 5.7-2.—Economic analysis by "STP" for alternative B.

USFS SURFACING THICKNESS PROGRAM
Economic Analysis

Problem Number : 5.7
Problem Description : Double Bituminous Surface Treatment over 12 inches of aggregate
Date of Analysis : 8/1/1994
Filename : (null)

SUMMARY OF INPUT AND RESULTS

Physical Geometry

Length (feet)	5280
Top Width (feet)	12.0
Turnout Factor / Curve Widening	1.3
Side Slopes	2: 1

Surfacing Construction Costs

	Layer #1	Layer #2
Thickness (inches)	0.5	12.0
Volume (CY)	128.0	3559.1
Unit cost ($/CY)	108.00	12.00
Total Surfacing Cost ($)	13823	42709

Subgrade Preparation Additional Cost ($)	0
Total Maintenance Cost ($/mi/yr)	450
Total Operational Cost ($/mi/yr)	0
Discount Rate (percent)	4.00
Analysis Period (years)	15
Equivalent Uniform Annual Cost ($/year)	3887
Net Present Worth ($)	43212

Note: Salvage Value = $33,000

Figure 5.7-3.—Economic analysis by "STP" for alternative C.

Chapter 6
Appendices

6.1 Glossary of Terms

AASHTO: American Association of State Highway and Transportation Officials.

Adverse Grades: when loaded commercial vehicles negotiate uphill grades.

Aggregate: a natural or manufactured granular material of mineral composition such as sand, gravel, shell, slag, or crushed stone.

Aggregate-Surfaced Road: road that has an unbound aggregate material as the surface course.

Analysis Period: the period of time (usually years) for which the economic analysis is to be made.

Base Course: the layer or layers of specified or selected material of designed thickness placed on a subbase or a subgrade to support a surface course.

Bituminous Surface Treatment (BST): one or more repetitions of a sprayed asphalt cement (liquid or emulsified) layer followed by a layer of aggregate; typically each successive aggregate layer size becomes smaller.

California Bearing Ratio (CBR): test for determining the strength and supporting power of disturbed soils as recompacted under standard procedures (AASHTO T-193).

Design Criteria: the requirements governing the selection of elements and standards for a road or section of road.

Design Elements: the physical characteristics of a road (such as travelway width, slopes, and pavement structure) that, when combined, comprise the planned facility.

Design Rut Depth: the rut depth used in the design algorithm.

Design Standards: the definitive lengths, widths, and depths of the individual elements (such as 14-foot travelway, 3/4:1 cut slopes, and 6 inches of crushed aggregate).

Dense-Graded Aggregate: aggregate composed of particles that vary across a wide range, typically with 8 to 15 percent silt and clay, that result in relatively slow permeable matrix. An ideal well-graded aggregate.

Discount Rate (Interest Rate): a percentage figure representing the rate of interest money can earn over the period of time under analysis.

Earth Road: road that consists of the native soil as the surface course, with the top portion compacted so as to withstand traffic loads.

Equivalent Single-Axle Load (ESAL): a mixed combination of axle loads and axle configurations is converted to an equivalent 18,000-pound (18-kip) single-axle load. These are summed up over the analysis period.

Equivalent Single-Wheel Load (ESWL): the load on a single tire that will cause a preselected parameter of equal magnitude (e.g. deflection) as that resulting from a multiple-wheel load at the same location within the pavement structure.

Equivalency Factor: a numerical factor that expresses the relationship of a given axle load to another axle load in terms of their effect on the serviceability of a pavement structure. In this guide, all axle loads are equated in terms of the equivalent number of repetitions of an 18-kip single axle.

Equivalent Uniform Annual Cost (EUAC): a uniform annual cost (or benefit) that is the equivalent, spread over the entire period of analysis, of all costs or disbursements incurred (or benefits received) on a project.

Favorable Grades: when loaded commercial vehicles have to negotiate downhill grades.

Flexible Pavement: an asphalt pavement structure which maintains intimate contact with and distributes loads to the subgrade and depends on aggregate interlock, particle friction, and cohesion for stability.

French Drain: term used in the early days of road building to imply the use of coarse rock to intercept and transmit water. Commonly called trench drains, it consists of a perforated, slotted-jointed, or porous pipe, usually 6 to 8 inches in diameter, surrounded by a pervious aggregate and a drainage filter.

Life-Cycle Costs: all costs and benefits that are involved in the provisions of a roadway during its complete life cycle. It includes construction costs, maintenance and rehabilitation costs, user costs, etc.

Low-Volume Road: a roadway generally subjected to low levels of traffic; in this guide, structural design is based on a range of 18-kip ESAL's from 20 to 70,000 for aggregate-surfaced roads.

Maintenance: the preservation of the entire roadway, including surface, shoulders, road sides, structures, and such traffic control devices as are necessary for its safe and efficient utilization.

Moisture Content (Water Content): weight of water in a moist soil, expressed as a percentage of the dry weight of moist soil.

Net Present Worth (NPW): the net cumulative present worth of a series of costs and benefits stretching over time.

Open-Graded Aggregate: aggregate comprised of particles that are primarily sand and gravel, typically 0 to 5 percent silt and clay, resulting in a relatively rapid permeable matrix.

Operational Thickness: the aggregate that can be expected to be lost or damaged during the operation of the road.

Pavement Performance: the trend of serviceability with load applications.

Pavement Rehabilitation: work undertaken to extend the service life of a roadway. This includes placement of additional surfacing material and/or other work necessary to return an existing roadway to a condition of structural or functional adequacy. This could include the complete removal and replacement of the pavement structure.

Pavement Structure: subbase, base course, or surface course, or combination thereof, placed on a subgrade to support the traffic load and distribute it to the roadbed.

Performance Period: the period of time that an initially constructed or rehabilitated pavement structure will last (perform) before reaching its terminal serviceability; this is also referred to as the "design period."

Prepared Roadbed: in-place roadbed soils compacted or stabilized according to provisions of applicable specifications.

Present Value (PV) or Present Worth (PW): an economic concept that represents the translation of specified amounts of costs or benefits occurring in different time periods into a single amount at a single instant (usually the present).

R-Value: the resistance value of the soil as determined through the Hveem stabilometer method. The R-value ranges from 0 (liquid) to 100 (infinitely rigid solid).

Resilient Modulus: a measure of the modulus of elasticity of roadbed soil or other pavement material.

Roadbed: the graded portion between top and side slopes, prepared as a foundation for the pavement structure.

Roadbed Material: the material below the subgrade in cuts and embankments and in embankment foundations, extending to such depth as affects the support of the pavement structure.

Road Management Objectives (RMO's): document that establishes the intended purpose of an individual road based upon management direction and access management. Includes the design, maintenance, and operational criteria for the individual road.

Rock: soil or mineral deposit that cannot be readily excavated by power equipment; or if after immersion in water, there is no disintegration or softening; or a naturally occurring consolidated aggregation of one or more minerals constituting the crust of the earth. There is no sharp line of demarcation that divides soil and rock.

Rut Depth: the greatest distance from the bottom of the wheel track to an imaginary plane that bridges completely across the wheel track, commonly measured perpendicular to the road surface.

Salvage Value: the value of a roadway remaining at the end of the study or analysis period.

Saturation (Degree of): the relative proportion of water in the voids of an earth material, expressed as a percentage.

Selected Material: a suitable native material obtained from a specified source such as a particular roadway cut or borrow area, having specified characteristics to be used for a specific purpose.

Serviceability: the ability of a pavement structure to serve its intended function at any particular time.

Single-Axle Load: the total load transmitted by all wheels of a single axle extending the full width of the vehicle.

Soil: accumulation or deposit of earth material derived from the disintegration of rocks, or transported by water or wind. Typically it can be readily excavated by power equipment.

Stone: crushed or naturally angular particles of rock.

Structural Thickness: the aggregate or material necessary to support vehicle loads and repetitions without regard to operational loss.

Subbase: the layer or layers of specified or selected material of designed thickness placed on subgrade to support a base course.

Subgrade: the top surface of a roadbed upon which the pavement structure and shoulders are constructed.

Surface Course: the top layer of a pavement structure designed to accommodate the traffic load, resist skidding, traffic abrasion, and the disintegrating effects of climate.

Tandem Axle Load: the total load transmitted to the road by two consecutive axles extending across the full width of the vehicle.

Traffic Service Level: a road's significant traffic characteristics and operating conditions. Reflects the speed, travel time, traffic interruptions, safety, driver comfort, convenience, and operating costs which in turn affect the road's design elements.

Unbound Aggregate: aggregate that has not been treated to make it more stable. Material used to treat the aggregate would include cementing agents (Portland cement, lime fly ash, or asphalt cement); modifiers (lime); or waterproofing agents (asphalt cement).

Well-Graded: soil or aggregate comprised of particles that vary in size across a wide range, from its largest particle to its smallest particle size. An ideal well-graded material is one in which the particles vary in amount according to size such that the void spaces among the larger particles are filled by smaller particles with leftover space filled with even smaller particles.

6.2 "STP" Computer Program User's Guide

6.2.1 Introduction

This appendix contains the "STP" User's Guide and some background information on the development and use of the aggregrate design method developed for the Forest Service by ARE Inc. - Engineering Consultants. The background information was adapted from *Aggregate Surfacing Design Guide - Final Report*, August 1991, by Witcomb, Yapp, and Myers.

In 1988, the Forest Service reviewed the current designs of aggregate and asphalt road surfacings and produced a "Surfacing Design Evaluation Report" for internal use and discussion.[1] Three key recommendations resulted from that report:

1. Adopt the revised 1986 *AASHTO Design Guide* and the companion program (DNPS86/PC) for bituminous-surfaced roads.

2. Develop a surfacing design guide for aggregate and unsurfaced roads using existing technology.

3. Incorporate the concept of multiple-user levels into the design process. The user levels imply differing levels of complexity of operation and variability of design.

This project was initiated to develop a guide and companion computer program to assist in the structural design of aggregate-surfaced and earth roads. A Forest Service Advisory Board consisting of representatives from several Forest Service Regions was appointed to provide technical guidance during the project. Initially, the project focused on reviewing existing technology related to the structural design of aggregate-surfaced roads. That review indicated that research efforts to develop relationships for designing aggregate surfaces are scarce.[2]

Several existing relationships were identified as potential candidates for this *Surfacing Design Guide*; however, no clear choice for adoption was discovered. All design methods currently available had some serious limitations. After considerable review, a relationship developed by the U.S. Army Corps of Engineers in 1978[3] was jointly selected by the Advisory Board and the consultant as the thickness design algorithm for

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[1]USDA Forest Service, "Surfacing Design Evaluation Report," unpublished, June 1988.

[2]ARE Inc., "Aggregate Surfacing Design Guide and Computer Program - - Synthesis Report," Februrary 1989.

[3]Barber, V.C., E.C. Odom, and R.W. Patrick, "The Deterioration and Reliability of Pavements," Technical Report S-78-8, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss., July 1978.

inclusion into the *Surfacing Design Guide* and computer program. This algorithm has little, if any, field experience in its use; however, this is also true for most of the design algorithms reviewed. The equation was developed through a review of previous field data by researchers at the U.S. Army Corps of Engineering Waterways Experiment Station. The intent during its development was to provide a relationship as a starting point which could be then refined through field experiments and the performance of roads designed with this algorithm.

In spite of the above reservations, this design algorithm was selected for the following reasons:

1. The design algorithm contains the design factors that were most important to the Forest Service.

2. The equation appears to be stable with respect to the range of design inputs selected for use.

3. The algorithm was the most sensitive to changes in tire pressure. The thickness differences resulting from tire pressure variation were greatest for lower strength materials as was expected. The magnitudes were in the expected range as well.

4. The design algorithm provided significantly reduced thickness requirements than those from *Chapter 50* for similar design inputs. This was consistent with the general perception that the *Chapter 50* design method for aggregate surfaces was conservative.

The project team and Advisory Board emphasized that need for field studies to refine the design algorithm is still critical to the development of aggregate surfacing design techniques for use by the Forest Service. Focused small-scale field validation experiments are vital to the continued use and acceptance of any design method proposed as a result of this project. Two "focused small-scale" field tests have been completed to validate the application of the U.S. Army Corps of Engineers 1978 equation to Forest Service road conditions. These tests at the U.S. Army Corps of Engineering Waterways Experiment Station (WES) (14) and on the Willamette National Forest near Lowell, Oregon (8) indicate that the 1978 U.S. Army Corps of Engineers equation is valid for low volume Forest Service roads described in this *Surfacing Design Guide*. The WES and Willamette National Forest data are being added to the 1978 U.S. Army Corps of Engineers equation to develop a revised design algorithm. A new version of the "STP" computer program will be released at that time.

In short, there has been some disappointment with the current state of technology in this area. However, it was important to move forward with a design method that could be immediately implemented using existing technology, which includes the factors felt to be most important to the

Forest Service. Continued monitoring and improvement of the method will be important to its eventual success. It is also important that designers recognize that during the initial phases of the implementation, designs must be done with considerable judgment and that performance of the resulting surfaces should be monitored. The experience gained through this process will be useful in refining the design algorithm.

6.2.2 Practical Input Limits for "STP"

Timber volume:	0.03 to 89 MMBF (Note 1)
% Non-log truck traffic:	0 to 100
Total 18k ESAL's:	20 to 70,000 (Note 1)
Surface CBR (C_1):	20 to 100
Subgrade CBR (C_2):	3 to 30
C_1/C_2 ratio:	1 to 7
Allowable rut depth:	Maximum of half the structural thickness

Note 1: The algorithm used for this program was based on a maximum of 70,000 total 18-kip ESAL's (equates to approximately 89 MMBF assuming a single-lane road, tire pressures at 80 psi, 0.005 MMBF per log truck, equivalency factor for loaded log truck of 3.17 and an unloaded log truck of 0.76). Traffic greater than this amount may have variables other than rutting dictating the structural thickness. These variables could be the timing and method of road maintenance, or the material properties of the aggregate.

6.2.3 "STP" Computer User's Guide

This section provides a user's manual or guide to the Surfacing Thickness Program (STP). It is intended that the user will use the *Surfacing Design Guide* in the preceding chapters as a reference for more detailed information when assembling the appropriate input variables, particularly those for material characterization. However, some help screens are also included with the program to aid the designer as much as possible, as well as warning messages to indicate if values entered are out of range. This computer program can run on IBM-compatible personal computers using MS-DOS. It requires 640k RAM. The monitor may be either monochrome or color.

Four files are required for the program to run:

STP.EXE	Contains the executable program
CHOICES.TXT	Contains pop-up menus
HELP.TXT	Contains the help screens
VEHICLES.TXT	Contains the array for the vehicle equivalency factors

The most current version of the program is Version 2.01 (January 1993). Two previously released versions were Version 1.02 (March 1990) and Version 1.04 (August 1991).

The rest of this section is organized as a series of notes that accompany the program menus and screens. General menus are first presented, followed by the earth design module, the aggregate-surfaced new construction design module, the aggregate-surfaced reconstruction design module, and finally, the economic analysis module. The user is encouraged to refer to the preceding chapters as much as possible if guidelines are desired when entering a variable.

Help Screens

The help screens provided in the program are stored in an accompanying file, HELP.TXT. Users may modify this file to suit their needs. *Caution:* There are three items that the user must be aware of:

1. Any line in the HELP.TXT file that begins with an asterisk (*) must *not* be modified. The program keys onto these lines so that the help screens will appear at the appropriate locations.

2. The HELP.TXT file *must* remain in ASCII format, so ASCII word processors can be used to modify the file. Text editors like PC-Write, Norton Commander, EDLIN, or SideKick may be used. Word processors similar to WordPerfect or WordStar may *not* be used unless the document is saved as a ASCII file.

3. The HELP.TXT file has a maximum limit of 500 lines.

To determine if a file is in ASCII format, type the following at the DOS prompt:

```
TYPE HELP.TXT
```

If the user can read this file on the monitor as it scrolls by, and there are no unusual symbols (such as smiling faces) present, then the file is in ASCII format.

Pop-up Menus

Choices for the pop-up menus are stored in the CHOICES.TXT file and may be modified with a text editor, using the same directions as the HELP.TXT file above. Currently, two pop-up menus exist as illustrated later in this section:

- Vehicle type and equivalency factors
- Reliability factors

However, if the CHOICES.TXT file is modified, the corresponding VEHICLE.TXT file *must* also be modified. The VEHICLES.TXT file contains an array of equivalency factors that the program reads in sequential order. Therefore, if the order of vehicles or the equivalency factors in

CHOICES.TXT are changed, a corresponding change must occur in VEHICLES.TXT. The user may add vehicles to the list in both files. *Caution*: It must be noted that the format of this file *cannot* be changed; i.e., the first column must either be the vehicle number or the reliability factor.

Data Files

Input data files (*.DAT) are not saved in ASCII format. This is to prevent any possible corruption of the data file. However, saving the results to an output file is an option in the program, and the output is in ASCII format. Five default output file names are used:

- EAR.OUT = Earth design result summary
- AGG.OUT = Aggregate new construction design result summary
- RECON.OUT = Aggregate reconstruction design result summary
- RUT.OUT = Rut depth analysis result
- ECO.OUT = Economic analysis result

If an existing file with any of the above names is present in the current directory, it will be overwritten. Therefore, users should rename their files to prevent any loss of data. Since these files are in ASCII, users may also modify them with a text editor if desired.

```
USFS Surfacing Thickness Program - Version 2.0

This program was developed by ARE Inc - Engineering
Consultants as part of Contract No. 53-04H1-8-6230 for
the USDA - Forest Service.

Version 2.0 1992

Press any key to continue . . .
```

1. Type "STP" to start the program. This will be the first screen.

ACKNOWLEDGMENTS

The Surfacing Thickness Program
was funded by:
U.S. Department of Agriculture
Forest Service

The computer program is available on request with the understanding that the U.S. Department of Agriculture cannot assure its accuracy, completeness, reliability, or suitability for any other purpose than that reported. The recipient may not assert any proprietary rights thereto nor represent it to anyone as other than a Government-produced computer program. For cost information, please write Pete Bolander, USFS Region 6, P.O. Box 3623, Portland, OR 97208, (503) 326-3249 or John Steward, Forest Service - USDA, 14th and Independence SW, 201 14th Street SW, Washington DC 20250 (202) 205-1448.

Press any key to continue . . .

1. This is the Acknowledgments screen. Note that there are two points of contact listed if the user wishes to obtain additional copies of the program.

```
USFS Surfacing Thickness Program

                MAIN MENU

  Earth Thickness Design
  Aggregate - New Construction Design
  Aggregate - Reconstruction Design
  Rut Depth Analysis
  Cost (Economic) Analysis
  Regional Design Systems
  Exit to DOS

<F1>=Help.  Use arrow keys to select.
   <Esc> returns to previous menu
```

1. Use the arrow keys to highlight the module desired. Press <Enter> to make a selection. It is also possible to press the first letter, such as "A" to select "Aggregate Thickness Design."

2. Pressing <ESC> key escapes the current screen and returns to the previous screen.

3. Press <F1> displays the Help menu. The Help menus will be screen-specific (i.e., relates only to the current screens). The Help screen for the Main Menu is shown on the next page. The user may modify help screens through the HELP.TXT file if desired. This has been explained previously.

4. All the above options in the Main Menu are discussed in preceding chapters of this *Surfacing Design Guide.*

5. The item "Regional Design System" is an option that is intended for future needs. Eventually, Region-specific design methods may be included as a part of a subroutine to this program. Currently, this feature has not yet been implemented.

<PgDn> for more

Earth Thickness Design	- Determines rut depths for a native-surfaced road from user-defined traffic, soil strengths (CBR) and seasonal data.
Aggregate - New Construction Design	- Design thickness of aggregate on aggregate-surfaced road using traffic soil strengths and seasonal data.
Aggregate - Reconstruction Design	- Determines the thickness of new aggregate required to resurface an existing aggregate-surfaced road.
Rut Depth Analysis	- Determines the allowable traffic for a given aggregate-surfaced road and allowable rut depth.
Cost (Economic) Analysis	- An economic analysis of different surfacing alternatives using life-cycle costs.
Regional Design System	- This is proposed customized design method for region-specific criteria. This feature has NOT yet been implemented. See your Regional geotechnical engineer.
Exit to DOS	- This allows you to exit the STP program back to the Disk Operating System (DOS). Pressing <ESC> will also allow you to exit the program.

Press the ENTER key or the ESC key to exit help and continue

1. This is the Help screen for the Main Menu. All Help screens will be of the same general format. Use the <PgDn> key to view additional pages.

2. All help screens may be modified by the user as explained previously in this appendix.

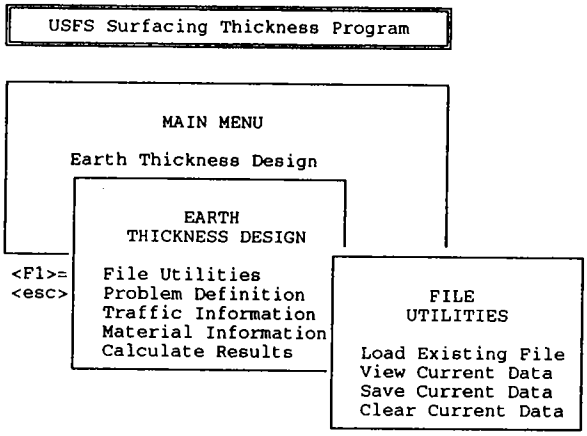
```
USFS Surfacing Thickness Program

                MAIN MENU

        Earth Thickness Design

                EARTH
            THICKNESS DESIGN

<F1>=     File Utilities          select.
<esc>     Problem Definition
          Traffic Information
          Material Information
          Calculate Results
```

1. This is the Earth Thickness Menu. The user enters Traffic & Material information and obtains the resultant design thickness in "Calculate Results."

2. Use arrow keys to highlight the option desired, or press first letter of each option.

3. Press <F1> to obtain a Help screen.

4. Press <ESC> to go to previous menu.



1. This is the File Utilities screen.

2. When starting a new problem, the user can load an existing file and use or modify that data as required. Alternatively, the user can enter new data and then save the new problem using "Save Current Data." The data file saved is not in ASCII so as to protect the user from any possible data corruption.

3. "Clear Current Data" will remove all existing data inputs and return the user to the Earth Thickness Menu screen.

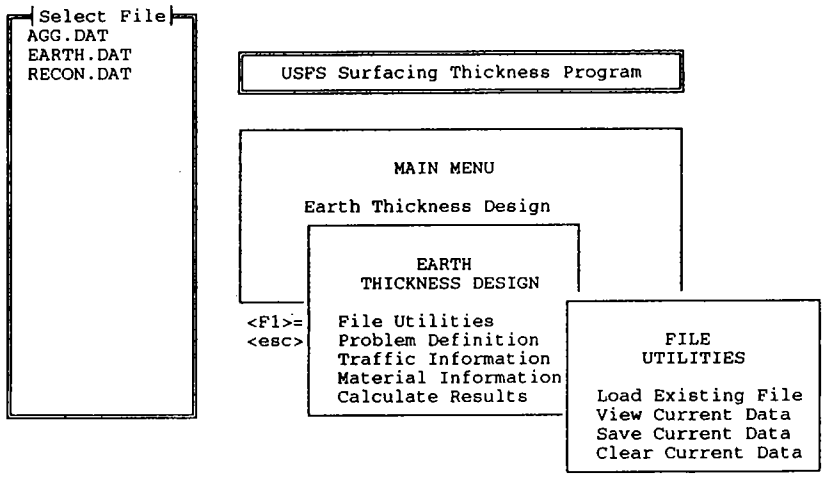
4. Press <F1> to obtain a Help screen, <ESC> to exit to previous menu.

```
USFS Surfacing Thickness Program

RETRIEVE DATA FILE
Enter file name:  *.DAT

 To pick from list press enter
 (Or press <ESC>
 to ignore...
```

1. Data files may be saved using any format as long as they meet DOS requirements (i.e., not greater than eight alphanumeric characters with a 3-character extension such as XXXXXXXX.XXX). However, it is suggested that a ".DAT" extension be used to indicate a data file.

2. The Save Current Data screen is similar to this one.

3. If the user cannot remember an old file, pressing the [ENTER] key at the *.DAT field will bring up the following menu on the next page. The asterisk (*) is a wildcard character. Note that if the user requested a listing of all "*.DAT" files (i.e., data files with a .DAT extension), then only those files will be listed. To obtain a listing of all files in the current directory, type "*.*".



1. Use arrow keys to highlight the desired file and press <Enter> to retrieve.

2. Note that only files with a .DAT extension are listed in this case.

```
EARTH DATA SUMMARY

Problem No:            Road 2A
Problem Description:   Road 2A, Sample NF, Oregon
                       MP 1.2 to MP 1.3

      Traffic Data:                          Materials Data:

                                                   Compacted  Uncompacted
  Timber Volume:  10.00 MMBF              Season     CBR          CBR
                   7925 18k ESALS
 Other Vehicles:      0 18k ESALS           1       10.0         6.0
                                            2        5.0         3.0

Total 18k ESALS:   7925

                  <Press any key to continue>

                                          Save Current Data
                                          Clear Current Data
```

1. This is the View current data summary.

2. Press <ESC> to go to previous menu.

```
USFS Surfacing Thickness Program

MAIN MENU

Earth Thickness Design

Earth
THICKNESS DESIGN

PROBLEM DEFINITION

PROBLEM NUMBER        Road 2A

PROBLEM DESCRIPTION
Road 2A, Sample NF, Oregon
MP 1.2 to MP 1.3
```

1. Type in problem number and description in fields. Press <ESC> when done.

2. To save the data entered here, the user has to go to the File Utilities Menu and select "Save Current Data." To retrieve the data, select "Load Existing File" from the File Utilities Menu.

3. Press <F1> to obtain a Help screen.

4. Press <F1> twice to obtain the key definitions.

```
                    TRAFFIC INFORMATION

        Timber Volume            :  10.00  MMBF
        Conversion Factor        :   5000  BF for 1 Std
        % Non-Log Truck Traffic  :     25     Log Truck
    Timber Volume   18K ESALS -->   7925
                     Equivalency
 Veh. No Vehicle Type    Factor   Passes   18-Kip ESAL

                         0.000        0            0
                         0.000        0            0
                         0.000        0            0
                         0.000        0            0
                         0.000        0            0
                         0.000        0            0
                         0.000        0            0
                         0.000        0            0
                         0.000        0            0
                         0.000        0            0
                   Vehicle Type  18K ESALS -->

                          TOTAL 18K ESALS --> 7925
```

1. This is the Traffic Information screen for the Earth Design.

2. The Traffic Information may be entered by timber volume, and/ or vehicle type. Press <F1> to bring up a Help screen for more information.

3. The timber volume calculation is shown below as:

   (Timber Volume/Conversion Factor)*(1 + % Non-log Truck)*(EF)*(F_R)

   i.e.,

   (10 MMBF/5 MBF) (1.25) (3.17) (1.00) = 7,925 18k ESAL's

   The default conversions are 5 MBF to one standard log truck, and 25 percent for the non-log truck factor.

4. Press <F2> when the cursor is in the "Vehicle Type" field to bring up the appropriate pop-up menu (see next page). Then select the appropriate vehicle by using the cursor to highlight the desired vehicle, then <Enter> to select. To enter a vehicle not listed in the pop-up, enter a zero in the vehicle number column.

5. The "Total 18^k ESAL's" shown in either option will include the effects of the reliability factor. Note that this algorithm was developed for a total 18 kip ESAL's between 200 and 50,000. Values outside this range will result in a warning message.

Vehicle Type Pop-up

Veh. No.	Description of Vehicle	Equivalency Factor	Tire Pressure (psi)	Comment
1	18-Kip ESAL	1.00	80	
2	Empty Log Truck	0.29	64,25	CTI-10k steer,16k drive
3	Empty Log Truck	0.76	80	Total weight 26 kips
4	Empty Log Truck	1.00	90	
5	Standard Log Truck	1.07	50	Total weight 80 kips
6	Standard Log Truck	1.28	64,52,52	CTI-10k steer,35k dr & tr
7	Standard Log Truck	1.95	70	Total weight 80 kips
8	Standard Log Truck	3.17	80	Total weight 80 kips
9	Standard Log Truck	4.16	90	
10	Standard Log Truck	5.30	100	Total weight 80 kips
11	Off Hwy Log Truck	1.90	50	Total Weight 108 Kips
12	Off Hwy Log Truck	3.43	70	Total Weight 108 Kips
13	Off Hwy Log Truck	5.58	80	Total Weight 108 Kips
14	Off Hwy Log Truck	9.33	100	Total Weight 108 Kips
15	Dump Truck	0.68	50	46,000 GVW
16	Dump Truck	1.31	70	46,000 GVW
17	Dump Truck	2.01	80	46,000 GVW
18	Dump Truck	3.35	100	46,000 GVW

Cursor keys scroll, ENTER selects and ESC exits choice menu

1. This is the first page of the Vehicle Type pop-up menu. Press <F2> at the "Vehicle Type" field to get this screen. Use arrow keys to highlight selection, and <Enter> to select.

2. The user may add to or modify this pop-up by using an ASCII text editor to modify the CHOICES.TXT file in the current directory. However, the user must also make sure that the corresponding changes are performed to the VEHICLES.TXT file as well to ensure program integrity. *Note*: It is important that these *.TXT files remain in ASCII.

3. Note that two triple-axle trucks have been included in the pop-up. The equivalency factors determined for these vehicles are preliminary in nature and caution should be used when including them in any analyses. It is preferable that users obtain more precise values for their needs.

```
USFS Surfacing Thickness Program

MATERIAL INFORMATION - EARTH DESIGN

                ESTIMATED    COMPACTED UNCOMPACTED
                % TRAFFIC      CBR        CBR
                ---------    -------    --------
SEASON 1          75.0        10.0        6.0
SEASON 2          25.0         5.0        3.0
                ---------
TOTAL (%)         100.0
```

1. This is the Seasonal Factors Menu for the Earth Design. Note that only two seasons are allowed.

2. Also, the compacted CBR should not be greater than two times the uncompacted CBR or a warning message will occur. Press <F1> (Help) for guidelines on the selection of appropriate CBR's.

```
RESULTS SUMMARY - EARTH DESIGN

PROBLEM NUMBER        Road 2A

PROBLEM DESCRIPTION
Road 2A, Sample NF, Oregon
MP 1.2 to MP 1.3


Compacted Thickness (inches)  . . . .    6.0
Rut Depth (inches)    . . . . . . . .   10.6

                    Damage Ratios
Season 1              Season 2            Total
--------              --------           -------
  0.09                  0.88               0.96

Press <Alt-P> for Printer or <Alt-F> for File!
```

1. This is the results summary for the earth road design subroutine.

2. Press <ALT-P> to print. The printer must be connected to a parallel port (LPT1:).

3. Press <ALT-F> to print the output to a file. The file name is EAR.OUT. Successive outputs will overwrite this file, so users must rename the file if they wish to save it.

TIP
If printing problems result with the <ALT-P> option, use <ALT-F> instead. To print the EAR.OUT file, type the following at the DOS prompt: TYPE EAR.OUT>PRN

USFS SURFACING THICKNESS PROGRAM
Earth Design

Problem Number : Road 2A
Problem Description : Road 2A, Sample NF, Oregon
MP 1.2 to MP 1.3
Date of Analysis : 7/28/1994
Filename : EARTH.DAT

SUMMARY OF INPUT AND RESULTS

Timber Volume : 10 MMBF
Conversion Factor : 5000 BF for 1 Std Log Truck
Percent Non-Truck Traffic : 25

Timber Volume 18K ESALS : 7925

Vehicle Type	Equivalency Factor	Actual Passes	No. Passes of 18K ESALS
	0.00	0	0
	0.00	0	0
	0.00	0	0
	0.00	0	0
	0.00	0	0
	0.00	0	0
	0.00	0	0
	0.00	0	0
	0.00	0	0
	0.00	0	0
		Vehicle Type 18K ESALS =	0
		TOTAL 18K ESALS =	7925

Reliability Factor : 1.00

	Estimated Traffic	Compacted CBR	Uncompacted CBR	Damage Ratios
Season 1	75.0	10	6	0.09
Season 2	25.0	5	3	0.88
TOTAL =	100.0 Percent			0.96

Compacted Thickness . . . . . 6.0 inches
Rut Depth . . . . . 10.6 inches

1. This is a sample EAR.OUT file.

```
USFS Surfacing Thickness Program

                MAIN MENU

 Earth Thickness Design
 Aggregate - New Construction Design

                AGGREGATE
             THICKNESS DESIGN

<F1>=   File Utilities                select.
<esc>   Problem Definition
        Traffic Information
        Material Information
        Calculate Results
```

1. This is the Aggregate—New Construction Design Menu. The user enters Traffic & Seasonal information and obtains the resultant design thickness in "Calculate Results."

2. Use arrow keys to highlight the option desired, or press first letter of each option.

3. The File Utilities and Problem Definition screens are similar to the Earth Thickness Design and are explained earlier in the appendix.

4. Press <F1> to obtain a Help screen.

5. Press <ESC> to go to previous menu.

```
                    | TRAFFIC INFORMATION |

      Timber Volume              :   0.00  MMBF
      Conversion Factor          :   5000  BF for 1 Std
      % Non-Log Truck Traffic    :     25      Log Truck
   Timber Volume   18K ESALS -->      0
                    Equivalency
Veh. No Vehicle Type     Factor    Passes    18-Kip ESAL

 3  Empty Log Truck     0.760      4000           4378
 8  Standard Log Truck  3.170      2000           9130
40 Washington 208 w/t 16.970         2             49
13 Off Hwy Log Truck   5.580      2000          16070
                       0.000         0              0
                       0.000         0              0
                       0.000         0              0
                       0.000         0              0
                       0.000         0              0
                       0.000         0              0
                 Vehicle Type 18K ESALS -->    29626
                       TOTAL 18K ESALS -->    29626

      Reliability Factor :    1.44 Aggregate Design Only
```

1. This is the Traffic Information screen for the Aggregate Design. The only difference from the Earth Design is that a reliablility factor is used in the analysis.

2. Pressing <F2> when the cursor is in the "Reliability Factor" field will bring up the "Reliability Factor" pop-up.

3. The "Total 18k ESAL's" shown in either option will include the effects of the reliability factor. Note that this algorithm was developed for a total 18 kip ESAL's between 200 and 50,000. Values outside this range will result in a warning message.

4. Pressing <F1> will bring up a Help screen. Press <F1> twice to list the key definitions.

5. To edit the pop-up menus, the user may modify a file called CHOICES.TXT with a text editor. This file *must* be edited in ASCII format, as previously discussed.

Reliability Level Pop-up

Reliability Factor	TSL	Reliability Level
1.00	D	50%
1.44	C	70%
2.32	B	90%

Cursor keys scroll, ENTER selects and ESC exits choice menu

1. Press <F2> at the "Reliability Factor" field to obtain this pop-up.

2. Use arrow keys to scroll to desired factor and hit <Enter> to make selection. This value will now be entered in the field.

```
Warning:        The total 18-kip ESALs entered is either greater
                than 50,000 or less than 200.  The program will
                calculate the results based on the maximum or
                minimum allowable number.

Discussion :    The algorithm used for this program was based
                on a maximum of 50,000 total 18 kip ESALs and a
                minimum of 200 18-kip ESALs.
                Traffic greater than 50,000 may have variables
                other than rutting dictating the structural thickness.
                These variables could be the timing and method of road
                maintenance or the material properties of the aggregate

Recommendations: 1) Reduce the analysis period to keep the design traffic
                    less than 50,000 or more than 200 18-kip ESALs.
                 2) Evaluate the sensitivity of your situation
                    to traffic as shown in Figure    of the
                    surfacing Design Guide.


          <Press any key to Continue>
```

1. This is the warning message that occurs when the total number of 18-kip ESAL's entered is:

   a. less than 200 or
   b. greater than 50,000.

USFS Surfacing Thickness Program

MATERIAL INFORMATION - EARTH DESIGN

	ESTIMATED % TRAFFIC	SUBGRADE CBR	SURFACE CBR
SEASON 1	20.0	3.0	20.0
SEASON 2	80.0	15.0	60.0
SEASON 3	0.0	0.0	0.0
SEASON 4	0.0	0.0	0.0
TOTAL (%)	100.0		

1. This is the Material Information screen.

2. After the user enters the subgrade CBR, the surface CBR is automatically calculated (Surface CBR = 4 x Subgrade CBR). However, the user may manually override this value, if desired.

3. If surface CBR is more than four times subgrade CBR, a warning message will pop-up (see next page). After the user has read the warning, pressing any key will return the user to the Material Information screen. If the CBR's are not changed, the program will calculate aggregate thickness based on the data entered, not the data calculated.

4. Press <F1> to obtain a Help screen.

5. Press <F1> twice to obtain key definitions.

```
USFS Surfacing Thickness Program

WARNING!  Algorithm was developed for
surface CBR not less than 20 and not
greater than 4 times subgrade CBR.
In addition, subgrade CBR is assumed
to be greater than 3.  Aggregate
thickness will be calculated based on
the data you entered.  Press <F1> Help
for further explanation.
    <Press any key to Continue>
```

1. This is the warning message that occurs when:

   a. Surface CBR > 4 x Subgrade CBR
   b. Subgrade CBR < 3
   c. Surface CBR < 20

2. After the user has read the warning, pressing any key will return the user to the Material Information screen. If the CBR's are not changed, the program will ignore the $C_1 > 4C_2$ ratio and calculate aggregate thickness based on the data entered.

```
┌─┤CALCULATE RESULTS - AGGREGATE DESIGN├──────────────────────────────┐
│                                                                      │
│   PROBLEM NUMBER       Road 1A                                       │
│                                                                      │
│   PROBLEM DESCRIPTION                                                │
│   Road 1A, Sample NF, Oregon                                         │
│   MP 3.4 to MP 3.6                                                   │
│                                                                      │
│   Allowable Rut Depth (inches)  . .          2.0                     │
│   Aggregate Loss (inches) . . . . .          0.0                     │
│    (typically 1 inch for 10 MMBF)                                    │
│   Structural Thickness (inches) . .         11.5                     │
│   Total Aggregate Thickness (inches):       11.5                     │
│   Practical Min. Thickness  (inches):        4.0                     │
│                     Damage Ratios                                    │
│   Season 1  Season 2  Season 3  Season 4    TOTAL                    │
│   --------  --------  --------  --------    -----                    │
│      0.97      0.01      0.00      0.00     0.98                     │
│   Press <Alt-P> for Printer or <Alt-F> for File!                     │
```

1. This is the results summary for the Aggregate Design subroutine.

2. The user may enter a value in the "Allowable Rut Depth" and "Aggregate Loss" fields.

3. The program calculates "Structural Thickness" based on the "Allowable Rut Depth" shown here, as well as the "Traffic and Seasonal Information" previously entered. The "Aggregate Loss" may be added to the "Structural Thickness" for a "Total Aggregate Thickness." The user should round off the results as appropriate.

4. A warning message will occur if the rut depth exceeds half of the aggregate structural thickness (see next page).

5. Seasonal damage ratios are displayed and summed for the user. The program has selected a "Structural Thickness" so that the resulting "Total Damage Ratio" is ≤ 1.0.

6. Press <ALT-P> to print. The printer must be connected to a parallel port (LPT1:).

7. Press <ALT-F> to print the output to a file. The default file name is AGG.OUT. Successive outputs will overwrite any existing files, so users rename files if they wish to save them.

TIP
If printing problems result with the <ALT-P> option, use <ALT-F> instead. To print the AGG.OUT file, type the following at the DOS prompt: TYPE AGG.OUT>PRN

```
WARNING!  Allowable rut depth should be
          between 1 and 6 inches.

     <Press any key to Continue>
```

```
WARNING! Rut Depth exceeds 1/2 structural thickness.
         This may represent a bearing capacity failure
         Reduce the allowable rut depth to less than
         1/2 the structural thickness.  Also verify
         traffic information.

              <Press any key to continue>
```

1. The first screen is the warning message that occurs if rut depth is greater than half of the aggregate structural thickness. Check your inputs if this occurs.

2. The second screen is the warning message that occurs if rut depth is greater than half of the aggregate structural thickness. Check your inputs if this occurs.

USFS SURFACING THICKNESS PROGRAM
Aggregate Design

Problem Number : Road 1A
Problem Description : Road 1A, Sample NF, Oregon
MP 3.4 to MP 3.6
Date of Analysis : 7/28/1994
Filename : AGG.DAT

SUMMARY OF INPUT AND RESULTS

Timber Volume : 0 MMBF
Conversion Factor : 5000 BF for 1 Std Log Truck
Percent Non-Truck Traffic : 25

Timber Volume 18K ESALS : 0

Vehicle Type	Equivalency Factor	Actual Passes	No. Passes of 18K ESALS
3 Empty Log Truck	0.76	4000	4378
8 Standard Log Truck	3.17	2000	9130
40 Washington 208 w/t	16.97	2	49
13 Off Hwy Log Truck	5.58	2000	16070
	0.00	0	0
	0.00	0	0
	0.00	0	0
	0.00	0	0
	0.00	0	0
	0.00	0	0
		Vehicle Type 18K ESALS =	29626
		TOTAL 18K ESALS =	29626

Reliability Factor : 1.44

	Estimated Traffic	Surface CBR	Subgrade CBR	Damage Ratios
Season 1	20.0	20	3	0.97
Season 2	80.0	60	15	0.01
Season 3	0.0	0	0	0.00
Season 4	0.0	0	0	0.00
TOTAL =	100.0 Percent			0.98

Allowable Rut Depth : 2.0 inches

Aggregate Loss : 0.0 inches
Structural Thickness Required : 11.5 inches

Total Aggregate Thickness Req'd : 11.5 inches

1. This is a sample AGG.OUT file.

```
AGGREGATE RECONSTRUCTION DESIGN

                    Materials & Results

Existing Section:

C (exist):  20.0   Existing Agg. thickness:  4.0 inches
  C (sub):  15.0       CBR of new material: 55.0
                       Allowable rut depth:  2.0

 Results:

 Thickness of resurfacing material required: 4.1 inches

      Press <Alt-P> for Printer or <Alt-F> for File!
```

1. This is the Aggregate-Reconstruction Design, Materials and Results screen. File Utilities Problem Definition and Traffic Information have been explained under Earth Thickness or Aggregate-New Construction Design.

