Geosynthetic Engineering:
Geosynthetic Separators

Course No: G04-005

Credit: 4 PDH

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16. ABSTRACT This manual is an updated version of the Geotextile Design & Construction Guidelines, used for the FHWA training course Geosynthetic Engineering Workshop. The update was performed to reflect current practices and codes for geotextile design, and has been expanded to address geogrid and geomembrane materials. The manual was prepared to enable the Highway Engineer to correctly identify and evaluate potential applications of geosynthetics as an alternative to other construction methods and as a means to solve construction problems. With the aid of this text, the Highway Engineer should be able to properly design, select, test, specify, and construct with geotextiles, geocomposite drains, geogrids and related materials in drainage, sediment control, erosion control, roadway, and embankment on soft soils applications. Steepened slope and retaining wall applications also are addressed, but designers are referred to the FHWA Demonstration Project No. 82 references on mechanically stabilized earth structures for details on design. Application of geomembranes and other barrier materials to highway works are summarized within. This manual is directed toward geotechnical, hydraulic, roadway, bridge and structures, and route layout highway engineers.			
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5.0 GEOSYNTHETICS IN ROADWAYS AND PAVEMENTS

5.1 INTRODUCTION

The most common use of geosynthetics is in road and pavement construction. Geotextiles increase stability and improve performance of weak subgrade soils **primarily by separating the aggregate from the subgrade**. In addition, geogrids and some geotextiles can provide strength through friction or interlock developed between the aggregate and the geosynthetic. Geotextiles can also provide filtration and drainage by allowing excess pore water pressures in the subgrade to dissipate into the aggregate base course and, in cases of poor-quality aggregate, through the geotextile plane itself.

In this chapter, each of the geosynthetic functions will be discussed and related to design concepts and performance properties. Selection, specification, and construction procedures will also be presented.

5.1-1 Functions of Geosynthetics in Roadways and Pavements

A geosynthetic placed at the interface between the aggregate base course and the subgrade functions as a *separator* to prevent two dissimilar materials (subgrade soils and aggregates) from intermixing. Geotextiles and geogrids perform this function by preventing penetration of the aggregate into the subgrade (localized bearing failures) (Figure 5-1). In addition, geotextiles prevent intrusion of subgrade soils up into the base course aggregate. Localized bearing failures and subgrade intrusion occur in very soft, wet, weak subgrades. Subgrade intrusion can also occur under long term dynamic loading due to pumping and migration of fines, especially when open-graded base courses are used. It only takes a small amount of fines to significantly reduce the friction angle of select granular aggregate. Therefore, separation is important to maintain the design thickness and the stability and load-carrying capacity of the base course. Soft subgrade soils are most susceptible to disturbance during construction activities such as clearing, grubbing, and initial aggregate placement. Geosynthetics can help minimize subgrade disturbance and prevent loss of aggregate during construction. Thus, the primary function of the geotextile in this application is separation, and can in some cases be considered a secondary function for geogrids.

The system performance may also be influenced by functions of **filtration** and **drainage** (Table 1-1). The geotextile acts as a filter to prevent fines from migrating up into the aggregate due to high pore water pressures induced by dynamic wheel loads. It also acts as a drain, allowing the excess pore pressures to dissipate through the geotextile and the subgrade soils to gain strength through consolidation and improve with time.

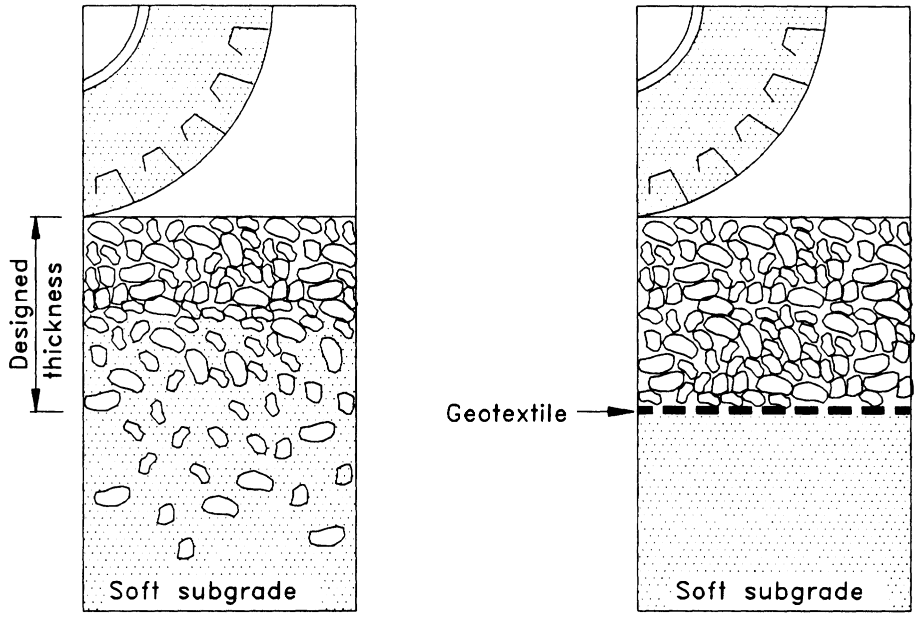


Figure 5-1 Concept of geotextile separation in roadways (after Rankilor, 1981).