2. Note only one season in this design.

3. Use arrow keys to enter input.

4. Press <F1> to obtain a Help screen.

5. Press <ESC> to go to previous menu.

USFS SURFACING THICKNESS PROGRAM
Aggregate Reconstruction Design

Problem Number : Road 1A
Problem Description : Road 1A, Sample NF, Oregon
MP 3.4 to MP 3.6
Date of Analysis : 7/28/1994
Filename : AGG.DAT

SUMMARY OF INPUT AND RESULTS

Timber Volume : 0 MMBF
Conversion Factor : 5000 BF for 1 Std Log Truck
Percent Non-Truck Traffic : 25

Timber Volume 18K ESALS : 0

Vehicle Type	Equivalency Factor	Actual Passes	No. Passes of 18K ESALS
3 Empty Log Truck	0.76	4000	4378
8 Standard Log Truck	3.17	2000	9130
40 Washington 208 w/t	16.97	2	49
13 Off Hwy Log Truck	5.58	2000	16070
	0.00	0	0
	0.00	0	0
	0.00	0	0
	0.00	0	0
	0.00	0	0
	0.00	0	0
		Vehicle Type 18K ESALS =	29626
		TOTAL 18K ESALS =	29626

Reliability Factor : 1.44

CBR (existing) 20.0

CBR (subgrade) 15.0

Existing aggregate thickness . . . . . 4.0 inches

CBR of new material. . . . . 55.0 inches

Allowable rut depth. . . . . 2.0 inches

Thickness of resurfacing material required . . 4.1 inches

1. This is a sample of RECON.OUT.

```
USFS Surfacing Thickness Program

                MAIN MENU

      Earth Thickness Design
      Aggregate-New Construction Design
      Aggregate-Reconstruction Design
      Rut Depth Analysis
                 COST (ECONOMIC)
                    ANALYSIS
<F1>=                                  select.
<esc>
                Rut Depth
                Analysis Menu
                File Utilities
                Problem Definition
                Calculate Results
```

1. This is the Rut Depth Analysis Menu.

2. Use arrow keys to highlight the option desired, or press first letter of each option.

3. The File Utilities and Problem Definition screens are similar to the Earth Thickness Design and are explained earlier in the appendix.

4. Press <F1> to obtain a Help screen.

5. Press <ESC> to go to previous menu.

```
RUT DEPTH ANALYSIS

Total Aggregate Thickness:     4   inches
             Subgrade CBR:     5
            Aggregate CBR:    20
      Allowable rut Depth:     2.0 inches
       Reliability Factor:     1.0

        Allowable Traffic:   113 18k ESALS

      Press <Alt-P> for Printer or <Alt-F> for File!
```

1. This is the Rut Depth Analysis screen. User inputs total aggregate thickness, subgrade CBR, aggregate CBR, rut depth, and reliability factor. Defaults values are shown initially on the screen.

2. Use arrow keys to enter input.

3. Press <F1> to obtain Help screen.

4. Press <ESC> to go to previous menu.

```
USFS Surfacing Thickness Program

                MAIN MENU

     Earth Thickness Design
     Aggregate-New Construction Design
     Aggregate-Reconstruction Design
     Rut Depth Analysis
     Cost (Economic) Analysis

<F1>=      COST (ECONOMIC)          select.
<esc>         ANALYSIS

     File Utilities
     Problem Definition
     Calculate Results
```

1. This is the Economic Analysis Menu.

2. The File Utilities and Problem Definition are similar to those for the Aggregate Thickness Design.

```
┌┤ECONOMIC ANALYSIS├──────────────────────────────────────────────────────────┐
│                                                                              │
│  Physical Geometry                Surfacing Construction Costs               │
│                                                                              │
│Length (feet)        600                          Mat'l #1    Mat'l #2        │
│Top Width (feet)    12.0  Thickness (inches)        5.0         3.0          │
│Turnout Factor/                   Volume (CY)     154.5        90.3          │
│Curve Widening       1.3    Unit Cost ($/CY)      10.00       15.00          │
│Side Slopes (H:V) 2 : 1                          ────────    ────────         │
│                                 Total Surfacing                              │
│                                       Costs ($) 1545.       1354.            │
│                                                                              │
│            Subgrade Prep. Add'l Cost ($)      2000.                          │
│            Total Maintenance Costs ($/mi/yr)   500.                          │
│            Total Operational Costs ($/mi/yr)   200.                          │
│            Salvage Value ($)                     0.                          │
│            Discount Rate (percent)               4.                          │
│            Analysis Period (years)                 10                        │
│     Equivalent Uniform Annual Cost ($/year)    684.                          │
│                     Net Present Worth ($)     5544.                          │
│                                                                              │
│         Press <Alt-P> for Printer or <Alt-F> for File!                       │
└──────────────────────────────────────────────────────────────────────────────┘
```

1. This is the Economic Analysis screen.

2. The default for the "Turnout/Curve Widening Factor" is 1.30. When no turnouts are present, enter 1.0. DO NOT ENTER ZERO!

3. The program will calculate the surfacing volumes for Materials 1 and 2 based on the physical geometry information. The initial "Surfacing Construction Cost" is calculated based on unit costs entered by the user. In addition, the program allows the user to enter an initial "Subgrade Preparation Cost" if appropriate, as well as uniform annual maintenance and operation costs. Finally, given an "Interest Rate" and "Analysis Period," both the "Equivalent Uniform Annual Cost" and "Net Present Worth" are calculated. The defaults for the interest rate and analysis period are 4 percent and 10 years, respectively.

4. Press <ALT-P> to print. The printer must be connected to a parallel port (LPT1:).

5. Press <ALT-F> to print the output to a file. The file name is ECO.OUT. Successive outputs will overwrite any existing file, so users must rename these existing files if they wish to save them.

TIP
If printing problems result with the <ALT-P> option, use <ALT-F> instead. To print the ECO.OUT file, type the following at the DOS prompt: TYPE ECO.OUT>PRN

USFS SURFACING THICKNESS PROGRAM
Economic Analysis

Problem Number : Road 1A
Problem Description : Road 1A, Sample NF, Oregon
MP 3.4 to MP 3.6
Date of Analysis : 7/28/1994
Filename : AGG.DAT

SUMMARY OF INPUT AND RESULTS

Physical Geometry

Length (feet)	600
Top Width (feet)	12.0
Turnout Factor / Curve Widening	1.3
Side Slopes	2: 1

Surfacing Construction Costs

	Layer #1	Layer #2
Thickness (inches)	5.0	3.0
Volume (CY)	154.5	90.3
Unit cost ($/CY)	10.00	15.00
Total Surfacing Cost ($)	1545	1345

Subgrade Preperation Additional Cost ($)	2000
Total Maintenance Cost ($/mi/yr)	500
Total Operational Cost ($/mi/yr)	200
Discount Rate (percent)	4.00
Analysis Period (years)	10
Equivalent Uniform Annual Cost ($/year)	684
Net Present Worth ($)	5544

1. This is a sample ECO.OUT file.

6.2.4 "STP" Computer Input Forms

Earth Surfacing Design - STP

Problem Name: _____ Road Number: _____
Problem Number: _____ Traffic Service Level: _____
Project Designer: _____ Problem Description: _____
Date: _____ _____

Traffic Information

1) Timber Volume:
   1a: Timber Volume (MBF): _____
   1b: Conversion Factor: 5 MBF/truck or _____
   1c: % Non-Log Truck Traffic: .25 or _____
   1d: ESALs = (_____) * ((_____) /(_____)) * (1 + (_____))

   = (Equivlency Factor of log truck)*((1a)/(1b))*(1c)

   = _____

2) Vehicle Type:

Vehicle	Tire Pressure	E.F.	No. of Passes	No. passes * Equivalency Factor
			Sum =	

Refer to the Figures in Section 3.2 of the "Surfacing Design Guide For Low Volume Roads," or the computer program STP for the selection of the Equivalency Factors (E.F.).

3) Total # ESALS:
   Total # ESALs = ESALs due to timber volume + ESALs due to vehicle type
   = _____ + _____ = _____

Seasonal Information

1) Number of Seasons:
   _____A) One season
   _____B) More than one season
   Operating Season: _____
   No. of Months: _____ ESALs per Month: _____

Season No.	Dates of Season	# Months in Season	Timber ESAL per Season	Vehicle ESAL per Season	ESAL per Season	% Traffic
1						
2						
					(Total)	

2) Uncompacted CBR:

A) Soil Type: _____ Obtained from: _____

B) CBR per Season:

Season No.	Expected Moisture Conditions	CBR	Remarks
1	_____	_____	_____
2	_____	_____	_____

CBRs obtained from:

___Figure 3.4-2 ____Best Estimate ____SRI ____Lab Tests

___Historical Data base ___Other: _____

3) Compacted CBR:

A) Season 1 Uncompacted CBR * 4 = ____

Season 2 Uncompacted CBR * 4 = ____

B) Expected subgrade conditions during construction:

____Wet ___Moist ___Dry

C) Expected compaction during construction:

___Method 1 (80-85% T-99) ___Method 2 (85-90% T-99)

___Method 3 (90-95% T-99) ___Method 4 (95-97% T-99)

___Method 5 (90-97% T-99) ___Method 6 (95% T-180)

D) Step C CBR For Season 1 _____

Season 2 _____

E) Design CBR per Season:

CBR	_____	_____	(use minimum value from Step A or Step D)
Season No.	1	2	

Output

Calculated Rut Depth: _____

Remarks

_____

_____

_____

_____

Aggregate Surfacing Design - STP

Problem Name: _____
Problem Number: _____
Project Designer: _____
Date: _____

Road Number: _____
Traffic Service Level: _____
Problem Description: _____
_____

Traffic Information

1) Timber Volume:
   1a: Timber Volume (MBF): _____
   1b: Conversion Factor: 5 MBF/truck or _____
   1c: % Non-Log Truck Traffic: .25 or _____
   1d: ESALs = (_____) * ((_____) /(_____)) * (1 + (_____))

   = (Equivlency Factor of log truck)*((1a)/(1b))*(1c)
   = _____

2) Vehicle Type:

Vehicle	Tire Pressure	E.F.	No. of Passes	No. passes * Equivalency Factor
			Sum =	

Refer to the Figures in Section 3.2 of the "Surfacing Design Guide For Low Volume Roads," or the computer program STP for the selection of the Equivalency Factors (E.F.).

3) Reliability:

Traffic Service Level:	D	C	B
Reliability Factor:	1.00	1.44	2.32
Reliability:	(50%)	(70%)	(90%)

4) Total # ESALs:
   Total # ESALs = (Timber ESALs + Vehicle ESALs) * Reliability Factor
   = (_____ + _____) * _____ = _____

Seasonal Information

1) Number of Seasons:
   _____A) One season
   _____B) More than one season
   Operating Season: _____
   No. of Months: _____ ESALs per Month: _____

Season No.	Dates of Season	# Months in Season	Timber ESAL per Season	Vehicle ESAL per Season	ESAL per Season	% Traffic
1						
2						
3						
4						
					(Total)	

2) Subgrade CBR:

A) Soil Type: _____ Obtained from: _____

B) Expected subgrade conditions during construction:
____Wet ___Moist ___Dry

C) Expected compaction during construction:
___Method 1 (80-85% T-99) ___Method 2 (85-90% T-99)
___Method 3 (90-95% T-99) ___Method 4 (95-97% T-99)
___Method 5 (90-97% T-99) Method 6 (95% T-180)

D) CBR per Season:

Season No.	Expected Moisture Conditions	CBR	Remarks
1	_____	_____	_____
2	_____	_____	_____
3	_____	_____	_____
4	_____	_____	_____

CBR's obtained from:
___Figure 3.4-2 ____Best Estimate ____SRI ____Lab Tests
___Historical Data base ___Other: _____

3) Surface CBR:

A) Season 1 Subgrade CBR * 4 = ____
Season 2 Subgrade CBR * 4 = ____
Season 3 Subgrade CBR * 4 = ____
Season 4 Subgrade CBR * 4 = ____
Note: if result is < 20 use 20 and skip the remainder of Part 3.

B) Type of Aggregate
___Pit Run Maximum Size: _____
___Grid Rolled Maximum Size: _____
___Screened Aggregate
___Crushed, Grading: ___A ___B ___C ___D ___E
___F ___G ___H ___J ___K
___L ___M ___N ___O ___Other: _____
___Cinders ___Sand & Gravel ___Fracture Rock
SE=___ PI=___

C) Aggregate Quality
___Marginal ___Good ___Excellent

D) "A" Value From Figure 3.4-3
= base value + additional coefficients
= _____ + _____ = _____

E) Moisture Factor Correction

1) Quality of Drainage

___Excellent ___Good ___Fair ___Poor ___Very Poor

2) % time road exposed to moisture levels approaching saturation

Season:	1	2	3	4
# months in season approaching saturation	_____	_____	_____	_____
# months in season	_____	_____	_____	_____
percent exposed	_____	_____	_____	_____
moisture factor from Figure 3.4-4	_____	_____	_____	_____

F) New "a" value
= Step D * Step E _____ _____ _____ _____

G) CBR from Figure 3.4-5
Note: CBR at 100% of T-99
_____ _____ _____ _____

H) Adjust CBR to match expected field density,
= Step G/1.0 for 100% T-99
= Step G/1.3 for 95% T-99 _____ _____ _____ _____
= Step G/1.7 for 90% T-99

I) Max of Step A, or 20 _____ _____ _____ _____

J) Design CBR, lesser of
Step H or Step I _____ _____ _____ _____

Aggregate Thickness

A) Structural Thickness: _____ (from "STP" @ ____" rut depth))
B) Aggregate Loss: _____
C) Total: _____
D) Twice the maximum particle size: _____
E) Recommended: _____
(Maximum of Step C, Step D, or 4 inches, round to the nearest whole number)

Remarks

_____
_____
_____
_____

Reconstruction Design - STP

(One Season Only)

Problem Name: _____ Road Number: _____
Problem Number: _____ Traffic Service Level: _____
Project Designer: _____ Problem Description: _____
Date: _____ Operating Season: _____

A. Existing Conditions

Layer	Thickness	Material Description	CBR
Existing	_____	_____	_____
Subgrade	N/A	_____	_____

B. Traffic Information

1) Timber Volume:
   1a: Timber Volume (MBF): _____
   1b: Conversion Factor: 5 MBF/truck or _____
   1c: % Non-Log Truck Traffic: .25 or _____
   1d: ESALs = (_____) * ((_____) /(_____)) * (1 + (_____))

   = (Equivlency Factor of log truck)*((1a)/(1b))*(1c)
   = _____

2) Vehicle Type:

Vehicle	Tire Pressure	E.F.	No. of Passes	No. passes * Equivalency Factor
_____	_____	_____	_____	_____
_____	_____	_____	_____	_____
_____	_____	_____	_____	_____
_____	_____	_____	_____	_____
_____	_____	_____	_____	_____
			Sum =	_____

3) Reliability:

Traffic Service Level:	D	C	B
Reliability Factor:	____1.00	____1.44	____2.32
Reliability:	(50%)	(70%)	(90%)

4) Total # ESALs:
   Total # ESALs = (Timber ESALs + Vehicle ESALs) * Reliability Factor
   = (_____ + _____) * _____ = _____

C. Proposed New Aggregate Info and CBR

1) Type of Aggregate
   ___Pit Run Maximum Size: _____
   ___Grid Rolled Maximum Size: _____
   ___Screened Aggregate
   ___Crushed, Grading: ___A ___B ___C ___D ___E
   ___F ___G ___H ___J ___K
   ___L ___M ___N ___O ___Other: _____
   ___Cinders ___Sand & Gravel ___Fracture Rock

2) Aggregate Quality

___Marginal ___Good ___Excellent

SE=___ PI=___

3) "A" Value From Figure 3.4-3

= base value + additional coefficients

= _____ + _____ = _____

4) Moisture Factor Correction

a) Quality of Drainage

___Excellent ___Good ___Fair ___Poor ___Very Poor

b) % time road exposed to moisture levels approaching saturation

Season: __1__

months approaching saturation _____

percent exposed _____

moisture factor from Figure 3.4-4 _____

5) New "a" value

= Step 3 * Step 4 _____

6) CBR from Figure 3.4-59

Note: assume CBR at 100% of T-99 _____

7) Adjusted CBR to match expected field density,

= Step 6/1.0 for 100% T-99 _____

= Step 6/1.3 for 95% T-99 _____

= Step 6/1.7 for 90% T-99 _____

D. Aggregate Thickness

A) Structural Thickness: _____ (from "STP", @ ____" Rut Depth)

B) Aggregate Loss: _____

C) Total: _____

D) Twice the maximum particle size: _____

E) Recommended: _____

(Maximum of Step C, Step D, or 4 inches, round to the nearest whole number)

E. Remarks

_____

_____

_____

_____

6.2.5 Equivalency Factor Determination

As described in section 3.2.1, the standard axle type selected was the 18-kip equivalent single-axle load, with a tire pressure of 80 psi. The standard axle has an equivalency factor of 1.0. The design algorithm shown below was used to calculate equivalency factors for other axle types and configurations.

$$RD = 0.1741 \frac{P_k^{0.4704} \; t_p^{0.5695} \; R^{0.2476}}{(\log t)^{2.002} \; C_1^{0.9335} \; C_2^{0.2848}} \qquad \text{(Eq. 6.2.5-1)}$$

where:

RD = rut depth, inches
P_k = equivalent single-wheel load (ESWL), kips
t_p = tire pressure, psi
t = thickness of top layer, inches
R = repetitions of load or passes
C_1 = CBR of top layer
C_2 = CBR of bottom layer

Note that P_k is the equivalent single-wheel load (ESWL). As defined by Yoder and Witczak[1], an ESWL ". . .is the load on a single tire that will cause an equal magnitude of a preselected parameter (such as deflection, stress or strain) at a given location within a specific pavement system to that resulting from a multiple-wheel load at the same location within the pavement structure." The U.S. Army Corps of Engineers[2] has developed a series of curves to calculate the ESWL as a percentage of the axle load. For a single-axle dual-wheel load, the ESWL ranged from 31–53 percent of the total axle load, and for the tandem-axle dual-wheel load, it ranged from 17–35 percent. For a single-axle single-wheel (such as the steering axle of a truck) load, the range is 52–63 percent. The ranges are due to different aggregate thicknesses. For this *Surfacing Design Guide*, the appropriate factor for an aggregate thickness of 15 inches was used. Therefore, the single-axle, dual-wheel conversion factor is 48 percent, for the tandem-axle is 29 percent, and for the single-axle, single-wheel, it is 57 percent.

To calculate equivalency factors for the various loads and wheel configurations we will assume a typical surface structure, repetitions, and tire pressure, and determine the rut resulting from an 18k ESAL. Using this rut depth, the number of repetitions for other axle loads and wheel configurations is calculated for the same surface structure and tire pressure. The ratio of passes for the 18-kip to that for another load and wheel configuration then becomes the equivalency factor for other load and wheel configurations.

---

[1]Yoder and Witczah, op. cit.

[2]Chou, Y.T., "Design Criteria for Aggregate-Surfaced Roads and Airfields," *Technical Report* GL-89-5, U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, MS, 1989.

To calculate the rut depth for the standard axle (i.e. 18-kip ESAL) at a tire pressure of 80 psi, the following steps are performed:

1. Convert 18k ESAL to ESWL. For a single-axle dual-wheel load, the conversion factor is 0.48.

   Therefore, $ESWL_{18}$ = (18 kips) (48%)
   = 8.64 kips

2. Assume R = 10,000 passes of the 18-kip ESAL's.
3. Assume t = 4" of aggregate thickness.
4. Assume C_1 = 40 and C_2 = 10
5. Tire pressure = 80 psi
6. The rut depth for the standard vehicle is then calculated as:

$$RD18 = 0.1741 \left(\frac{P_k^{0.4704}\, t_p^{0.5695}\, (10{,}000)^{0.2476}}{(\log 4")^{2.002}\, (40)^{0.9335}\, (10)^{0.2848}} \right)$$

$$= 0.0780\, (P_k^{0.4704}\ t_p^{0.5695})$$

$$= 0.0780\, (\, (8.64 \text{ kips})^{0.4704}\, (80 \text{ psi})^{0.5695}\,)$$

$$RD_{18} = 2.61 \text{ inches}$$

Equivalency Factors: The following steps describe the calculation of the equivalency factor for another vehicle. As an example, assume a standard log truck, with two tandem axles and a steering axle. The tandem axle load is 35 kips, the steering axle is a single-wheel 10-kip single axle, and tire pressures are 100 psi.

1. First, obtain the ESWL's for both axles.

   $ESWL_{35}$ = (29%) (35 kips) = 10.15 kips
   $ESWL_{10}$ = (57%) (10 kips) = 5.70 kips

2. Now calculate the number of repetitions for each axle given a rut depth of 2.61 inches and using the same assumptions as before for t, C_1, and C_2. Using equation 6.2.5-1:

$$RD = 0.1741 \quad \frac{P_k^{0.4704}\ t_p^{0.5695}\ R^{0.2476}}{(\log t)^{2.002}\, C_1^{0.9335}\, C_2^{0.2848}} \qquad \text{(Eq. 6.2.5-1)}$$

Substituting:

$$2.61'' = \frac{0.1741\ (10.15\ \text{kips})^{0.4704}\ (100\ \text{psi})^{0.5695}\ R_{35}^{\ 0.2476}}{(\log 4)^{2.002}\ (40)^{0.9335}\ (10)^{0.2848}}$$

Solving for R_{35}: R_{35} = 4,418 ESAL's

Similarly for R_{10}: R_{10} = 13,223 ESAL's

3. The equivalency factor is the ratio of the number of repetitions of the standard axle to the number of repetitions of the actual axle.

   For the 35-kip tandem axle, the equivalency factor is:

$$EF_{35} = \frac{10{,}000}{4{,}418} = 2.26 \qquad \text{(See Figure 3.2-5)}$$

   For the 10-kip single axle, the equivalency factor is:

$$EF_{10} = \frac{10{,}000}{13{,}223} = 0.76 \qquad \text{(See Figure 3.2-5)}$$

   Therefore, the equivalency factor for the truck is:

$$EF_{truck} = EF_{35}\ (2\ \text{tandem axles}) + EF_{10}\ (1\ \text{steering axle})$$
$$= 2.26\ (2) + 0.76\ (1)$$
$$EF_{truck} = \underline{5.28}$$

Figures 3.2-1 through 3.2-5 in section 3.2 summarize equivalency factors for a variety of load and axle configurations as well as for tire pressures of 25, 50, 70, 80, and 100 psi, respectively. Note that there may be small differences in the equivalency factors. This is due to round-off errors. Figure 3.2-6 illustrates equivalency factors for triple axles on a flexible pavement with a P_t of 2.0. This figure is derived from the AASHTO Guide.

6.2.6 Reliability Factor Determination

AASHTO describes the concept of reliability as follows:

> "The reliability of a pavement design performance process is the probability that a pavement section designed using the process will perform satisfactorily over the traffic and environmental conditions for the design period."

The design algorithm used in this guide to predict rut depth is a deterministic model. It represents not necessarily the best fit of all the data,

but instead a "good fit" as indicated by the error and correlation values. The reliability of a facility can be determined in terms of the probability that a given rut depth will occur under given circumstances. It is a statistical measure of the probability that a pavement will perform in a given manner during its life. To address the concept of reliability in this *Surfacing Design Guide*, stochastic models were developed by Barber et al.[1] Much of this discussion is excerpted from their report. The expected value E(RD) and variance VRD models for the rut depth equation are shown in figure 6.2.6-1.

Determination of reliability: Each variable in the two models is used in terms of its respective mean and variance and in turn an expected value and variance of rut depth is determined. As previously stated, reliability as defined and used in this guide is the probability that the rut depth will not exceed some predetermined value subject to conditions that are expressed by the independent variables.

If the rut depth is normally distributed, the reliability statistic P used to determine the reliability R that the rut depth will not exceed some maximum value RD_A can be expressed by:

$$P = \frac{RD_A - E(RD)}{\sqrt{V(RD)}} \qquad \text{(Eq. 6.2.6-1)}$$

where:

E(RD) = expected value of the rut depth
V(RD) = variance of the rut depth

Figure 6.2.6-2 illustrates a standard normal distribution curve and the parameters utilized to compute the reliability statistic P. In order to determine reliability R from Figure 6.2.6-3 or, that is, the area under the distribution curve defined by E(RD) and V(RD) and to the left of maximum rut depth RD_A, enter the table with the value of P determined previously and read the area under the distribution curve that is the reliability. As an example, assume the following values:

RD_A = 3 in
E(RD) = 2 in.
V(RD) = 1 in.

then

$$P = \frac{RD_A - E(RD)}{\sqrt{V(RD)}} = \frac{3 - 2}{1} = \frac{1}{1} = 1$$

[1] Barber, V.V., E.C. Odom, and R. W. Patrick, "The Deterioration and Reliability of Pavements," *Technical Report* S-78-8, U.S. Army Engineers Waterways Experiement Station, Vicksburg, MS, July 1978.

If figure 6.2.6-3 is entered with a value of 1 in the left-hand column, interpolation is not necessary. It can be seen immediately that R = 0.8413, which means that there is a probability of 0.8413 that the rut depth will not exceed a predetermined maximum value of 3 inches. Figure 6.2.6-3 is typical of similar tables found in most statistics textbooks.

Figure 6.2.6-4 summarizes the reliability levels (%) obtained for different traffic levels and aggregate thicknesses. The variables used to obtain these numbers are shown in the bottom portion of figure 6.2.6-4. Note that the standard deviation used for tire pressure and material CBR's was 10 percent. The variance is the square of the standard deviation.

The results are graphically shown in figure 6.2.6-5, where the reliability levels are plotted against traffic for aggregate thicknesses of 6, 8, and 10 inches. From this, it may be determined that the allowable traffic at a reliability level of 50 percent is approximately twice that at 90 percent. In short, the reliability factor (F_R) to be used in a design for a 90 percent level is approximately 2. Figure 6.2.6-6 summarizes the reliability factors obtained for different thicknesses.

For design, the most conservative factors were selected (i.e. for t = 4") and these are the results shown in section 3.3.4.

$$RD = \frac{0.1741\ P_K^{0.4707}\ t_P^{0.5695}\ R^{0.2476}}{(\log t)^{2.002}\ C_1^{0.9335}\ C_2^{0.2848}} = Q \text{ in the following equations.}$$

$$E[RD] = Q\left\{1 + 0.5\left(\frac{0.8695}{\mu_t^2 \log \mu_t}\left\{\frac{1.3038}{\log \mu_t} + 1\right\}\sigma_t^2 - \frac{0.2491\sigma_{PK}^2}{\mu_{PK}^2} - \frac{0.2452\sigma_{tp}^2}{\mu_{tp}^2} - \frac{0.1863\sigma_R^2}{\mu_R^2} + \frac{1.8049\sigma_{C1}^2}{\mu_{C1}^2} + \frac{0.3659\sigma_{C2}^2}{\mu_{C2}^2}\right)\right\}$$

$$V[RD] = Q^2\left\{\left(\frac{0.4707\sigma_{Pk}}{\mu_{Pk}}\right)^2 + \left(\frac{0.5695\sigma_{tp}}{\mu_{tp}}\right)^2 + \left(\frac{0.2476\sigma_R}{\mu_R}\right)^2 + \left(\frac{-0.8695\sigma_t}{\mu_t \log \mu_t}\right)^2 + \left(\frac{-0.9335\sigma_{C1}}{\mu_{C1}}\right)^2 + \left(\frac{-0.2848\sigma_{C2}}{\mu_{C2}}\right)^2\right\}$$

$$- 0.25\ Q^2\left\{\left[\frac{0.8695}{\mu_t^2 \log \mu_t}\left(\frac{1.3038}{\log \mu_t} + 1\right)\sigma_t^2\right]^2 + \left[\frac{-0.2491}{\mu_P^2}\sigma_P^2\right]^2 + \left[\frac{-0.2452}{\mu_{tp}^2}\sigma_{tp}^2\right]^2 + \left[\frac{-0.1863}{\mu_R^2}\sigma_R^2\right]^2 + \left[\frac{1.8049}{\mu_{C1}^2}\sigma_{C1}^2\right]^2 + \left[\frac{0.3659}{\mu_{C2}^2}\sigma_{C2}^2\right]^2\right\}$$

Figure 6.2.6-1.—Gravel surfaced facility expected value variance, and rutting models.

where:

μ_1 = mean or average of variable i.
σ_1 = standard deviation of variable i.
σ_i^2 = variance of variable i.
i = t (aggregate thickness).
t_p = tire pressure.
p_k = ESWL
R = number of repetitions.
C_1 = aggregate CBR.
C_2 = subrade CBR.
E(RD) = expected value of the rut depth.
V(RD) = variance of the rut depth.

Figure 6.2.6-1.—Gravel surfaced facility expected value variance, and rutting models (cont'd.).

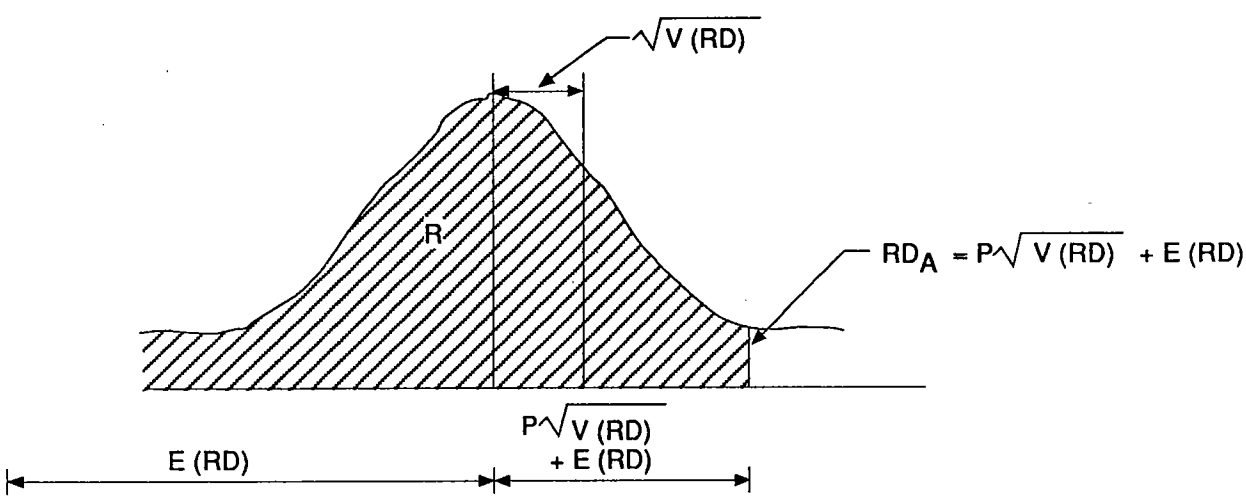


Figure 6.2.6-2.—Standard normal distribution curve illustrating E(RD), $\sqrt{V(RD)}$, and RD_A.

P	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	0.5000	0.5040	0.5080	0.5120	0.5160	0.5199	0.5239	0.5279	0.5319	0.5359
0.1	0.5398	0.5438	0.5478	0.5517	0.5557	0.5596	0.5636	0.5675	0.5714	0.5753
0.2	0.5793	0.5832	0.5871	0.5910	0.5948	0.5987	0.6026	0.6064	0.6103	0.6141
0.3	0.6179	0.6217	0.6255	0.6293	0.6331	0.6368	0.6406	0.6443	0.6480	0.6517
0.4	0.6554	0.6591	0.6628	0.6664	0.6700	0.6736	0.6772	0.6808	0.6844	0.6879
0.5	0.6915	0.6950	0.6985	0.7019	0.7054	0.7088	0.7123	0.7157	0.7190	0.7224
0.6	0.7257	0.7291	0.7324	0.7357	0.7389	0.7422	0.7454	0.7486	0.7517	0.7549
0.7	0.7580	0.7611	0.7642	0.7673	0.7704	0.7734	0.7764	0.7794	0.7823	0.7852
0.8	0.7881	0.7910	0.7939	0.7967	0.7995	0.8023	0.8051	0.8078	0.8106	0.8133
0.9	0.8159	0.8186	0.8212	0.8238	0.8264	0.8289	0.8315	0.8340	0.8365	0.8389
1.0	0.8413	0.8438	0.8461	0.8485	0.8508	0.8531	0.8554	0.8577	0.8599	0.8621
1.1	0.8643	0.8665	0.8686	0.8708	0.8729	0.8749	0.8770	0.8790	0.8810	0.8830
1.2	0.8849	0.8869	0.8888	0.8907	0.8925	0.8944	0.8962	0.8980	0.8997	0.9015
1.3	0.9032	0.9049	0.9066	0.9082	0.9099	0.9115	0.9131	0.9147	0.9162	0.9177
1.4	0.9192	0.9207	0.9222	0.9236	0.9251	0.9265	0.9279	0.9292	0.9306	0.9319
1.5	0.9332	0.9345	0.9357	0.9370	0.9382	0.9394	0.9406	0.9418	0.9429	0.9441
1.6	0.9452	0.9463	0.9474	0.9484	0.9495	0.9505	0.9515	0.9525	0.9535	0.9545
1.7	0.9554	0.9564	0.9573	0.9582	0.9591	0.9599	0.9608	0.9616	0.9625	0.9633
1.8	0.9641	0.9649	0.9656	0.9664	0.9671	0.9678	0.9686	0.9693	0.9699	0.9706
1.9	0.9713	0.9719	0.9726	0.9732	0.9738	0.9744	0.9750	0.9756	0.9761	0.9767
2.0	0.9772	0.9778	0.9783	0.9788	0.9793	0.9798	0.9803	0.9808	0.9812	0.9817
2.1	0.9821	0.9826	0.9830	0.9834	0.9838	0.9842	0.9846	0.9850	0.9854	0.9857
2.2	0.9861	0.9864	0.9868	0.9871	0.9875	0.9878	0.9881	0.9884	0.9887	0.9890
2.3	0.9893	0.9896	0.9898	0.9901	0.9904	0.9906	0.9909	0.9911	0.9913	0.9916
2.4	0.9918	0.9920	0.9922	0.9925	0.9927	0.9929	0.9931	0.9932	0.9934	0.9936
2.5	0.9938	0.9940	0.9941	0.9943	0.9945	0.9946	0.9948	0.9949	0.9951	0.9952
2.6	0.9953	0.9955	0.9956	0.9957	0.9959	0.9960	0.9961	0.9962	0.9963	0.9964
2.7	0.9965	0.9966	0.9967	0.9968	0.9969	0.9970	0.9971	0.9972	0.9973	0.9974
2.8	0.9974	0.9975	0.9976	0.9977	0.9977	0.9978	0.9979	0.9979	0.9980	0.9981
2.9	0.9981	0.9982	0.9982	0.9983	0.9984	0.9984	0.9985	0.9985	0.9986	0.9986
3.0	0.9987	0.9987	0.9987	0.9988	0.9988	0.9989	0.9989	0.9989	0.9990	0.9990
3.1	0.9990	0.9991	0.9991	0.9991	0.9992	0.9992	0.9992	0.9992	0.9993	0.9993
3.2	0.9993	0.9993	0.9994	0.9994	0.9994	0.9994	0.9994	0.9995	0.9995	0.9995
3.3	0.9995	0.9995	0.9995	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996	0.9997
3.4	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9998

Figure 6.2.6-3.—Normal distribution function F(P) = R.

Traffic (ESAL)	Reliability Levels (%)			
	t=4"	t=6"	t-8"	t=10"
8,150	11.24	97.70	99.99	99.99
16,300	2.88	75.36	99.96	99.99
32,600	0.66	33.94	96.06	99.99
65,200	0.15	8.95	66.42	98.32
97,800	0.07	3.45	39.90	89.62
130,400	0.04	1.67	24.26	75.68
163,000	0.02	0.93	15.39	61.18
195,600	0.02	0.58	10.17	48.72
228,200	0.01	0.38	7.02	38.51
260,800	0.01	0.27	5.01	30.57
293,400	0.01	0.19	3.67	24.45
326,000	0.01	0.15	2.77	19.66
489,000	0.01	0.05	0.88	7.55
652,000	0.01	0.02	0.38	3.48
978,000	0.01	0.01	0.11	1.06
1,304,000	0.01	0.01	0.05	0.43
1,630,000	0.01	0.01	0.02	0.21
2,445,000	0.01	0.01	0.01	0.06
3,260,000	0.01	0.01	0.01	0.02

Variables	Mean	Standard Deviation	Variance
Pk(18-kip)	8.64	0.5	0.25 kips
Tire pressure	80	8	64 psi
Agg. CBR, C1	40	4	16%
Subgrade CBR, C2	10	1	1%
Allow. Rut Depth	2 inches		

Figure 6.2.6-4.—Reliability levels for different aggregate thicknesses.

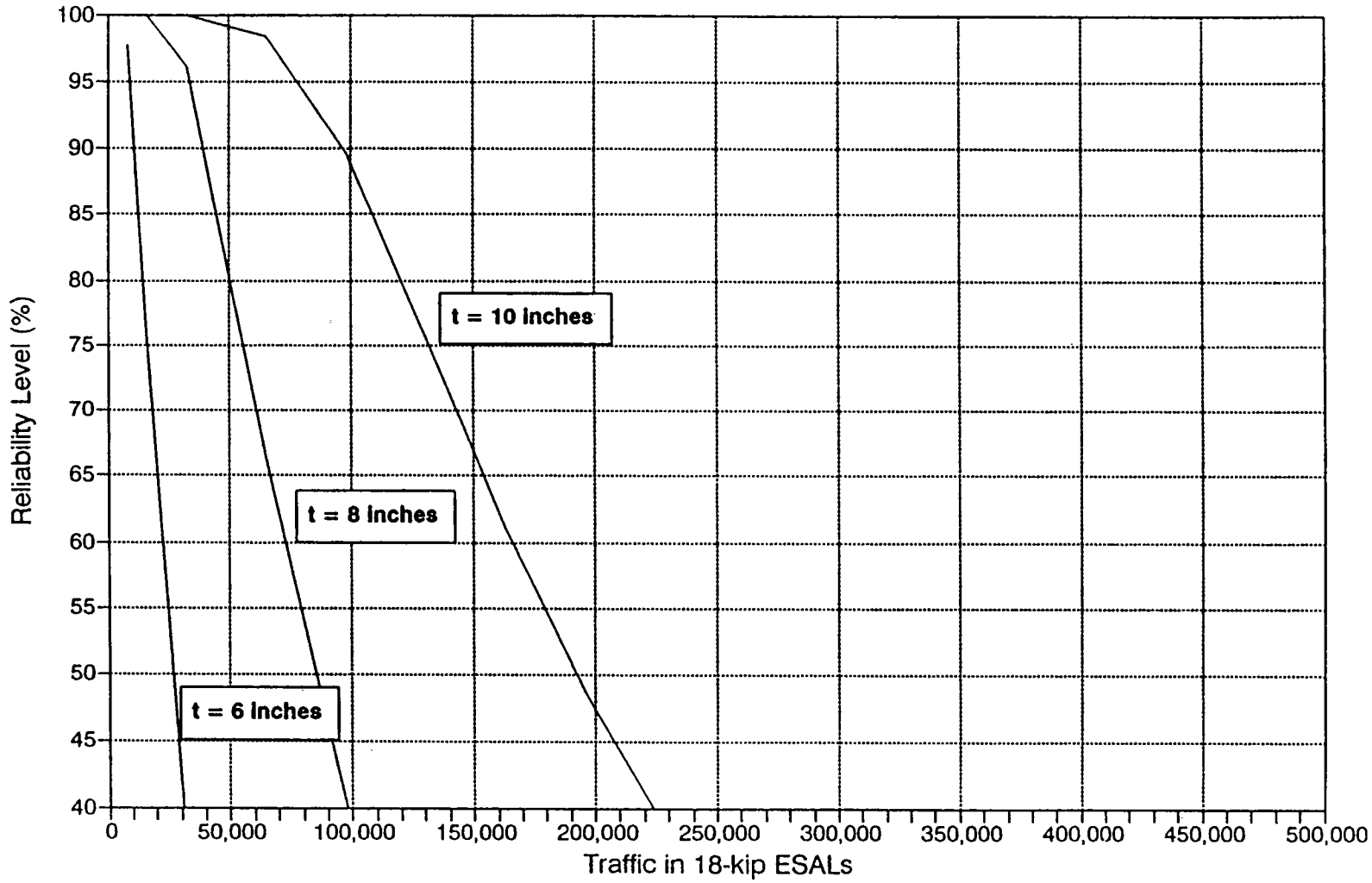


Figure 6.2.6-5.—Reliability level vs. traffic.

Reliability Level %	F_R for different thicknesses t=4"	t=6"	t=8"	t=10"
50	1.0	1.0	1.0	1.0
70	1.44	1.38	1.36	1.34
90	2.23	2.11	2.03	1.98

Figure 6.2.6-6.—Reliability factors for design.

6.3 General Material Characteristics

Typically a pavement structure is ". . . a combination of subbase, base course and surface course placed on a subgrade to support the traffic load and distribute it to the roadbed." In a flexible pavement, the surface course is generally asphalt concrete. However, for aggregate-surfaced roads and earth roads, the surface course is aggregate or in-place road-bed soil, respectively. Figure 6.3-1 illustrates the differences between a conventional asphalt concrete pavement, aggregate-surfaced, and earth-surfaced roads.

Since this *Surfacing Design Guide* addresses only earth or aggregate-surfaced roads, there are two material types that need to be considered in the use of this guide. They include the native subgrade materials and the aggregate materials that comprise the unbound layer placed upon the subgrade. These materials may be soil or rock, but often will be a combination. Definitions vary for soil and rock and are addressed below. Various rock types are discussed in the aggregate section and may be relative when reviewing subgrade material.

6.3.1 Subgrade

Generally subgrade soils are categorized into one of the following types:

- fine-grained (silt & clay size) soils;
- coarse-grained (sand size or larger) soils;
- organic soils; and
- mixture of any of the above materials.

Of these soils, silt and clay have the smaller particles. Together they are termed "fines" since they have particles barely visible to the naked eye. The sizes of soil particles are measured by the size of the sieve mesh opening upon which the particles are retained. This defines the sands and gravels from the fine-grained sizes. An example of the particle sizes and resulting gradations are shown in figure 6.3-2.

- Fine-grained soils. Clay soils tend to be hard when dry and soft when wet. They will shrink and swell as the water content changes. They also feel greasy when wet. Silt has a soft flour-like feel when dry and very little stability when saturated. Because the individual particles are not normally visible to the unaided eye, silt is often incorrectly classified as clay. The silt differs by its lack of plastic (putty-like) properties. Figure 6.3-3 describes field tests for classification of fine-grained soils based on their dilatancy, dry strength, and toughness or plasticity.

- Coarse-grained soils. Coarse-grained soils have a majority of sand or gravel size material. Silt and clay size particles can be present as well.

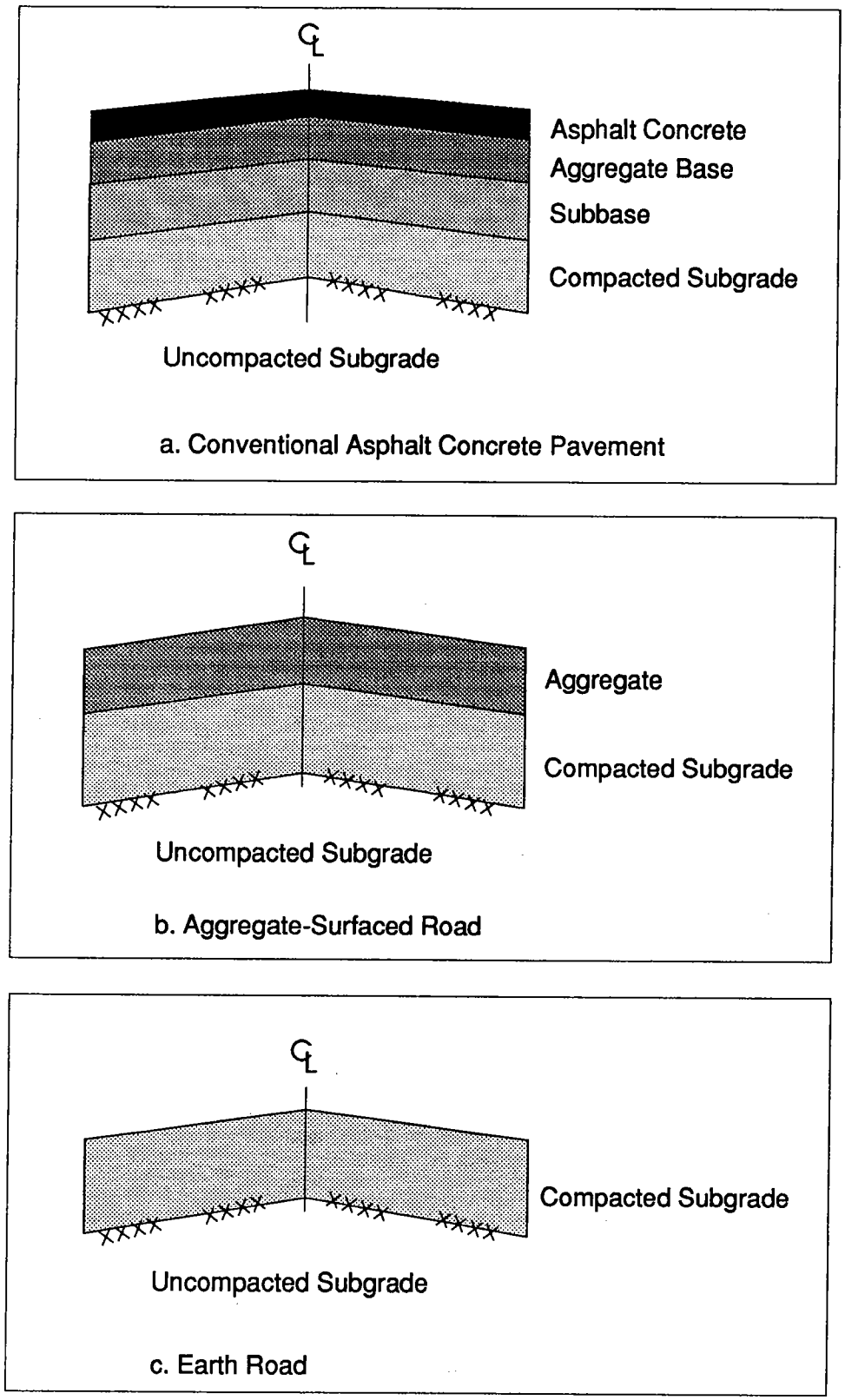
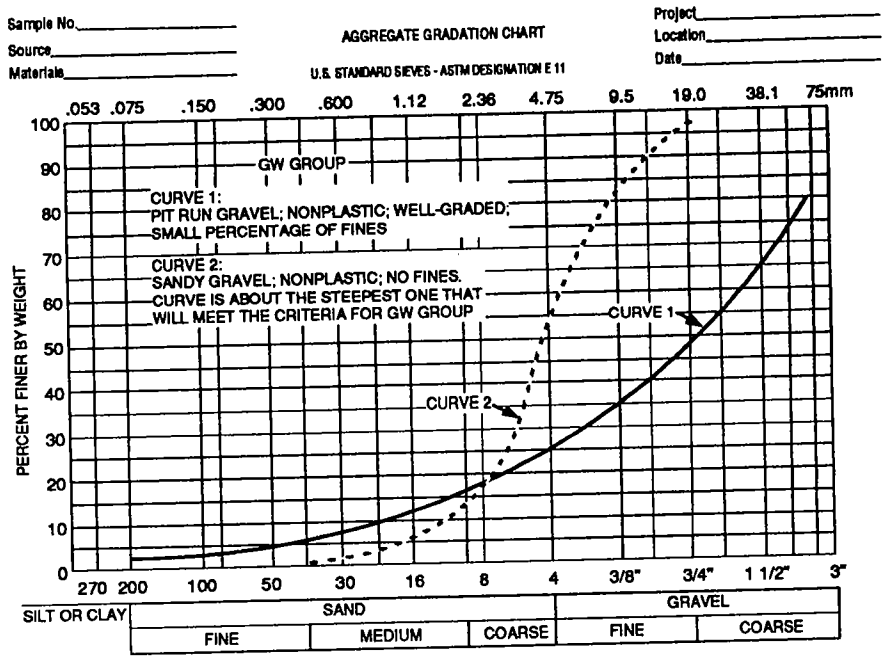
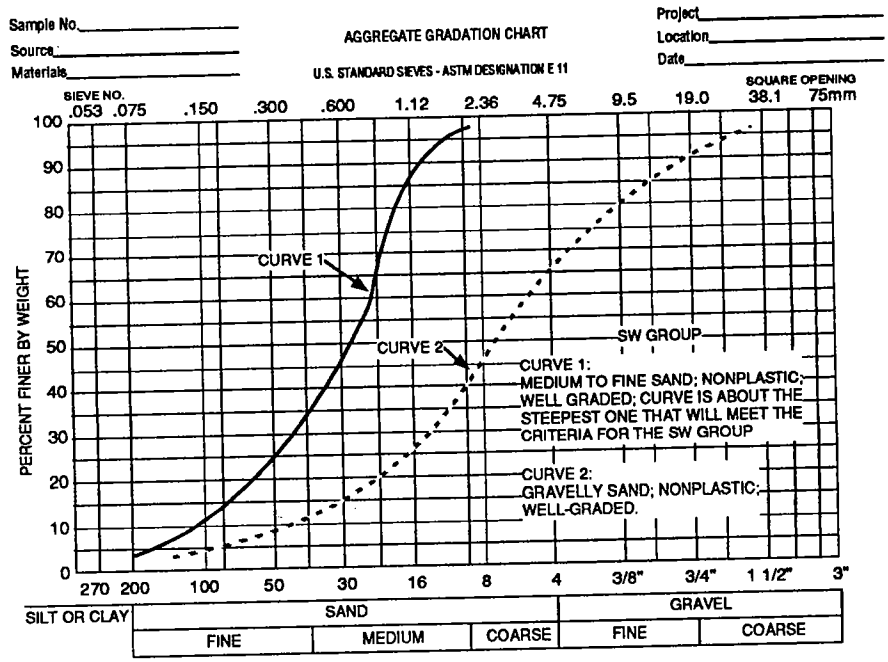


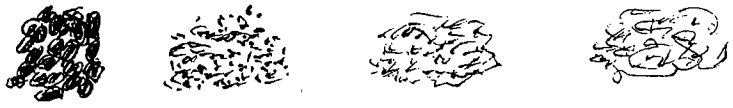
Figure 6.3-1.—Typical cross-sections of different surface types.



Typical example of GW soil



Typical example of SW soil



GRAVEL COARSE SAND MEDIUM SAND FINE SOIL SILT CLAY AND COARSE

Figure 6.3-2.—Grain size curve.

These procedures are to be performed on the minus No. 40 sieve size particles, approximately $\frac{1}{64}$ in. For field classification purposes, screening is not intended; simply remove by hand the coarse particles that interfere with the tests.

Dilatancy (Reaction to shaking)

After removing particles larger than No. 40 sieve size, prepare a pat of moist soil with a volume of about one-half cubic inch. Add enough water if necessary to make the soil soft but not sticky.

Place the pat in the open palm of one hand and shake horizontally, striking vigorously against the other hand several times. A positive reaction consists of the appearance of water on the surface of the pat which changes to a livery consistency and becomes glossy. When the sample is squeezed between the fingers, the water and gloss disappear from the surface, the pat stiffens, and finally it cracks or crumbles. The rapidity of appearance of water during shaking and of its disappearance during squeezing assist in identifying the character of the fines in a soil.

Very fine clean sands give the quickest and most distinct reaction whereas a plastic clay has no reaction. Inorganic silts, such as a typical rock flour, show a moderately quick reaction.

Dry Strength (Crushing characteristics)

After removing particles larger than No. 40 sieve size, mold a pat of soil to the consistency of putty, adding water if necessary. Allow the pat to dry completely by oven, sun, or air drying, and then test its strength by breaking and crumbling between the fingers. This strength is a measure of the character and quantity of the colloidal fraction contained in the soil. The dry strength increases with increasing plasticity.

High dry strength is characteristic for clays of the CH group. A typical inorganic silt possesses only very slight dry strength. Silty fine sands and silts have about the same slight dry strength, but can be distinguished by the feel when powdering the dried specimen. Fine sand feels gritty whereas a typical silt has the smooth feel of flour.

Toughness (Consistency near plastic limit)

After removing particles larger than No. 40 sieve size, a specimen of soil about one-half inch cube in size is molded to the consistency of putty. If too dry, water must be added and if sticky, the specimen should be spread out in a thin layer and allowed to lose some moisture by evaporation. Then the specimen is rolled out by hand on a smooth surface or between the palms into a thread about one-eighth inch in diameter. The thread is then folded and rerolled repeatedly. During this manipulation the moisture content is gradually reduced and the specimen stiffens, finally loses its plasticity, and crumbles when the plastic limit is reached.

After the thread crumbles, the pieces should be lumped together and a slight kneading action continued until the lump crumbles.

The tougher the thread near the plastic limit and the stiffer the lump when it finally crumbles, the more potent is the colloidal clay fraction in the soil. Weakness of the thread at the plastic limit and quick loss of coherence of the lump below the plastic limit indicate either inorganic clay of low plasticity, or materials such as Kaolin-type clays and organic clays which occur below the A-line.

Highly organic clays have a very weak and spongy feel at the plastic limit.

Source: *Earth Manual*, U.S. Department of the Interior, Bureau of Reclamation, 2nd Ed., 1974.

Figure 6.3-3.—Field identification procedures for fine-grained soils or fractions.

Actual soils used on a project will not normally be 100 percent of any one size but will be a mix. Terms such as "silty gravel" or "sandy clay" are used to describe mixed soils. Some general properties associated with different soil types are shown in figure 6.3-4 and figure 6.3-5. Mixed soil commonly takes on the characteristics of the major size fraction unless there is close to 25 percent fines in the soil; it then leans toward the fine-grained characteristics.

Several systems are available to classify soil materials. Most are based on particle size and plasticity of the material. This allows one to predict compaction, settlement, drainage, frost susceptibility, and excavation and embankment characteristics of the material. One of the most common classification schemes is the Unified Soil Classification System. A flowchart for this classification system is shown in figure 6.3-6. It may help the road designer make an initial classification of the subgrade material. Figure 6.3-7 provides additional information about the characteristics of different soils as classified under the Unified Soil Classification System.

Another popular classification system is the American Association of State Highway and Transportation Officials (AASHTO) method shown in figure 6.3-8. Both systems are used for classification of subgrade materials.

6.3.2 Aggregates

Aggregates commonly refer to natural or manufactured granular mineral material used in construction. They may include unprocessed material (pit-run) or processed material (screened, grid rolled, or crushed). Aggregates can be classified as a coarse-grained soil. The aggregate characteristics that are important to its use depend on its intended purpose. Aggregates in pavement structures are typically used for either the base course or the surface course. Their use then defines the type of aggregate. Ideally:

- Base course: Granular material with angular particles; well-graded with 0–10 percent fines (open-graded); high permeability; no swelling; well-compacted; durable (function is to support traffic by distributing the wheel load to the subgrade).

- Surface course: Granular materials; well-graded with 7–12 percent plastic fines, or 8–15 percent non-plastic fines to act as a binder (dense-graded); well-compacted; durable (function is to seal the surface from water infiltration and provided a smooth driving surface).

A granular, well-graded material which is well-compacted and has a high degree of angularity yields a product that is most resistant to deformation (has high strength). Dense-graded implies that the aggregate includes the full range of particle sizes, from very fine to coarse, allowing a high density. Durability of the material depends largely on the origin of the particular aggregate particles.

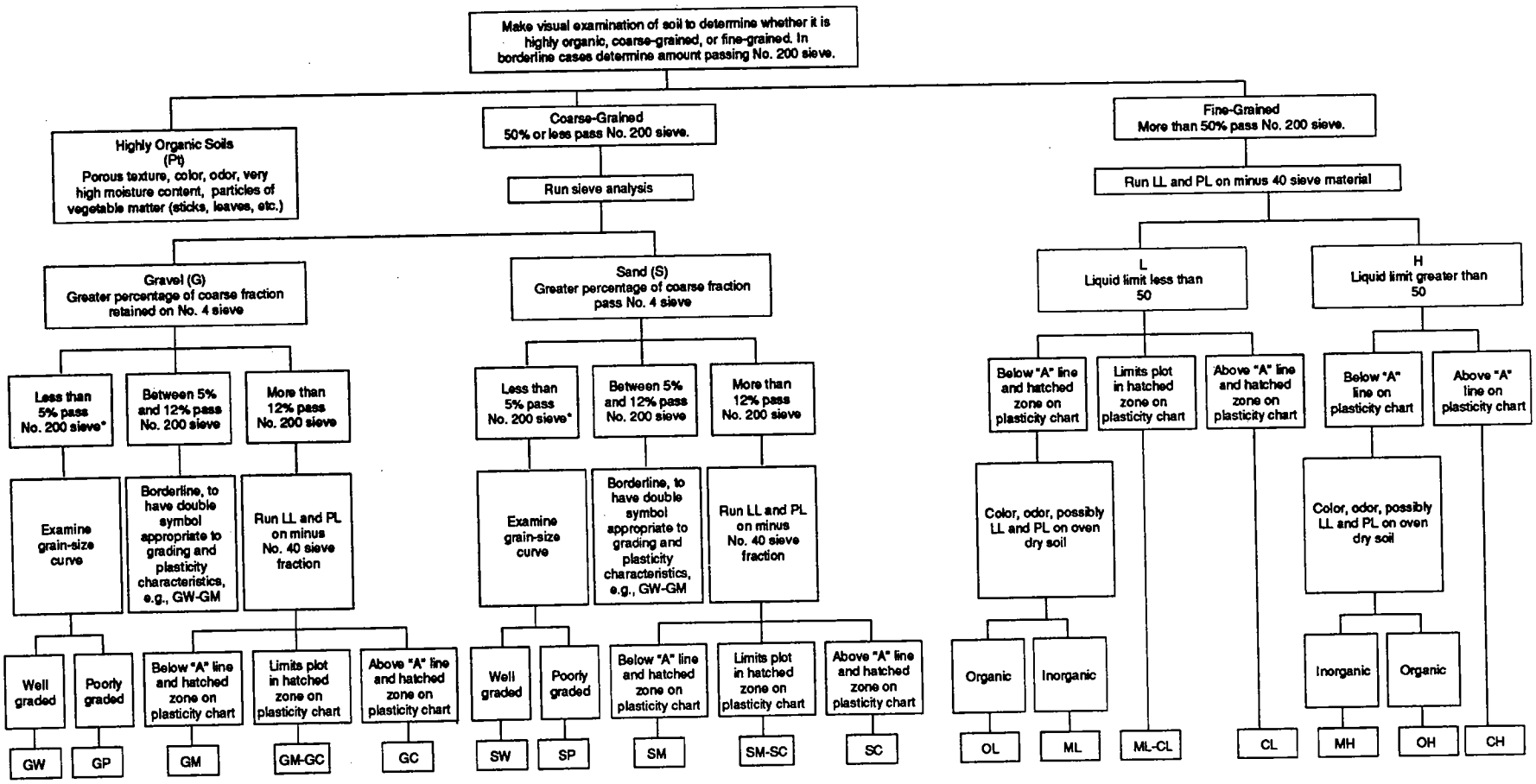
Property	Coarse-grained soils	Fine-grained (or plastic) soils	Organic soils
Volume change with changes in water content	Little or none	Little to great shrinkage with drying, swell with wetting; may exert high swell pressure	Shrinks with drying; swells, but not with high swell pressure
Load-sustaining power	High, especially when confined or when containing fines	Low with soft or sensitive clay to high with firm or stiff clay	Low
Compression under static load	Little	High with soft clay to low with stiff or firm clay	Very high and difficult to control
Workability during prolonged wet periods	Good	Poor	Fair to poor
Ease of drainage	Easily drained	Difficult to drain	Often difficult to drain
Compactibility	Compacts to high density, especially with vibratory loads	Difficult to compact high density except under favorable conditions	Very difficult to compact; spongy

Figure 6.3-4.—Properties associated with major soil types.

USCS	Subgrade	Use		Compaction
		Subbase	Base	
GP	Good to excellent	Good	Fair to good	Good
GW	Excellent	Excellent	Good	Good
GM	Good to excellent	Good	Fair to good	Good
GC	Good	Fair	Very poor to poor	Fair
SW	Good	Fair to good	Poor	Good
SP & SM	Fair to good	Fair to good	Very poor to poor	Good
SC	Poor to fair	Poor	NS	Fair
ML	Poor to Fair	NS	NS	Fair
MH	Poor	NS	NS	Very poor to poor
CL	Poor to fair	NS	NS	Fair to good
CH	Poor to fair	NS	NS	Poor to fair

Note: USCS = Unified Soil Classification System
NS = Not Suitable

Figure 6.3-5.—Selected engineering performance characteristics of Unified Soil Classification System groups.



Note: Sieve sizes are U.S. Standard.
* % fines interfere with free-draining properties use double symbol such as GW-GM, etc.
Source: Federal Aviation Administration, "Airport Pavement Design and Evaluation", FAA Advisory Circular 150/5320-6C, 1978

Figure 6.3-6.—Flowchart for Unified Soil Classification System.

UNIFIED SOIL CLASSIFICATION
INCLUDING IDENTIFICATION AND DESCRIPTION

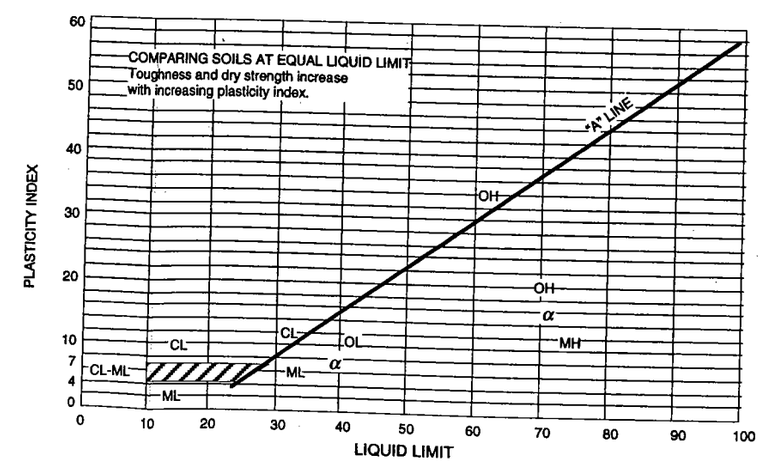
Field Identification Procedures (Excluding particles larger than 3 in. and basing fractions on estimated weights)				Group Symbol	Typical Names	Information Required for Describing Soils
COARSE-GRAINED SOILS More than half of material is larger than No. 200 sieve size (The No. 200 sieve size is about the smallest particle visible to the naked eye)	GRAVELS More than half of coarse traction is larger than No. 4 sieve size (For visual classification, the 1/2" size may be used as equivalent to the No. 4 sieve size)	CLEAN GRAVELS (Little or no fines)	Wide range in grain size and substantial amounts of all intermediate particle sizes	GW	Well-graded gravel, gravel-sand mixtures, little or no fines	Give typical name, indicate approximate percentages of sand and gravel, mdx size, angularity, surface condition, and hardness of the coarse grains, local or geologic name, and other pertinent descriptive information, and symbol in parentheses. For undisturbed soils add information on stratification, degree of compactness, cementation, moisture conditions and drainage characteristics. EXAMPLE: Silty sand, gravelly; about 20% hard, angular gravel particles 1/2 in. maximum size, rounded and subangular sand grains coarse to fine; about 15% non-plastic fines with low dry strength; well compacted and moist in place, alluvial sand; (SM)
			Predominantly one size or a range of sizes with some intermediate sizes missing	GP	Poorly graded gravels, gravel-sand mixtures, little or no fines	
		GRAVELS WITH FINES (Appreciable amount of fines)	Non-plastic fines (for identification procedures see ML below)	GM	Silty gravel, poorly graded gravel-sand-silt mixtures	
			Plastic fines (for identification procedures see CL below)	GC	Clayey gravels, poorly graded gravel-sand-clay mixtures	
	SANDS More than half of coarse traction is smaller than No. 4 sieve size	CLEAN SANDS (Little or no fines)	Wide range in grain size and substantial amounts of all intermediate particle sizes	SW	Well-graded sands, gravelly sands, little or no fines	
			Predominantly one size or a range of sizes with some intermediate sizes missing	SP	Poorly graded sands; gravelly-sandslittle or no fines.	
		SANDS WITH FINES (Appreciable amount of fines)	Non-plastic fines (for identification procedures see ML below)	SM	Silty sands, poorly graded sand-silt mixture.	
			Plastic fines (for identification procedures see CL below)	SC	Clayey sands, poorly graded sand-clay mixtures.	
Identification Procedures on Fraction Smaller than No. 40 Sieve Size						
FINE-GRAINED SOILS More than half of material is smaller than No. 200 sieve size (The No. 200 sieve size is about the smallest particle visible to the naked eye)	SILTS AND CLAYS Liquid limit less than 50	Dry Strength (Crushing Characteristics)	Dilatancy (Reaction to Shaking) / Toughness (Consistancy near Plastic Limit)			Give typical name, indicate degree and character of plasticity, amount and maximum size of coarse grains, color in wet condition, odor if any, local or geologic name, and other pertinent descriptive information, and symbol in parentheses. For undisturbed soils add information on structure, stratification, consistency in undisturbed and remolded states, moisture and drainage conditions. EXAMPLE: Clayey silt, brown, slightly plastic, small percentage of fine sand; numerous vertical root holes; firm and dry in place; loess; (ML)
		None to slight	Quick to slow / None	ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands with slight plasticity	
		Medium to high	None to very slow / Medium	CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays	
		Slight to medium	Slow / Slight	OL	Organic silts and organic silt-clays of low plasticity	
	SILTS AND CLAYS Liquid limit greater than 50	Slight to medium	Slow to none / Slight to medium	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts	
		High to very high	None / High	CH	Inorganic clays of high plasticity, fat clays	
		Medium to high	None to very slow / Slight to medium	CH	Organic clays of medium to high plasticity	
HIGHLY ORGANIC SOILS		Readily identified by color, odor, spongy feel and frequently by fibrous texture		PT	Peat and other highly organic soils	

Use grain curve in identifying the fractions as given under field identification

Laboratory Classification Criteria

Determine percentages of gravel and sand from grain size curve. Depending on percentage of fines (fraction smaller than No 200 sieve size) coarse-grained soils are classified as follows:
Less than 5% GW, GP, SW, SP
More than 12% GM, GC, SM, SC
5% to 12% Borderline cases requring use of dual symbols

$Cu = \frac{D_{60}}{D_{10}}$ Greater than 4; $Cu = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between 1 and 3	
Not meeting all gradation requirements for GW	
Atterberg limits below "A" line or PI less than 4	Above "A" line with PI between 4 and 7 are borderline cases requiring use of dual symbols.
Atterberg limits above "A" line of PI greater than 7	
$Cu = \frac{D_{60}}{D_{10}}$ Greater than 6; $Cu = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between 1 and 3	
Not meeting all gradation requirements for SW	
Atterberg limits below "A" line or PI less than 4	Above "A" line with PI between 4 and 7 are borderline cases requiring use of dual symbols.
Atterberg limits above "A" line with PI greater than 7	



PLASTICITY CHART
FOR LABORATORY CLASSIFICATION OF FINE GRAINED SOILS

Boundary classifications: - Soil possessing characteristics of two groups are designated by combinations of group symbols. For example GW - GC, well graded gravel-sand mixture with clay binder.
All sieve sizes on this chart are U.S. standard

Source: *Earth Manual*, U.S. Department of the Interior, Bureau of Reclaimation, 2nd Edition, 1974

Figure 6.3-7.—Unified Soil Classification System Chart.

AASHTO (AASHO) Soil Classification Chart

General Classification	Granular Materials (35% or less passing No. 200)							Silt-Clay Materials (More than 35% passing No. 200)			
	A-1		A-3	A-2				A-4	A-5	A-6	A-7
Group Classification	A-1-a	A-1-b		A-2-4	A-2-5	A-2-6	A-2-7				A-7-5;A-7-6
Sieve analysis:											
Percent passing:											
No. 10	50 max.	—	—	—	—	—	—	—	—	—	—
No. 40	30 max.	50 max.	51 min.	—	—	—	—	—	—	—	—
No. 200	15 max.	25 max.	10 max.	35 max.	35 max.	35 max.	35 max.	36 max.	36 min.	36 min.	36 min.
Characteristics of fraction passing No. 40:											
Liquid limit	—		—	40 max.	41 min.	40 max.	41 min.	40 max.	41 min.	40 max.	41 min.
Plasticity index	6 max.		N.P.[a]	10 max.	10 max.	11 min.	11 min.	10 max.	10 max.	11 min.	11 min.[b]
Group index	0		0	0		4 max.		8 max.	12 max.	16 max.	20 max.
Usual types of significant constituent materials	Stone fragments gravel and sand		Fine sand	Silty or clayey gravel and sand				Silty soils		Clayey soils	
General rating as subgrade	Excellent to good					Fair to poor					

[a] N.P. = not plastic
[b] Plasticity index of A-7-5 subgroup is equal to or less than LL minus 30. Plasticity index of A-7-6 subgroup is greater than LL minus 30.
Source: AASHTO, 1961.

Figure 6.3-8.—AASHTO Soil Classification Chart.

Various rock classification systems exist which are used in determining the applicability of a material for use as an aggregate (11). Figure 6.3.9 lists various rock types (origins) and some of their construction and durability characteristics. Figure 6.3-10 denotes one rock classification based on strength and weathering. Knowledge of the regional geologic history will be useful when determining the characteristics of a rock material. For example: (1) igneous and metamorphic rocks probably will correspond more to their typical engineering properties than sedimentary rocks; (2) nonfoliation of metamorphic rocks generally indicates high strength; and (3) shale typically is an unsound material; it tends to break down through each wet/dry cycle. Experience is always most helpful in determining crushing, disintegration, and performance characteristics of an aggregate.

Binding in the surface course is normally provided by a combination of the clay particles and a well-graded aggregate with good frictional characteristics. The capacity to resist wear and tear of traffic on the surface has been shown to be a large extent represented by the binding capability of the surface material (12).

The clay constituent provides the necessary cohesion to hold the surface together. Since the cohesion varies with the moisture content, the clay can be depended upon for the "cementing action" only when the moisture content is within a certain desirable range. During extended dry periods there is not sufficient moisture to develop the cohesion required to prevent surface abrasion, resulting in loss of material and causing dust. Dust abatement applications help prevent drying and loss of moisture. Conditions in wet weather may be just as unsatisfactory because of excessive moisture. Under these conditions, the cohesion of the clay fraction may completely vanish. The clay then becomes a lubricant instead of a binder.

Well-graded aggregate provides a dense matrix that resists the shear and compressive forces applied by traffic, especially on increasing grades and sharper horizontal alignments. Gradations that match the following equation (known as the Talbot or maximum density equation) provide that dense matrix.

$$P = (d/D)^n (100) \qquad \text{(Eq. 6.3-1)}$$

where:

- P = Percent passing sieve size "d" expressed in inches
- d = sieve size opening expressed in inches for which the percent passing (P) is applicable
- D = maximum aggregate size in inches
- n = an empirical gradation exponent generally taken to be 1/3 to 1/2 for well-graded materials, frequently 0.45 is used

Some rock sources have difficulty producing the above gradation, so either sand, silt, or clay is blended with the crushed aggregate or the normal crushing operations are modified to include the use of an impact crusher to meet it.

Rock	Excavation method	Fragmentation	Deterioration
Granite, diorite	Explosives	Irregular fragments, depending on blasting pattern.	Likely to be resistant.
Basalt	Explosives	Irregular fragments depending on joints.	Likely to be resistant.
Tuff	Machines* to explosives	Irregular, often with excessive fines.	Many forms deteriorate rapidly.
Sandstone, conglomerate	Explosives; machines if weathered, thin-bedded	Slabby to irregular, depending on bedding. Excess fines, depending on cementing.	Depends on character of cementing. Some deteriorate into silty sand.
Mudstone, siltstone, shale	Machines*	Small blocks to thin slabs and chips.	Many slake or break down rapidly into clay, accompanied by consolidation and loss of strength: should be considered suspect unless tests show otherwise.
Limestone: massive	Explosives	Irregular fragments, sometimes slabby.	Shaley seams deteriorate, otherwise resistant except to acids.
Coquina, chalk	Machines*	Porous fragments, excess fines common.	Some porous forms soften on wetting, others become partially cemented with alternate wetting and drying.
Quartzite	Explosives	Irregular, very angular.	Likely to be resistant.
Slate and schist	Explosives	Irregular, slabby to flaky, depending on laminations.	Some deteriorate on alternate wetting and drying.
Gneiss	Explosives	Irregular fragments, sometimes elongated or slabby.	Likely to be resistant.
Mine waste and industrial waste	Machines	Depends on the material, in most cases irregular.	Most forms (except igneous rock mine waste) should be considered susceptible until experience or tests show otherwise.

* Although excavation machinery alone can be used, loosening by explosives before excavation can be cheaper.

Figure 6.3-9.—Rocks as construction materials

DEGREE OF WEATHERING

REPRESENTATIVE		ALTERED	WEATHERED			
			>GRAVEL SIZE		<SAND SIZE	
Micro Fresh State (MFS) A	Visually Fresh State (VFS) B	Stained State (STS) C	Partly Decomposed State (PDS) D		Completely Decomposed State (CDS) E	
UNIT WEIGHT RELATIVE ABSORPTION		COMPARE TO FRESH STATE	NON-PLASTIC	PLASTIC	NON-PLASTIC	PLASTIC

ESTIMATED STRENGTH

REACTION TO IMPACT OF 1 LB. BALLPEEN HAMMER				REMOLDING[1]
"Rebounds" (Elastic) (RQ) A	"Pits" (Tensional) (PQ) B	"Dents" (Compression) (DQ) C	"Craters" (Shears) (CQ) D	Moldable (Friable) (MQ) E
>15000 psi[2] >103 MPa	8000-15000 psi[2] 55-103 MPa	3000-8000 psi[2] 21-55 MPa	1000-3000 psi[2] 7-21 MPa	<1000 psi[2] <7 MPa

(1) Strength Estimated by Soil Mechanics Techniques
(2) Approximate Unconfined Compressive Strength

DISCONTINUITIES

VERY LOW PERMEABILITY			MAY TRANSMIT WATER	
Solid (Random Breakage) (SRB) A	Solid (Preferred Breakage) (SPB) B	Solid (Latent Planes Of Separation) (LPS) C	Nonintersecting Open Planes (2-D) D	Intersecting Open Planes (3-D) E
			ATTITUDE	INTERLOCK

UNIT WEIGHT

Greater Than 160 pcf 2.55 g/cc A	150-160 pcf 2.40-2.55 g/cc B	140-150 pcf 2.25-240 g/cc C	130-140 pcf 2.10-2.25 g/cc D	Less Than 130 pcf 2.10 g/cc E

DESIGN NOTATION

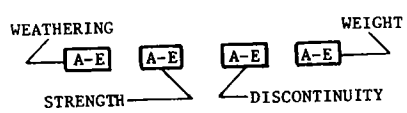


Figure 6.3-10.—Intact rock classification based on field tests by Willamson and Kuhn.

6.4 Dynamic Cone Penetrometer (DCP) User's Guide

OPERATOR
DCP FIELD MANUAL

USDA - FOREST SERVICE
December 1993

DESCRIPTION AND APPLICATION OF
DYNAMIC CONE PENETROMETER

Summary

The dynamic cone penetrometer (DCP) is a device for measuring the in situ strength of paving materials and subgrade soils. The DCP was introduced in the 1960s, however, very few highway agencies are familiar with it or have used it. It is extensively used by the U.S. Air Force. Currently, DCP testing procedures are being developed in an American Society for Testing and Materials (ASTM) subcommittee. The DCP penetration rate (PR) can be used to identify pavement layer boundaries and subgrade strata and to estimate the CBR values of those layers.

The DCP test is performed by driving the cone into the pavement/subgrade by raising and dropping the hammer. The cone penetration is recorded for each drop and termed the PR. After the test is done, the soil CBR values can be determined using the following equations:

$$CBR = \frac{405.3}{(PR)^{1.259}} \quad \text{(for } 60^\circ \text{ cone)} \qquad \text{(Eq. 6.4-1)}$$

where:

PR = penetration rate measured in mm/blow

or

$$CBR = 1.23\ (\text{blows}/100\ \text{mm})^{1.259}$$

References and bibliography of DCP publications are at the end of this field manual.

Purpose and Scope

The purpose of this field manual is to describe the DCP, its use, and the application of data obtained by its use. Procedures are presented for using the DCP to measure soil strength and for correlating soil strength.

DCP consists of a cone of specific dimensions, driven into the road structure or subgrade by a drop hammer of specified weight, falling a specified distance. The penetration is recorded against the accumulated number of blows.

This PR in mm/blow has been correlated to CBR values. See equation in correlation. Also, for some operators it is convenient to convert blows/ 100 mm to CBR. It is this correlation that provides the link between the simple, inexpensive field tests, and rational access road pavement design and evaluation. The DCP can be used to determine three features of a road structure:

- the CBR of the subgrade for new construction or beneath existing pavements;
- the CBR of the materials above the subgrade for existing pavements; and
- an estimate of thickness of the material layers for existing pavements.

The DCP is therefore an instrument that can be used to assist in the design of new surfacing structures (by providing an estimate of the subgrade CBR as input to a pavement design procedure), as well as in the evaluation of existing pavement structures (by indicating the existing material thickness and CBR together with the subgrade CBR).

Definition of Terms

Certain terms used in this report are defined as follows:

- AASHTO T-193 (1992) CBR (California Bearing Ratio). A measure of the bearing capacity of the soil based on its shearing resistance. CBR is calculated by dividing the unit load required to force a piston into the soil by the unit load required to force the same piston, the same depth, into a standard sample of crushed stone and multiplying by 100.
- DCP value. Rate of cone penetration, mm per drop hammer blow.

Description of Instrument

The DCP consists of a 16-mm diameter steel rod with a steel cone attached to one end which is driven into the pavement or subgrade by means of a sliding hammer (see figure 6.4-1). The angle of the cone is 60° and the diameter of the base of the cone is 20 mm. The diameter of the cone is 4 mm larger than that of the rod to ensure that the resistance to penetration is only exerted on the cone. The DCP is driven into the soil with an 8-kg drop hammer, which slides on a 16-mm diameter steel rod, and strikes an anvil. The hammer has a fall height of 575 mm. The steel rod is scored at 20-mm and 100-mm intervals so the depth of penetration can be measured.

Use

Before the DCP is used, it should be inspected to ensure that all of the joints are tight and the cone is in good condition. If there is no band (wear indicator) around the base of the cone (see figure 6.4-1) or the point becomes blunt, the cone must be replaced.

(a) Two people are recommended to operate the DCP. One person should hold the instrument by its handle in a vertical position to raise and release the hammer. Care should be exercised when raising the hammer to ensure that the hammer is touching the upper stop (bottom of the handle), but not lifting the cone before it is allowed to drop. The operator must also be sure the hammer falls freely and its downward movement is not affected by a hand movement. The second person should ensure that the instrument is held vertical while noting the penetration of the cone, counting the number of hammer drops between measurements, and recording the data. The second person is also responsible for determining the number of hammer drops required before penetration determinations are obtained. TO AVOID INJURY, THE OPERATOR'S HANDS AND FINGERS MUST BE CLEAR OF THE ANVIL WHILE IT IS BEING USED.

(b) The first few blows of the drop hammer will not be representative of the actual DCP value because the imprint area of the cone tip after the first blow will be smaller than after subsequent blows. Therefore, the cone must be driven completely into the soil (to the wear indicator band as shown in figure 6.4-1) before DCP values are determined. After the cone has been driven into the soil, the depth of penetration shall be determined by counting the number of blows (full drop of the hammer weight). The operator has the option to record either the number of mm per blow or the number of blows to drive the cone a predetermined distance. The choice is a function of the purpose of the exploration. Some examples follow that may help in determining the option to use.

(1) Record the number of blows for every 100 mm. Once this is done, a rough idea of the sequence of materials can be determined and a plan for further DCP's can be made.

(2) Determine the thickness as well as the CBR's of an existing aggregate-surfaced road and its subgrade. Record the number of blows for every 40 or 60 mm until the cone penetrates into the "weaker" subgrade material and then record the number of blows for every 100 mm.

(3) Determine the CBR of a "soft" subgrade. Record the distance the cone travels for each blow. This is recommended whenever the CBR's are expected to be less than 5 or the penetration per blow is more than 40 mm.

Continue penetration for at least 460 mm (18 inches) into the subgrade unless one obtains refusal. REFUSAL FOR ALL PRACTICAL PURPOSES CAN BE CONSIDERED APPROACHING 2.5 mm/BLOW (40 BLOWS PER 100 mm). DAMAGE OF THE DCP CAN OCCUR AT PENETRATIONS LESS THAN 2.5 mm/BLOW.

No subgrade material is ever uniform in composition. Rock fragments tend to be found throughout a soil layer. Therefore, some interpretation

will have to be made when observing the PR of the DCP. If the cone penetrates in a uniform, consistent fashion for each blow, that penetration more than likely represents the true field CBR. If the penetration per blow is erratic, possibly the cone is pushing a rock fragment ahead or to the side. If this occurs, it should be noted in the remarks column of the data sheet (see figure 6.4-2). Some users find it helpful to record and plot the penetration for each blow to help in determining if a rock fragment has been encountered.

(c) After the DCP has been driven to the desired depth, it shall be extracted from the soil by bumping the drop hammer against the top stop. Since the DCP may be easily damaged during this operation, caution must be exercised. The drop hammer must be raised in a vertical direction (rather than in an arc or some angle other than 90° to the surface of the soil) or the rod may be bent or broken where it connects to the anvil.

Number of Measurements

Soil conditions are extremely variable; therefore, as many penetrometer measurements should be taken in a given area as needed to characterize the materials. Current pavement design methods require use of average CBR's. Projects should be segmented using judgment and consideration of the variable soil types. DCP readings that are consistently close to the same value in uniform soil conditions require fewer measurements in a project segment.

Depths at which Readings Should Be Made

Soil strength usually increases with depth, but in some cases a thin, hard crust will overlie a soft layer or the soil will contain thin layers of hard and soft material. For this reason and the fact that many vehicles will affect the soil to depths of 460 mm (18 in.) or more, it is recommended that each penetration be made to a depth of at least 460 mm unless prevented by a very hard condition at a lesser depth. When penetration cannot be made to the 460 mm depth, the DCP shall be extracted and another attempt made within the proximity of the initial test.

Correlation of DCP Values with CBR

The CBR is widely used to express values of soil strength; many paved highways and nearly all aggregate-surfaced and unsurfaced roads are constructed according to the CBR design procedure. It is suggested that the DCP data obtained at each location be recorded on a sheet similar to figure 6.4-2 with CBR values obtained from figure 6.4-3. Figure 6.4-4 can be used when CBR's are less than 10.

$$CBR = \frac{405.3}{(PR)^{1.259}} \quad \text{(for } 60^\circ \text{ cone)}^*$$

where:

PR = Penetration rate measured in mm/blow (DCP value)

To convert blows per 100 mm to CBR:

CBR = 1.23 times (blows per 100 mm) raised to the 1.259 power
= $1.23\ (\text{blows}/100\ \text{mm})^{1.259}$

*From "Techniques for Pavement Rehabilitation - A Training Course," FHWA-HI-93-056, 5th Edition, March 1993. p. 120.

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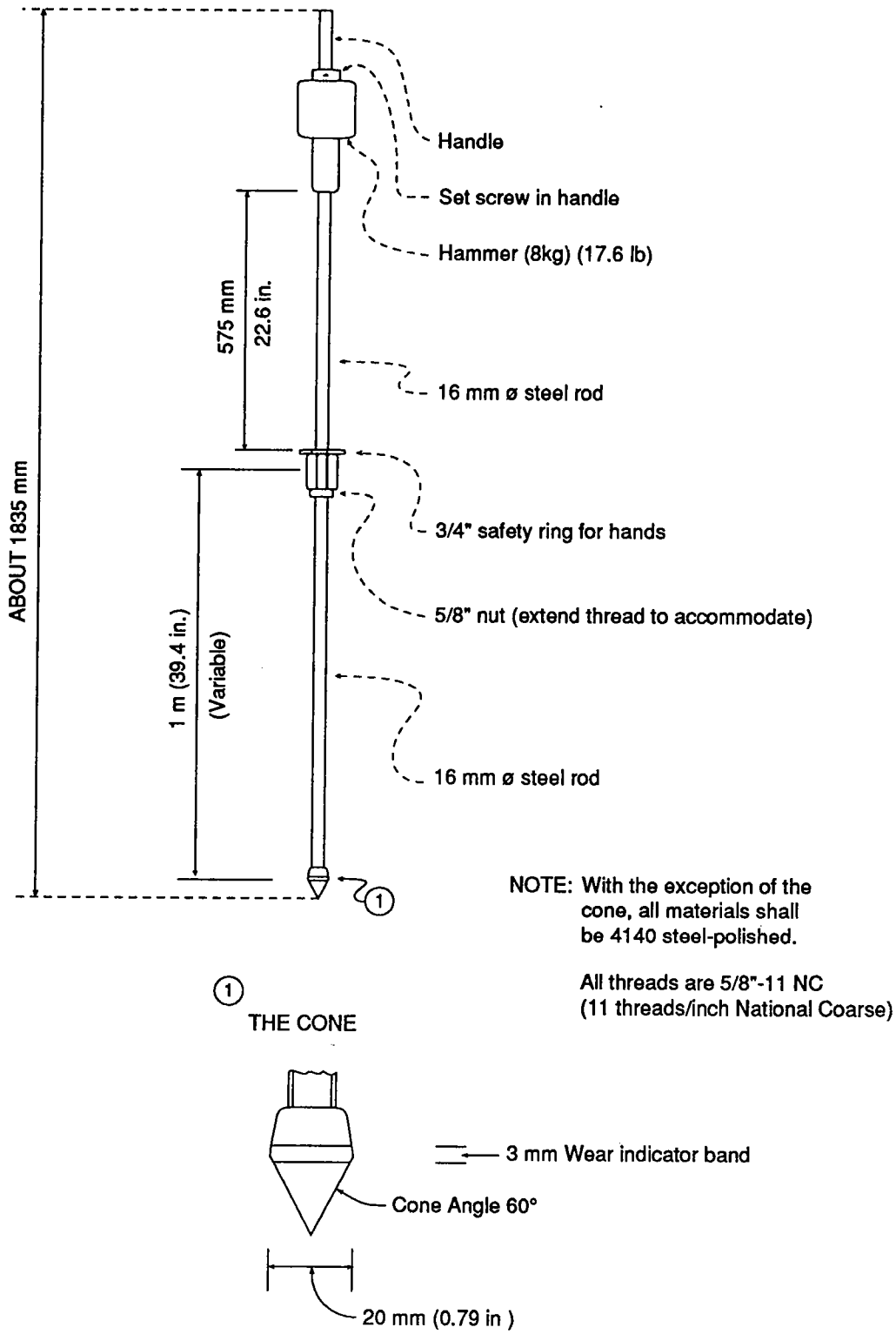

Figure 6.4-1.—The dynamic cone penetrometer.