System performance may also be improved through reinforcement. Geogrids and geotextiles provide reinforcement through three possible mechanisms.

1. *Lateral restraint of the base and subgrade* through friction and interlock between the aggregate, soil and the geosynthetic (Figure 5-2a).
2. *Increase in the system bearing capacity* by forcing the potential bearing capacity failure surface to develop along alternate, higher shear strength surfaces (Figure 5-2b).
3. *Membrane support* of the wheel loads (Figure 5-2c).

When an aggregate layer is loaded by a wheel or track, the aggregate tends to move or shove laterally, as shown in Figure 5-2a, unless it is restrained by the subgrade or geosynthetic reinforcement. Soft, weak subgrade soils provide very little lateral restraint, so when the aggregate moves laterally, ruts develop on the aggregate surface and also in the subgrade. A geogrid with good interlocking capabilities or a geotextile with good frictional capabilities can provide tensile resistance to lateral aggregate movement. Another possible geosynthetic reinforcement mechanism is illustrated in Figure 5-2b. Using the analogy of a wheel load to a footing, the geosynthetic reinforcement forces the potential bearing capacity failure surface to follow an alternate higher strength path. This tends to increase the bearing capacity of the roadway.

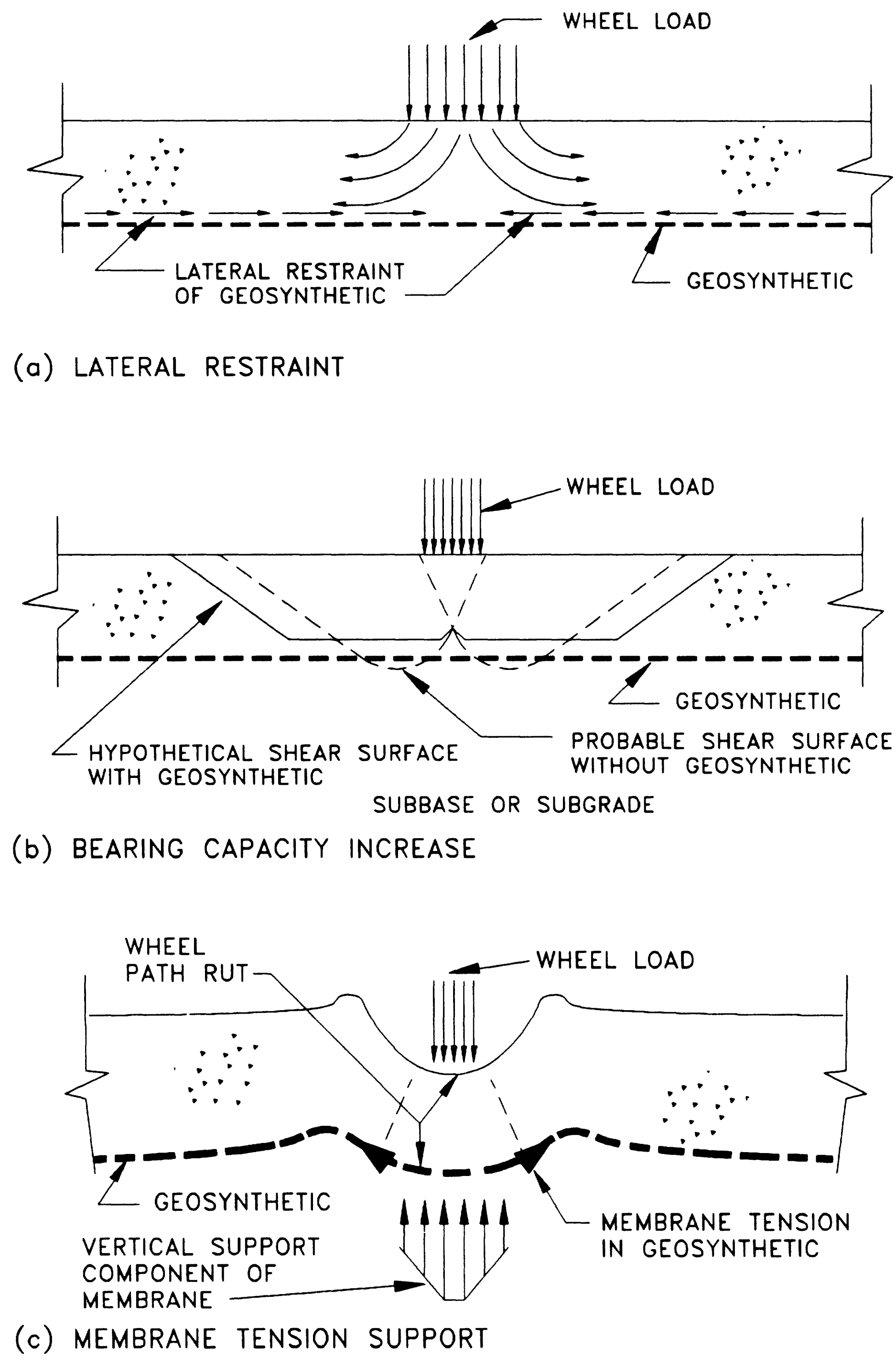


Figure 5-2 Possible reinforcement functions provided by geosynthetics in roadways: (a) lateral restraint, (b) bearing capacity increase, and (c) membrane tension support (after Haliburton, et al., 1981).

A third possible geosynthetic reinforcement function is membrane-type support of wheel loads, as shown conceptually in Figure 5-2c. In this case, the wheel load stresses must be great enough to cause plastic deformation and ruts in the subgrade. If the geosynthetic has a sufficiently high tensile modulus, tensile stresses will develop in the reinforcement, and the vertical component of this membrane stress will help support the applied wheel loads. As tensile stress within the geosynthetic cannot be developed without some elongation, wheel path rutting (in excess of 100 mm) is required to develop membrane-type support. Therefore, this mechanism is generally limited to temporary roads or the first aggregate lift in permanent roadways.

5.1-2 Subgrade Conditions in which Geosynthetics are Useful

Geotextile separators have a 20+ year history of successful use for the stabilization of very soft wet subgrades. Based on experience and several case histories summarized by Haliburton, Lawmaster, and McGuffey (1981) and Christopher and Holtz (1985), the following subgrade conditions are considered to be the most appropriate for geosynthetic use in roadway construction:

- Poor soils