Project: _____ Date: _____

Road No: _____ Station/M.P.: _____ By: _____

No. of Blows	Cumulative Depth of Penetration (mm)	Penetration (mm)	DCP Value (mm/blow)	(blow/100mm)	CBR %	Soil Type Remarks

Remarks: _____

Figure 6.4-2.—Dynamic cone penetrometer data sheet.

Project: DCP Date: Yesterday

Road No: _____ Station/M.P.: _____ By: _____

No. of Blows	Cumulative Depth of Penetration (mm)	Penetration (mm)	DCP Value (mm/blow)	(blow/100mm)	CBR %	Soil Type Remarks
EXAMPLE 1						
6	50	50	8.3		28	Aggregate Surface
8	100	50	6.2		41	" "
7	150	50	7.1		34	" "
1	200	50	50.0		2.9	Possible Sub-grade Contact
2	250	50	25.0		7	" "
1	300	50	50.0		2.9	" "
1	350	50	50.0		2.9	" "
20	400	50	2.5		128	" "
40+	450 (refusal)	50	1.2			Probable Rock Contact
EXAMPLE 2						
14	100	100		14	34	Aggregate Surface
8	200	100		8	17	" "
3	300	100		3	4.9	Possible Sub-grade Contact
21	400	100		21	57	" "
40+	450	50				Probable Rock Contact

Remarks: _____

Figure 6.4-2.—Dynamic cone penetrometer data sheet (cont'd.).

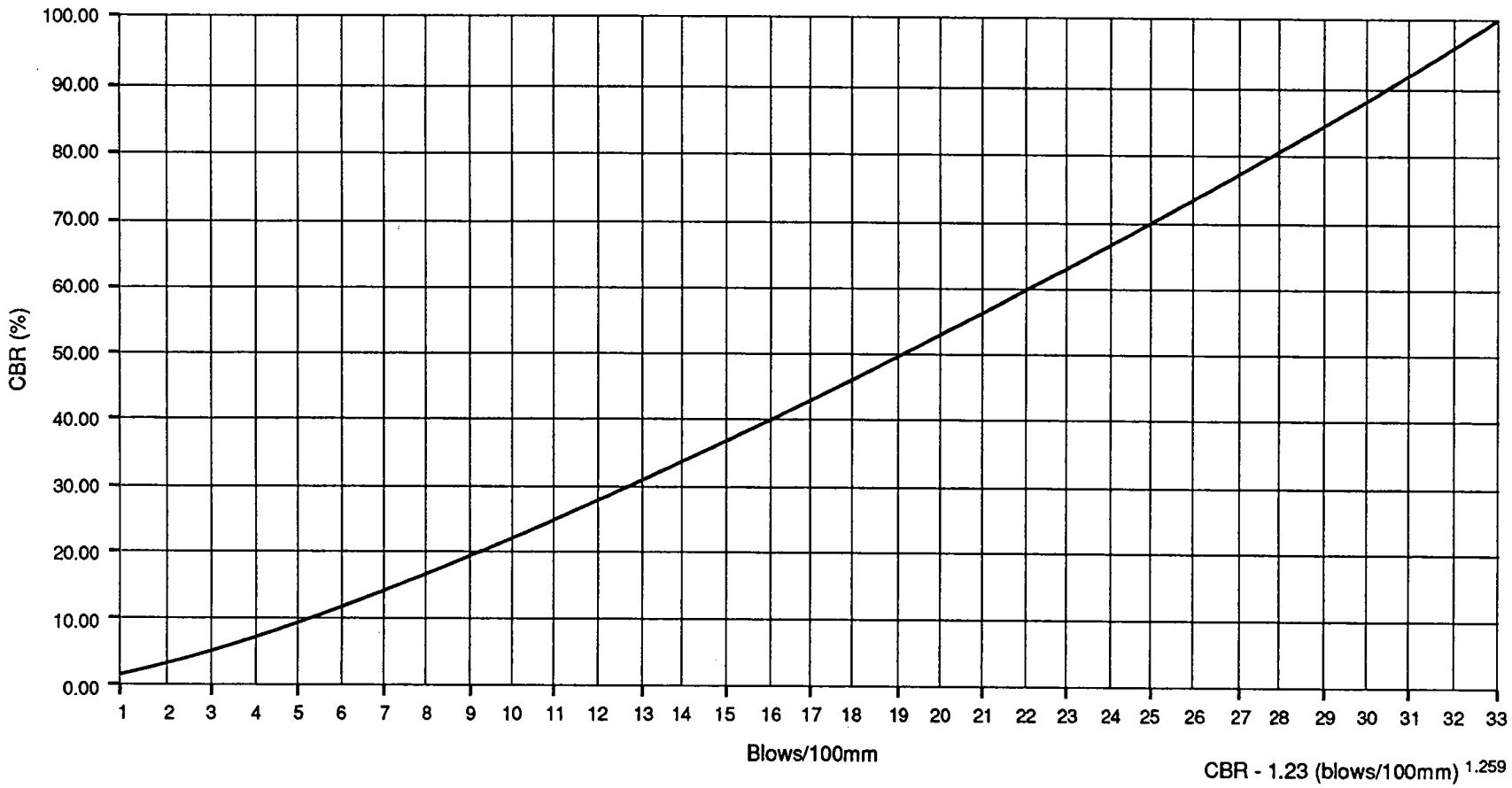

Figure 6.4-3.—DCP CBR values.

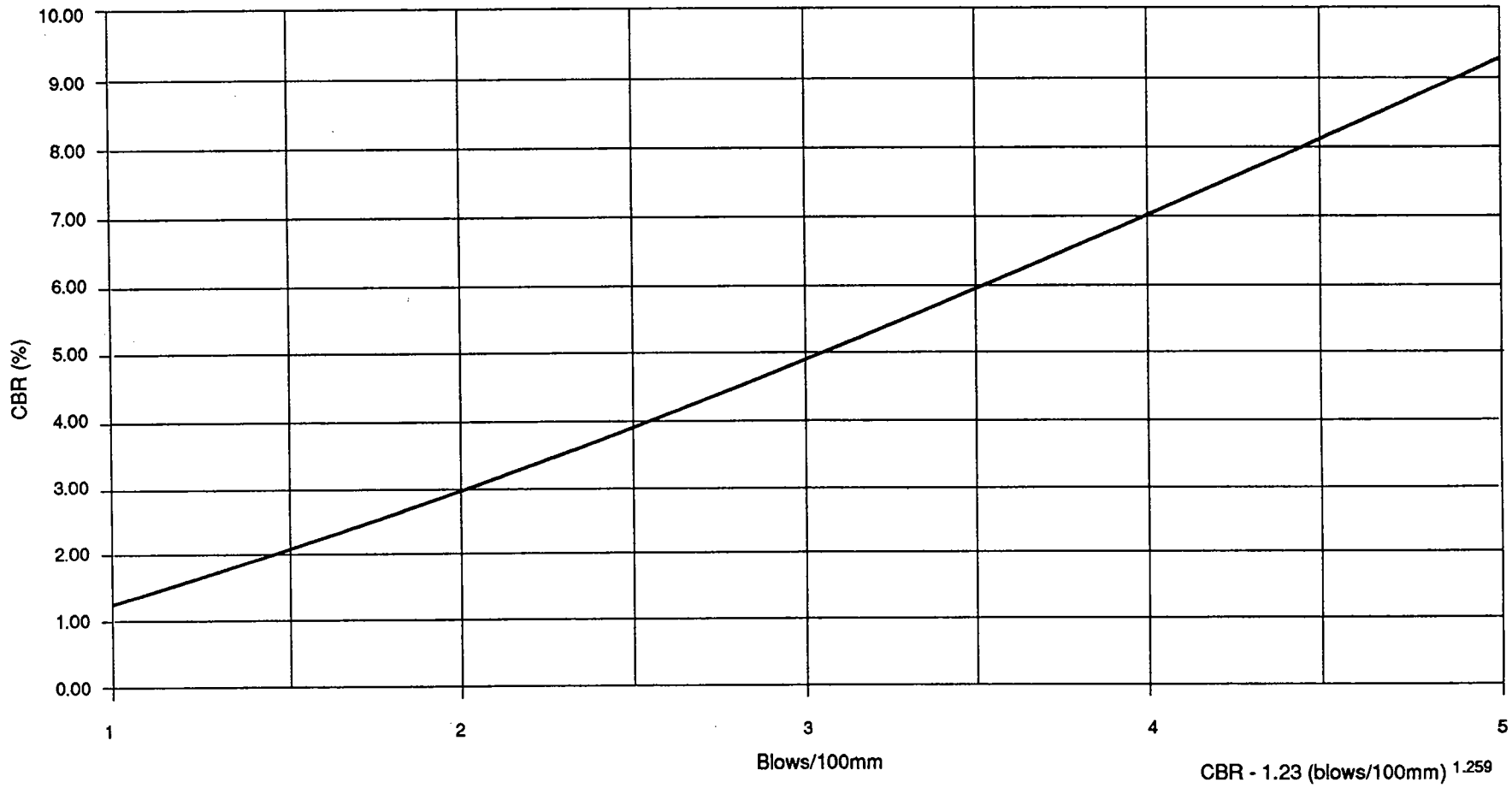

Figure 6.4-4.—Low range CBR values for DCP.

6.5 Design with Geotextiles

This appendix is borrowed from Chapter 5, "Using Geotextiles as Separators in Roadways" in the unpublished report, "FHWA Geotextile Design and Construction Guideline" by Christopher and Holtz (1989). In April 1990 the guideline was revised and published by Christopher and Holtz. This appendix does not include any of the revisions made at that time.

Editor's notes have been inserted to adapt to Forest Service conditions or explain references not included in the appendix. Figures 5.2 to 5.16 have been also added for use by the reader.

Users of this appendix are encouraged to obtain a copy of the referenced FHWA publications on geotextiles for guidance in situations not covered here. These FHWA publications are: FHWA *Geotextile Engineering Manual* (1985); FHWA *Geotextile Design and Construction Guideline* by Christopher and Holtz (1990); and *Guidelines for Use of Fabrics in Construction and Maintenance of Low-Volume Roads*, by Steward, Williamson, and Mohney (1977), Report No. FHWA-TS-78-205. Current interim geotextile specifications can be found in AASHTO M-288-92 *Interim Geotextile Specifications for Highway Applications*.

5.1 Background

A major cause of failure of roadways constructed over soft foundations is contamination of the aggregate base courses with the underlying soft subgrade soils. Contamination occurs due to:

- penetration of the aggregate into the weak subgrade because of localized bearing capacity failure under stresses exerted by the wheel loads, and

- intrusion of fine-grained soils into the aggregate because of pumping or subgrade weakening due to excess pore water pressures.

The associated subgrade weakening and loss in aggregate thickness result in inadequate structural support which often leads to premature failure of the system. Subgrade stabilization problems most often occur at sites with fine-grained soils (silts and clays) with a high water content, some sensitivity to remolding, and low undrained shear strength. If the ground water table is also at or near the surface, problems during construction can occur.

A geotextile can be placed between the aggregate and the subgrade to act as a separator to prevent the subgrade and aggregate base course from mixing, thus maintaining the desired design thickness of the roadway. gate due to high water pressures and as a drain by allowing pore water dissipation in the underlying soil through the geotextile. In addition, the geotextile may provide reinforcement through:

- lateral restraint of the base and subgrade through friction between the aggregate, soil and the geotextile.

- increase in the bearing capacity of the system by interfering with the incipient bearing capacity failure surface, which forces the failure surface along an alternate surface.

- a membrane support of the wheel loads.

These mechanisms are also applicable to geogrids when they are used in roadways. However, grids cannot provide the separation and filtration functions. Therefore they must be used together with a geotextile in roadway applications.

The primary and secondary functions of geotextiles in roadway applications are shown in Figure 5.1.

These geotextile functions, when considered in the design of roadways over soft subgrades, can lead to several possible cost and performance benefits including:

- reducing the intensity of stress on the subgrade and preventing the subbase aggregate from penetrating into the subgrade (function: separation).

- preventing subgrade fines from pumping into the subbase (function: separation and filtration).

- preventing contamination of the subbase materials which may allow more open-graded free draining aggregate to be considered in the design (function: filtration).

- reducing the depth of excavation required for removal of unsuitable subgrade materials (function: separation and reinforcement).

- reducing aggregate thickness required to stabilize the subgrade (function: separation and reinforcement). (Aggregate reduction in the structural design may or may not be considered.)

- providing for less subgrade disturbance during construction (function: separation and reinforcement).

- maintaining the integrity and uniformity of the pavement should settlement of the subgrade occur (function: reinforcement). The geotextile does not prevent settlement of the subgrade, but its use can result in more uniform settlement (Boutrup and Holtz, 1983). Geotextiles will help reduce differential settlement in transition areas from cut to fill.

- reducing maintenance and extending the life of the pavement (functions: all).

The following sections will discuss geotextile selection and design methodology to take advantage of the above possible benefits.

5.2 Applications

On the basis of service life, traffic, or desired performance roads are broadly classified into two categories, permanent and temporary. Permanent roads include both paved and unpaved systems which are required to remain in service over a number of years, usually 10 or more. Permanent roads may be required to handle well over one million vehicles during the design life of the road (typically more on the order of 1×10^9 vehicles). On the other hand, temporary roads, such as haul roads and access roads are in most cases unpaved. They are required to remain in service for short periods of time (usually less than one year) and are usually required to support less than 10,000 vehicles during the life of the system. Temporary roads also include detours, construction platforms, and stabilized working tables necessary for the construction of permanent roads and embankments over soft subgrades.

One of the most significant geotextile applications is allowing access of construction equipment into sites where the soils are too weak to support the initial construction efforts. It is often the case that even if the finished road section could be supported by the subgrade, there may be no way of actually placing the construction excavation and replacement with select granular materials. Such sites require stabilization through demucking, placement of stabilization aggregate, lime stabilization or other similar expensive operations. Geotextiles can often be a cost-effective alternate to these procedures.

5.3 Roadway Design Using Geotextiles

Certain principles are common to all types of road systems, regardless of the design method. Basically, the design of any road involves a study of each of the components of the system including the pavement, aggregate base courses, and subgrade, and their behavior under load and their ability to carry that load under various climatic and environmental conditions when placed in the roadway section. All road systems, whether permanent or temporary, derive their support from the underlying subgrade[1]. Thus, the geotextile functions are similar for either temporary or permanent roadway applications. However, due to road performance requirements, design methodologies for temporary roads cannot be used to design permanent roads. The main difference in the design is related to the performance requirements. Temporary road design usually allows for some rutting to occur over the design life as rutting may not necessarily impair service. Obviously, ruts are not desirable in permanent roads. Therefore, the design of geotextiles in these two applications will be presented separately.

5.4 Design Guidelines for Temporary Roads

There are two main approaches to the design of unpaved roads. The first approach assumes no reinforcing effect of the geotextile; that is, the geotextile acts as a separator only. The second approach does take the possible reinforcing effect of the geotextile into consideration. It appears that the separation function is more important for low embankments with relatively small live loads where ruts of 2 to 4 inches are anticipated. In these cases, a design which assumes no reinforcing effect is generally conservative. On the other hand, for large live loads on thin embankments where deep ruts (>4 inches) may occur and for higher embankments on softer subgrades, the reinforcing function becomes increasingly important if stability is to be maintained. It is for these latter cases that analyses considering reinforcing have been developed and appear to be appropriate.

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[1]Ed. Note: "Temporary roads" are comparable to aggregate-surfaced local and collector roads accessing areas for timber harvest and rock haul. These types of roads are designed to develop visible and measurable rutting in the surface during their design life. "Permanent roads" are comparable to higher volume, aggregate-surfaced, arterial roads and asphalt-surfaced roads. For these low-rutting roads using geotextiles, please see the parent documents, FHWA "Geotextile Engineering Manual," (1985) and FHWA "Geotextile Design and Construction Guidelines," by Christopher & Holtz (1989).

The method presented in these guidelines considers mainly the separation function. It was selected because it can be adapted to a wide variety of conditions. Other design methods considering reinforcing are covered in the FHWA "Geotextile Engineering Manual". For road embankments where stability of the foundation is questionable, you should refer to chapter 5 in the Manual[2] and chapter 7 in these Guidelines[3] for information on reinforced embankments.

The design method presented herein was developed by Steward, Williamson, and Mohney (1977) for the Forest Service. The method allows the designer to consider:

- number of vehicle passes (up to 10,000);
- equivalent axle loads;
- axle configurations;
- tire pressures;
- subgrade strengths; and
- rut depths.

The following limitations apply:

- The aggregate layer must be:
  - Compacted to CBR 80[4];
  - Cohesionless (non-plastic).
- Vehicle passes are limited to 10,000.
- Geotextile survivability criteria must be considered.
- Subgrade shear strength as measured by the CBR, less than 3.

For subgrades stronger than CBR of 3 geotextiles are rarely required for separation, although they may provide for some drainage and filtration. In this case, the principles developed in chapter 2 in these Guidelines[5] are applicable, just as they are for weaker subgrades.

The design method is based on both theoretical analysis and empirical (laboratory and field) tests. Based on these results, Steward et al. (1977) determined that a certain amount of rutting would occur under different traffic conditions, both with and without a geotextile separator, for a

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[2]Ed. Note: "Manual" refers to the FHWA "Geotextile Engineering Manual," used for implmenting workshops in 1985-1987.

[3]Ed. Note: "Guidelines" refers to the FHWA "Geotextile Design and Construction Guideline," by Christopher and Holtz (1989).

[4]Ed. Note: Compaction is typically performed by hauling vehicles and tracked vehicles used for spreading the aggregate. Aggregates having compacted CBR less than 80 may be used over the geotextile; however, CBR 80 material is required to support repeated wheel loads.

[5]Ed. Note: "Guidelines" refers to the FHWA "Geotextile Design and Construction Guildelines," by Christopher and Holtz (1989).

given stress level acting on the subgrade. They present this stress level in terms of a classical bearing capacity factor. These factors and conditions are given in Table 5-1.

5.5 Geotextile Example

[This example was added by the authors of the *Surfacing Design Guide*; the original report did not have an example. Strength measurements (field c values): 7.5, 6.9, 4.9, 4.2, 3.7, 3.0, 3.0, 2.5, 2.4.

Given: 1000 passes of log truck @ 80,000 GVW
(dual wheel tandem weight = 35,000 lbs)

Determine: Aggregate depth with and without geotextile if tire pressure was 70 psi

Solution: Determine 75th percentile strength measurement (strength value at which 75 percent of the soil strength readings are higher than this value) = 3.0

For 70 psi without geotextile from Figure 5.14, depth = 19" $cN_c = 3(2.8) = 8.4$

For 70 psi with geotextile from Figure 5.14, depth =11" $cN_c = 3(5.0) = 15$

5.6 Design Guidelines for Permanent Roads and Highways

The recommended design method for permanent roads, as discussed in the FHWA "Geotextile Engineering Manual," is based on the following concepts:

1. No structural support is assumed to be provided by the geotextile and therefore no reduction is allowed in aggregate thickness required for structural support.

2. Aggregate savings will be achieved through a reduction in the required stabilization aggregate not used for structural support.

3. Standard methods are used to design the overall pavement system (i.e. AASHTO, CBR, R-value, etc.).

4. The design method is actually used to design the first lift, which is called the "stabilizer lift" since it provides sufficient stabilization to the subgrade to allow access of normal construction equipment for the remaining lifts.

5. Once the stabilizer lift is complete, the construction can proceed normally as per standard road design methods.

6. The method does not include evaluation of settlement or drainage requirements, which must also be considered as in a conventional design.

Basically, the method assumes that the stabilizer lift is actually an unpaved road which will be exposed to relatively few vehicle passes (i.e., construction equipment only) and which can tolerate 2 to 3 inches of rutting under the equipment loads.

The design consists of the following steps:

1. Estimate the need for a geotextile based on the subgrade strength (CBR<3) and by past performance in similar types of soils.

2. Design the roadway for structural support using your normal permanent pavement design methods; provide no allowance for the geotextile.

3. Determine if more subbase[6] than that required for structural support has been added due to susceptibility of soils to pumping and subbase intrusion. If so, reduce that subbase by 50 percent and include a geotextile in the design at the subbase/subgrade interface.

4. Determine additional subbase required for stabilization of subgrade during construction activities by using a 3-inch rutting criteria for construction equipment and the procedures outlined in section 5.4, "Design Guidelines for Temporary Roads."

5. Compare the subbase geotextile system determined for constructability in step 4 with the geotextile subbase system determined in step 3 and use the system with the greatest thickness.

6. Check the geotextile strength requirements for survivability as will be discussed in section 5.8.

7. Check the geotextile filtration characteristics on the basis of the gradation and permeability of the subgrade, the water table conditions, and the retention and permeability criteria given in chapter 2 of these guidelines.[7]

8. Follow installation procedures covered in section 5.11.

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[6]Ed Note: Subbase reffered to is commonly called "pit run" or "subgrade reinforcement."

[7]Ed. Note: "Guidelines" refers to the FHWA "Geotextile Design and Construction Guidelines," by Christopher and Holtz (1989).

Other design methods for improving the structural capacity of permanent roads using geotextiles (e.g., Hamilton and Pearce, 1981) and geogrids (e.g., Haas, 1986; Haas, et al., 1988) have been proposed. NCHRP research currently underway at the Georgia Institute of Technology is directed towards answering the remaining questions regarding geosynthetics in permanent roadways.

5.7 Design Example

Relevant examples are included in the FHWA publications "Geotextile Engineering Workshop Design Examples" (FHWA-H1-89-002), and "Geotextile Engineering Manual" (FHWA-86-203).[8]

5.8 Geotextile Survivability

The selection of the geotextile to be used for either permanent or temporary roads is basically the same. If the roadway system is designed correctly, then the stress at the geotextile level due to the weight of the aggregate and the traffic should be not greater than the bearing capacity of the soil, which is relatively low (maximum of 30 psi) for subgrades where geotextiles are used. However, the stresses applied to the subgrade and the geotextile during construction may exceed those applied to the materials in service. Therefore, selection of the geotextile is usually governed by the anticipated construction stresses. This is the concept of geotextile survivability that the geotextile must survive during the construction operations if it is to perform its intended function.

Table 5-2 relates the construction elements (i.e. equipment, aggregate characteristics, subgrade preparation and subgrade strength) to the severity of the loading imposed on the geotextile. If one or more of these items falls within a particular severity category (i.e., low, moderate, or high to very high), then geotextiles meeting these survivability requirements should be considered. However, some judgment is required in using these criteria. For example, if you were going to have a heavy-weight dozer operating on a cleared but soft subgrade using coarse, angular aggregate fill in lifts of 12 inches, then a moderate to high survivability geotextile probably should be specified.

The strength of the geotextile required to survive the most severe conditions anticipated during construction can then be determined from Table 5-3 as provided by Task Force 25. Geotextiles that meet or exceed the survivability requirements could thus be considered acceptable for the project. It is important to realize that these survivability requirements were not based on any systematic research but on the properties of geotextiles which apparently have performed satisfactorily as separators in temporary roads and similar applications. There is currently some question as to the validity of the numbers with current research indicating that elongation may also be a factor. However, in the absence of any other information, they can be used as minimum interim values. The user is cautioned to use judgment and experience in selecting final

[8]Ed. Note: Modified to state publications that include examples.

specification values and should verify the geotextile survivability for major projects by conducting field tests under site specific conditions.

These field tests would involve trial sections using several geotextile samples on a couple of typical subgrades at the site, and with different types of construction equipment. After construction, the samples would be exhumed and examined as to how well they tolerated the imposed construction stresses. These tests could be done during design or after the contract was let, similarly to what is recommended for riprap placement (section 3.8, item 6e) of these Guidelines[9]. In this case, the contractor is required to demonstrate that the proposed subgrade condition, equipment, and aggregate placement will not damage the geotextile. Then, if necessary, additional subgrade cleaning, increased lift thickness, and/or different construction equipment could be utilized. In rare cases, the contractor may even have to supply a different geotextile.

The selected geotextile must retain the underlying subgrade and allow the underlying subgrade to freely drain. Thus, the geotextile must be checked by using the drainage and filtration requirements discussed previously in chapter 2 of these Guidelines[10] and as summarized in Table 5-4.

5.9 Cost Considerations

Once the decision has been made about geotextile requirements, it is important that the minimum required properties be detailed so that substitution of fabrics with lower performance properties and lower cost will not occur. Fabric selection based on cost alone will not provide successful results in most cases.

Estimation of construction cost and benefit-cost ratios for geotextile-stabilized road construction is straight forward and basically the same as that required for reviewing alternative pavement designs. Primary factors include:

- The geotextile cost.
- Cost of constructing the conventional design versus a geotextile design (i.e. stabilization requirements for conventional design versus geotextile design):
  - stabilization aggregate requirements;
  - over-excavation and replacement requirements;
  - operational and technical feasibility;
  - construction equipment and time requirements;

[9]Ed Note: "Guidelines" refers to the FHWA "Geotexile Design and Construction Guideline" by Christopher and Holtz (1989).

[10]Ed Note: "Guidelines" refers to the FHWA "Geotexile Design and Construction Guideline" by Christopher and Holtz (1989).

- Cost of conventional maintenance during road service life versus improved service anticipated by using geotextile; estimated through pavement management programs.

- Regional past experience.

Annual cost formulas such as the Baldock method (Illinois Department of Transportation, 1982) can be used, utilizing an appropriate present worth factor to obtain the present worth of future expenditures.

Cost tradeoffs should also be evaluated for different construction and fabric combinations. This includes subgrade preparation and equipment control versus geotextile survivability. In general, higher cost geotextiles with a higher survivability on the existing subgrade will be less expensive than the additional subgrade preparation cost necessary to use geotextiles with a lower survivability.

5.10 Specifications

Specifications should generally follow the guidelines in Section 1.6 of these Guidelines.[11] The main considerations include the minimum geotextile requirements for design and those obtained from the survivability, retention, and filtration requirements in section 5.8, as well as the construction requirements covered in section 5.11. As with other applications, it is very important for an engineer's representative to be on-site during placement to observe that the correct geotextile has been delivered; that the specified construction sequence is being followed in detail; and that there is no damage to the geotextile. The following draft specification, slightly modified, from AASHTO-AGC-ARTBA Task Force 25 is an example.

[11]Ed Note: "Guidelines" refers to the FHWA "Geotextile Design and Construction Guideline" by Christopher and Holtz (1989).

AASHTO-AGC-ARTBA
Task Force 25
Specification Guide for Geotextiles Used In
Separation and Filter Applications
(Draft of September, 1987 with Slight Modifications)

1. Description

This work shall consist of furnishing and placing a geotextile primarily for use as a separator and filter to prevent mixing of dissimilar materials such as subgrades and surfaced and unsurfaced pavement structures, zones in embankments, foundations and select fill materials. The geotextile shall be designed to allow passage of water while retaining in situ soil without clogging. This specification does not address reinforcement applications which require an engineered project specific design.

2. Materials

Fibers used in the manufacture of geotextile and the threads used in joining geotextiles by sewing shall consist of long chain synthetic polymers, composed of at least 85% by weight polyolefins, polyesters, or polyamides. Both the geotextile and threads shall be resistant to chemical attack, mildew, and rot. These materials, based on construction survivability conditions defined in Table 5-2, shall conform to the physical requirements of Tables 5-3 and 5-4.

3. Construction Methods/Requirements

3.1 Geotextiles Packaging and Storing: Geotextile rolls shall be furnished with suitable wrapping for protection against moisture and extended ultra-violet exposure prior to placement. Each roll shall be labeled or tagged to protect product identification sufficient for field identification as well as inventory and quality control purposes. Rolls shall be stored in a manner which protects them from the elements. If stored outdoors, they shall be elevated and protected with a waterproof cover.

3.2 Geotextile Exposure Following Placement: Exposure of geotextiles to the elements between lay down and cover shall be as soon as possible but not more than 3 days to minimize damage potential.

3.3 Site Preparation: The installation site shall be prepared by cleaning, grubbing, and excavation or filling to the design grade.

NOTE: Soft spots and unsuitable areas will be identified during site preparation or subsequent proof rolling. These areas shall be excavated and backfilled with select material compacted to normal procedures.

3.4 Installation: Geotextile installation shall proceed in the direction of construction. The geotextile shall be laid and overlapped in the direction as shown on the plans and shall be as wrinkle free as possible. On curves, the fabric may be folded or cut to accommodate the curve. As shown in Figure 5-17, the fold or overlap of cut pieces shall be in the direction of construction, and pinned, stapled or weighted with cover material. The minimum initial cover will comply with the plans and specifications or shall be selected with aid of Table 5-2. Placement and grading of fill, subbase, or base material shall proceed in the direction of construction. Ruts that occur in placed material during construction shall be filled with the appropriate material which should be subsequently compacted.

3.5 Joints, Seams and Overlays: Where seams are required, they shall be joined by either sewing, sealing, or overlapping. All seams shall be subject to approval of the engineer. Both factory and field sewn or sealed seams shall conform to the requirements of Table 5-3. Optional, overlapped seams shall have a minimum overlap of 12 inches or as shown on the plans.

3.6 The contractor shall patch rips or tears in the geotextile as approved by the engineer (repairs shall be performed by placing a new layer of fabric extending beyond the defect in all directions a minimum of the overlay required for parallel rolls. Alternatively, the defective section shall be replaced as directed by the engineer).

4. Method of Measurement

4.1 The geotextile shall be measured by the number of square yards computed from the payment lines shown on the plans or from payment lines established in writing by the engineer. This excludes seam overlaps.

4.2 Excavation, backfill, bedding and cover materials are separate pay items.

5. Basis of Payment

5.1 The accepted quantities of geotextile shall be paid for at the contract unit price square yard in place.

5.2 Payment will be made under:

Pay Item	Pay Unit
Separator Geotextile	square yard

5.11 Installation Procedures

Successful use of geotextiles in roadways requires proper installation. Figure 5.18 shows the proper sequence of construction when using geotextiles. Even though the installation techniques appear fairly simple, a majority of the problems with geotextiles in roadways have occurred as the result of improper construction techniques. If the geotextile is ripped or punctured during construction activities, it likely will not perform as desired. If the geotextile is placed with a lot of wrinkles or folds, it will not be tensioned, and therefore will not provide any reinforcing effect. Other problems occur due to insufficient cover over fabric, rutting of the subgrade prior to placing the fabric, and placing lift thicknesses such that the bearing capacity of the soil is exceeded. These step-by-step procedures should be followed, along with good engineering observations of all construction activities.

1. The site should be cleared, grubbed, and excavated to design grade, taking care to strip all topsoil, soft soils, or any other unsuitable materials (Figure 5.18a). If moderate site conditions exist (i.e., CBR greater than 1), lightweight proofrolling operations should be considered to aid location of unsuitable materials to be removed. Isolated pockets where over-excavation is required should be pitched and backfilled to promote positive drainage. Optionally, special drain tiles with outlets installed to drain these isolated areas could be used.

2. During stripping operations, care should be taken not to disturb the subgrade. This may require the use of lightweight dozers or grade-alls for low strength, saturated noncohesive and low cohesive soils. For extremely soft ground, such as peat bog areas, consideration should be given to not over-excavate the surface materials so that advantage can be taken of the root mat, if it exists. In this case, all vegetation should be cut off square at the ground surface. Sawdust or sand can be placed over stumps or roots that extend above the ground surface to cushion the geotextile. Remember, the subgrade preparation must correspond to the survivability properties of the geotextile.

3. Once the subgrade along a particular segment of the road alignment has been prepared, the geotextile should be rolled in line with the placement of the new roadway aggregate (Figure 5.18b). Field operations can be expedited if the geotextile is presewn in the factory to design widths such that it can be unrolled in one continuous sheet. The geotextile should not be dragged across the subgrade. The entire roll should be placed and rolled out as smoothly as possible. Wrinkles and folds in the fabric should be removed by stretching and staking as required.

4. Parallel rolls of geotextiles should be overlapped, sewn or tied as required. Specific requirements are reviewed in detail later in the section.

5. For curves, the geotextile should be folded or cut and overlapped in the direction of the turn (previous fabric on top) (Figure 5.17). Folds in the geotextile should be stapled or pinned 5 feet on center.

6. When geotextile intersects an existing pavement area, the fabric should extend to the edge of the old system. For widening or intersecting existing roads where fabric has been used, consideration should be given to anchoring the fabric at the roadway edge. Ideally, the edge of the roadway should be excavated down to the existing fabric and the existing fabric sewn to the new fabric. Overlaps, staples, and pins could also be utilized.

7. Before covering, the condition of the geotextile should be observed by a qualified inspector experienced in the use of these materials to determine that no holes, rips, tears, or such, have occurred in the fabric. If any defects are observed, the section of the fabric containing the defect should be repaired by placing a new layer of fabric extending beyond the defect in all directions a minimum of the overlap required for parallel rolls. Alternatively, the defective section can be replaced.

8. The subbase aggregate should be end-dumped on the fabric from the edges of the fabric or on the previously placed aggregate (Figure 5.18c). For very soft subgrades, pile heights should be limited to prevent possible subgrade failure. The maximum placement lift thickness for such soils should not exceed the design thickness of the road.

9. The first lift of aggregate should be spread and graded down to 12 inches or to the design thickness if less than 12 inches prior to compaction (Figure 5.18d). At no time should equipment be allowed on the road with less than 8 inches (6 inches for CBR 2) of compacted aggregate over the fabric. For extremely soft soils, lightweight construction vehicles will likely be required for access on the first lift. Construction vehicles should be limited in size and weight such that rutting in the initial lift is no greater than 3 inches. If rut depths exceed 3 inches, it will be necessary to decrease the size and/or weight of the construction vehicles or to increase the lift thickness. For example, it may be necessary to reduce the size of the dozer required to blade out the fill or possibly to deliver the fill in half-loaded rather than fully loaded trucks.

10. The first lift of subbase aggregate should be compacted by "tracking" with the dozer and then compacted with a smooth-drum vibratory roller to obtain a minimum compacted density (Figure 5.18e). For very soft soils, design density should not be

anticipated for the first lift. In this case, compaction requirements should be reduced. One possible recommendation would be to allow compaction of 5 percent less than the required specification density.

11. Construction should be performed parallel to the road alignment. Turning should not be permitted on the first lift of subbase aggregate. Turnouts may be constructed at the road edge to facilitate construction.

12. If the geotextile is to provide some reinforcement, pretensioning of the fabric should be considered. For pretensioning, the area should be proof-rolled by a heavily loaded rubber-tired vehicle such as a loaded dump truck. The wheel load should be equivalent to the maximum expected for the site. The vehicle should make at least four passes over the first lift in each area of the site. Alternatively, once the design aggregate has been placed, the roadway could be used for a time prior to paving such that prestressing the fabric in key areas could be obtained.

13. Any ruts that form during construction should be filled in as shown on Figure 5.19 to maintain adequate cover over the fabric. In no case should ruts be bladed down as this would decrease the amount of aggregate cover between the ruts.

14. All remaining subbase aggregate should be placed in lifts not exceeding 9 inches in loose thickness and compacted to the appropriate specification density.

5.11.1 Overlaps

Overlaps can be used to provide continuity between adjacent geotextile rolls, through frictional resistance between the overlaps. Also, a sufficient overlap is required to prevent soil from squeezing into the aggregate at the fabric joint. The amount of overlap depends primarily on the soil conditions and the potential for equipment to rut the soil. If the subgrade will not rut under construction activities, only a minimum overlap sufficient to provide some pullout resistance is required. As the potential for rutting and squeezing of soil increases, the required overlap increases. Since rutting potential can be related to CBR, it can be used as a guideline for the minimum overlap required as shown in Table 5-5.

The geotextile can be stapled or pinned at the overlaps to maintain them during construction activities. Ten to twelve-inch-long nails should be placed at a minimum of 50 feet on centers for parallel rolls and 5 feet on centers for roll ends.

Fabric widths should be selected such that overlaps of parallel rolls occur at the center line and at the shoulder. Overlaps should not be placed along anticipated main wheel path locations.

Overlaps at the end of rolls should be in the direction of the aggregate placement (previous roll on top).

5.11.2 Seams

When seams are required for separation applications, it is recommended that the seams meet the same tensile strength requirements for survivability as required for the geotextile, in the direction perpendicular to the seam (as determined by the same testing methods) (see Table 5-3). (Seaming IS discussed in detail in chapter 1 of these Guidelines.[12]) All factory or field seams should be sewn with thread having the same or greater durability and strength as the fabric. "J-seams" with interlocking stitches are recommended. Alternatively, if bag-type stitches which can unravel or butt-type seams are used, seams should be double-sewn with parallel stitching spaced no more than 1/4 to 1/2 inch apart. Double sewing is required to provide a safety factor against undetected missed stitches. The strength of the geotextile may actually have to be greater than specified, in order to provide seam strengths equal to the specified tensile strength.

For certain types of geotextiles such as nets, webs, and grids, tying or interlocking with wire cables, plastic pipe, or such may be required. Consult the manufacturer.

5.12 Field Inspection

The field inspector should review the field inspection guidelines in chapter 1, section 1.7 of these Guidelines.[13] Particular attention should be paid to the factors that affect geotextile survivability: subgrade condition, aggregate placement, lift thickness, and equipment operations.

5.13 Selection Considerations

For the geotextile to perform its intended function as a separator in roadways, it must be able to tolerate the stresses imposed on it during construction; the geotextile must have sufficient survivability to survive the anticipated construction operations. Geotextile selection for roadways is usually controlled by survivability. The guidelines given in section 5.8 are most important in this regard. As mentioned, the specific geotextile property values given in Table 5-3 have been questioned and are subject to revision. In the meantime, for important projects you are strongly encouraged to conduct your own field trials as described in section 5.8.

[12]Ed. Note: "Guidelines" refers to the FHWA "Geotextile Design and Construction Guildeline," by Christopher and Holtz (1989).

Table 5-1

Bearing Capacity Factors for Different Ruts and Traffic Conditions both with and without Geotextile Separators

(After Steward, Williamson, and Mohney, 1977)

	Ruts (in.)	(Passes of 18 kip axle equivs.)	Bearing Capacity Factor, N_c
Without Geotextile:	<2	>1000	2.8
	>4	<100	3.3
With Geotextile:	<2	>1000	5.0
	>4	<100	6.0

The following design procedure is recommended:

1. Determine the subgrade soils strength in the field using the field CBR test, cone penetrometer, or vane shear test. The undrained shear strength of the soil, c, can be obtained from the following relationships:[15]

   - For field CBR, c in psi = 4 X CBR.
   - For the WES cone penetrometer, c = cone index divided by 10 or 11.
   - For the vane shear test, c is directly measured.

   Other in-situ tests such as the Dutch cone penetrometer test (CPT) may be used, provided local correlations with undrained shear strength exist. Use of the standard penetration test (SPT) is not recommended for soft clays.

2. Make the strength determinations at several locations where the soil appears to be the weakest. Strength should be evaluated at a depth of 0 to 9 inches and from 9 to 18 inches; 6 to 10 strength measurements are recommended at each location to obtain a good average value.[15]

[14]Ed. Note: The strength relationships used are general and approximate. Carefully read the manufacturer's literature for shear vanes and cone penetrometers to determine the soil strength parameter being measured. Calibrate the field test equipment when in doubt.

[15]Ed. Note: Take enough tests at each location (say within a 3-foot diameter area) and depth to determine the range of readings for each area.

3. Determine the maximum single wheel load, tire pressure, maximum dual wheel load, tire pressure and the maximum dual tandem wheel load and tire pressure anticipated for the road during the design period. For example, a 10 yd^3 dump truck with tandem axles will have a dual wheel load of approximately 8,000 lb. A motor grader has a wheel load of approximately 5,000 to 10,000 lb.

4. Estimate the maximum amount of traffic anticipated for each design vehicle class.

5. Establish the amount of tolerable rutting during the design life of the roadway. For example, 2 to 3 inches of rutting is generally acceptable during construction.

6. Obtain appropriate subgrade stress level in terms of the bearing capacity factors in Table 5-1.

7. Determine the required aggregate thickness from the USFS design (Figures 5.2 to 5.16) for each maximum loading. Enter the curve with bearing capacity factors (N_c) of 2.8, 3.3, 5.0 and 6.0 times the design[16] subgrade undrained shear strength (c) to evaluate each required stress level ($C \cdot N_c$).

8. Select the design thickness based on the design requirements. The design depth should be given to the next highest 1 inch thickness as obtained from step 5.

9. Check the geotextile drainage and filtration requirements gradation of the subgrade, the permeability of the subgrade, the water table conditions, and the retention and permeability criteria given in chapter 2.[17] In high water table conditions, filtration criteria may also be required.

10. Check the survivability criteria as discussed in section 5.7.

11. Specify geotextiles which meet or exceed these criteria.

12. Follow construction recommendations as covered in section 5.11.

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[16]Ed. Note: The design subgrade shear strength is recommended at the 75th percentile (75% of measurements higher than design value).

[17]Ed. Note: "Guidelines" refers to the FHWA "Geotextile Design and Construction Guideline," by Christopher and Holtz (1989).

Table 5-2

Relationship of Construction Elements to Severity of Loading Imposed on Geotextile in Roadway Construction

	SEVERITY CATEGORY		
VARIABLE	LOW	MODERATE	HIGH TO VERY HIGH
Equipment	Lightweight dozer (8 psi) wheeled equipment (8-40 psi)	Mediumweight dozer; light (>40 psi)	Heavyweight dozer; loaded dump truck
Subgrade Condition	Cleared	Partial cleared	Not cleared
Subgrade Strength (CBR)	<0.5	1-2	>3
Aggregate	Rounded sandy gravel	Coarse angular gravel	Cobbles, blasted rock
Lift Thickness (in.)	18	12	6

Table 5-3

Geotextile Strength Required for
Survivability During Construction

AASHTO-AGC-ARTBA JOINT COMMITTEE
(Interim Specifications)
Mimimum[1] Fabric Properties Required for Fabric Survivability[18]

Required Degree	Puncture Strength[3]	Tear Survivability (lbs)	Grab Strength[2] Trap[5] of Fabric (minimum values) (lbs)	Burst Strength[4] (psi)
Very High	270	110	430	75
High	180	75	290	50
Moderate	130	40	210	40
Low	90	30	145	30

[1]All values represent minimum average roll values (i.e., any roll in a lot should meet or exceed the minimum values in this table). Note: These values are normally 20 percent lower than manufacturer's reported typical values.

[2]ASTM D-4632. Grab Method.

[3]ASTM D-4833.

[4]ASTM D-3787, Diaphragm Test Method.

[5]ASTM D-4535, either principal direction.

[18]Ed. Note: The values in Table 5.3 are similar to Table 820-1 in "Forest Service Specifications for Construction of Roads and Minor Drainage Structures," EM-7720-100R, 1985.

Table 5-3	Table 720-1
Very High	(C) Heavy Duty Stabilization
High	(B) Normal Stabilization
Moderate, Low	(A) Seperation

Table 5-4

Geotextile Drainage and
Filtration Requirements

I. RETENTION

Wovens:[19] $O_{95} \leq D_{85}$

Nonwovens: $O_{95} \leq 1.8\ D_{85}$

For both: $O_{95} \geq 0.3$ mm (U.S. No. 50 sieve)

II. PERMEABILITY

$k_{geotextile}\ k_{soil}$

III. CLOGGING

Filtration tests may be warranted in high water table situations. See section 2.3.3 of these Guidelines.[20]

Table 5-5

Recommended Minimum Overlap Requirements

CBR	Minimum Overlap
Greater than 2	1 - 1.5 feet
1 - 2	2 - 3 feet
0.5 - 1	3 feet or sewn
Less than 0.5	Sewn
All roll ends	3 feet or sewn

[19]Ed. Note: O_{95} is the opening size of the geotextile at which 95 percent of openings are smaller when measured with sand. D_{85} is the size of the soil particle where 85 percent of particles are smaller than this size.

[20]Ed. Note: "Guidelines" refer to the FHWA "Geotextile Design and Construction Guideline," by Christopher and Holtz (1989).

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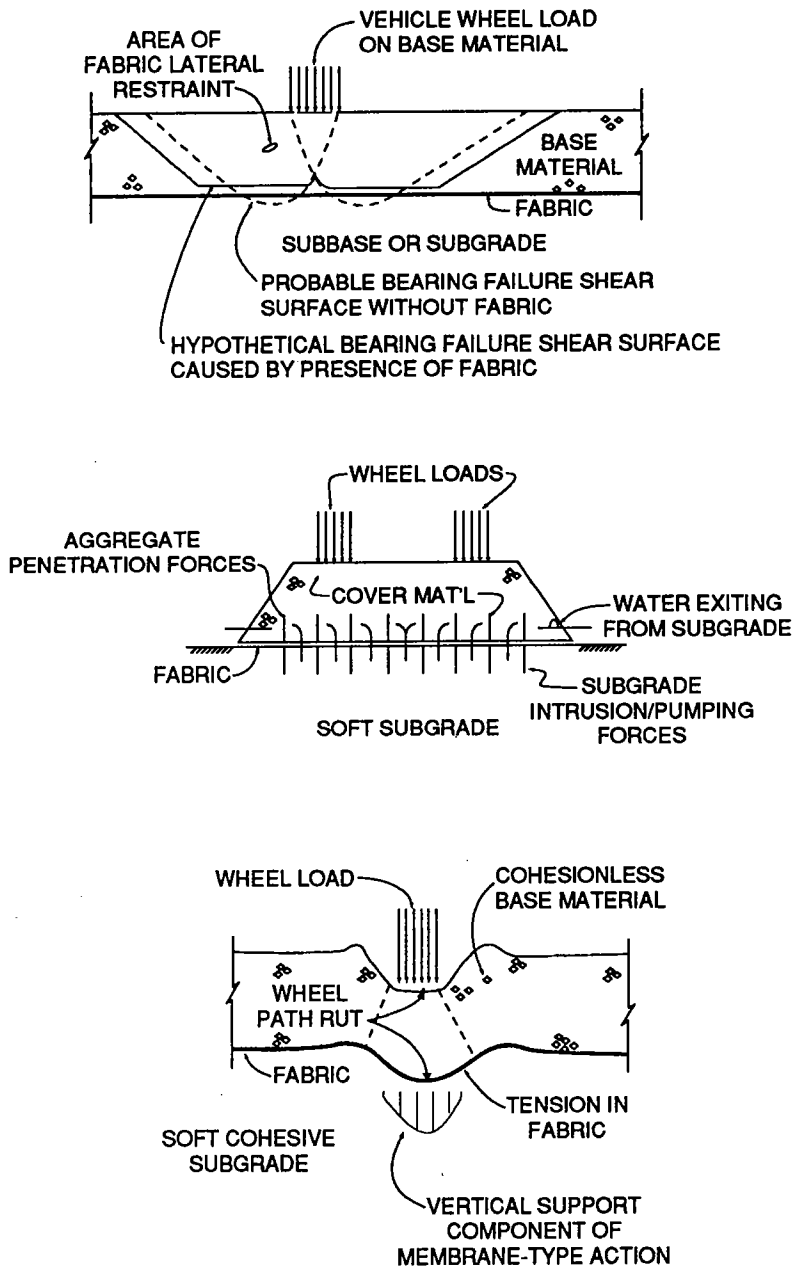


Figure 5.1 Primary and secondary functions of geotextile in roadway applications.

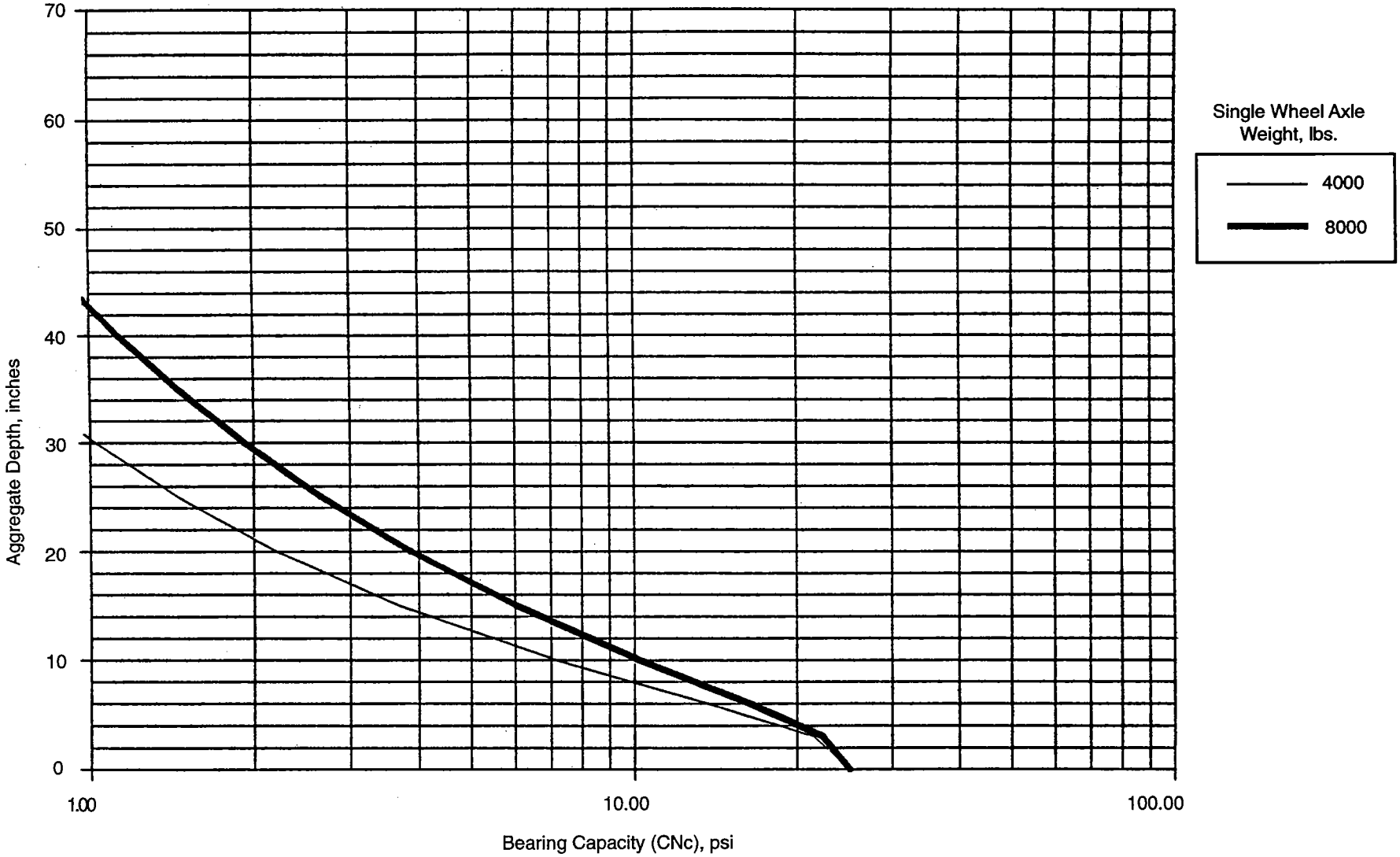


Figure 5.2 Single wheel load, one layer system, tire pressure = 25 psi.

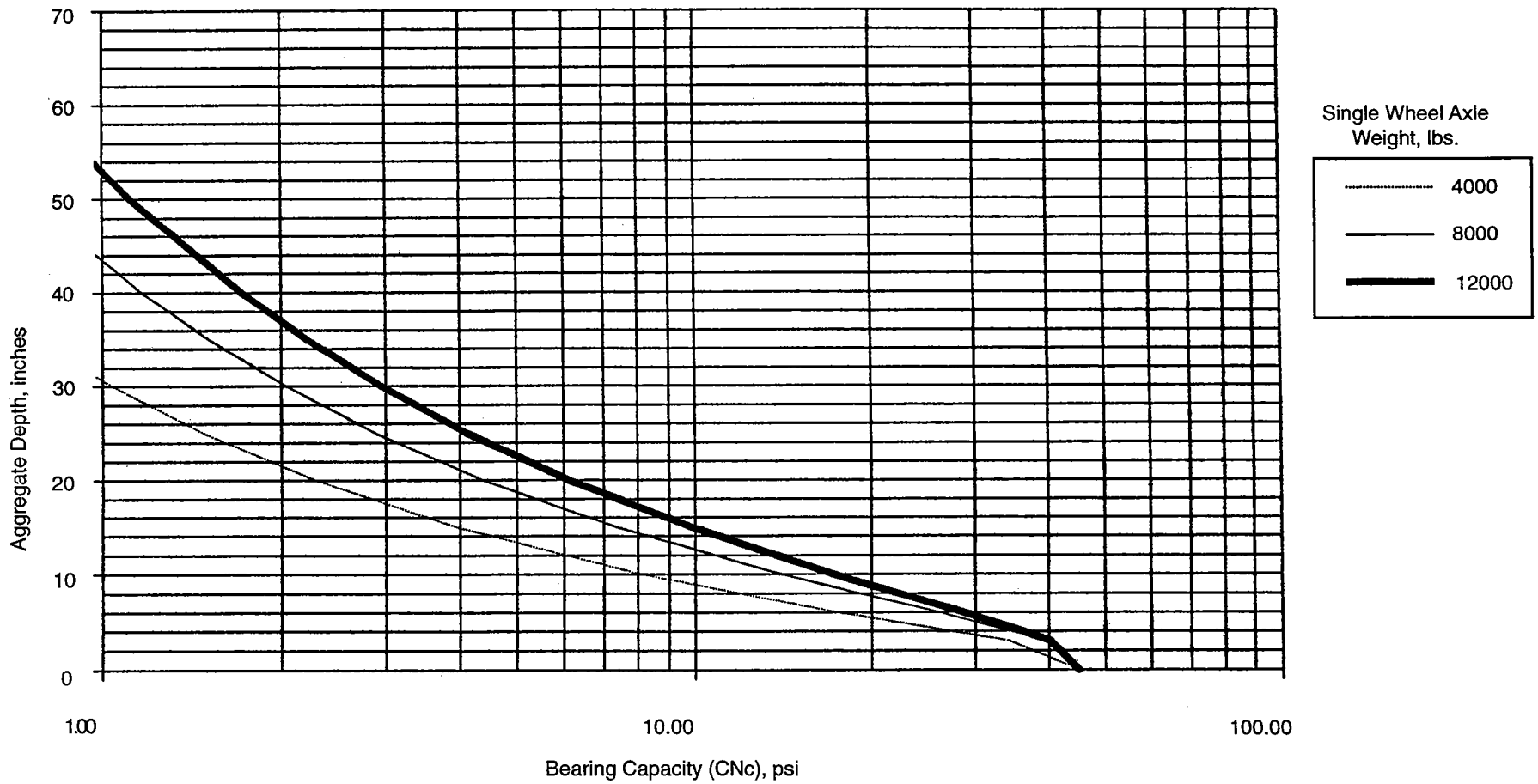


Figure 5.3 Single wheel load, one layer system, tire pressure = 45 psi.

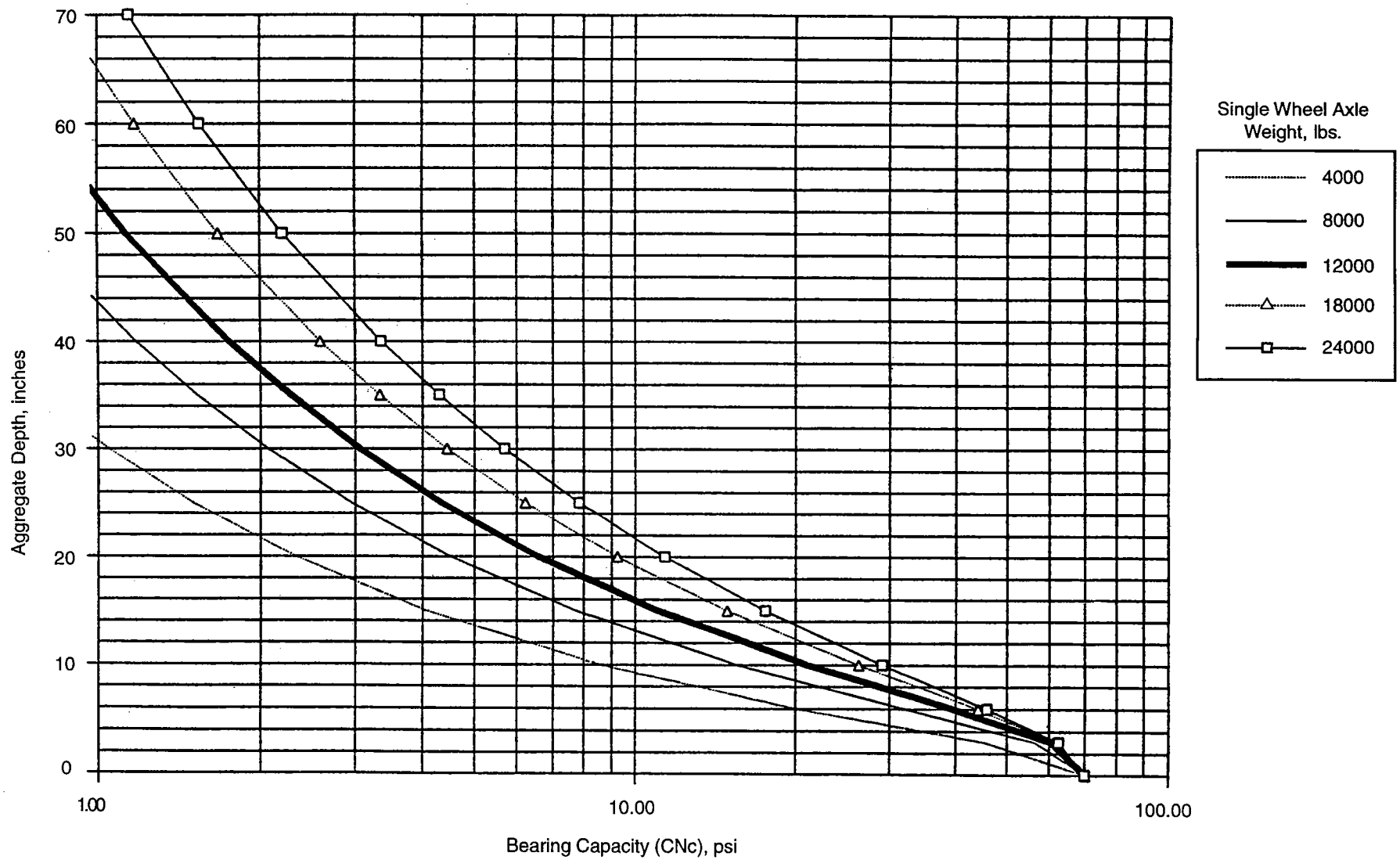


Figure 5.4 Single wheel load, one layer system, tire pressure = 70 psi.

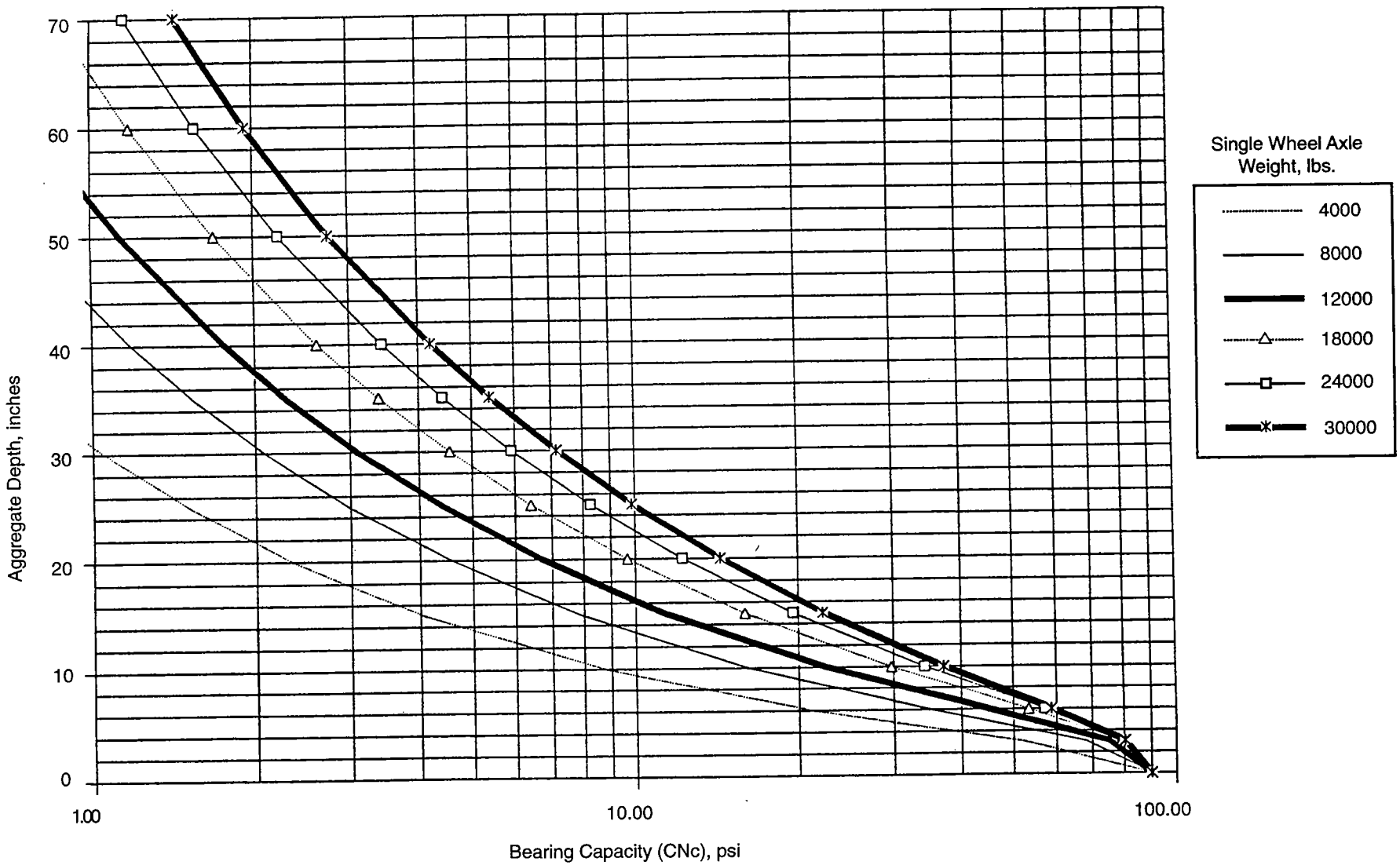


Figure 5.5 Single wheel load, one layer system, tire pressure = 90 psi.

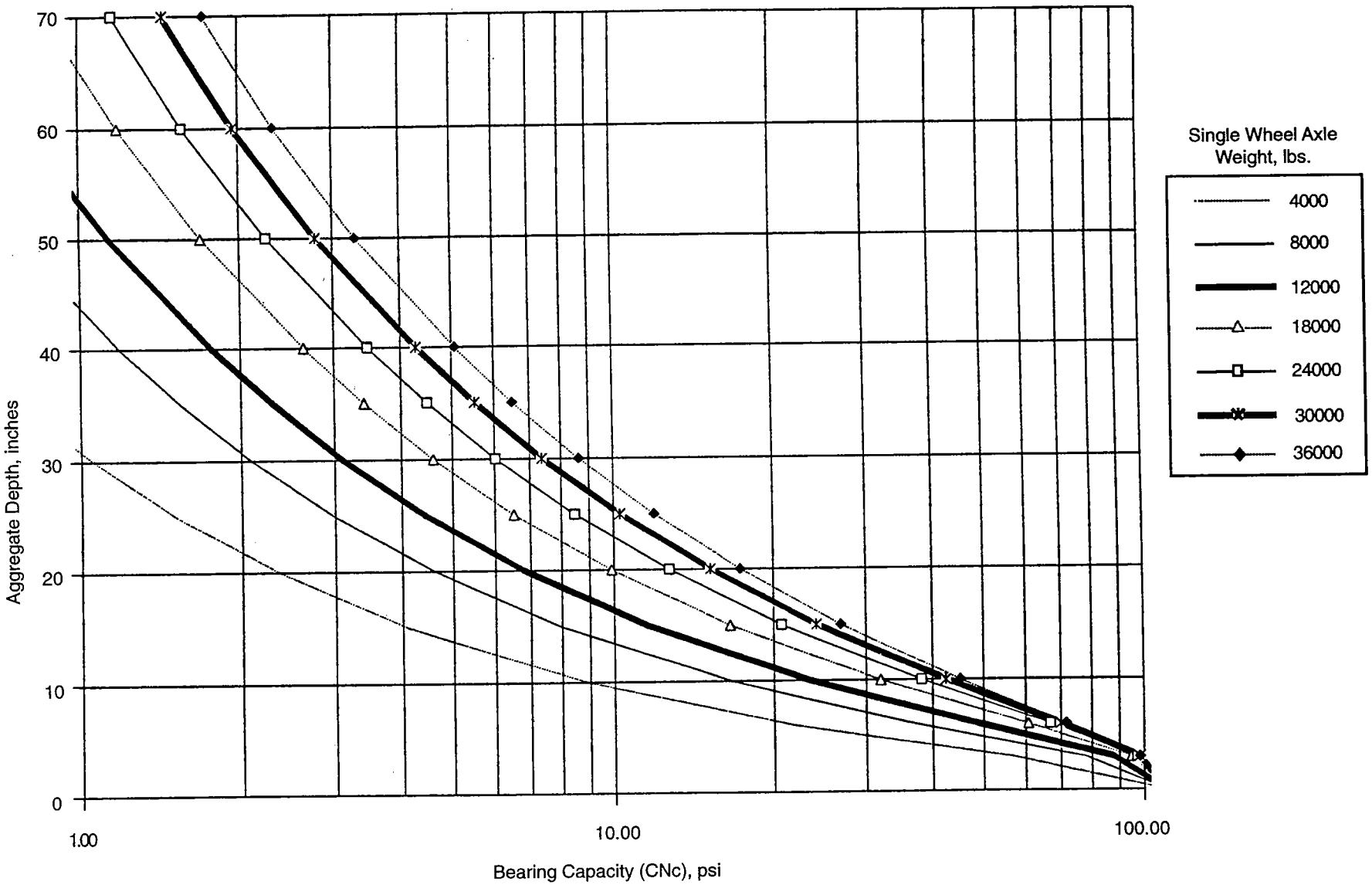


Figure 5.6 Single wheel load, one layer system, tire pressure = 110 psi.

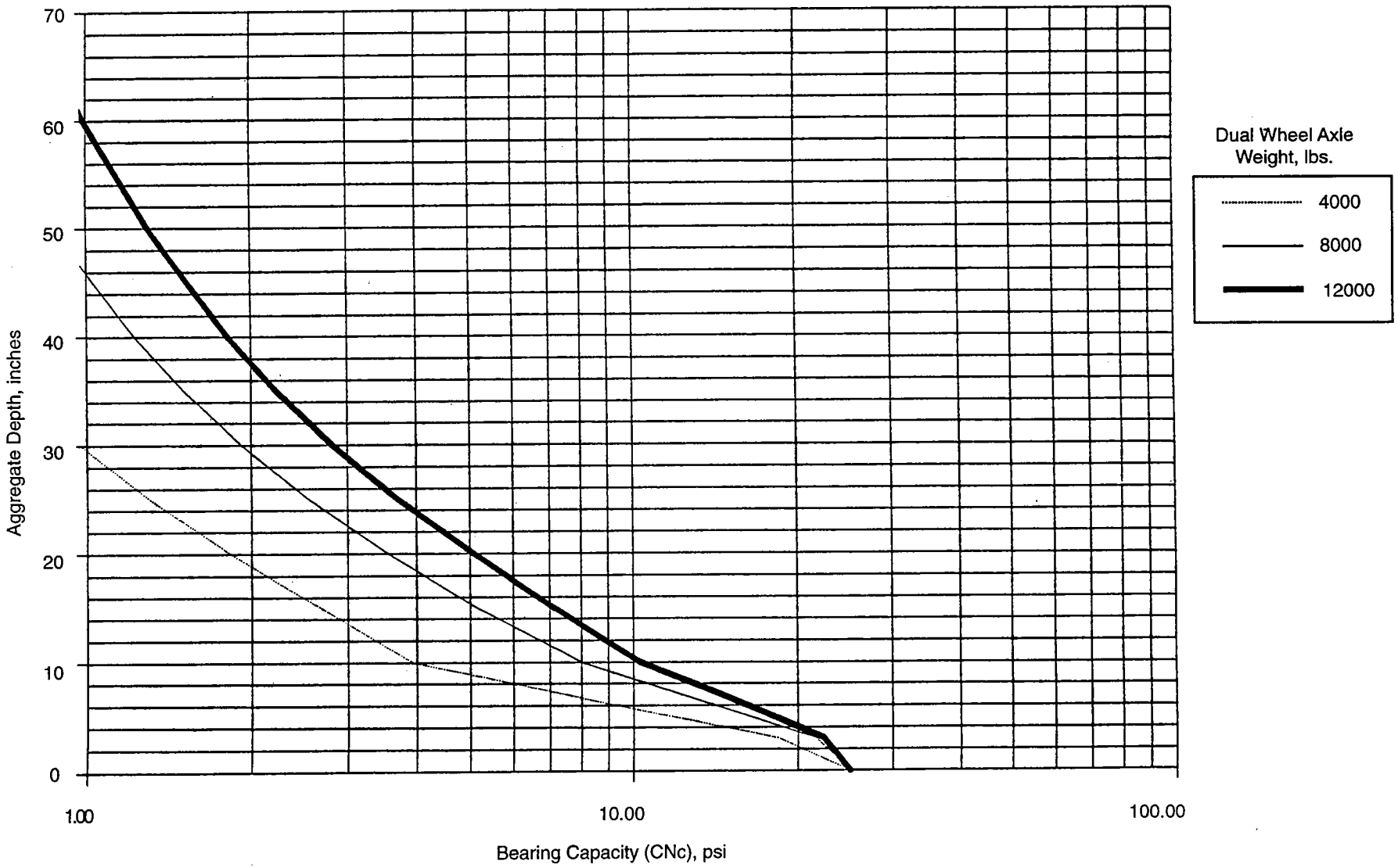


Figure 5.7 Dual wheel load, one layer system, tire pressure = 25 psi.

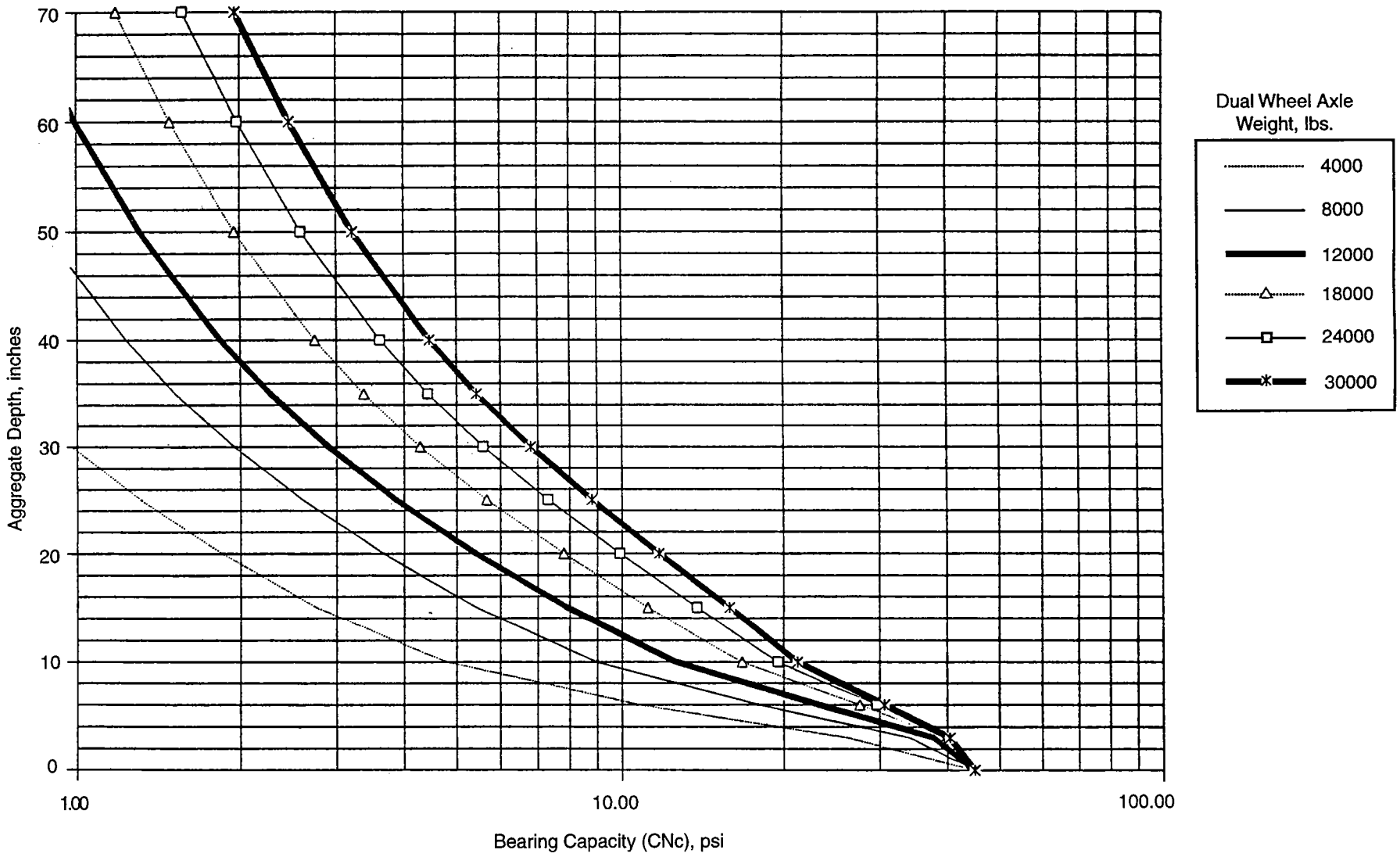


Figure 5.8 Dual wheel load, one layer system, tire pressure = 45 psi.

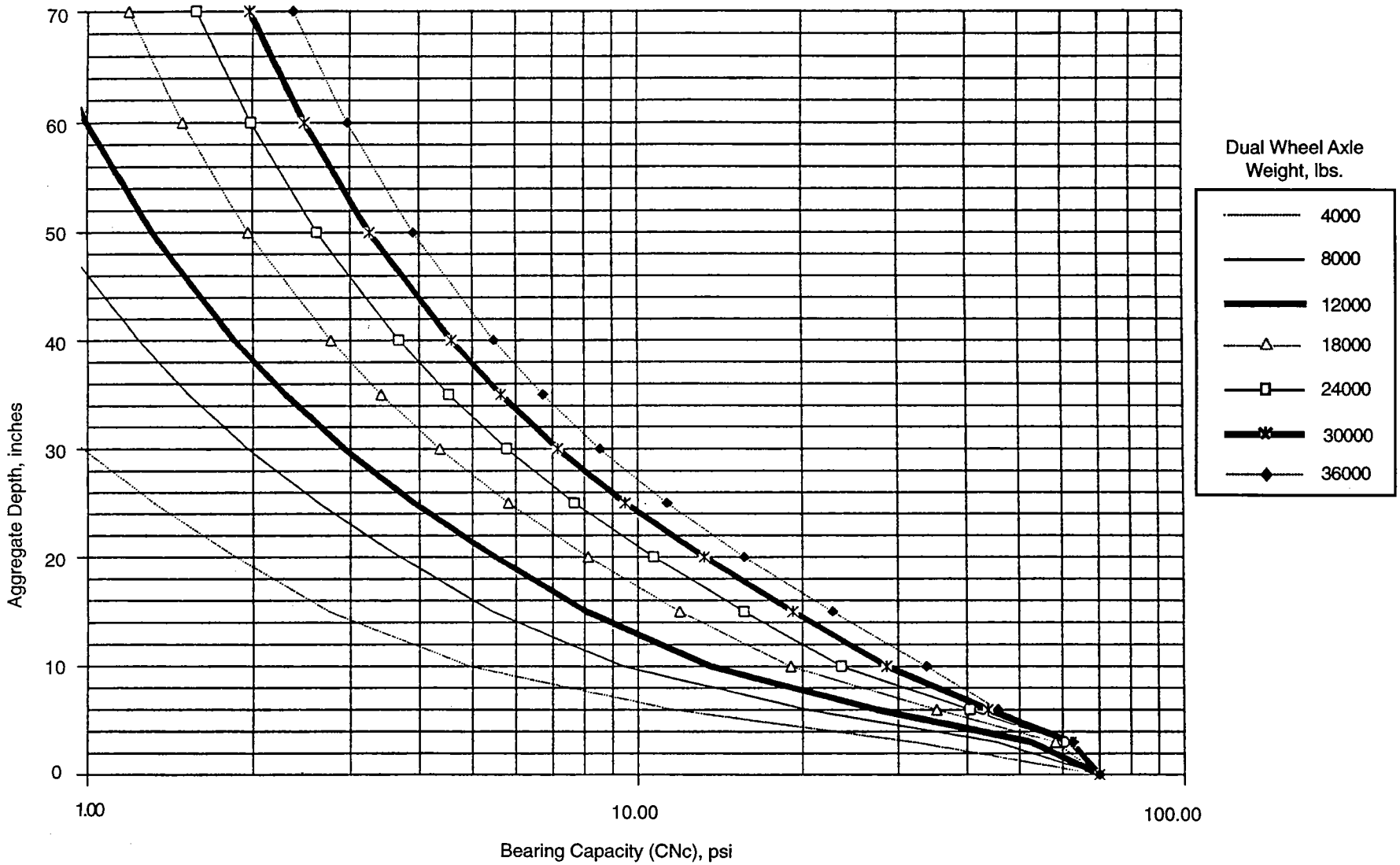


Figure 5.9 Dual wheel load, one layer system, tire pressure = 70 psi.

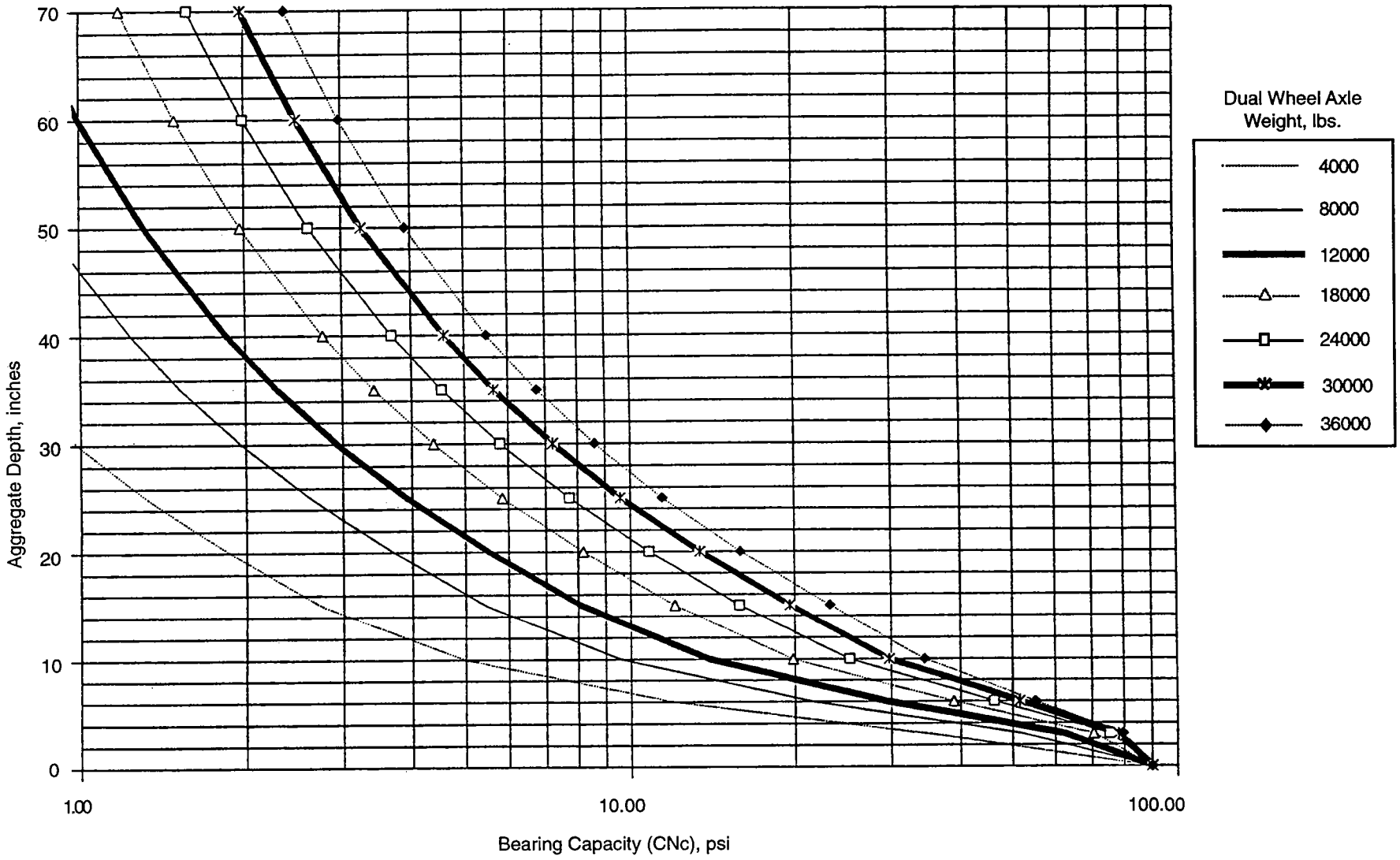


Figure 5.10 Dual wheel load, one layer system, tire pressure = 90 psi.

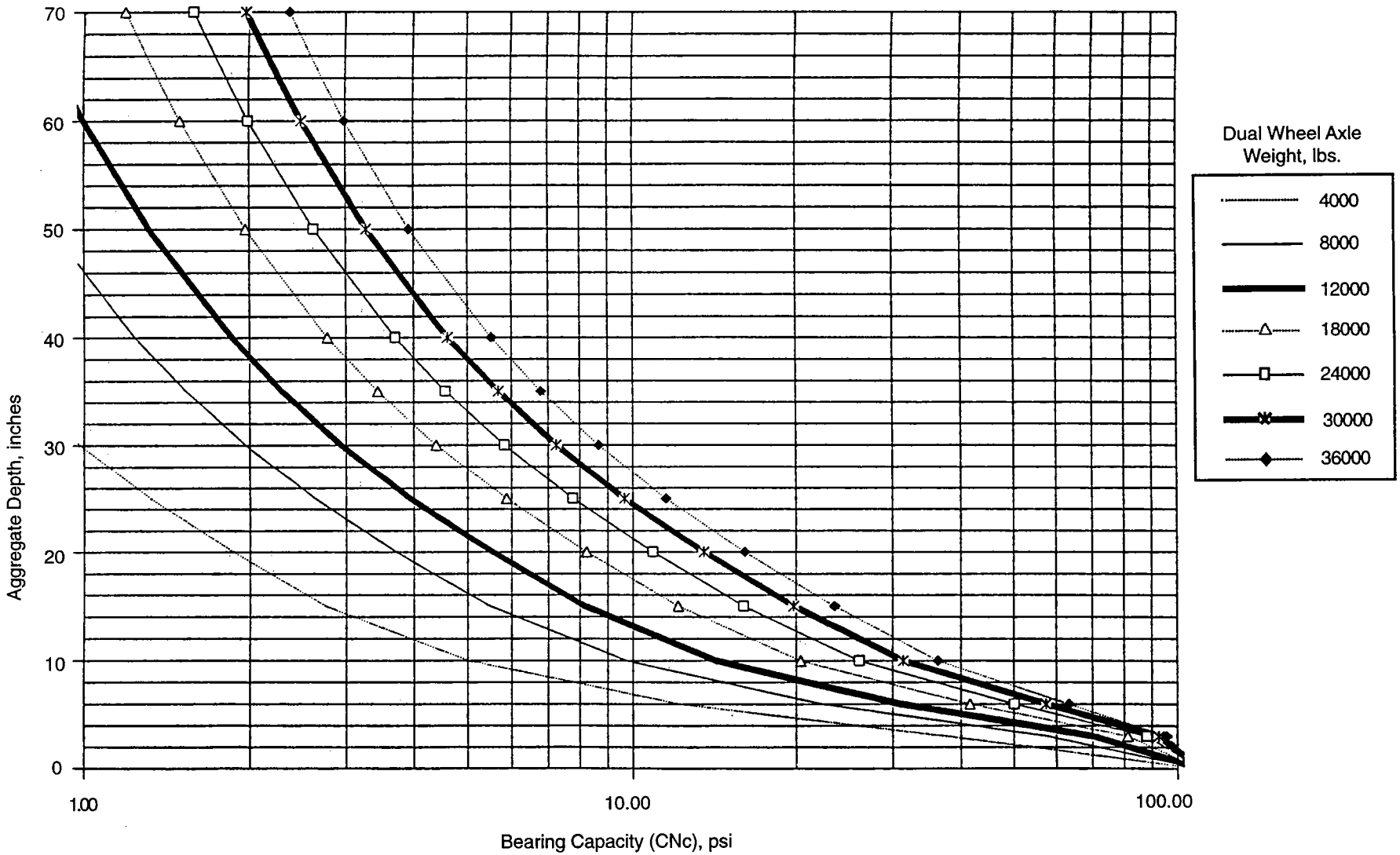


Figure 5.11 Dual wheel load, one layer system, tire pressure = 110 psi.