  (USCS: SC, CL, CH, ML, MH, OL, OH, and PT)
  (AASHTO: A-5, A-6, A-7-5, and A-7-6)
- Low undrained shear strength
  $\tau_f = c_u < 90$ kPa
  CBR < 3 {Note: CBR as determined with ASTM D 4429 Bearing Ratio of Soils in Place (1994)}
  $M_R \approx 30$ MPa
- High water table
- High sensitivity

Under these conditions, geosynthetics function primarily as separators and filters to stabilize the subgrade, improving construction conditions and allowing long-term strength improvements in the subgrade. If large ruts develop during placement of the first aggregate lift, then some reinforcing effect is also present. As a summary recommendation, the following geotextile functions are appropriate for the corresponding subgrade strengths:

Undrained Shear Strength (kPa)	Subgrade CBR	Functions
60 - 90	2 - 3	Filtration and possibly separation
30 - 60	1 - 2	Filtration, separation, and possibly reinforcement
< 30	< 1	All functions, including reinforcement

As the geosynthetic allows for subgrade improvement with time, AASHTO M288 has identified applications where the undrained shear strength is less than about 90 kPa (CBR about 3) as *stabilization* applications. From a foundation engineering point of view, clay soils with undrained shear strengths of 90 kPa are considered to be stiff clays (Terzaghi and Peck, 1967, p 30) and are generally quite good foundation materials. Allowable footing pressures on such soils equal 150 kPa or greater. Simple stress distribution calculations show that for **static** loads, such soils will readily support reasonable truck loads and tire pressures, even under relatively thin granular bases.

Dynamic loads and high tire pressures are another matter. Some rutting will probably occur in such soils, especially after a few hundred passes (Webster, 1993). If traffic is limited, as it is in many temporary roads, or if shallow (< 75 mm) ruts are acceptable, as in most construction operations, then a maximum undrained shear strength of about 90 kPa (CBR = 3) for geosynthetic use in highway construction seems reasonable. However, for soils that are seasonally weak (*e.g.*, from frost heave) or for high fines content soils which are susceptible to pumping, a geotextile separator may be of benefit in preventing migration of fines. This is especially the case for permeable base applications. Even on firm subgrades, a geotextile placed beneath the base functions as a separator and filter, as illustrated in Figure 5-3. A greater range of geotextile applicability is recognized in the M288 specification (AASHTO, 1997) with a CBR ≥ 3 the geotextile application is identified as separation. Further discussion of potential applicability of geotextiles on soils with CBR > 3 is presented in Appendix G of this manual, and the complete M288 specification is presented in Appendix D.

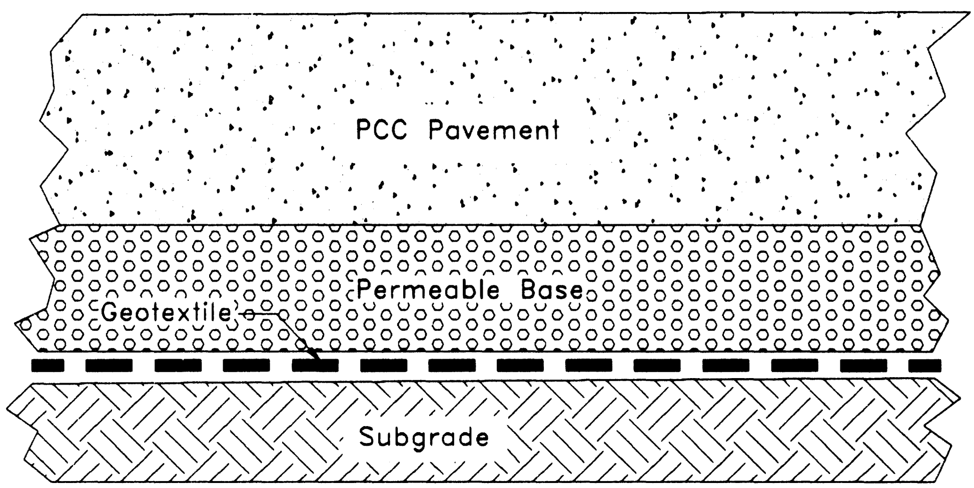


Figure 5-3 Geotextile separator beneath permeable base (Baumgartner, 1994).

5.2 APPLICATIONS

5.2-1 Temporary and Permanent Roads

Roads and highways are broadly classified into two categories: permanent and temporary, depending on their service life, traffic applications, or desired performance. Permanent roads include both paved and unpaved systems which usually remain in service 10 years or more. Permanent roads may be subjected to more than a million load applications during their design lives. On the other hand, temporary roads are, in most cases, unpaved. They remain in service for only short periods of time (often less than 1 year), and are usually subjected to fewer than 10,000 load applications during their services lives. Temporary roads include detours, haul and access roads, construction platforms, and stabilized working *tables* required for the construction of permanent roads, as well as embankments over soft foundations.

Geosynthetics allow construction equipment access to sites where the soils are normally too weak to support the initial construction work. This is one of the more important uses of geosynthetics. Even if the finished roadway can be supported by the subgrade, it may be virtually impossible to begin construction of the embankment or roadway. Such sites require stabilization by dewatering, demucking, excavation and replacement with select granular materials, utilization of stabilization aggregate, chemical stabilization, etc. Geosynthetics can often be a cost-effective alternate to these expensive foundation treatment procedures.

Furthermore, geosynthetic separators enable contractors to meet minimum compaction specifications for the first two or three aggregate lifts. This is especially true on very soft, wet subgrades, where the use of ordinary compaction equipment is very difficult or even impossible. Long term, a geosynthetic acts to maintain the roadway design section and the base course material integrity. Thus, the geosynthetic will ultimately increase the life of the roadway.

5.2-2 Benefits

Geosynthetics used in roadways on soft subgrades, may provide several cost and performance benefits, including the following.

1. Reducing the intensity of stress on the subgrade and preventing the base aggregate from penetrating into the subgrade **(function: separation)**.
2. Preventing subgrade fines from pumping or otherwise migrating up into the base **(function: separation and filtration)**.
3. Preventing contamination of the base materials which may allow more open-graded, free-draining aggregates to be considered in the design **(function: filtration)**.
4. Reducing the depth of excavation required for the removal of unsuitable subgrade materials

(function: separation and reinforcement).

5. Reducing the thickness of aggregate required to stabilize the subgrade **(function: separation and reinforcement).**
6. Reducing disturbance of the subgrade during construction **(function: separation and reinforcement).**
7. Allowing an increase in subgrade strength over time **(function: filtration).**
8. Reducing the differential settlement of the roadway, which helps maintain pavement integrity and uniformity **(function: reinforcement).** Geosynthetics will also aid in reducing differential settlement in transition areas from cut to fill. {NOTE: Total and consolidation settlements are not reduced by the use of geosynthetic reinforcement.}
9. Reducing maintenance and extending the life of the pavement **(functions: all).**

Geosynthetics are also used in permanent roadways to provide capillary breaks to reduce frost action in frost-susceptible soils, and to provide membrane-encapsulated soil layers (MESL) to reduce the effects of seasonal water content changes on roadways on swelling clays.