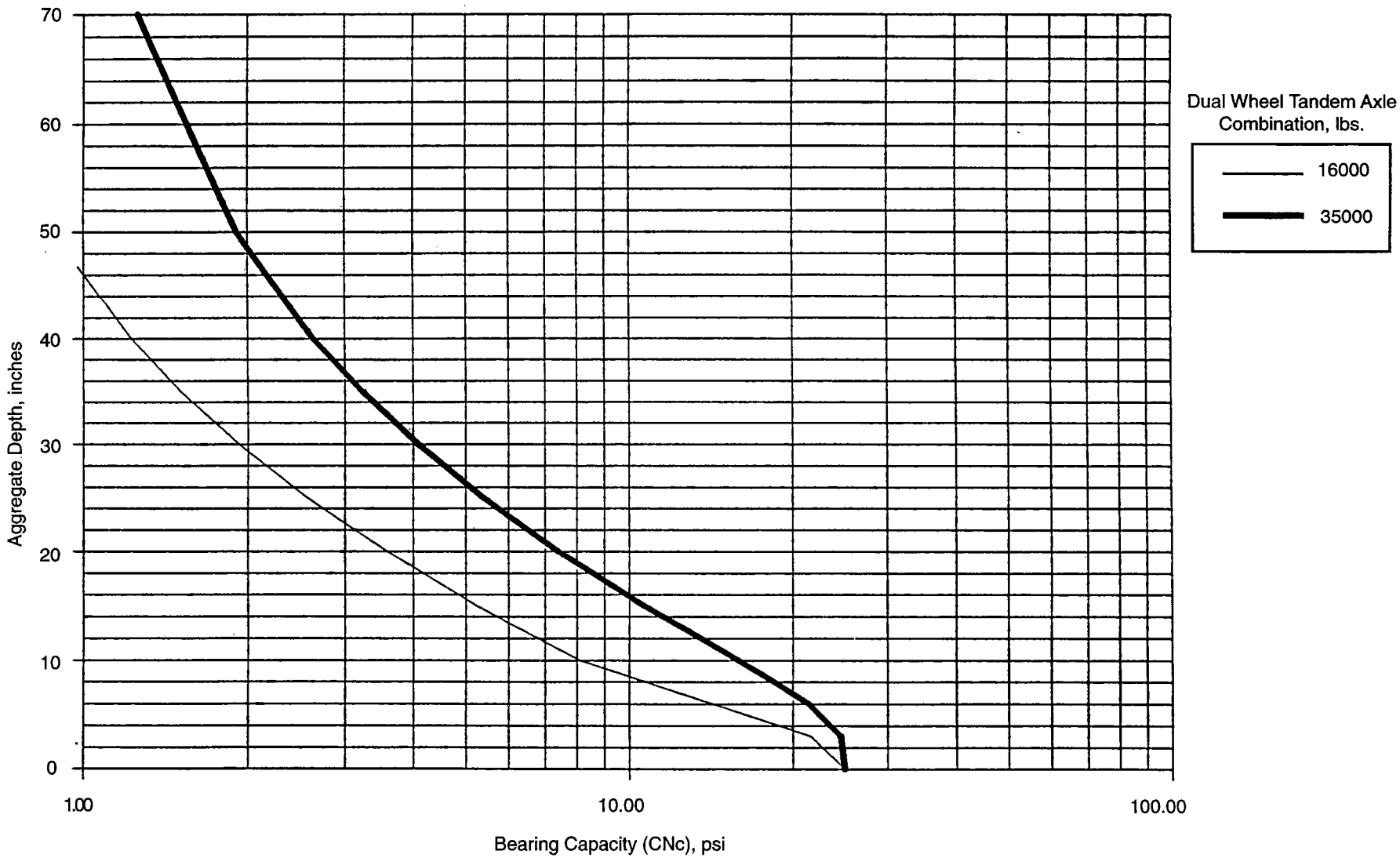


Figure 5.12 Tandem axle load, one layer system, tire pressure = 25 psi.

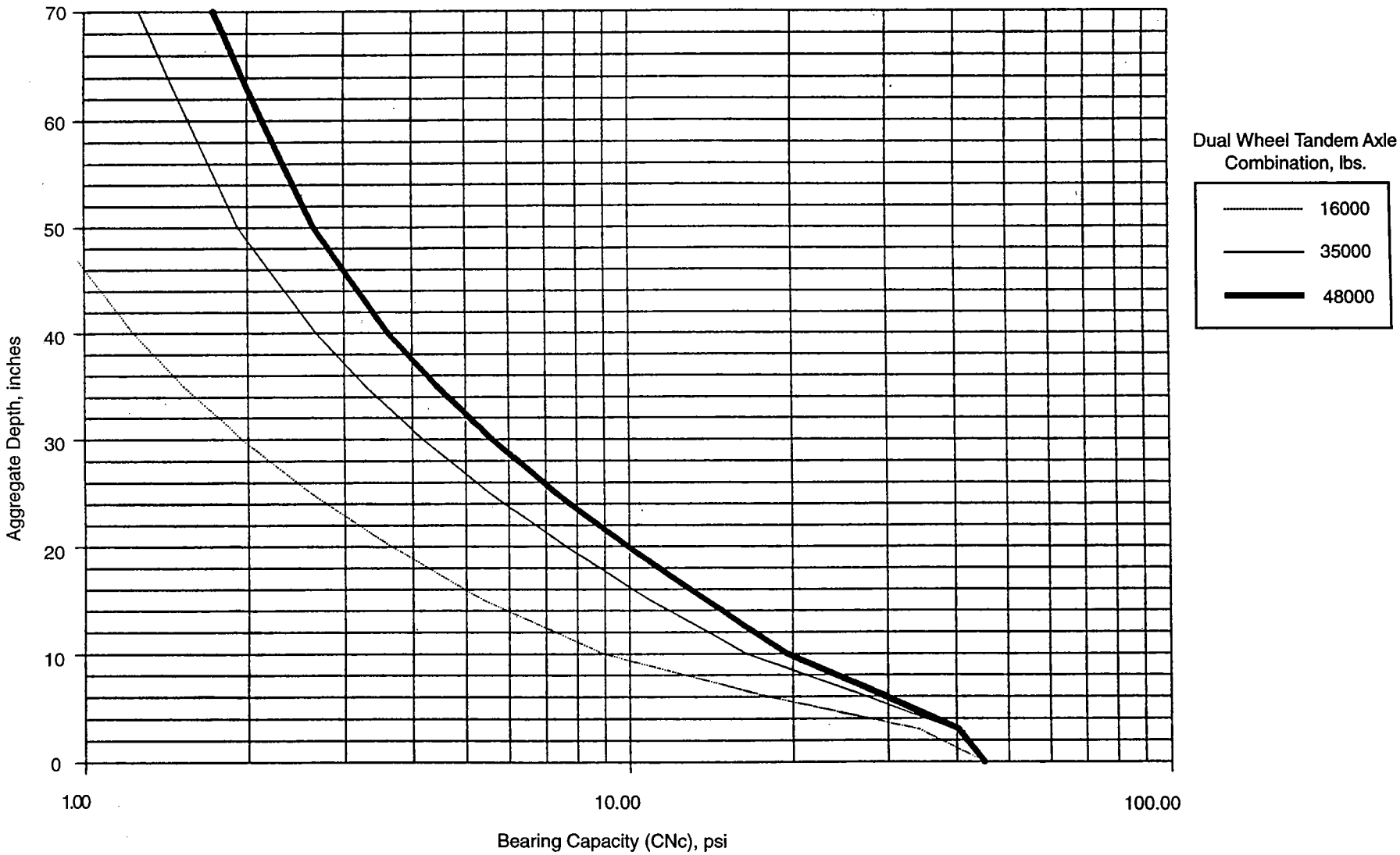


Figure 5.13 Tandem axle load, one layer system, tire pressure = 45 psi.

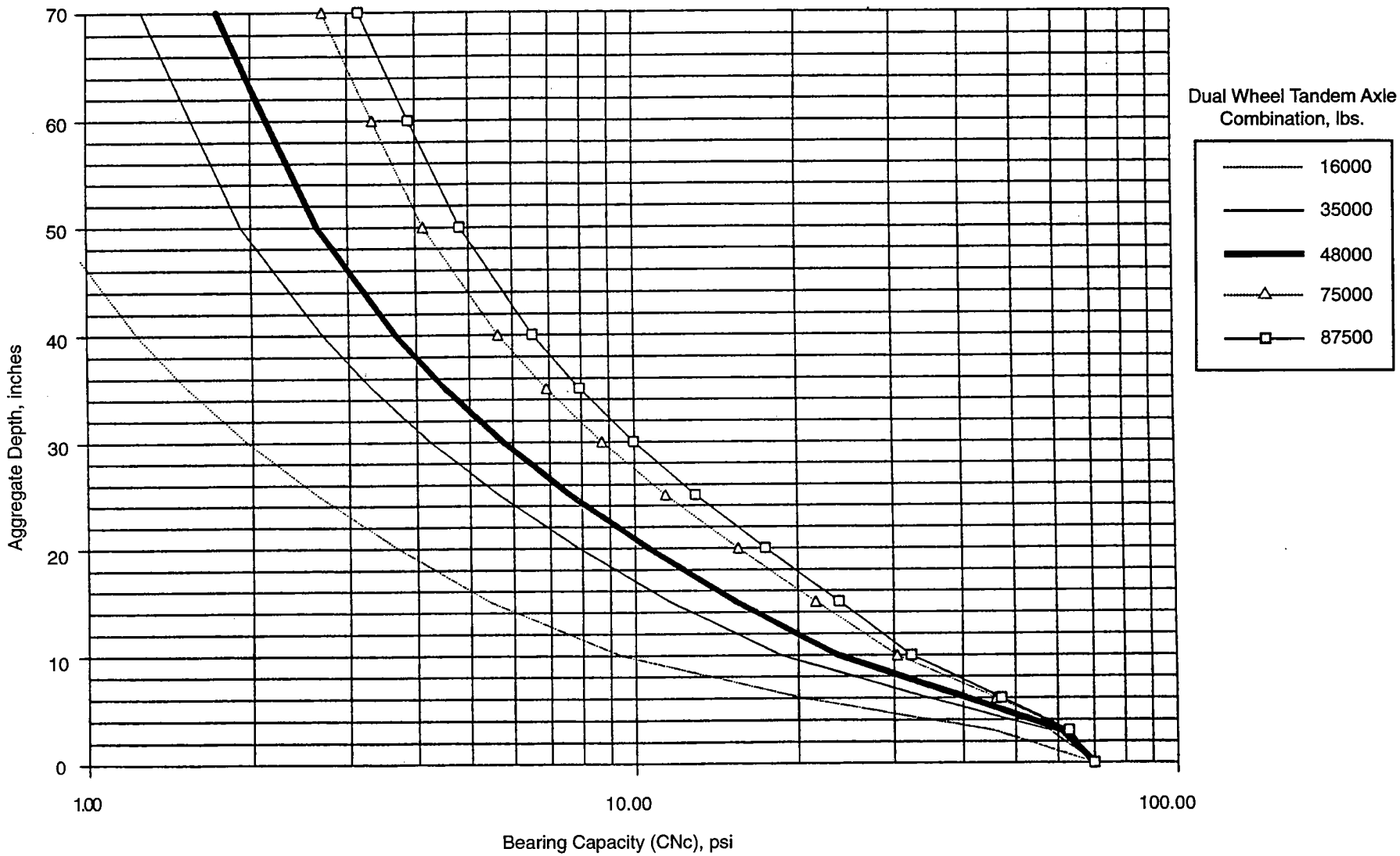


Figure 5.14 Tandem axle load, one layer system, tire pressure = 70 psi.

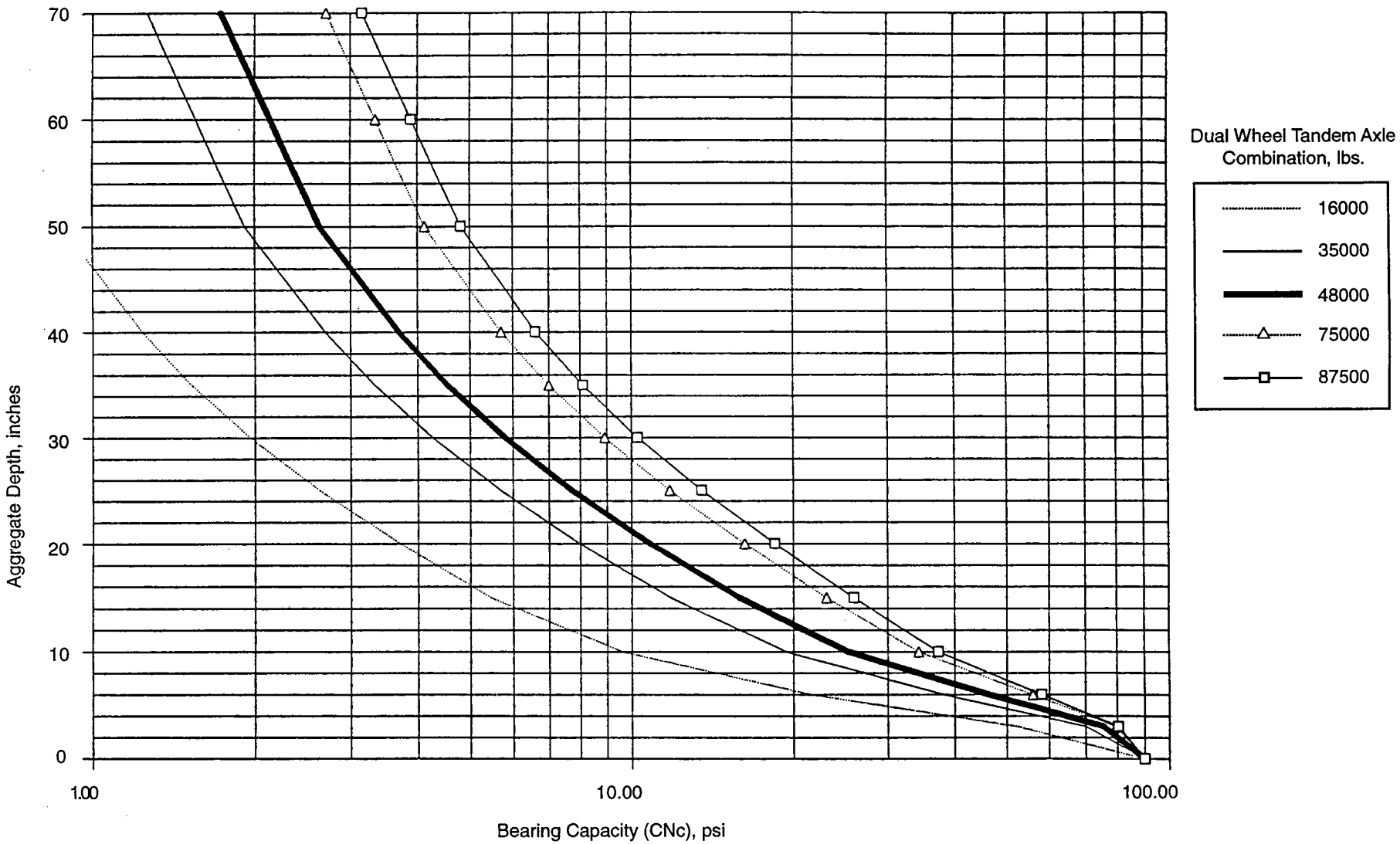


Figure 5.15 Tandem axle load, one layer system, tire pressure = 90 psi.

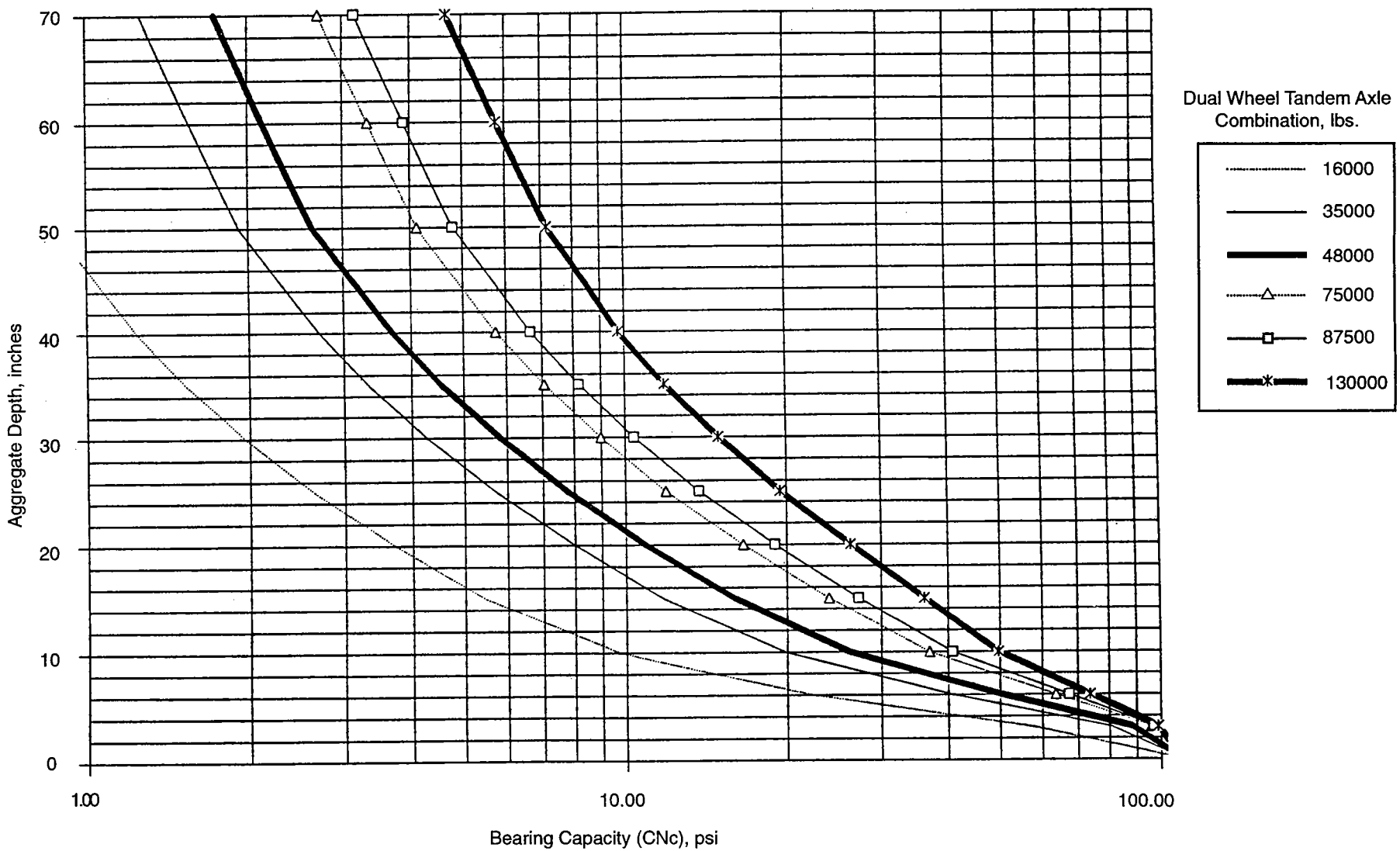
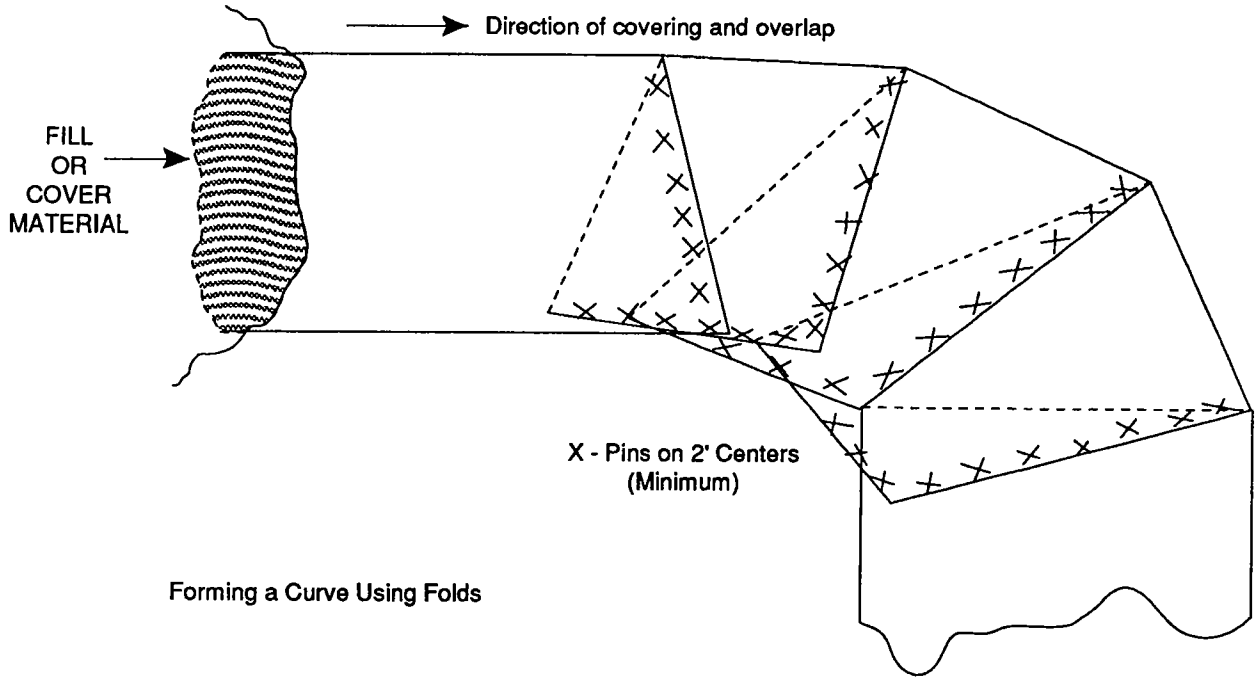


Figure 5.16 Tandem axle load, one layer system, tire pressure = 110 psi.



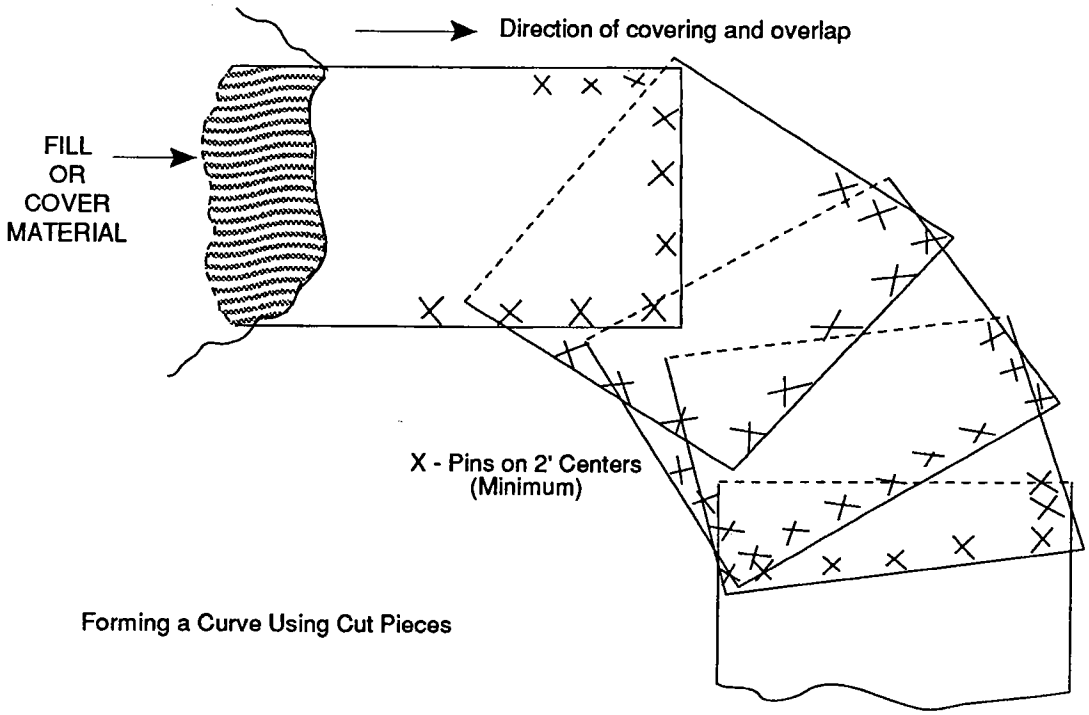
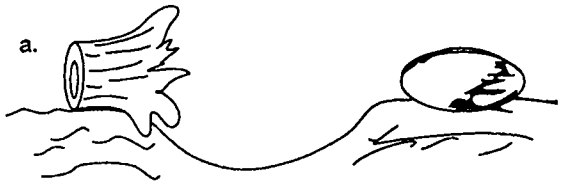


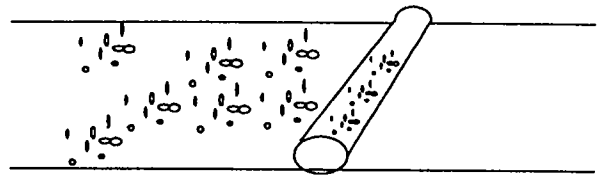
Figure 5.17 Forming curves using geotextiles.

a.



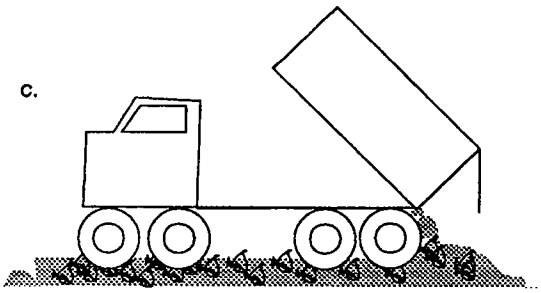
1. Prepare the ground by removing stumps, boulders, etc,; Fill in low spots.

b.



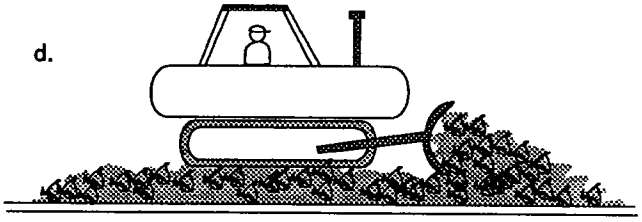
2. Unroll the geotextile directly over the ground to be stabilized. If more than one roll width is required, overlap rolls. Inspect geotextile.

c.



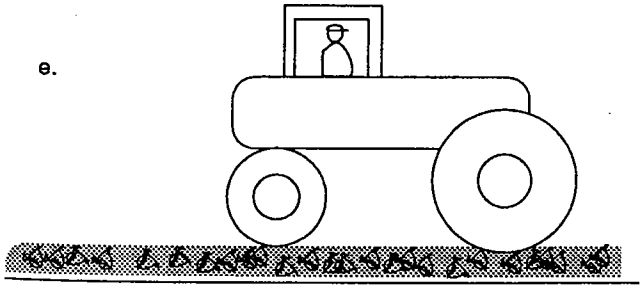
3. Back dump aggregate onto previously placed aggregate. Do not drive directly on the geotextile. Maintain at least 6" to 1' cover between truck tires and geotextile. [11]

d.



4. Spread the aggregate over the geotextile to the design thickness.

e.



5. Compact the aggregate using dozer tracks or vibratory roller. [12,13]

11. Ed Note: For temporary roads, the entire depth of aggregate, determined using figure 5.2 to 5.16, must be placed before loaded trucks are driven across aggregate.

12. Ed Note: Use extreme caution using vibrating mode over wet subgrades.

13. Ed Note: Adjust final depth in the field (2 to 3 inch increments) during construction if rutting greater than 2 to 4 inches occurs under a few passes of haul trucks, after aggregate is spread and compacted.

Figure 5.18 Construction sequence using geotextiles.

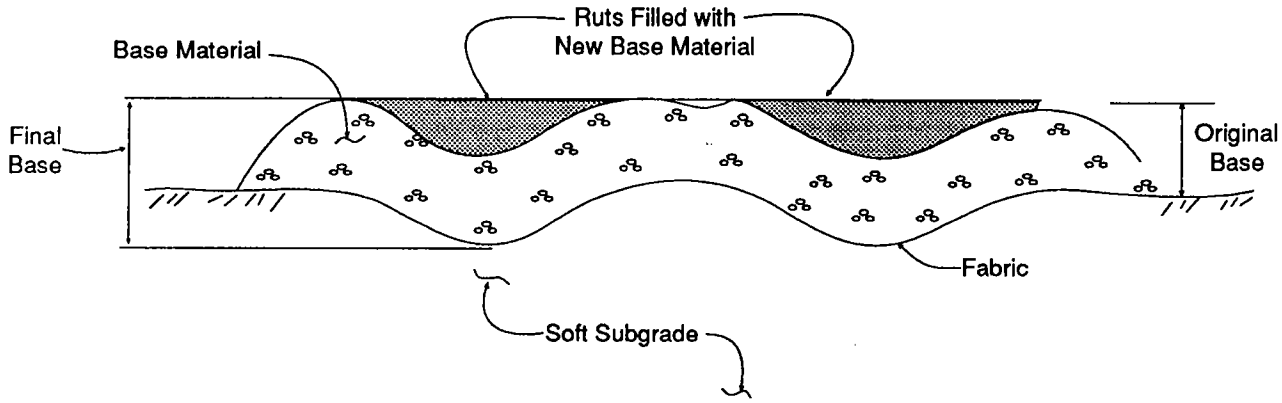


Figure 5.19 Repair of rutting with additional base material.

6.6 Alternative Surfacing Materials—Design Method

6.6.1 Introduction

There are many alternative surfacing materials. Most have no established procedures for designing them to support traffic loads. This appendix provides information and points to resources that will help you put alternative surfaces to use on your projects.

Interest in alternative wood particles surfacing is growing (i.e. chunkwood technology). Because the potential use of these materials is high, an effort was undertaken to develop a thickness design method for wood surfacing based on full scale laboratory testing of hog fuel, woodchip and aggregate materials. The results of this and other wood application studies and projects are presented here in the form of a construction and design guideline for application on your upcoming projects.

6.6.1.1 Road Management Objectives

Road Management Objectives (RMO's) guidelines are established in FSM 7712.37. On the basis of management direction, they establish the specific intended purposes (FMS 7701, paragraph 7), of new projects. Criteria to consider are design, operation, maintenance. The planning stage determines the intended use and life of the road. During this stage the design criteria (FSM 7721.1) for determining standards are: cost of transportation, safety, and impacts on land and resources. Other design criteria for consideration are: legal requirements, ecosystem effects, road users, vehicle characteristics, and traffic requirements. During both stages considerations should be given to all types of road surfaces including earth or native surfaces, rock aggregate, and alternative surfaces.

6.6.1.2 Alternative Surfaces

The Forest Service maintains over 350,000 miles of arterial, collector, and local roads. The majority of these are single-lane low standard roads with either native or rock aggregate surfaces. Rock aggregates are often needed for providing a surfacing to help support heavy truck loads. The competition for and scarcity of rock resources makes the cost very high to provide rock surfacing in some areas. Limiting use of these roads to dry seasons when soil strength is high is often an adequate means of allowing their use without providing surfacing. But some areas require surfacing for extended wet season use, year-round structural support over wet or weak soils, traction, or erosion control. When rock is expensive, alternative materials should be considered since they can be cost competitive with rock surfaces in some areas.

The term "alternative materials" refers to materials not commonly used by the Forest Service today. Examples of alternative materials include:

- Non-rock "aggregates": wood chips, chunkwood, rubber tire chunks, oyster shells.
- Structural elements: metal landing mats, paving blocks, logs.
- Chemical additives: lime, cement, organic and petrochemical resins (see appendix 6.7)

6.6.1.3 Alternative Surface for Forest Road Study

In the early 1980's, Oregon State University undertook a study, "Evaluation of Alternative Surfaces for Forest Roads," for USFS San Dimas Technology and Development Center. The scope of this study included a comprehensive review of Naval civil engineering lab reports, U.S. Army Corps of Engineers Waterways Experimentation Station and Cold Regions Research and Engineering laboratory reports, selected U.S. companies, and U.S. Forest Service experiences with alternative materials for road surfacing. A detailed study of the most feasible materials was then undertaken, demonstration projects built and evaluated, and reports written providing the cost, characteristics, and benefits of each material. Finally, a PC program "ALTSURF" was developed to enable the user to determine and compare total life cycle costs for alternative materials as well as aggregate-surfaced roads (1,2). A list of the most promising materials for Forest Service use includes: wood and bark chips, chemical stabilization, reusable aggregates, sand seal membrane, marginal aggregate, and steel landing mats for emergency access use.

6.6.1.4 Alternative Wood Surfaces

Wood has long been used in a variety of ways for road construction. Perhaps the most familiar application is in wooden bridges, for decking as well as for structural purposes. For temporary or emergency purposes, especially in swampy circumstances, corduroy roads were built with logs placed adjacent and parallel to each other, crosswise to the direction of travel. Even wooden blocks were used for street paving (5). Wood fibers and paper mill sludge have been used for erosion control and road surface stabilization.

The use of sawdust, chips, or chunks for road embankments, subgrades, or surfaces is of relatively recent origin. These materials vary in size and shape. Generally, sawdust is three-eights of an inch or less in greatest dimension and flat in shape. Woodchips vary from about 1/2 to 3 inches in their greatest dimension and are flat in shape. Chunkwood varies from about 2 to 4 inches in length and is blocky and angular in shape. In the field, products such as small diameter logs or snags, logging slash (debris), and stumps can be produced during construction or logging activities. Then, by using specialized equipment they are turned into other products such as hogged fuel (shredded wood and bark), woodchips or woodchunks and used for construction. In addition, some of the products such as hogged fuel, sawmill pile run, woodchips, or shake mill spall can be purchased locally from lumber mills or lumber processing plants (see Guide Special Project Specification, Section 703W —Wood Aggregate). (Note: Many of the material names in this section are common or local names within the Pacific Northwest Softwood Industry. Other names for similar materials may be used in other locations.)

Chunkwood is the term describing wood fragments produced from trees or logging residues by a woodchunking machine (19). It was originally produced as an efficiently sized material for use as fuel, raw material for flakeboard, and pulping (24). Experimental use has shown it can function well as a road building material. Chunkwood was first used on the Chequamegon National Forest in 1987 for a swamp crossing, "Sugar Sand" stabilization, and low areas with standing water (8). Other demonstration roads were built in Mississippi, Oregon, Alaska, Pennsylvania, and British Columbia, Canada. Use is limited at the time of this writing due to lack of machinery to produce chunks. Only experimental machines exist at this time.

Chunkwood fragments vary widely in size, with a typical chunk about the size of a person's fist. A typical chunkwood product has both larger and wider ranges of particle sizes than woodchips, hogged fuel, or sawdust. This results in good particle interlock to form a relatively stable matrix. Chunkwood is more permeable than chips, so water readily flows through it whereas woodchips form a relatively impermeable matrix that can disrupt natural drainage. These are highly desirable characteristics for embankment and subgrade construction. Chunkwood has a weight of about one-fifth that of gravel and is an excellent lightweight fill material.

Compared to mineral aggregates, wood may not be as durable. This biodegradable characteristic may be considered desirable for temporary roads because the material will easily support natural revegetation, acting as both a growth medium and mulch. All wood and bark materials have similar characteristics such as the ability to support vehicle loads as a fill material or base, high compressibility, lightweight, and compatible when constructed with conventional equipment and methods. Most can also be used as a surfacing material, but because of their high compressibility, traffic is limited to high clearance vehicles unless special precautions are taken during construction and maintenance is performed periodically during use. In some situations a road can be built entirely of wood materials, while others can be built by combining wood materials with sand, gravel, aggregate, and geotextiles. Woodchips, shavings, hogged fuel and bark materials are not as permeable or durable as chunkwood (because of its larger particle volume), but may be available locally and may have an economic advantage over other materials.

6.6.1.5 Other Alternative Surfaces

Other nonwood aggregate materials that have been studied include rubber tires and tire chunks (22, 23). These can be used as subgrade reinforcement, fill, or base material. They may be suitable as a road surfacing and have ride and construction characteristics similar to chunkwood such as lightweight, good drainage, large particle size, and high compressibility. They are not biodegradable and no leachate problems have been found in environmental studies (22, 23). Some tire punctures have resulted from driving on surfaces with tire chunks that have steel wire reinforcement protruding from their edges. For this reason, rubber chunks and chips may be more suitable to road fill and base than surfacing.

Other locally available materials such as oyster shells, coral, and metal processing slag have been used successfully as road surfacing, but are beyond the scope of this document.

6.6.2 Applications

Alternative nonrock aggregate materials can be used in most of the ways that traditional rock aggregates can be used. As with any material, knowledge of its properties and performance characteristics are needed before proceeding with design. Table 6.6.1 lists some of these basic properties.

6.6.2.1 Running Surface Characteristics of Wood and Rubber

Desirable qualities for a running surface include low cost, ease of construction and maintenance, impermeability, and good friction characteristics for braking, climbing steep grades, and general traction. As with rock aggregates, particle sizes and their shapes greatly influence how various aggregates may behave. Dense three-quarters of an inch minus aggregate has good surfacing characteristics but may become muddy with too many fines or surface contamination. Open-graded 2-inch aggregate is not impermeable nor does it have good stability on grades, curves, or shoulders. The range of wood and rubber aggregates listed below varies from fine, dense, low permeability materials such as sawdust, chips, and hogged fuel to coarse, loose, high permeability materials such as chunkwood or rubber chunks. They vary in frictional characteristics and their particle shape influences the compaction achieved during construction. Not all these materials make ideal surfacing. Running surfaces provided directly by wood or rubber aggregates are similar to rock aggregate surfaces in the following ways:

- They spread the stress of a wheel load onto the subgrade.
- They can be maintained with conventional equipment such as a bulldozer or grader.
- They have similar construction methods for hauling, dumping, spreading, and compacting.
- They can be combined with geotextiles to provide separation and/or reinforcement.

They differ in the following ways:

- They provide a softer, more flexible ride, similar to low tire pressure equipment.
- They develop ruts 3–10 inches deep depending on the method of surfacing compaction. Large particles and deep ruts may make passage of low clearance vehicles impossible or dangerous to their undercarriage. High clearance vehicles may be required to operate on these roads. The depth of rut developed is controllable through compaction and maintenance. A 3–5 inch rut is common on many projects.

- They provide less traction when wet or dry, limiting use to grades of about 8 percent.

- They are biodegradable.

- Vehicle traffic causes a further breakdown in particle size, which increases surfacing stability, improves particle interlocking, and results in a reduced rate of rutting.

Coarse wood aggregates such as chunkwood, hogged fuel, and large chipped wood can be mixed with rock aggregates or soil to fill void spaces and achieve a denser, less flexible material. This mixing can improve the frictional characteristics to improve traffic ability.

6.6.2.2 Base Characteristics of Wood and Rubber

Desirable qualities of a base material include low cost, ease of construction, good drainage, and good ability to distribute surfacing stresses to the underlying subbase or subgrade. Wood and rubber aggregates can provide base material varying in drainage ability from excellent to poor (this is not always a required characteristic of a base material). Wood or rubber aggregate base covered with rock aggregate surfacing may result in a more desirable combination of cost and performance where rock costs are high but a "normal" road surface is required for other reasons such as steep grades, low clearance vehicle traffic, or the desire for a higher quality surface.

6.6.2.3 Light Fill Characteristics of Wood and Rubber

Wood and rubber aggregates can also be used as lightweight fill material in landslide areas and to "bridge" over soft subgrades or wet areas such as peat or muskeg subgrades, where a thick but lightweight fill material is required to prevent displacement of the underlying material. These environments require geotechnical investigation and design to determine how much material is required to support a vehicle load but will not cause a failure by adding too much weight. Wood and rubber aggregates have an advantage of weighing 30–50 percent of typical aggregate materials. Table 6.6.1 summarizes various alternative materials characteristics.

Table 6.6.1.—General properties of alternative aggregates.

Product	Drainage	Sizes	Shape
Hogged fuel	moderate	6" to .2"	shredded fibers
Sawmill pile run	poor	4" long	shredded fibers to fine dust
Wood shavings	moderate	1" wide	curled thin shavings
Sawdust	poor	1/8" to 3/8" wide	thin chips
Woodchips	moderate	4" to .2"	plate shaped chips
Chunkwood	excellent	12" diameter to 2.5"	disks, wedges, and blocks
Rubber chunks	excellent	8" minues	shredded or chopped tires

6.6.3 Roadway Design Considerations

6.6.3.1 Material Properties

Laboratory and field testing of wood, bark, and rubber aggregates have shown that these materials can be tested and assigned engineering properties for use in rational design methods. Wood products obtained from industry are likely to vary widely in particle size, shape, and distribution; wood type; moisture content; age; and weathered condition. Therefore, these materials should be tested if they are to be used in high-risk applications. Many standard soil tests are applicable to wood and rubber products. Estimates from one point modulus tests indicate chunkwood has an elastic modulus of approximately 1500 psi. This value is low because it represents the unit load divided by the resulting unit axial deformation in a material. Wood and rubber aggregates deform more than aggregate for the same load during a modulus test and thus have lower modulus values. Limited shear testing results indicate they have relatively high strength despite being very flexible and are comparable to moderate strength rock aggregate (ref., Hodek, Ralph J.; Shook, Larry W.). Many wood and bark aggregates will change their engineering properties with traffic due to increased density and degradation. Even with a change in properties, these materials remain relatively flexible.

Table 6.6.2.—Sample strength and drainage characteristics.

Phi	Apparent Cohesion	Poisson's Ratio	Permeability
Chunkwood: 37 degrees	2 psi	0.3	20 feet/min.
Hogged fuel: 31–34 degrees	0 psi	-	0.002 feet/min.

6.6.3.2 Design Charts

Forest Service demonstration projects and laboratory tests at Michigan Technological University have supplied much information leading to the ability to design road fills with wood and rubber aggregates (11, 23). Additional definitive data is required to enable surfacing design with these materials using the basis already described in this Guide and appendix 6.2 for aggregate surfaces. To close this gap, the Willamette National Forest undertook a full scale test of aggregate, cedar shavings, hogged fuel, and chunkwood surfacing materials. To accomplish this, various thicknesses (6 to 36 inches) of these surfacing materials were constructed with load (pressure) cells placed throughout the surfacing and on the subgrade. A test vehicle was then driven onto the various surfaces. Each time the load cells were read to determine the pressure felt on the subgrade and within the surface. The information gathered during these tests is represented in figure 6.6.1. The chart converts an aggregate design thickness into wood particle thickness. A thickness design method is included in section 6.6.5. The complete results and conclusions of this test project are presented in a separate engineering report, "Load Testing of Wood Products and Aggregate Surfacing and Development of a Rational Surfacing Thickness Design Method" (24).