5.3 POSSIBLE FAILURE MODES OF PERMANENT ROADS

Yoder and Witczak (1975) define two types of pavement distress, or failure. The first is a structural failure, in which a collapse of the entire structure or a breakdown of one or more of the pavement components renders the pavement incapable of sustaining the loads imposed on its surface. The second type failure is a functional failure; it occurs when the pavement, due to its roughness, is unable to carry out its intended function without causing discomfort to drivers or passengers or imposing high stresses on vehicles. The cause of these failure conditions may be due to excessive loads, climatic and environmental conditions, poor drainage leading to poor subgrade conditions, and disintegration of the component materials. Excessive loads, excessive repetition of loads, and high tire pressures can cause either structural or functional failures.

Pavement failures may occur due to the intrusion of subgrade soils into the granular base, which results in inadequate drainage and reduced stability. Distress may also occur due to excessive loads that cause a shear failure in the subgrade, base course, or the surface. Other causes of failures are surface fatigue and excessive settlement, especially differential of the subgrade. Volume change of subgrade soils due to wetting and drying, freezing and thawing, or improper drainage may also cause pavement distress. Inadequate drainage of water from the base and subgrade is a major cause of pavement problems (Cedergren, 1987). If the subgrade is saturated, excess pore pressures will develop under traffic loads, resulting in subsequent softening of the subgrade. Under dynamic loading, fines can be literally pumped up into the subgrade or base.

Improper construction practices may also cause pavement distress. Wetting of the subgrade during construction may permit water accumulation and subsequent softening of the subgrade in the rutted areas after construction is completed. Use of dirty aggregates or contamination of the base aggregates during construction may produce inadequate drainage, instability, and frost susceptibility. Reduction in design thickness during construction due to insufficient subgrade preparation may result in undulating subgrade surfaces, failure to place proper layer thicknesses, and unanticipated loss of base materials due to subgrade intrusion. Yoder and Witczak (1975) state that a major cause of pavement deterioration is inadequate observation and field control by qualified engineers and technicians during construction.

After construction is complete, improper or inadequate maintenance may also result in pavement distress. Sealing of cracks and joints at proper intervals must be performed to prevent surface water infiltration. Maintenance of shoulders will also affect pavement performance.

As indicated in the list of possible benefits resulting from geosynthetic use in permanent roadway systems (section 5.2-2), properly designed geosynthetics can enhance pavement performance and reduce the likelihood of failures.

5.4 ROADWAY DESIGN USING GEOTEXTILES

Certain design principles are common to all types of roadways, regardless of the design method. Basically, the design of any roadway involves a study of each of the components of the system, (surface, aggregate base courses and subgrade) detailing their behavior under traffic load and their ability to carry that load under various climatic and environmental conditions. All roadway systems, whether permanent or temporary, derive their support from the underlying subgrade soils. Thus, the geotextile functions are similar for either temporary or permanent roadway applications. However, due to different performance requirements, **design methodologies for temporary roads should not be used to design permanent roads**. Temporary roadway design usually allows some rutting to occur over the design life, as ruts will not necessarily impair service. Obviously, ruts are not acceptable in permanent roadways. In the following two sections, recommended design procedures for both temporary and permanent roads are presented. Our permanent road and pavement design basically uses geotextiles for the construction or stabilization lift only; the base course thickness required to adequately carry the design traffic loads for the design life of the pavement is not reduced due to the use of a geotextile. There is some evidence, however, that suggests a geogrid placed at the bottom of the aggregate base may permit a 10 to 20% base thickness reduction, as noted in Appendix G, Recent Roadway Research.

5.5 GEOTEXTILE SURVIVABILITY

Selecting a geotextile for either permanent or temporary roads depends upon one thing -- the survivability criteria. If the roadway system is designed correctly, then the stress at the top of the subgrade due to the weight of the aggregate and the traffic load should be less than the bearing capacity of the soil plus a safety factor. However, the stresses applied to the subgrade and the geotextile during construction may be much greater than those applied in service. **Therefore, selection of the geotextile in roadway applications is usually governed by the anticipated construction stresses.** This is the concept of geotextile survivability -- the geotextile must survive the construction operations if it is to perform its intended function.

The geotextile strength required to survive the most severe conditions anticipated during construction is listed in Table 5-1 (a Class 1 geotextile per AASHTO M288 (1997)). Geotextiles that meet or exceed these survivability requirements can be considered acceptable for most projects. The selected geotextile must also retain the underlying subgrade soils, allowing the subgrade to drain freely, consolidate, and gain strength. Thus, the geotextile must be checked, using the drainage and filtration requirements discussed in Chapter 2. Default geotextile requirements are presented in Table 5-1.

The survivability requirements in Table 5-1 were based on both research and on the properties of geotextiles which have performed satisfactorily as separators in roads and in similar applications. In the absence of any other information, they should be used as **minimum** property values. Judgment and experience may be used to reduce the geotextile requirements as indicated by AASHTO M288.

Geotextiles with less survivability strength (*i.e.*, a Class 2 geotextile per AASHTO M288 (1997)) may be acceptable for applications where a *moderate* level of survivability is needed. Table 5-2 relates the elements of construction (*i.e.*, equipment, aggregate characteristics, subgrade preparation, and subgrade shear 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.*, moderate or high), then geotextiles meeting those survivability requirements should be selected. A Class 1 geotextile should be used for the high category, and a Class 2 geotextile may be considered for the moderate category. Variable combinations indicating a NOT RECOMMENDED rating suggests that one or more variables should be modified to assure a successful installation. Some judgment is required in using these criteria.

TABLE 5-1

GEOTEXTILE PROPERTY REQUIREMENTS[1,2,3]

FOR GEOTEXTILES IN STABILIZATION APPLICATIONS

(after AASHTO, 1997)

Property	ASTM Test Method	Units	Requirement	
SURVIVABILITY			Geotextile Class 1[4]	
			Elongation	
			< 50%[5]	> 50%[5]
Grab Strength	D 4632	N	1400	900
Sewn Seam Strength[6]	D 4632	N	1200	810
Tear Strength	D 4533	N	500	350
Puncture Strength	D 4833	N	500	350
Burst Strength	D 3786	kPa	3500	1700
Ultraviolet Stability (Retained Strength)	D 4355	%	50% after 500 hours of exposure	
DRAINAGE AND FILTRATION[7]				
Apparent Opening Size	D 4751	mm	< 0.6 for < 50% passing 0.075 mm sieve < 0.3 for > 50%passing 0.075 mm sieve	
Permittivity	D 4491	sec^{-1}	0.5 for < 15% passing 0.075 mm sieve 0.2 for 15 to 50% passing 0.075 mm sieve 0.1 for > 50% passing 0.075 mm sieve	

NOTES:

1. Acceptance of geotextile material shall be based on ASTM D 4759.
2. Acceptance shall be based upon testing of either conformance samples obtained using Procedure A of ASTM D 4354, or based on manufacturer's certifications and testing of quality assurance samples obtained using Procedure B of ASTM D 4354.
3. Minimum; use value in weaker principal direction. All numerical values represent minimum average roll value (*i.e.*, test results from any sampled roll in a lot shall meet or exceed the minimum values in the table). Lot samples according to ASTM D 4354.
4. Default geotextile selection. The engineer may specify a Class 2 geotextile (see Appendix D) for moderate survivability conditions, see Table 5-2.
5. As measured in accordance with ASTM D 4632.
6. When seams are required. Values apply to both field and manufactured seams.
7. Also, the geotextile permeability should be greater than the soil permeability.

TABLE 5-2
CONSTRUCTION SURVIVABILITY RATINGS
(after Task Force 25, 1990)

Site Soil CBR at Installation[1]	< 1		1 to 2		> 3	
Equipment Ground Contact Pressure (kPa)	> 350	< 350	> 350	< 350	> 350	< 350
Cover Thickness[2] (compacted, mm)						
100[3,4]	NR[5]	NR	1[5]	1	2[5]	2
150	NR	NR	1	1	2	2
300	NR	1	2	2	2	2
450	1	2	2	2	2	2

NOTES:
1. Assume saturated CBR unless construction scheduling can be controlled.
2. Maximum aggregate size not to exceed one-half the compacted cover thickness.
3. For low-volume, unpaved roads (ADT < 200 vehicles).
4. The 100 mm minimum cover is limited to existing road bases and is not intended for use in new construction.
5. NR = NOT RECOMMENDED. High survivability relates to a Class 1 geotextile and Moderate survivability relates to a Class 2 geotextile, per AASHTO M288 (1997).

Survivability of geogrids and geotextiles for major projects should be verified by conducting field tests under site-specific conditions. These field tests should involve trial sections using several geosynthetics on typical subgrades at the project site and implementing various types of construction equipment. After placement of the geosynthetics and aggregate, the geosynthetics are exhumed to see how well or how poorly they tolerated the imposed construction stresses. These tests could be performed during design or after the contract was let, similar to the recommendations for riprap placement (Section 3.8-1). In the latter case, the contractor is required to demonstrate that the proposed subgrade condition, equipment, and aggregate placement will not damage the geotextile or geogrid. If necessary, additional subgrade preparation, increased lift thickness, and/or possibly different construction equipment could be utilized. In rare cases, the contractor may even have to supply a different geosynthetic.