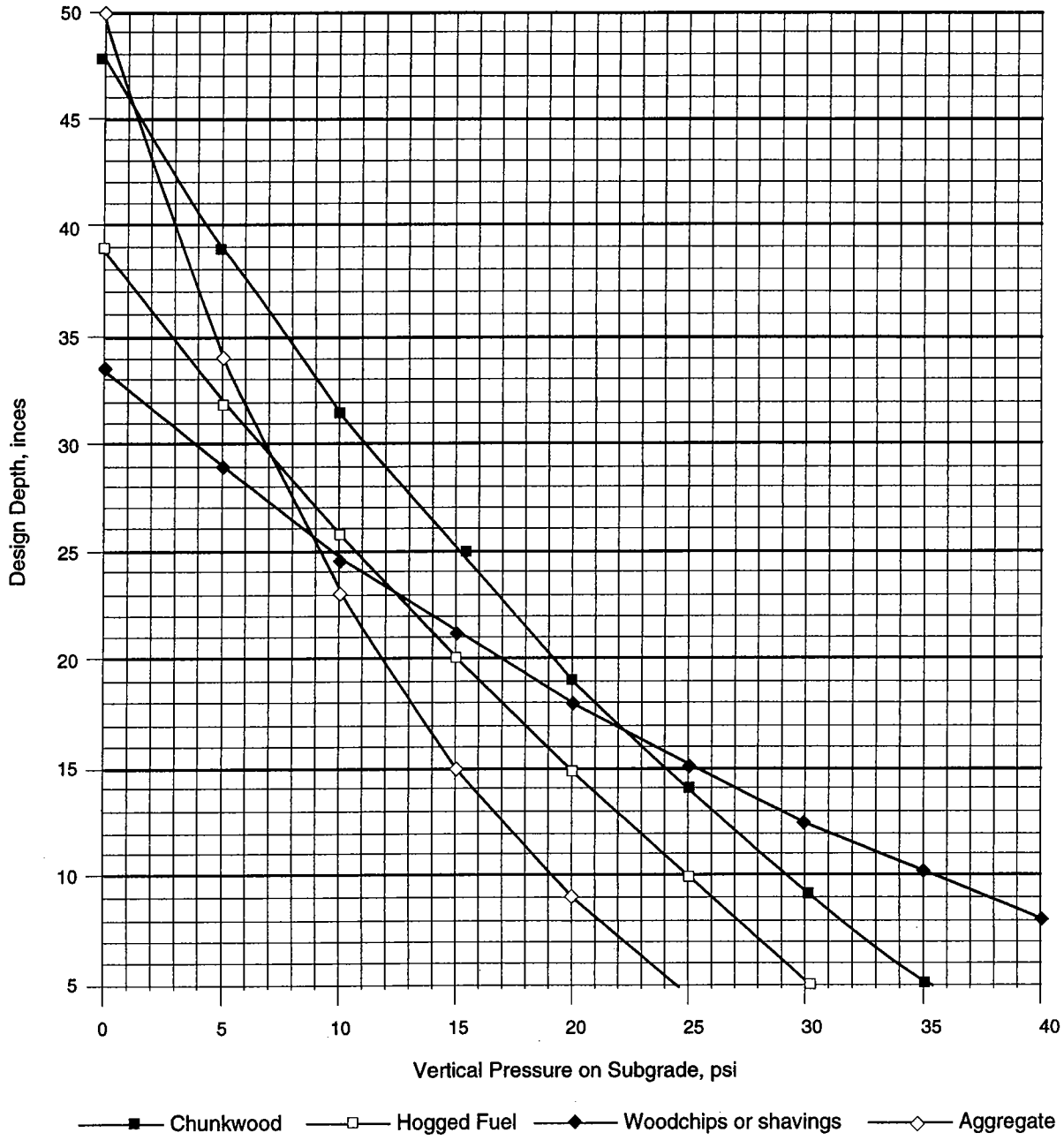


Figure 6.6.1.—Material conversion chart.

6.6.3.3 Compaction Density

Compaction of wood and rubber particle surfacing reduces the material's volume 20–50 percent. Compaction method, particle shape, and distribution of sizes controls the majority of this reduction. Laboratory tests (AASHTO T-99) can be run and results compared to loose unit weight to obtain reasonable compaction factors or design quantities. Unit weights for wood particle and rubber aggregates vary from 20 pcf loose and dry to as much as 60 pcf compacted and saturated. Typical unit weight values compacted with field moisture average about 40 pcf.

6.6.3.4 Permanent Rutting, Effect of Maintenance

During or shortly after construction, vehicle wheels quickly rut any surface material. The amount can vary from being imperceptible in asphalt surfaces to easily seen in wood or rubber particle surfaces. Rutting is caused by wheel loads compressing, deforming, and breaking down wood particles which causes them to shift into a denser configuration by filling in void space. This tends to increase the strength of the surfacing. A second phenomenon can be seen by watching a vehicle drive over wood-surfaced road. As the tire rolls up from the surface it will pick up pieces of surfacing. This slowly scatters the surface material over a wider area outside the wheel path, resulting in the formation of a depression or "rut" in the wheel path.

6.6.3.5 Road Width/Off Tracking

Rutting or "channelization" can be reduced by trucks reducing speeds when entering chunkwood areas; "off-tracking" or splitting the wheel tracks to heal the rutting; and by proper maintenance. This requires the road surface width to be sufficient to allow off-tracking without coming dangerously close to the road shoulder. Vehicles should travel at least 18 inches from the edge of the running surface because wood and rubber shoulders are relatively loose and less stable than aggregate surfaces.

6.6.3.6 Traffic Ability, Traction, Braking

Every surfacing material must be used within its limitation to guarantee success. Wood or rubber particle surfacing limitations are:

- maximum grade dry: approximately 8 percent
- maximum grade wet: approximately 7 percent
- minimum surfacing thickness: the greater of 8 inches or twice the maximum particle size;
- minimum shoulder width: 18 inches.

These maximum grades are less than those for most rock aggregate surfaces because the friction developed between a tire and wood or rubber surfacing is not as great as between a tire and aggregate surfacing. Tire slippage on steep grades or skidding from braking causes some tearing out of surface materials, although most of the movement consists of the tire sliding on the surfacing. One brake-skid test of an empty 10 cylinder dump truck traveling at about 25 mph on a "flat" chunkwood surface resulted in a favorable comment by the driver.

Sudden turning will weight the outside wheels more than the inside wheels, causing the surfacing to compress more under the outside wheel and increasing vehicle tilt angle. The rut which develops under these

flexing surfaces as the tire rolls by, as well as the permanent rut developed within the surface, give additional lateral support to the tires on the curves. This and other vehicle direction changes may be felt by the driver. As with low tire pressure vehicles, this flexing, tilting, and softer ride is not so much a problem with the surfacing as a characteristic of the surfacing which requires getting used to.

These surfacing materials require more power at given speeds because the wheels have to climb out of the depression they form while traveling the road and because of tire slippage on the relatively loose surface texture. Traffic speeds are slower than for an aggregate surface. These factors can restrain large truck speed to less than 10 mph initially, but speed will improve with road usage as the surface compacts, surfacing materials (especially wood) break down, and ride smoothness increases.

6.6.3.7 Surfacing Characteristics

6.6.3.8 Maintainability

Wood particle surfacing can be graded with standard grading equipment including ripping teeth, grader, and bulldozer blades. There have been some reports of a tendency for woodchip surfacing to form layers that break into slabs during grading. These can be easily broken with ripping teeth and bladed smooth again. Maintenance to remove ruts often can be best accomplished by adding more material to fill the ruts and compacting. This will strengthen the wheel path surfacing as opposed to scarifying and blading, which will loosen the surfacing in the wheel path area and reduce its strength.

6.6.3.9 Useful Life

The life of wood particle surfacing and fills is not well-known, but demonstration projects using wood surfacing and lightweight fill projects indicate material will remain useful as surfacing from 5 to 12 years, possibly longer, depending on climate, biological factors, wood species, particle size and variation, and density. Surfacing materials will start to deteriorate soon after application, causing particles to become smaller and softer with time. Larger materials such as chunkwood are more durable than finer materials such as mill run because of their lesser surface area-to-volume ration. Excavation of sawdust piles in the Northwest U.S. at abandoned mill sites indicate wood decay is often limited to the outer 1 to 2 feet of materials with deeper material like new after 20 years (10). For more information, see section 6.6.9, "Biodegradable Characteristics."

6.6.4 Road Design Guidelines

6.6.4.1 Geometric Design

Road alignment differs little from typical aggregate roads. No special requirements are necessary, although an 18-inch minimum width shoulder is recommended to keep vehicles away from potentially unstable shoulder material. Turnouts are necessary because passing a vehicle on a single-lane road by driving onto the shoulder would be unsafe. It is

desirable to have sufficient road width to allow off-tracking vehicles to reduce rutting and improving overall surface compaction. Wood and rubber particle surfaces can be built directly on native earth surfaces with brushed and flush cut stumps. This can be a cost-effective construction method but will result in considerable surface thickness variation and rolling grades. This may be acceptable for low level roads and a necessary construction method for very soft and/or wet areas. Maximum grades are limited to 7–8 percent but short steeper pitches can be used if the vehicle can maintain momentum through the section. It may be desirable to super elevate sharp corners to reduce the amount of vehicle tilting experienced by the driver.

6.6.4.2 Material Selection

6.6.4.2.1 Subgrade Reinforcement

Subgrade reinforcement can consist of wood particles; construction slash such as root wads, small trees, brush, and limb; geotextile fabrics; rubber particles (including tires); or conventional rock materials. Wood and rubber particle materials float but can be pushed into, mixed, or placed on top of soft soils, mud holes, clay pockets, or wet soil areas to improve subgrade strength. The coarser, more open materials such as chunkwood can drain better without becoming unstable, whereas sawdust will saturate and become weak like a fine-grained soil. Lateral stability of wood and rubber particle fill varies. The coarser materials such as chunkwood and rubber chunks tend to be more stable and drain better than sawmill pile run, sawdust, or hogged fuel.

The use of geotextile fabric acts as a reinforcement, measurably decreasing the wood, rubber, or rock aggregate pavement deflection under loading. It is also an effective separator to prevent the loss of surfacing material into the voids of an underlying material (such as chunkwood) or into soft subgrade.

6.6.4.2.2 Lightweight Fills

The extremely light weights of wood and rubber surfacing make them good lightweight fill materials over soft soils or for large fills in unstable slope areas. Wood or rubber materials weigh about one-third (40 pcf) as much as soil or rock fills. Swamp or muskeg crossings stand out as excellent applications for lightweight chunkwood fills. Chunkwood's high permeability is one factor that makes it more desirable than other wood particle materials for use in lightweight fills. In such an application it is recommended that trees and slash from the right-of-way clearing that are not recovered for chunking be concentrated in the area of the intended forest road. Unless the road is to have an extremely short life, it is also recommended than an 8-ounce or thicker nonwoven needle-punched geotextile fabric be placed over the concentrated slash before applying the chunkwood. (This type of fabric is recommended because of its ability to stretch severely before tearing.) The combination of fabric and slash will strengthen the swamp mat, and the fabric will prevent the loss of chunkwood particles to the underlying peat through the natural holes in the vegetative mat. Without the fabric separator, the

chunks inevitably will be pumped through these holes under load of the traffic. Another option is to place the chunkwood directly on the cleared subgrade with the optional use of geotextile.

In a swamp crossing application, the load supporting capability of the road is critical and is directly related to the overall depth of the road. The method outlined in this section for weak subgrades (6.6.4.4, step 1B) may be used for thickness design. These applications should be designed by a materials engineer. As a minimum a chunkwood or wood particle lift of at least 30 inches is recommended if the entire depth is to be built of chuckwood. Chunkwood roads can be readily reshaped and more chunkwood added as needed from a nearby stockpile. Where the chunkwood is to be enveloped in geotextile fabric and covered with an aggregate surfacing course, a minimum chunkwood depth of at least 24 inches is initially recommended for the swamp crossing.

Submerged wood materials kept in a saturated state can last indefinitely, but if they are exposed to oxygen as a result of seasonal drying, they will decompose, eventually reducing in volume. This can cause depressions or unstable fill areas to develop, which may be acceptable for short- or intermediate-term roads with gradable surfacing material but is not recommended for permanent roads.

6.6.4.2.3 Base Material

These are typically structural support as well as drainage materials of lesser or equal quality and cost to surfacing materials. Often, a single material is used to provide the entire base/surfacing function. Coarser, more open materials will provide better drainage than fine-grained materials. Wood particle products other than chunkwood should be tested for permeability if drainage is a critical factor. In general, wood and rubber materials will provide better drainage than fine-grained silt or clay soils. Their permeability decreases as they age and compress. Chunkwood is an excellent base material relative to other wood materials because of its large particle size, open structure, and greater longevity. A minimum base thickness of 8 inches is recommended for all wood particle bases.

6.6.4.2.4 Surface Material

Hogged fuel, woodchips, chunkwood, or rubber chunks are suitable surfacing materials. Rubber chunks may have wires protruding from them that can cause flat tires, so the source should be checked before construction. A different surface materials may have to be used. Finer materials tend to be slippery and unstable, especially when wet. These materials may be used to meet the function of fill, base, and surfacing. Other surfacing options include a mix of aggregate and wood particles that produce a material with greater frictional characteristics. A mix of chunkwood or other coarse materials with rock aggregate can produce a denser material with improved stability. The combination of wood and rubber particle base with an aggregate surface can provide the high friction, stable, easy maintenance characteristics of aggregate with the low cost, biodegradable, lightweight characteristics of wood aggregates. This combination may cost less or meet project objectives better than a

surface of just one material. Any commercially produced wood particle material may contain contaminants from mill operations. This possibility should be investigated beforehand.

Table 6.6.3.—Recommended use of alternative aggregates.

Product	Subgrade Reinforcement	Base*	Surfacing	Lightweight Fill Material	Erosion Control
Hogged fuel	G	G	G	G	M
Sawmill pile run	P	P	P	M	M
Sawdust	P	P	P	M	P
Wood shavings	M	G	M	M	P
Woodchips	G	G	M	M	M
Chunkwood	E	E	G	E	G
Rubber chunks or shreds	E	E	G-N/A	E	G
Logging—construction, slash	E	P	N/A	P	G

Subjective ratings: E = excellent, G = good, M = moderate, P = poor
*Note: Geotextile may be needed over very weak subgrades

6.6.4.3 Construction and Maintenance

Wood or rubber particle base and surfacing construction can be divided into two basic types: methods for weak subgrades, and methods for normal subgrades. Construction of normal subgrades can proceed as for aggregate-surfaced roads and surfacing can be placed in lifts to aid compaction. Construction on soft subgrades with or without a geotextile can also proceed as for aggregate-surfaced roads with the surfacing being placed in one lift, back-dumped, and spread with a bulldozer pushing the material forward onto unsurfaced subgrade. Special care should be taken with weak subgrades to minimize disturbance, especially in peat where up to 90 percent of its shear strength can be lost once disturbed.

6.6.4.3.1 Compaction Method and Effects

Compaction method will control the amount of rutting which develops in a wood or rubber surfacing. Compaction in lifts rather than full depth will reduce rutting in a given amount of surfacing. In addition, compaction with rubber-tired rollers, loaded vehicles, or loads will produce greater density than steel wheel rollers or cat tracks. To minimize wheel track rutting, the entire surface must be compacted in thin (8–12 inch) lifts, preferably by a rubber-tired heavy vehicle. The objective of compaction is to break down particles into smaller sizes, rearranging them into a denser, more stable configuration.

For a given wood rubber surfacing material, it is the depth surfacing under the rutted surface (constructed depth minus rut depth) which determines the structural capacity. The surrounding unrutted surfacing material "surcharge" is to small to add significant support by resisting an uplift (bearing capacity) type of subgrade failure. The rutted depth will

vary from about 10 to 50 percent, depending on the method of construction and compaction used. Thus, during the thickness design of a wood or rubber surfacing material an adjustment must be made that estimates the amount of rutting that will be experienced in the surfacing based solely on the construction and compaction methods used. Table 6.6.4 is used to make this depth adjustment in the thickness design method.

Table 6.6.4.—Thickness adjustment for construction method used.

Compaction Method	Placement Method 6-10 Layer Placement	> 12" Single Layer	> 18" Single Layer
C-rubber: full surface compaction by: rubber tired roller, loaded rubber tied haul vehicle, motor grader	3"	4"	5"
C-steel: partial surface compaction by: rubber tired vehicles, bulldozer tracks, steel wheel roller	4"	5"	6"

6.6.4.3.2 Maintenance Methods and Effects

As ruts develop, they can be filled with material from stockpiles or the surface can be leveled by blading material into the ruts and compacting. Surface blading will tend to weaken the road surface by decreasing the depth of surfacing in portions of the wheel path area, whereas filling ruts from stockpiles will increase the overall surfacing depth and continue to strengthen the wheel path area. Compaction of this loosened or fill material will reduce rutting. If no maintenance is performed, ruts will increase with each vehicle load, reaching as much as 12 inches or more in depth. This may eventually result in vehicle clearance problems and prevent entry of administrative traffic. Frequent maintenance is necessary to allow passage of moderate clearance (truck) vehicles.

Because maintenance can affect the amount of rutting developed in the surface, the method of maintenance is important. An estimate of the maximum rut which will be allowed to develop must be made in order to adjust the surfacing thickness accordingly. Table 6.6.5 is used to make this depth adjustment in the thickness design method. Notice that the type of maintenance can have the effect of either increasing or decreasing the surfacing thickness.

Table 6.6.5.—Thickness adjustment for maintenance method used.

Maintenance by surface blading;

MB-frequent:	Maintenance to prevent rut from developing deeper than 4" = 0"
MB-periodic:	Maintenance to prevent rut from developing deeper than 6" = 2"
MB-occasional:	Maintenance to maintain high clearance vehicle access = 4"

Maintenance by filling in ruts from a stockpile and compacting;

MF-frequent:	Maintenance to prevent rut from developing deeper than 4" = 2"
MF-periodic:	Maintenance to prevent rut from developing deeper than 6" = -1"
MF-occasional:	Maintenance to maintain high clearance vehicle access = 0"

6.6.5 Thickness Design Method

Wood particle, rubber, or composite surfaces are designed initially as aggregate surfaces using either the "STP" program (for subgrade CBR's greater than 3) or appendix 6.5 (for subgrade CBR's less than or equal to 3). This thickness is then converted into an equivalent amount of alternative surfacing material using figure 6.6.1. Finally, thickness adjustments are made to account for the construction, compaction and maintenance methods used (see tables 6.6.4, 6.6.5). The following assumptions are made when using either "STP" or appendix 6.5 methods:

- Good quality crushed rock is assumed to be the surfacing material.
- When using "STP", a 2-inch surface rut is used in the design.

The specific steps in the thickness design method are as follows:

Step 1A. Design method for subgrade CBR's > 3:

Using "STP" software to determine structural thickness:

1. Enter Main Menu and choose: "Aggregate - New Construction Design."
2. Complete "Problem Definition", then enter "Traffic Information" using standard methods. A "Reliability Factor" appropriate for your project should be used.
3. Enter "Material Information" using a surface CBR of 30 or 4 times the subgrade CBR, whichever is less, but not less than 20.
4. Enter "Calculate Results." Find the aggregate structural thickness.
5. GO TO STEP 2.

Step 1B. For subgrade CBR's less than or equal to 3:

Use appendix 6.5 to determine the structural thickness:

1. Follow the steps in appendix 6.5 to determine the design depth (structural thickness) from the appropriate design chart for your project.
2. GO TO STEP 2.

Step 2. Convert the aggregate structural thickness to that for another material:

On the Material Conversion Chart (figure 6.6.1)

1. Find the structural thickness from step 1A or 1B on the vertical axis.
2. Draw a line horizontally to intersect the curve or aggregate.
3. From that point, draw a vertical line to intersect the curve for the new material.
4. From that point, draw a horizontal line to the left, back to the structural thickness axis to obtain the converted structural thickness for your design material.
5. GO TO STEP 3.

Step 3. Determine the design thickness(es):

A. Single material design:
   Total Design Depth = converted structural thickness + compaction adjustment + maintenance adjustment

B. Composite of aggregate surface (at least 4 inches in depth) and wood particle base:
   1. Subtract desired aggregate surfacing thickness from the unconverted structural thickness to obtain the structural base thickness.
   2. Go to STEP 1A or 1B and proceed through the design process to obtain a converted structural base thickness for the base material you are using.
   3. Determine the total composite design depths:
      Surfacing = aggregate surface loss + aggregate surfacing thickness
      Base = converted structural base thickness

Surfacing composed of a mixture of wood particles and aggregate require the designer use judgment in determining the characteristics of the mix. The Material Conversion Chart in figure 6.6.1 can then be used to convert a structural thickness obtained by "STP" or through appendix 6.5 to the mixed material thickness. A mixed material curve can then be drawn between the curves for aggregate and the wood material used to approximate its characteristics. It is recommended the curve be drawn closer to the wood material curve regardless of the mix used.

6.6.5.1 Extending the Life of Wood Surfaces

The following items can be used singly or in groups to increase the life of a wood surfacing, base, or fill:

1. Use of a geotextile separator between subgrade and surfacing or between surfacing and base will prevent migration of finer material and loss of surfacing strength.

2. Use of aggregate surfacing will reduce the stress of an underlying wood base resulting in less rutting, compaction, and breakdown of material from wheel loads. This scenario should be designed by a materials engineer and a minimum of 6 inches of dense-graded aggregate placed over the wood base.

3. Keep moisture and air away and water level from fluctuating within the surface or base by:
   a. Positive subgrade drainage and/or sealed ditches;
   b. Dense-graded aggregate surfacing to shed water from the surface;
   c. Sealing the edges of a wood base or surfacing with soil, dense aggregate, or emulsion.
   d. Continual submergence of wood material will also prevent deterioration.

4. Use of larger wood materials will reduce deterioration because each piece will have a lower surface-to-volume ratio. On the other hand, fine wood products can form a tight enough structure to substantially decrease the amount of air which penetrates. Either material kept constantly saturated will last longer than one in a wet-dry seasonal cycle.

6.6.6 Cost Considerations

Oregon State University developed the software ALTSURF during the Alternative Surfacing Study of 1984. The program calculates the cost of constructing alternate surfacing materials after the user inputs detailed information. Copies can be obtained from the San Dimas Technology and Development Center (2).

Site-produced material can be estimated using the ALTSURF software or done by hand using time and equipment methods. Many wood surfacing materials can be obtained commercially, making the cost estimating process very similar to that of commercially produced rock aggregate. One major difference is the reduced unit weight of wood or rubber material, which is about 30 percent of that for rock aggregate. This enables large volumes of material to be hauled in steak bed or chip trucks, reducing hauling costs considerably.

Chunkwood production, at a rate of about 110 MBF, 220 cords, or 550 green tons per mile in flat terrain, will cost approximately $5,500 per mile (assuming logging and chunking costs about $50 per MBF, $25 per cord, or $10 per green ton). These figures are for an application of an

8-inch depth of chunkwood on a 14-foot-wide road. Production rates for the existing chunker machine are dependent on setup configuration and material being chunked. Some estimated rates are:

- Dry material—8 to 10 tons/hr (27 to 33 cu yd./hr.) (material skidded to chunker).

- Green material—20 tons/hr. (70 cy yd./hr.), (material skidded to chunker and most trees in 8 to 9 inch diameter range).

Estimated costs are:

• Stumpage:	$ 4.60 per cord
• Felling:	$ 5.00 per cord
• Limbing:	$ 3.00 per cord
• Skidding:	$ 5.00 per cord
• Chunking:	$ 8.00 per cord
• Spreading:	$ 5.00 per cord
TOTAL	$ 30.60 per cord

Projected costs: $30.60/7.6 yards per cord = $4.03 per cubic yard loose.

These figures are estimates and will vary greatly as to the actual out-of-pocket money for the contractor. Limbing would not be necessary for most of the 8- to 12-inch diameter material for the Missoula Technology and Development Center (MTDC) Chunkwood Machine (19). Dry material does cause some heating problems with the cutter blades. Green material brought to the machine with a forwarder is the most productive method of producing chunkwood. The diameter of material fed to the chunker may have to be reduced for some especially hard or tough species of hardwood trees such as beech or hard maple to decrease the current chunker design wear and tear.

6.6.7 Installation and Construction Practices

For weak subgrades, CBR < 3, (See figure 5-19 in appendix 6.5): In marginal, wet, or swampy soils, it is recommended that stumps be flush cut and slash left in place or spread and used as subgrade reinforcement. The subgrade should have a minimum of 6 inches of logging or construction slash cover to enable construction equipment to operate over the subgrade. Geotextiles may be used to prevent mixing and reduce the thickness of material required. Equipment should not be allowed to operate over geotextiles.

For normal subgrades: In this instance standard construction practices apply. With the use of wood aggregate as surface or base course, it is recommended that compaction be by rubber-tired rollers or operating equipment. Not recommended are sheepsfoot or vibrating rollers.

6.6.8 Field Inspection Tips

Measures must be taken to assure that the surfacing and base materials used are placed and compacted so that the thickness does not vary more than 2 inches from that shown on the contract drawings and is not

consistently above or below the specified thickness. Quantity measurements should be taken at the end of material placement and compaction but before commercial haul. Depths can be checked by digging test holes by hand with a narrow-ended pick or with the aid of a backhoe. The surfacing should be first be leveled across the road on an area 1-foot-wide to average out ruts and rises created from construction equipment. On weak subgrades with flush cut stumps and construction slash, maintaining a 2-inch tolerance may not be practical but care should be taken that the average depth of surfacing meets the required design depth. Specifying placement to a predetermined elevation may simplify contract administration of the surface thickness. The wood product used must be the type shown on the drawings and meet the specifications (dimensions) for that product. Compaction is an issue that must be monitored with appropriate maintenance actions.

6.6.9 Maintenance Tips

For the purposes of maintenance, wood aggregate needed for repairs or filling ruts shall be of the type used for construction (i.e., hogged fuel, sawmill pile run, or chunkwood) and obtained from stockpiles or purchased from a supplier. Types of equipment to be used for blading may be a front-end loader, motor patrol grader without a front-end blade, a lightweight crawler tractor with a blade, or a rock rake. A push blade appears to work better for some materials. It is not intended nor is it necessary to have a smooth motor patrol grader finish. For roads with gradients greater than 6 percent, rock aggregate mixed with or capping the wood aggregate should be considered to provide traction. If chunkwood is placed on the roadbed surface during the winter months, care should be taken not to allow it to mix with the snow during placement so the wood fibers have a chance to overlap and interlock. This will aid in traffic ability during construction and reduce lateral movement of chunkwood of the roadbed surface.

6.6.10 Environmental Concerns, Issues

6.6.10.1 Leachate

Wood materials decomposing in anaerobic environments can produce leachate in concentrated amounts sufficient to affect aquatic habitats or domestic water supplies under unique circumstances. Fine-grained wood particles such as sawdust, fine chips, and wood/bark fiber mixes densely compacted in roadfills are among the materials sizes more likely to produce leachate. Cedar can produce tannic acid leachate; other species may also be of concern. Freely draining woodfills of large chips or chunkwood are unlikely to produce undesirable leachate due to higher permeability and less wood surface area exposed to contact with the ground water.

6.6.10.2 Biodegradeable Characteristics

Wood aggregates are biodegradable, which may be a desirable characteristic for some environmentally sensitive projects. The estimated life of wood aggregate surfacing used in past projects appears to be from 5–10 years, although in arid environments this may be exceeded. The wood species, moisture, amount of use, magnitude of wheel loads, and biologi-

cal forces (wood-consuming organisms) are all factors that contribute to the life of wood aggregates. The most noticeable effect which occurs shortly after application and use is the mechanical breakdown of particles from wheel loads. Traction and braking forces as well as compression and bending from supporting wheel loads all contribute to this breakdown. Since the less surface area per particle, the slower it deteriorates. Mechanical breakdown tends to speed the decomposition process. Vegetative growth has been observed to occur within a few years after construction when surfaces have not been in continuous use. Where thick layers of sawdust and woodchips have been constructed, some have found these materials to remain substantially unchanged after several years of service.

Chunkwood roads built on the Chequamegon National Forest in Wisconsin have been in place for 5 years and are still very usable. Observations of the road site 3 years later have shown that some decay has taken place where the chunkwood was wetted in spring and then dried out during the summer, but that road was still very serviceable with little or no maintenance. Submerged material that remain wet as would be the case in swamp crossings have been in place in Minnesota for 15 years and are in excellent condition.

6.6.10.3 Dust, Sediment

Wood particle surfacings are essentially dust free and are a suitable material to reduce dust production on roads. As little as 4 inches of thickness may be sufficient to reduce dust generation substantially. Wood particle materials may also be effective sedimentation reducing materials. They can act as a mulch to keep soil moist, as a buffer and absorbent layer to rain. Wood particles float so they are not suited as an erosion control material in areas where substantial runoff in the form of streams or floods could wash the lightweight material away.

6.6.10.4 Road Obliteration

Roads with wood particle surfacing can be obliterated by ripping thin wood layers or pushing wood surfacing off the road to spread it out which will aid subgrade revegetation. Wood-surfaced roads left untraveled in areas with vegetation may revegetate within a few years of disturbance. Alders and firs have been noted in Pacific Northwest forests growing in hogged fuel and chip roads as soon as 3 years after construction.

6.6.10.5 Reuse of Materials

Reuse of wood particle surfacing may have applications in many temporary road areas. With aggregate surfacing, care must be taken to prevent contamination of surfacing with subgrade soil during surfacing removal or to leave some surfacing on the ground. On thin surfaces they may reduce the amount of surfacing recovered to as low as 50 percent. Because wood particle surfaces tend to have many voids, the mix of some fine soil with them may improve their stability and stiffness so they can be removed from a site with less care, greater speed, and at a higher recovery rate than aggregate surfaces.

6.6.11 Specifications

The guide specifications in this section were developed around the current Forest Service specifications in use in 1993. They are provided at the back of this appendix for assistance in future projects. Two maintenance specifications are included, 838W for contract maintenance; T-839W is for maintenance as part of a timber sale contract. The other sections of the guide specifications can be used for either a public works contract or a timber sale contract. These should be modified to reflect the current agency specifications and construction technology and practices.

SPECIAL PROJECT SPECIFICATION
Section 299W - Composite Road Construction

Description

299W.01
Work Description

This work shall consists of clearing and grubbing, excavation and embankment, and erosion control. Clearing and grubbing shall include treatment of merchantable timber, and disposal of construction slash, including all trees designated for source material for the wood aggregate. Excavation and embankment shall include borrow; drainage excavation; shaping the roadway, including approaches, turnouts, and turnarounds; ditch excavation; and disposal of excess excavation, regardless of its nature. Erosion control. when specified, consists of furnishing and placing required seed; fertilizer; and mulch, hogged fuel, or logging/ construction slash. Construction of the roadway shall conform to the dimensions SHOWN ON THE DRAWINGS and DESIGNATED on the ground.

Materials

299W.02
Requirement

Materials shall meet the following requirements:

(a) Seed shall meet the requirements of Federal Specification JJJ-S-181 and shall have been tested within the past 6 months.

Seed shall be certified to meet state requirements for containment or noxious or undesirable plant seeds.

(b) Mulch shall be grass, hay, or grain straw in an air dry condition or wood cellulose fiber. Mulch shall be free of noxious weeds, mold, or materials injurious to plant growth.

(c) Fertilizer shall be a standard commercial grade furnished in sealed containers with name, weight, and contents clearly marked.

(d) Hogged fuel shall meet the requirements of Section 703W and shall be used as a base or surface course material.

(e) Sawmill pile run shall meet the requirements of Section 703W and shall be used as surface course or lightweight fill material.

(f) Woodchips shall meet the requirements of Section 703W and shall be used as surface course material.

(g) Shake mill spall pile run shall meet the requirements of Section 703W and shall be used as surface or base course material.

(h) Chunkwood shall meet the requirements of Section 703W and shall be used as base or surface course material.

(i) Logging/construction slash shall come from the project or adjacent projects to be used as base course or erosion control as SHOWN ON THE DRAWINGS and DESIGNATED on the ground and shall meet the requirements of Section 703W.

(j) Logs DESIGNATED on the ground and SHOWN ON THE DRAWINGS shall be used to corduroy and shall meet the requirements of 703W.

Control of materials shall meet the requirements of Section 105.

Construction

299W.03 Clearing and Grubbing

All trees, snags, downed timber, brush, slash, and stumps within the clearing limits shall be removed and disposed of by:

(a) Decking or removing timber meeting utilization standards as SHOWN ON THE DRAWINGS.

(b) Decking unmerchantable timber as SHOWN ON DRAWINGS.

(c) Treating the logging/construction slash larger than 3 inches in diameter and 3 feet in length by one or more of the following methods as SHOWN ON DRAWINGS.

Method A. Incorporating slash in the embankment.

Method B. Windrowing slash outside the clearing limits. When slash is windrowed, it shall be placed approximately parallel to the roadway outside the toe of the fill slope.

Method C. Scattering slash outside the clearing limits.

Method D. Piling for future use or disposal.

Method E. Slash greater than 3 inches in diameter and less than 12 inches in diameter and 3 feet or more in length shall be source material for the wood aggregate.

(d) Logging/construction slash less than 3 inches in diameter and 3 feet in length may be incorporated into embankments as long as the material is distributed so that it does not result in concentrations or matting, or used as base course material.

Slash shall not be deposited in stream courses.

Fire dangerous dead trees or unstable live trees, DESIGNATED by the engineer within 200 feet slope distance of the centerline of roads shall be felled and disposed of in accordance with (a), (b), (c), or (d).

299W.04
Pioneering

Pioneering operations shall not undercut the final back slope, deposit material outside the roadway limits, or restrict drainage.

299W.05
Grubbing

Grubbing limits shall be as SHOWN ON THE DRAWINGS. Stumps outside the grubbing limits may remain, but shall be cut no higher than 12 inches above the original ground measured on the uphill side unless otherwise SHOWN ON THE DRAWINGS. Stumps within the grubbing limits through wet or marginal soils shall be flush cut and left in place to provide for subgrade stability.

299W.06
Excavation and Embankment

The roadway shall be constructed to conform to the typical sections SHOWN ON THE DRAWINGS. Embankment may be placed by side castings and end dumping. Hauling and spreading equipment shall operate uniformly over the full width of the embankment.

Unless otherwise SHOWN ON THE DRAWINGS, the roadbed shall be shaped and finished to that ordinarily accomplished by a crawler tractor with dozer blade to provide drainage of surface water. Individual rocks within the roadbed shall not protrude over 4 inches above the subgrade. A motor grader finish is not required.

Unless otherwise SHOWN ON THE DRAWINGS, the traveled way width shall not exceed the specified dimensions by more than 2 feet.

Rocks too large to incorporated in the embankment shall be placed outside the traveled way on the downhill side, so that they will not roll, obstruct drainage, or hinder the use and the maintenance of the roadbed.

The removal and disposition of unsuitable or excess borrow material will be SHOWN ON THE DRAWINGS.

The location of the wood aggregate stockpiles and aggregate processing equipment will be SHOWN ON THE DRAWINGS or DESIGNATED on the ground by the engineer.

Combination of rock aggregate, wood aggregate, and/or geotextiles will be as SHOWN ON THE DRAWINGS.

For roads receiving wood and/or rock aggregate base or surface course, geotextile shall be placed over the embankment material as SHOWN ON THE DRAWINGS. Geotextiles shall meet the requirements of Section 720.

Wood base or surface course shall meet the requirements of SPECIAL PROJECT SPECIFICATION, Section 703W - Wood Aggregate. Rock base or surface course shall meet the requirements of Section 703 - Aggregates or as SHOWN IN THE DRAWINGS.

Unless otherwise SHOWN IN THE DRAWINGS, the road surface shall be shaped and finished to that ordinarily accomplished by a motor patrol grader with or without a front-end blade, crawler tractor with dozer, front-end loader, or rock rake. Individual objects that protrude from the finished grade more than 4 inches shall be removed. A smooth motor grader finish is not required.

Compaction by static rollers, rubber tired rollers, or operating equipment shall continue until there is no visible displacement or as accepted by the engineer.

To facilitate seeding, slopes shall be left in a roughened condition.

299W.07 Erosion Control

Seasonal limitations for seeding are SHOWN ON THE DRAWINGS. The seeding shall not be accomplished during windy weather, nor when the ground is excessively wet, nor when the ground is frozen. The methods and rates of application, and types of seed, fertilizer, and mulch shall be SHOWN IN THE DRAWINGS. Materials shall be applied uniformly to the areas to be treated.

Slash or mulch shall be placed as SHOWN ON THE DRAWINGS. Application rates shall be as SHOWN ON THE DRAWINGS.

Measurement

299W.08 Method

The method of measurement, as described in Section 106, will be DESIGNATED in the SCHEDULE OF ITEMS.

Payment

299W.09 Basis

The accepted quantities will be paid for at the contract unit price for each pay item shown in the SCHEDULE OF ITEMS.

Payments will be made under:

Pay Item		Pay Unit
299(01)	Composite Road Construction	Sta.
299(02)	Composite Road Construction	Mi.
299(03)	Composite Road Construction	L.S.
299(04)	Geotextile	S.Y.

SPECIAL PROJECT SPECIFICATION
Section 34W - Aggregate Base or Surface Course

Description

304W.01 Work

This work shall consist of furnishing, hauling, and placing wood or rock aggregate base or surface course on the subgrade or base or stockpile site approved by the engineer.

Materials

304W.02 Source

Materials shall be obtained from sources or stockpiles SHOWN ON THE DRAWINGS or other approved sources.

Development and utilization of Government-furnished sources shall be in accordance with Section 611.

304W.03 Gradation

For rock aggregate grading requirements for crushing or screening operations shall meet the requirements of Subsection 703.06.

304W.04 Quality

All aggregate except Government-furnished stockpiles or from designated sources shall meet the quality requirements of Section 703 - Aggregate Base or Surface Course Subsection 703.06 or SPECIAL PROJECT SPECIFICATION Section 703W - Wood Aggregate unless otherwise SHOWN ON THE DRAWINGS.

Construction

304W.05 Mixing and Placing

The contractor may mix the rock aggregate and any required additive and water, mineral filler, and binder; or wood and rock aggregate by any one of the three following methods unless a required method is SHOWN ON THE DRAWINGS.

(a) Stationary Plant Method. The wood and rock aggregate shall be mixed to the required mixture as SHOWN ON THE DRAWINGS in an approved mixer.

(b) Travel Plant Method. After the wood and rock aggregate for each layer has been placed with an aggregate spreader or windrow sizing device, it shall be uniformly mixed with other required materials by a traveling mixing plant.

(c) Road Mix Method. The wood and rock aggregate shall be spread in uniform layers and proceed with approved equipment, with no segregation of size, and to a loose depth that shall have the required thickness when compacted.

Hauling equipment shall be operated over the surface of the previously constructed layer in a dispersed manner to minimize rutting or uneven compaction.

304W.06
Compaction

The aggregate shall be compacted by static rollers, rubber-tired rollers or operating spreading and hauling equipment over the full width of each layer of the aggregate.

The surface of each layer shall be bladed during the compaction operations to remove irregularities and produce a relatively smooth, even surface.

304W.07
Stockpiling

If shown in the SCHEDULE OF ITEMS or if the contractor elects to produce and stockpile wood or rock aggregates prior to placement, the aggregates shall be handled and stockpiled in accordance with the requirements of Subsection 105.10. Stockpile sites shall be at locations as SHOWN ON THE DRAWINGS or approved by the engineer.

304W.08
Thickness Requirements

The thickness of the compacted rock aggregate shall not vary more than 1 inch from the thickness SHOWN ON THE DRAWINGS.

For wood aggregate the compacted thickness shall not vary more than 2 inches from the thickness SHOWN ON THE DRAWINGS.

The compacted thickness shall not be consistently above or below the specified thickness.

Measurement

304W.09
Method

The method of measurement will be as described in Section 106. "Type" of aggregate in the SCHEDULE OF ITEMS refers to wood or rock base and surface course.

Payment

304W.10
Basis

The accepted quantities will be paid for at the contract unit price for each pay item shown in the SCHEDULE OF ITEMS.

Pay Item	Pay Unit	
304W(01)	Wood and Pit Run (maximum size 4 inches) mixture	C.Y.
304W(02)	Wood and Crushed Rock (maximum size 4 inches) Mixture	C.Y.
304W(03)	Hogged Fuel	C.Y.
304W(04)	Sawmill Pile Run	C.Y.
304W(05)	Woodchips	C.Y.
304W(06)	Shake Mill (Spall) Pile Run	C.Y.
304W(07)	Woodchunks	C.Y.
304W(08)	Logging Slash	Sta.
304W(09)	Logs	Sta.

703W.01 Wood Aggregate

Aggregate materials shall conform to the requirements shown below unless otherwise SHOWN ON THE DRAWINGS. No deleterious materials, clay lumps, or toxic substances should be included.

(a) Hogged Fuel. Hogged fuel shall consist of sawdust, bark chips, and wood chips less than 6 inches minus in the direction of the fiber.

(b) Sawmill Pile Run. Sawmill pile run shall consist of bark or sawdust chips, chunks, and shreds greater that 1/4 inch and less than 12 inches in the direction of the fiber.

(c) Woodchips. Woodchips shall consist of open-graded angular wood particles a maximum of 4 inches in the direction of the fiber. It shall be reasonably free of bark chips and rotted wood material.

(d) Shake Mill (Spall) Pile Run. Shake mill pile run shall consist of all spall created during the production of shakes.

(e) Woodchunks. Woodchunks shall consist of open-graded rounded wood particles cut normal to the centerline of the tree. Chunks shall measure greater than 2-1/2 inches in the direction of the fiber to a maximum of 6 inches in the direction of the fiber. Chunks are disk shaped blocks which have a maximum measure of 12 inches in diameter to a minimum of 3 inches in diameter. Partial chunks can be rectangular or circular in shape but should not have a fiber length of less 2-1/2 inches long. Chunks shall be reasonably free of bark chips and rotted wood material.

(f) Logging Slash. Logging slash shall consist of any unmerchantable material (including woody debris) created during logging activity.

(g) Logs. Logs shall be of any dimension or length required for the project.

Size:

(1) Hogged Fuel: 12-inch minus in the direction of the fiber.

(2) Sawmill Pile Run: greater than 1/4 inch and less than 12 inches in the direction of the fiber.

(3) Woodchips: Greater than 50 percent larger than 1/2 inch in the direction of fiber with a maximum of 4 inches in the direction of the fiber.

(4) Shake Mill (Spall) Pile Run: a maximum of the length of the shakes being produced by the mill.

(5) Woodchunks: a minimum of 2-1/2 inches and a maximum of 6 inches in the direction of the fiber.

(6) Logging Slash: no size limitation.

(7) Logs: no size limitation.

Tree Species

To reduce the possibility of creating toxic pollution from crossing areas of wet organic soils (peat lands), wet inorganic soils, or sensitive surface waters, trees should be those species with the least amount of resins, tannins, phenolics, or other acids. All tree species have various acids in their chemistry. Hardwoods should be considered as the more acceptable source as they would be less likely to release leachate.

Compaction

Wood aggregate surface and base course can be by compacted tracked vehicles, rubber tired rollers, or operating equipment. Not recommended are sheepsfoot or vibrating rollers.

Maintenance

At such times when rutting is over 4 inches in the wood aggregate, blading should be done by a motor patrol grader with a front-end blade or comparable equipment.

Measurement for Payment, Pay Method

Measurement and payment should be:

1. Construction - in accordance with Special Project Specification, Section 304W - Aggregate Base and Surface Course.

2. Maintenance - in accordance with Special Project Specification, Section 838W - Maintenance for Limited Use.

SPECIAL PROJECT SPECIFICATION
838W - Maintenance for Limited USB

1. Description

Road maintenance is the preservation of the road facility including surface, shoulders, miscellaneous structures, drainage from the traveled way and roadbed, sight distance, and all traffic control devices required to insure safe and efficient use by established road users and to protect adjacent resources.

2. Maintenance Requirements

a. Timing

Maintenance shall be performed during the contract period as often as indicated by the accepted schedule or subsequently ordered by the Government. The contractor shall commence maintenance within two weeks after receipt of written order unless otherwise stated in the order.

During operations, contractor shall minimize damage to ditches, slopes, and road surfaces. Where damage does occur, contractor shall restore the road to its prior condition within a reasonable period of time as designated by the Government.

b. Surface

While performing road maintenance work, contractor shall avoid permanently mixing aggregate surfaces with debris from side ditches, slides, or other sources. Contractor shall avoid blading aggregate from the road surface.

For blading purposes, equipment authorized for use are motor patrol grader with or without a front-end blade, front-end loader, crawler tractor with dozer blade, or rock rake or as accepted in writing by the government.

For compaction purposes, equipment authorized for use are static roller, rubber-tired roller, or operating equipment or as accepted in writing by the Government.

c. Drainage

1. Drainage shall be provided at existing drainage structures. Culverts providing drainage from road ditches shall have at least two-thirds of the end area usable. Culverts in live streams or natural watercourses requiring cleaning shall have the end area fully usable.

2. Cross ditches conforming to Drawing 838-1 shall be placed at staked locations to provide drainage across the full width of the roadbed. Except as provided in 2.c herein, materials removed from cross ditches and cleaning of existing drainage dips shall be bermed downgrade on the roadbed. Cross ditches shall be angled and shall discharge at points of least fill height or on natural ground.

3. Subject to such limitations, Contractor shall replace material eroded from fill slopes and clean out drainage ditches and culverts.

d. Intersections (see Drawing 838-2)

Intersections shown in the Road Listing for work under this Section shall be cross-ditched to drain over the full width of the listed road and define the traveled way of the adjacent road. Material removed from this cross ditch shall be placed as a berm on the roadbed and traveled way away from the intersection. A second cross ditch conforming to Drawing 838-1 shall be placed within sight of the intersection when possible, but in no case more than 100 feet from the intersection.

e. Objects on Roadbed (See Drawing 838-3)

1. Upon completion, no object extending over 6 inches above the road surface shall remain within a 10 foot usable traveled way width. Larger objects shall be selectively removed or repositioned to provide the usable width and lateral clearance required (see Drawing 838-3). The usable width shall be centered on the roadbed or positioned away from the fill slope.

   Contractor shall maintain existing cross-section of road by blading and shaping surface and shoulders, recovering displaced wood aggregate surfacing and/or embankment, or replacing wood aggregate surfacing and/or embankment with materials from Government designated stock pile sites or approved source. Banks shall not be undercut.

2. Logs and downed trees shall be cut to provide not less than 12 feet of opening for vehicle passage provided the remaining ends are in ground contact and do not interfere with drainage. The portion to be removed may be cut into chunks or left as one piece and placed in a stable position where it will not restrict drainage or vehicle passage. Limbs shall be selectively removed to provide stability or ground contact and shall be scattered downslope outside of the roadbed and drainage ways.

3. Rocks and other objects outside the 10-foot usable width may remain if drainage is provided from the road surfaces.

f. Slough and Slides (See Drawing 838-4)

1. Slough and slides may be left in place when surface drainage is provided for and at least 10 feet of width is available for vehicle passage. The roadbed upgrade immediately shall be cross-ditched. Any roadside ditch between the cross ditch and the remaining materials shall be filled and shaped to drain.

2. The contractor may reposition or ramp over slides and slough when the traveled way is less than 10 feet (see Drawing 838-4), providing the material is capable of supporting vehicles. Ramp profile gradient shall not exceed 12 percent nor have an out slope exceeding 6 percent. Ramped crossings shall be drained and bermed to a height of at least 6 inches on the outside of the ramped area.

3. Slough or slide materials which are not capable of supporting a vehicle shall be repositioned on the roadbed to provide the 10-foot width unless the Government orders it removed under Section 832.

4. Contractor shall perform all seasonal weather cleanup removal of bank slough, minor slides, and fallen timber which can practicably be accomplished by a motor patrol grader equipped with a front-end blade or comparable equipment, and by the use of hand tools.

   In removing material from slides or other sources, contractor shall haul excess material to locations designated by the Government.

g. Slumps (See Drawing 838-5)

1. The roadbed immediately upgrade of slumps shall be cross-ditched (See Section A-A of Drawing 838-1).

2. Slumps at the edge of the roadbed shall not be considered a part of the usable width. Usable width may be reduced to 8 feet provided a berm of at least 6 inches in height is placed on the undisturbed roadbed to divert surface water and provide a curb on the downhill side.

3. Roadbed slumps shall be ramped on both ends onto undisturbed roadbed to provide at least 8-foot usable width. No material shall be placed on the slumped area. Removed materials shall be bermed on the roadbed to guide vehicles to the ramp location, used to block any abutting ditches, and to divert water from entering the slump area. Ramp prefile gradient shall not exceed 12 percent. Areas within the slumps that could pond water shall be drained.

4. Roadbed cracks shall be sealed with native soil and wheel or tamper compacted to reduce the introduction of surface water.

h. Cutting Vegetation

Contractor shall remove brush or tree growth or other obstructions to improve visibility as such obstructions develop.

1. Trees, brush, and limbs shall be cut and removed to provide at least 12 feet of usable width centered on the existing usable road surface.

2. Encroaching limbs shall be removed to a height of 10 feet above the traveled way surface extending into the passageway from the side. Limbs extending laterally into the 12-foot width shall be cut within 6 inches of the trunk. Limbs extending down into the 10-foot height limitation may be cut or lopped as needed to meet the height requirement.

3. Brush and trees within the 12-foot usable width corridor shall be cut parallel to and within 2 inches of the traveled way surface.

4. Materials shall be scattered downslope outside the roadway.

3. Measurement

Measurement for all work under this section will be by the mile of existing centerline length expressed to the nearest one-tenth of a mile.

4. Payment

a. The accepted quantities will be paid for at the contract unit price shown in the Schedule of Items.

b. Payment will be made under:

Pay Item		Pay Unit
838(1)	Maintenance for Limited Use	Mile

SPECIAL PROJECT SPECIFICATION
T-839W - Maintenance for Project Use

1. Description

Road maintenance consists of providing minimum access required for purchaser's operations and associated Forest Service contract administration and preventing unacceptable resource or road damage including surface, shoulders, miscellaneous structures, drainage, sight distance, and all traffic control devices required to insure safe and efficient use by established road users and to protect adjacent resources. Purchaser's maintenance responsibility shall cover the before, during, and after operation period during any year when operations and road use are performed under the terms of the timber sale contract.

Purchaser shall perform road maintenance work commensurate with purchaser's use. All maintenance work shall be done currently, as necessary, in accordance with requirements set forth herein.

2. Maintenance Requirements

a. Purchaser shall maintain existing cross-section of road by blading and shaping surface and shoulders, recovering displaced wood aggregate surfacing and/or embankment, or replacing wood aggregate surfacing and/or embankment with materials from Government designated stockpile sites. Banks shall not be undercut.

   For blading purposes, equipment authorized for use are motor patrol grader with or without a front-end blade, front-end loader, crawler tractor with dozer blade, or rock rake or as accepted by the Government.

   For compaction purposes, equipment authorized for use are static roller, rubber-tired roller, or operating equipment or as accepted by the Government.

   While performing road maintenance work, purchaser shall avoid permanently mixing surfaces with debris from side ditches, slides, or other sources. Purchaser shall avoid blading material from the road surface.

b. During the contract period, purchaser is authorized to perform the following maintenance to provide vehicle passage and drainage:

   (1) Removing log, earth, and rock barriers and/or improving existing road junctions to enable vehicle access as mutually agreed.

(2) Smoothing or filling existing cross ditches and waterbars.

(3) Installing purchaser-furnished culverts or other agreed temporary drainage structures for shallow stream crossings.

(4) Removing brush, fallen trees, rocks, and other materials from traveled way and other locations that interfere with visibility, safety, and needed maintenance:

(a) All removed materials shall be placed away from drainages.

(b) Timber which meets utilization standards shall be limbed and removed or checked at agreed locations. Other woody materials, including limbs, shall be scattered off of and below the roadbed without creating concentrations.

(5) Clean and recondition drainage structures in accordance with Section T-831 and Section T-834.

(6) Reposition or ramp over slough and slides to provide adequate width of traveled way material.

(7) Provide traveled way drainage above slumps and seal cracks in slump area.

Unless Forest Service agrees to material being placed on slumps, the slumps shall be ramped on both ends into undisturbed roadbed to provide usable width and resurfaced with approved wood aggregate when directed by the Government.

c. During use, the traveled way shall not channel water along the road. Prior to seasonal periods of anticipated rains and runoff, purchaser shall additionally perform the following work:

(1) Shape the traveled way and disturbed roadbed to drain.

(2) Reinstall removed cross ditches and waterbars and provide any additional drainage structures necessary to offset changes through use and maintenance.

(3) Perform work outlined in 2a (5), (6), and (7).

(4) During periods of nonuse, purchaser shall replace original barrier or provide and maintain standard MUTCD, Type 3, barricades unless alternate type barriers are approved.

d. Purchaser shall perform preventive maintenance at the end of the haul season to minimize weather damage during the nonhauling period. This may include cross-ditching, post-hauling blading to remove ruts or other surface irregularities which would interfere with normal runoff of water, and cleaning of ditches and culverts.

e. Purchaser shall perform all seasonal weather cleanup removal of bank slough, minor slides, and fallen timber, which can practicably be accomplished by a motor patrol grader equipped with a front-end blade, or comparable equipment, and by the use of hand tools. Subject to such limitations, purchaser shall replace material eroded from fill slopes and clean out drainage ditches and culverts.

f. During purchaser's operations, purchaser shall minimize damage to ditches, slopes, and road surfaces. Where damage does occur, purchaser shall restore the road to its prior condition within a reasonable period of time as designated by the Government.

3. Posthaul Requirements

a. Roads designated in the road listing to be blocked shall conform to at least the minimum requirements of Section T-835. Unless otherwise agreed, purchaser-installed, temporary structures shall be removed and associated commercially obtained materials shall remain the property of the purchaser.

b. Purchaser improvements at road junctions shall be removed or reshaped as agreed to at the time of improvement.

c. Unless otherwise provided in special project specifications or the road listing, purchaser shall, upon completion of project use, perform such work as needed by equipment as specified in Section 2a to reasonably conform to the character of the existing road prior to purchaser's maintenance for project use. Work shall be in addition to requirements of Section 2b and in accordance with Section 3a or 3b. Upon acceptance of road maintenance by Forest Service, purchaser's road maintenance responsibility shall terminate.

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6.7 Nontraditional Surfacing Report Summaries

This appendix summarizes three reports that address nontraditional surfacing products and/or methods. The reports are:

1. "Nonstandard Stabilizers", Report No. FHWA-FLP-92-001, July 1992, by Douglas E. Scholen.

2. "Evaluation of Alternative Systems for Surfacing Forest Roads," Final Report, *Transportation Research Report* 85-6, Oregon State University, June 1985, by R.G. Hicks, R.D. Layton, J.W. Lund, et al.

3. "Field Guide for Alternate Systems for Surfacing Forest Roads", *Transportation Research Report* 85-7, Oregon State University, September 1985, by M.B. Takallou, R.D. Layton, and R.G. Hicks

6.7.1 Nonstandard Stabilizers

Abstract: A variety of nontraditional soil and aggregate stabilizers are presently available on the market. Attractions of these materials include ready availability, concentrated forms for minimum shipping costs, and low cost in-place mixing operations not requiring special and extensive equipment spreads. However, the short- and long-term benefits of these materials are not known or quantified; the various soils and environments under which the different materials would provide the best service is not known; the nature of the materials and the mechanism of their contribution is not clearly understood; and the specifications for design and construction are not available. Users have needed a systematic, independent assessment of these "nonstandard" stabilization materials.

In response, this study has provided over 160 miles of test and demonstration sections on more than 60 projects across the U.S. Stabilizer types included three pozzolans, four bioenzymes, two sulfonated oils, an ammonium cholide, a mineral pitch, and two clay fillers. All of these stabilizers have performed well when applied to the appropriate soils or aggregates. Figure 6.7.1-1 summarizes the products used and their location within the Forest Service as of the early 1990's.

Summary: Feldspar is the most abundant rock forming mineral, constituting 60 percent of the earth's crust. The weathering of feldspar results in hydrolysis of the rock mineral to clay minerals. The molecular structure of clays is latticed. The lattice is made up of repeating layers of silica oxides and alumina hydroxides and has charged metal cations, primarily potassium, sodium, calcium, and ionized water attached to the layers. The points of attachment within the lattice are called exchange positions because one cation may be exchanged for another in solution. The broken edges of the layers also form attachments. The more complex clays can absorb layers of ionized water between the lattice layers, allowing them to expand and lose density. In an electron micrograph, the clay structure appears like a disorderly pile of club sandwiches in which the layers of bread and meat are the repeating layers of the molecular lattice.

The stability of the lattice is tenuous; the type of bonds able to form between atoms result in an excess of electrons in the lattice and the net negative charge which must be balanced by metal cations in the surrounding environment. These cations are predominantly potassium in kaolin and illite clays and sodium or calcium in smectite. If the cations are withdrawn from the solution, hydrolysis will continue and the lattice structures will deteriorate spontaneously to allophane. If the hydronium ions are withdrawn, hydrolysis will proceed on to gibbsite and amorphous silica (opaline).

The key to stabilizing a clay soil lies in removing cations from the lattice, and/or replacing the weak cations with stronger cations which will tighten the lattice.

6.7.1.1 Stabilizer Chemistry of Sulfonated Oils

The oils selected for this purpose are called aromatic oils because their hydrocarbon molecular structure contains one or more rings of six carbon atoms similar to benzene that provides them with a characteristic aroma. The molecular structure of this ring leaves an extra electron free at each carbon. This high net (negative) electron density of the ring provides a strong attraction for the (positive) cations on the clay lattice.

Oils do not ionize in solution, and therefore cannot react with cations. To produce an ionized solution, the oil must be treated with an oxidizing agent such as sulfuric acid.

The injected solution is highly diluted because ionization increases with dilution. Unlike the standard stabilizers which actually enter into the final product of the process, these stabilizers act as catalysts to rearrange the molecular structure to a more stable configuration and release bonded moisture. The injected chemical does not become a part of the stabilized clay structure.

The injection of the stabilizer solution into the clays results in a highly concentrated "ion cloud" at the point of injection, attracting the cations away from the clay lattice. This reaction ultimately results in the silica molecules of the clay lattice donating electrons to the alumina molecules, and breaking out of the lattice to form silica gel. In this reaction, the silica sheet acts as the cathode by donating electrons, while the alumina sheet performs as the anode. The stabilizer anions catalyze the reaction by removing the metal cations from the solution. This is a redox reaction with an estimated potential of over 2 volts.

This sharp gradient at the ion cloud front results in rapid initial movement of ions into the clay mass surrounding the point of injection, controlled by Ke = coefficient of electro-osmotic hydraulic conductivity. For a silty clay, Ke is approximately 5×10^{-3} mm^2/volt seconds. By comparison, the coefficient of permeability for a silty clay might be 10^{-7} mm/second, requiring 10,000 times as long to traverse the same distance under a unity hydraulic head. It can be seen that the electrochemical potential provides a vastly greater efficiency for soil stabilization.

Project test results indicate that the scarification and sprinkling is equally effective as the injection, but that full depth penetration during scarification and mixing is critical. In this case the voltage gradient developed is small because of the higher dilution, and is lost after a few inches of penetration.

6.7.1.2 Enzymes

Enzymes are the catalysts of biological systems. A typical enzyme consists of a globular protein chain of over 300 amino acid residues plus a metal cation, and has a molecular weight approaching 35,000. The metal cation is located in a cleft in the globular mass of a size and shape that excludes all but certain specific organic molecules whose reactions are to be catalyzed. Various groups and linkages within the enzyme all work with the metal cation to cleave bonds and form new linkages in intermediate products. These then react to form the end product and to regenerate the original enzyme.

When the enzymes of a soil stabilizer are mixed with water and applied to the soil, there are several ways the enzymes can act, depending upon their design. One potential action would be similar to the action of the sulfonated oil catalysts breaking down the clay lattice to its ultimate products, by removing cations and attaching them to organic molecules. Other possibilities involve the catalyzing of reactions between the clay molecule or its constituents, and organic colloids present in the aggregate or supplied by bacterial action of bioenzymes. Because of the diversity of action available from enzymes, a combination of several activities from an enzyme stabilizer is also possible.

6.7.1.3 Clay Aggregate Mixes

The percentage of clay in subgrade soils varies widely, and in surfacing aggregates it is often very limited. Determining the percentage of clay required for optimum performance in any soil or aggregate may be the difference between success and failure of the stabilizer. This required percentage will vary with differences in climate and road grade encountered at the site. In general, projects in areas with low rainfall and flat grades can achieve good performance with less clay content than when rainfall is frequent and the grades are steep. A rule of thumb would require a minimum PI of 17, or a minimum passing 2 microns of 10 percent, as determined by hydrometer analysis, for the more severe conditions. Well-graded aggregates always provide for the best performance. Fine-grained subgrades need a thin coarse aggregate wearing surface added and cut into the treated material.

6.7.1.4 Stabilizer Chemistry of Lime Pozzolans

In nonclay aggregates, lime/pozzolan mixtures can be added to provide a binder between aggregate particles. Lime kiln dust and Class "C" fly ash contain both lime and pozzolanic ash, and perform as hydraulic cements without other constituents. Class "F" fly ash and hydrated lime can be added to perform in a similar fashion. Unlike Portland cement, these cements do not have a quick set, and will resume strength gain after a blading provided they are reworked with moisture present.

Both the silicates and the aluminates in the pozzolans are soluble at a pH above 12. At the elevated pH, the silicates and aluminates separate and go into solution to react with the calcium and form calcium aluminates and calcium silicates in which the calcium atom shares electrons with the oxygen atoms linked to the aluminum and silicon atoms. Because of substitutions that occur in the silica tetrahedra of the resulting structure, the molecules have a net negative charge, as well as a surface charge resulting from dipole effects.

These new compounds coalesce to particle size and precipitate to form a gel in the interstices of the aggregate particles present. After compaction, the charged surfaces of the particles in the gel attract ionized water, which crystallizes to form the hydration product associated with the molecular structure. The thickness of this layer of hydration ultimately may reach 10 to 15 microns, and is responsible for the strength achieved in the stabilized layer.

Stabilizers Tested

NAME	TYPE	USE	200	DISTRIBUTOR	TELEPHONE
Condor SS	Sulfntd Oil	Subgrade	40%	Prochemcl.SS	817-834-8890
ISS	Sulfntd Oil	Subgrade	40%	Envirnmtl.SS	817-332-7200
Road Bond	Sulfntd Oil	Agg.Surf.	20%	CSS.Technlgy	800-541-3348
Permazyme	Enzyme	Agg.Surf.	20%	Nat.PermZyme	800-648-0313
EMC^2	Bioenzyme	Agg.Surf.	15%	SS.Prodcts.Co	800-523-9992
BioCat	Bioenzyme	Agg.Surf	15%	SS.Prodcts.Co	800-523-9992

6.7.2 Evaluation of Alternative Systems for Surfacing Forest Roads

Abstract: This project is concerned with the evaluation of alternative surfacing systems capable of reducing capital investment for temporary or intermittent use forest roads. Alternative systems considered included those which (1) are capable of being moved as the hauling activity moves; (2) degrade after use; and (3) significantly reduce the amount of rock required. The overall objective of this study is to identify and analyze alternative systems for surfacing forest roads and to determine the applicability and cost effectiveness of each system. Specific objectives include: (1) a through literature search to identify alternate systems available; (2) a survey of at least 30 Forest Service field offices to determine needs and operating requirements for temporary or intermittent roads; (3) an evaluation of performance of 11 demonstration projects using alternate surfacing systems; (4) an analysis of the costs, benefits, and potential applications of each system; (5) an evaluation of adaptability, benefits, and life cycle costs for each system; (6) preparation of a guide for use by field engineers in the selection, placement, operation, and use of alternate surfacing systems; and (7) recommendations for

LOCATION	SUBGRADE/SURFACING	NOTES
Treatment: Sulfonated Naphthalene Gifford Pinchot NF Mt Adams District Road 3421	Ustable clay loam/Unstable and native	Injection method 500 feet
Gila NF New Mexico FR141	Clay subgrade	Rification/rippers 2.2 miles
Uinta NF Utah FH131	Clay subgrade	Scarification/rippers 3.5 miles
Kisatchie NF Louisiana FR204	Expansive Clay/Native	Injection, 4 miles
Sabine NF Texas FDR126	Expansive Clay/ — subgrade	Scarification/hydraulic chisel plow 0.8 mile
Sam Houston NF Texas FDR204	Expansive Clay/ —	Injection, I mile
Delta NF Mississippi FR703/707 3	Expansive clay/pitrun gravel	Scarification, 2 miles failed due to inadequare penetratioin
Treatment: Sulfonated D-Limonene Ozark NF Arkansas Jerusalem Road	—/crushed aggregate w/ clay shale	Blade mix, 11 mile
Treatment: Enzymes Ottowa NF Michigan FR214	—/crushed glacial till	Freeze/thaw condiitions, 1 mile
Ozark NF Arkansas FR1600, FR1505	Silty-low PI clay content/3/4″ minus well graded crushed rock with clay fines and shale	Blade mix, 6 mile
Rain Mine Carlin NV	Broken shale-siltstone/well graded pitrun siltstone talus 10% clay content	MgCl used also; freeze/thaw conditions
George Washington NF Northern Virginia FDR 52,95,95A,96,275	Crushed aggregate mixed with native clay	Freeze/thaw conditions 3.5 miles
Allegheny NF Pennsylvania FR185	silty/pitrun	Freeze/thaw condiitions, 0.9 mile
Pisgah NF North Carolina	—/crushed gniess with clay fines	Performing well as a dust palliative also
Gifford Pinchot NF Washington FR21, FR30	—/clean crushed basalt; no clay fines	Total failure due to no clay fines for reaction

Figure 6.7.1-1.—Chemical stabilizer use in the Forest Service.

LOCATION	SUBGRADE/SURFACING	NOTES
Willamette NF Oregon FR1802	Clayey silt/crushed rock with high amount of silt fines	Failed due to lack of clay fines, 2000 feet
BLM, Medford OR	Clay/creek gravel	Freeze/thaw conditions
Carson NF New Mexico FR310	Clayey silt/none	Freeze/thaw condiitions, 500 feet
Sam Houston NF Texas FR204	—/wide variety of crushed material; poor gradation	Subsurface injection with sulfonated napthalene, 2.7 miles
Chattahoochie NF Georgia Tallulah River Road	1% clay/crushed agg.	
Andrew Pickens NF South Carolina Burrell's Ford Road FR708	Low plasticity clay/gap graded aggregate	Steep grades/numerous curves, 2.7 miles
Appalachicola NF Florida FR309	<5% clay/sand and limerock	Ravelling from limerock
Treatment: Pine tar (Road Oyl) Santa Fe NF New Mexico Jacks Creek Road	Crushed aggregate Blade mixed 1.5"	To contain mine waste used for surface 3 miles
Treatment: Pozzolans Desoto NF MS FDR 202	Unbound sandy gravel with rounded aggregate	1% lime-kiln dust 12 miles, flat grades
Pisgah NF North Carolina Five projects	NP well-graded crushed aggregate	1% lime-kiln dust 14 miles, moderate to steep grades
Ozark NF Arkansas six projects	NP crushed aggregate and/or subgrade fine	10% C1"C" flyash 15 miles, flat to steep grades
Desoto NF Mississippi FDR 319	Unbound sandy gravel with rounded aggregate	2% 1:1 hygrated lime and C1"F" flyashh 8.4 miles, flat grades
Cherokee NF Tennessee FDR 87	NP crushed aggregate and/or subgrade fine	2% lime-kiln dust 12 miles, flat to moderate grades
Siuslaw NF Oregon Three projects	NP crushed aggregate	7% cement-kiln dust 6 miles, moderate to steep grades

Figure 6.7.1-1.—Chemical stabilizer use in the Forest Service (cont'd.).

future evaluation project requirements for more comprehensive field testing. Objective 6 is presented in a separate report entitled "Field Guide for Selection of Alternate Surfacing Materials."

Summary: From the projects evaluated, the following materials appear to have the highest potential for use: (1) wood and bark chips, (2) chemical stabilization, (3) geotextile and grid separation, (4) marginal aggregate, and (5) lignin sulfonate soil stabilization. The report recommends that the Forest Service should proceed to use the above materials, if cost effective, and establish a means to track and report the performance of these materials so Forest Service personnel can learn from one another's experience.

6.7.3 Field Guide for Alternative Systems for Surfacing Forest Roads

Abstract: This report describes an evaluation procedure for potential alternate surfacing systems for temporary or intermittent use roads and to compare their economy with normal aggregate-surfaced roads. It is developed strictly to aid field engineers in the selection, placement, construction, maintenance, and, if necessary, the recovery of temporary or intermittent surfaces. This field guide (1) identifies important criteria in the selection of alternate surfacings; (2) describes step-by-step procedures for construction, maintenance, and recovery; (3) identifies costs and benefits of the alternate surfacings; (4) provides an evaluation structure to identify which surfacing alternatives are most economical for temporary or intermittent surfaces; (5) describes step-by-step solutions to the two examples to demonstrate evaluation methodology, and; (6) describes a computer program to assist the field engineers in the selection of the most economical alternative surfacing for a given situation.

6.8 Road Surface Sediment Reports and Studies

"A Test of Normal Tire Pressure and Reduced Tire Pressure on Forest Roads: Sedimentation Effects." Randy B. Foltz and Edward R. Burroughs, Jr., USDA Forest Service. *Proceedings of the 1991 Forestry and Environment—Engineering Solutions Conference, ASAE Publication* 09-91, June 1991.

> Summary: Various simulated rainstorms were applied to various Forest Service roads before and after log truck traffic at normal and reduced tire pressures. The ratio of sediment yield for normal tire pressure compared to reduced tire pressure ranged from 1.1 times (dry run) to 2.2 times (wet run) and 2.3 times (very wet run). These increases in sediment yield and sediment concentration were caused by more concentrated flow in the deeper ruts formed in the normal tire pressure treatment area. The rut depth was .9 inches in the normal tire pressure tracks and .2 inches in the reduced tire pressure tracks.

"Application of Sediment Budget Studies to the Evaluation of Logging Road Impact." Leslie M. Reid, Thomas Dunne, and C. Jeff Cederholm, *N.Z. Journal Hydrology*, volume 20, pp. 49–62, 1981.

> Summary: The construction of a partial sediment budget provides a flexible, efficient, and economical means of evaluating changes in sediment production rates generated by changes in land use. Application of the method to a 40 percent clear felled area of the Northwestern United States demonstrated that landslides are responsible for about 60 percent of the road-related sediment production. An additional 20 percent is produced by surface erosion on gravel roads, and about 80 percent of this value is derived from roads along which logs are transported. In the terms of the production rate of sediment smaller than 2 mm in diameter, however, the sources are of near equal importance, and paving the haul roads will result in a 30 percent decrease in the production rate of fine-grained material.

"Cost Effectiveness Plus." *USDA Forest Service—Road TIPS*, EM-7700-5, October 1985.

> Summary: The placement of clearing slash immediately below logging roads in the Northern Region (Region 1) has been shown to be a cost-effective way to reduce slash disposal costs during construction and to effectively prevent downslope movement of road erosion material. These "filter windows" are described and shown in this article.

"Erosion from Simulated Rainfall on Mountain Rangeland in Utah." George E. Hart. *Journal of Soil and Water Conservation*, 39(5), pp. 330–334, September–October 1984.

Summary: Simulated rainfall was applied to large runoff plots that were bare or covered with sagebrush and grass. Soil erosion on the vegetated plots was negligible; on the bare plots soil loss averaged 1.9 t/ha from lower intensity rain on dry soil and 16.6 t/ha from higher intensity rain on prewet soil. Antecedent soil moisture condition had a pronounced effect on erosion. The Universal Soil Loss Equation greatly overestimated measured loss on dry soils, but was within 13 to 51 percent of measured losses on prewetted plots with 10 percent slopes. Comparison of predicted and measured soil losses on a 32 percent slope suggested that overestimation was due partly to the USLE's slope value.

"Forest Road Erosion in the Ouachita Mountains." R. Scott Beasley, Edwin L. Miller, and Steven C. Gough. *Proceedings of the Mountain Logging Symposium*—West Virginia University, Morgantown, pp. 202–213, 1984.

Summary: The quantity and disposition of sediment eroded from four segments of an established Forest road in the Ouachita Mountains of Arkansas were determined for each storm event that occurred between June 1, 1982 and May 31, 1983. Road segments (average length of 300 feet) were defined as the centerline distance from a vertical curve crest to the first crossdrain culvert, a mechanism for dispersing water from the upslope ditch onto vegetated sideslopes below the road. Slope gradients of the segments ranged from 1 to 7 percent and averaged 4 percent. Measurements at the outlet of each cross-drain were total discharge volumes, discharge rates and peaks, deposited sediment, suspended sediment, and downslope movement of deposited sediments. Concurrent measurements included sediment concentrations in a stream flow parallel to and about 150 feet below the road and rainfall amounts, durations, and intensities. Thirty-six storms produced annual sediment yields from the crowns, ditches, and backslopes of the road segments ranging from 7 t/ac to 34 t/ac (average 23 t/ac). One storm, which produced 13 inches of rainfall in 24 hours, accounted for about half of the total annual sediment yields. Deposited sediments, most of which moved only a short distance downslope, constituted about 41 percent of the total sediment yields. Close inspection of the slopes below the cross-drains revealed that, for all but the largest storms, much of the suspended sediments were trapped on-site as the road water infiltrated or was ponded in surface depressions. The only exception was a culvert that emptied into a natural ephemeral drainage. Roadbed slope gradient accounted for most of the variation in sediment losses among road segments. Measured rates of soil erosion were 1,200 percent less than previously reported predicted rates.

"Gravel and Grass Surfacing Reduces Soil Loss from Mountain Roads." L.W. Swift, Jr. *Forest Science*, volume 30(3), pp. 657–670, September 1985, Record No. 31796.

> Summary: Soil loss from Forest roads was measured on two soils in the southern Appalachian Mountains. Losses from a roadbed without surfacing (bare soil) and later with grass cover were compared with those from roadbeds surfaced with different types and amounts of rock. In the first 2 months after construction in a deep sandy loam saprolite, soil loss rates were eight times greater from the bare soil site than from roadbeds with 15 to 20 cm of gravel. Loss rates declined in a 6-month period of light traffic. The cumulative loss during the first 8 months after construction was over 200 t/ha from the bare soil roadbed and less than 35 t/ha from roadbeds surfaced with graded crushed rock or large (7.5 cm) washed stone. Loss rates rose as logging traffic began. At the conclusion of the timber sale, roads were reshaped and ungraveled portions grassed. During logging, a site with a thin layer (5 cm deep) of crushed rock became heavily rutted and additional gravel was added. In the third year, erosion rates on this lightly graveled site approximately equaled those of bare soil, twice that of a grassed roadbed.
>
> Where the road was built with the B horizon of sandy clay loam, soil losses with 5 cm and 15 cm of gravel were intermediate between the high and low losses from similar surfacings on sandy loam saprolite. Differences in soil loss and trafficability persisted into the fourth year. Maintenance of forest roads disturbed stabilized road surfaces and contributed to soil losses.

"Impacts of High-Intensity Rainstorms on Low-Volume Roads and Adjacent Land." Melvin Dittmer and Allan A. Johnson, USDA Forest Service. Low Volume Roads: First International Conference, Boise, Idaho. *Transportation Research Board Special Report* 160, June 1975.

> Summary: Describes the kinds of road failures that occurred during a January 1974 high-intensity rainstorm and describes some of the least expensive methods that can be used to mitigate those failures.

"Measuring Surface Erosion on Forest Roads and Estimating Costs of Erosion Control—Preliminary Results." Edward R. Burroughs, Donald F. Haber, Fredrick J. Watts, and Teresa L. Kadoch. USDA Forest Service. Low Volume Roads: Third International Conference. *Transportation Research Board Special Report* 898, 1983.

> Summary: Simulated rainfall was applied to three types of roadways on six sections of Forest road to measure runoff and sediment yield within the Silver Creek Experimental Watershed (Boise NF, Idaho). Objective was to verify the "ROSED" road

sediment model since the version used at that time required calibration for the particular locality where it was to be used. This paper was the result of the first year of a 6- to 10-year study. For the sites studied, the results show that sediment yield is correlated directly with the amount of loose soil on the road surface and inversely correlated with the D50 of the loose surface material. Note that native granitic material, dust oil on native material, and a BST were evaluated. The sediment yield from the native material is 3 times that for native material with dust oil and 10 times that for a BST.

"Rapid Evaluation of Sediment Budgets." Leslie M. Reid and Thomas Dunne, Draft dated May 29th, 1992.

Summary: Have not been able to get a copy of this paper yet.

"Reduced Tire Inflation Pressure—A Solution for Marginal-Quality Road Construction Rock in Southeast Alaska." William Powell and Bruce Brunette. USDA Forest Service. Fifth International Conference on Low-Volume Roads, *Transportation Research Board Special Report* 1291, volume 2, 1991.

Summary: Case history of a timber sale project that used CTI to reduce road maintenance costs, and reduce sediment production.

"Reduction of Soil Erosion on Forest Roads." Edward R. Burroughs, Jr. and John G. King. USDA Forest Service, Intermountain Research Station. *General Technical Report* INT-264, July 1989.

Summary: Summarizes the effectiveness of various road treatments and practices in reducing erosion and sediment transport. Findings include;

1. On unsurfaced travelways, logging traffic can increase sediment production by 1.9; a surface rutted by heavy truck traffic will produce 2.1 times the sediment yield of a smooth surface; a lift of aggregate reduced sediment production by 70 percent over a 5-month period in one study and 80 percent in another study.

2. On aggregate surfaced travelways, the thickness of the lift is important; dust oil and a BST reduce sediment when compared to sediment production from unsurfaced roads.

3. Information on fill slopes, sediment travel distances below the fill slope, cut slopes, and roadside ditches was included in this paper but those findings are not covered in this summary.

"Sediment Production Comparison Between the Use of Normal Tire Pressure and Central Tire Pressure on Forest Roads." Randy B. Foltz. USDA Forest Service, Intermountain Research Station. *Proceedings of the International Mountain Logging and Eighth Pacific Northwest Skyline Symposium*, Belevue, WA, December 1992.

> Summary: In addition to improved vehicle mobility and reduced road maintenance, the use of reduced tire pressure on heavy trucks can reduce sediment erosion on Forest roads. In the winter of 1992, a test using both reduced tire pressure and normal tire pressure was conducted on an aggregate surfaced road to determine sediment production from each tire pressure regime. The test was conducted for nearly 60 days during natural rainfall and runoff events. Sediment production decreased 2:1 when reduced tire pressure. These results are in agreement with earlier native surface road tests and demonstrate how reduced tire pressure lowers sediment production from forest roads.

"Sediment Production from Forest Road Surfaces." Leslie M. Reid and Thomas Dunne. *Water Resources Research*, vol. 20, no. 11, pp 1753–1761, November 1984. (Record No. 32530).

> Summary: Erosion on roads is an important source of fine-grained sediment in streams draining logged basins of the Pacific Northwest. Runoff rates and sediment concentrations from 10 road segments subject to a variety of traffic levels were monitored to produce sediment rating curves and unit hydrographs for different use levels and types of surfaces. These relationships were combined with a continuous rainfall record to calculate mean annual sediment yields from road segments of each use level. A heavily used road segment in the field area contributed 130 times as much sediment as an abandoned road. A paved road segment, along which cut slopes and ditches were the only sources of sediment, yielded less than 1 percent as much sediment as a heavily used road with a gravel surface.

"Sediment Production from Gravel Surfaced Forest Roads, Clearwater Basin, Washington." Leslie M. Reid. The Fisheries Research Institute, College of Fisheries, University of Washington, for the Washington Department of Natural Resources, 1981.

> Summary: Erosion on the surfaces of in-use gravel logging roads is a significant source of fine-grained sediment in logged basins of the Pacific Northwest. Runoff from 10 road segments subjected to a variety of traffic levels was monitored during a series of storms in the central Clearwater basin of Western Washington. The resulting data allowed the construction both of sediment rating curves for different road use levels and of unit hydrographs for different road surfaces. These relationships were combined then with a continuous rainfall record to calculate an average

annual sediment yield from road segments of each use level. Road segments used by more than 16 trucks per day contributed 130 times as much sediment as roads not subjected to truck traffic, and 1,000 times as much as abandoned roads. Measurements of sediment production on paved roads indicate that paving a heavily-used road will decrease the quantity of sediment reaching streams through road culverts by a factor of 240. These measurements also suggest that sediment production from backcuts is relatively insignificant if roads are in use; backcut erosion is responsible for about 0.4 percent of the sediment yield from a culvert on a heavily used road.

Comparison of the calculated sediment production rates from road surface erosion with those measured for road-related landslides shows surface erosion to be 2.5 to 4.1 times as important as road surface erosion in a hypothetical 10 km2, 40 percent logged basin with a road density of 2.5 km/km2, and a typical distribution of road use intensities. Road surface erosion in such a basin accounts for about 47 t/km2/yr, while road-related landslides are responsible for 115 to 194 t/km2/yr. If only sediment finer than 2 mm is considered, however, the contributions from these two sources are more equal. Erosion induced by this road distribution increases sediment production rate in the basin by a factor of 3.4 to 4.9 over the average reported rate of 82 t/km2/yr for undisturbed basins in similar areas. Measurements and estimates of sediment production rates from natural sources in the Clearwater area indicate that there is an average background sediment production rate of 79 t/km2/yr; the most important natural sediment sources are bank erosion and landslides.

"Soil Losses from Roadbeds and Cut and Fill Slopes in the Southern Appalachian Mountains." Lloyd, W. Swift Jr.. *Southern Journal of Applied Forestry*, volume 8(4), pp. 209–213, 1984.

Summary: Soil losses were measured on the cut, fill, and roaded surfaces of a Forest road at Coweeta Hydrologic Laboratory. Before grass was planted or gravel spread, roadbed surfaces had the least loss per unit area and loss was primarily waterborne fine particles. A large part of the soil loss from fill slopes was due to slippage of wet soils in early spring. Surface erosion of fills was negligible because storm water from the roadbed was not spilled across loose soil. The cut slopes eroded most, principally because soils were loosened by diurnal cycles of freezing and thawing in winter. This study shows that inclined surfaces of cut and fill slopes are potential sources of large soil loss but those losses can be mitigated by early establishment of grass cover and by design features to control storm water. Soil loss from roadbeds was greatly reduced by gravel surfacing.

"Surface Erosion Control on Roads in Granitic Soils." Edward R. Burroughs and John G. King, USDA Forest Service. *USDA Forest Service—Road TIPS.* EM-7700-5, October 1985.

> Summary: Simulated rainfall was used to generate runoff and sediment yield from Forest roads and fill slopes built in granitic soils to test the effectiveness of various surfacing materials, mulches, and barriers as erosion control treatments. An empirical equation was presented and used to estimate the relative effectiveness of gravel, dust oil, and a BST in reducing sediment yield relative to that of an unsurfaced road. Gravel, dust oil, and BST's reduce sediment yield by factors of 4.3, 7.7, and 91 relative to the sediment yield for a comparable unsurfaced road. Dense grass cover (97 percent) on 1.5:1 fill slopes reduces sediment yield by 99.6 percent of that from a bare slope with loose soil surface. Wood fiber mulch and a sediment barrier of cull logs and logging slash reduce bare slope sediment yield by 91 and 87 percent, respectively.

"Using Gravel to Reduce Soil Losses from minimum Standard Forest Roads." J.N. Kochendorfer and J.D. Helvey. *Journal of Soil and Water Conservation,* volume 42, pp. 46–50, 1987.

> Summary: Soil losses were monitored for 4 years on 11 sections of Forest road in the central Appalachians. The roads were used for both timber management and recreation. Nine road sections were located on a newly constructed, minimum standard truck road and two sections were on a graveled, higher standard road. Average annual soil losses ranged from 47 tons/acre on the ungraveled road sections to 6 tons/acre on the sections surfaced with 3 inches of clean limestone gravel. After the first year, traffic counts averaged 33/week on the minimum standard road and 60/week on the higher standard road. Soil losses on the gravel sections of the minimum standard road were similar to those measured on the higher standard roads.

"Validation of the WEPP Model for Forest Roads." William Elliot, Randy B. Foltz, and Charles Luce. USDA Forest Service, Intermountain Research Station. Presented at 1993 ASAE International Winter Meeting, December 1993.

> Summary: Rainfall simulation on five different soils was used to study erosion rates of recently graded non-graveled Forest roads. The erosion results observed on 24 Forest road erosion plots were compared to values predicted by the WEPP model, version 93.1. Hydraulic conductivity and soil erodibility values were predicted from methods developed for rangeland and cropland soils. It was found that on four out of the five soils, runoff values were closely predicted, and that the predicted erosion was not significantly different from observed erosion when using rangeland methods

for predicting soil erodibility. It was also found that interrill erosion rates were underpredicted when using rangeland methods for predicting soil erodibility, but slightly overpredicted when using cropland interrill erodibility prediction methods. Rill erosion rates for road wheel ruts were closely predicted from rangeland rill erodibility algorithms.

"Watershed Analysis Manual." *Timber, Fish, and Wildlife Publication* TFW-CEI-92-002, version 2.0, October 1993.

Summary: In section B "Surface Erosion: Roads," various factors are addressed to assist the determination of a road's surface erosion potential. Table B-7 provides correction factors to the computer program based on the type of travelway surface. Native surface factor is 1.0 and an asphalt surface factor is 0.03. Chart was developed from papers by Burroughs and King, 1989; Hayden et al., 1991; Kochendorfer and Helvey, 1984; Reid and Dunne, 1984; and Swift, 1984.

"The Effect of Aggregate Quality on Sediment Production From a Forest Road," Randy B. Foltz and Mark A. Truebe, USDA Forest Service, prepared for Low Volume Roads: Sixth International Conference, Transportation Research Board, Minneapolis, Minnesota, June 1995.

Summary: Aggregate is placed on forest roads in wet climates to provide structural support for traffic and in dry climates to reduce sediment production caused by precipitation. In both climates, suitable quality aggregate is often not readily available. The substitution of poorer quality aggregate can cause greater amounts of sediment than produced by good quality aggregate. To measure the differences in sedimentation rates, the Forest Service conducted a sediment study using two aggregate qualities. The study was conducted using natural rainfall and logging truck traffic on an aggregate-surfaced road during the winters of 1992 and 1993 in western Oregon and using simulated rainfall following the winter of 1993. The results showed that the quality of the aggregate made a notable difference in sediment production. When subjected to heavy logging truck traffic, a marginal quality aggregate produced from 2.9 to 12.8 times as much sediment as from a similar section surfaced with good quality aggregate. The greater difference occurred in the winter with the greater rainfall. While the good quality aggregate provided the expected level of sediment mitigation, the marginal quality aggregate did not. These results have important implications for road use and sediment production.

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6.10 Other Surfacing Design Resources

Organizations and Committees

U.S.D.A - Forest Service
Auditors Building
201 14th Street, S.W.
Washington, DC 20250
202-453-9400

American Association of State Highway and Transportation Officials (AASHTO)
444 N. Capitol Street, N.W.
Washington, DC 20001
202-624-5800

U.S. Army Engineer Waterways Experiment Station
3909 Halls Ferry Road
Vicksburg, MS 39180-6199
601-634-3376

Local Technology Transfer Centers
Check with your State Highway Office or local engineering school

Pavement Computer Programs and Software

McTrans
University of Florida
The Center for Microcomputers in Transportation
512 Well Hall
Gainesville, FL 32611
904-392-0378

PC-Trans
University of Kansas
Transportation Center
2011 Learned Hall
Lawrence, KS 66045
919-864-5655