5.6 DESIGN GUIDELINES FOR TEMPORARY AND UNPAVED ROADS

There are two main approaches to the design of temporary and unpaved roads. The first assumes no reinforcing effect of the geotextile; that is, the geotextile acts as a separator only. The second approach considers a possible reinforcing effect due to the geotextile. It appears that the separation function is more important for thin roadway sections with relatively small live loads where ruts, approximating 50 to 100 mm 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 roadways where deep ruts (> 100 mm) may occur, and for thicker roadways on softer subgrades, the reinforcing function becomes increasingly more important if stability is to be maintained. It is for these latter cases that reinforcing analyses have been developed and are appropriate.

The design method presented in this manual considers mainly the separation and filtration functions. It was selected because it has a long history of successful use, it is based on principles of soil mechanics, and it has been calibrated by full-scale field tests. It can also be adapted to a wide variety of conditions. Other methods considering reinforcement functions are described by Koerner (1994), Christopher and Holtz (1985) and Giroud and Noiray (1981). For roadways where stability of the embankment foundation is questionable (*i.e.*, $(\gamma H)/c > 3$), refer to Chapter 7 for information on reinforced embankments.

The following design method was developed by Steward, Williamson, and Mohney (1977) for the U.S. Forest Service (USFS). It allows the designer to consider:

- vehicle passes;
- equivalent axle loads;
- axle configurations;
- tire pressures;
- subgrade strengths; and
- rut depths.

The following limitations apply:

- the aggregate layer must be
  a) compacted to CBR 80,
  b) cohesionless (nonplastic);
- vehicle passes less than 10,000;
- geotextile survivability criteria must be considered; and
- subgrade undrained shear strength less than about 90 kPa (CBR < 3).

As discussed in Section 5.1-2, for subgrades stronger than about 90 kPa (CBR > 3), geotextiles are rarely required for stabilization, although they may provide some drainage and filtration. In this case, the principles developed in Chapter 2 are applicable, just as they are for weaker subgrades where drainage and filtration are likely to be very important.

Based on both theoretical analysis and empirical (laboratory and full-scale field) tests on geotextiles, Steward, Williamson and Mohney (1977) determined that a certain amount of rutting would occur under various traffic conditions, both with and without a geotextile separator and for a given stress level acting on the subgrade. They present this stress level in terms of bearing capacity factors, similar to those commonly used for the design of shallow foundations on cohesive soils. These factors and conditions are given in Table 5-3.

TABLE 5-3
BEARING CAPACITY FACTORS FOR DIFFERENT RUTS AND TRAFFIC CONDITIONS BOTH WITH AND WITHOUT GEOTEXTILE SEPARATORS
(after Steward, Williamson, and Mohney, 1977)

Condition	Ruts (mm)	Traffic (Passes of 80 kN axle equivalents)	Bearing Capacity Factor, N_c
Without Geotextile	<50 >100	>1000 <100	2.8 3.3
With Geotextile	<50 >100	>1000 <100	5.0 6.0

The following design procedure is recommended:

STEP 1. Determine soil subgrade strength.

Determine the subgrade soil strength in the field using the field CBR, cone penetrometer, vane shear, resilent modulus, or any other appropriate test. The undrained shear strength of the soil, c, can be obtained from the following relationships:

- for field CBR, c in kPa = 30 x CBR;
- for the WES cone penetrometer, c = cone index divided by 10 or 11; and
- for the vane shear test, c is directly measured.

Other in-situ tests, such as the static cone penetrometer test (CPT) or dilatometer (DMT), may be used, provided local correlations with undrained shear strength exist. Use of the Standard Penetration Test (SPT) is **not** recommended for soft clays.

STEP 2. Determine subgrade strength at several locations and at different times of the year.

Make strength determinations at several locations where the subgrade appears to be the weakest. Strengths should be evaluated at depth of 0 to 200 mm and from 200 - 500 mm; six to ten strength measurements are recommended at each location to obtain a good average value. Tests should also be performed when the soils are in their weakest condition, when the water table is the highest, etc.

STEP 3. Determine wheel loading.

Determine the maximum single wheel load, maximum dual wheel load, and the maximum dual tandem wheel load anticipated for the roadway during the design period. For example, an 8 m^3 dump truck with tandem axles will have a dual wheel load of approximately 35 kN. A motor grader has a wheel load of 22 to 44 kN.

STEP 4. Estimate amount of traffic.

Estimate the maximum amount of traffic anticipated for each design vehicle class.

STEP 5. Establish tolerable rutting.

Establish the amount of tolerable rutting during the design life of the roadway. For example, 50 to 75 mm of rutting is generally acceptable during construction.

STEP 6. Obtain bearing capacity factor.

Obtain appropriate subgrade stress level in terms of the bearing capacity factors in Table 5-3.

STEP 7. Determine required aggregate thickness.

Determine the required aggregate thickness from the USFS design charts (Figures 5-4, 5-5, and 5-6) for each maximum loading. Enter the curve with appropriate bearing capacity factors (N_c) multiplied by the design subgrade undrained shear strength (c) to evaluate each required stress level (cN_c).

STEP 8. Select design thickness.

Select the design thickness based on the design requirements. The design thickness should be given to the next higher 25 mm.

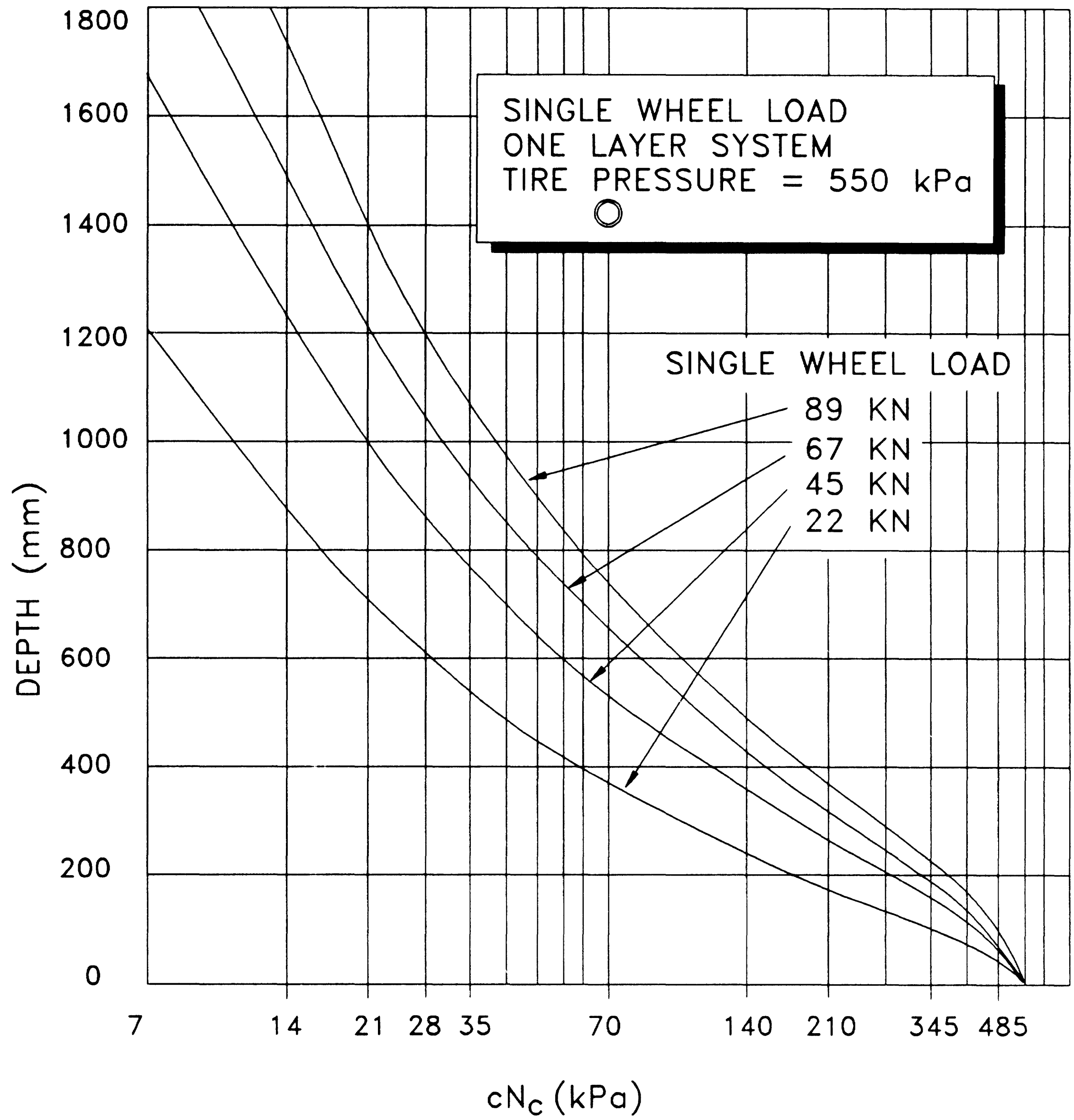


Figure 5-4 U.S. Forest Service thickness design curve for single wheel load (Steward et al., 1977).

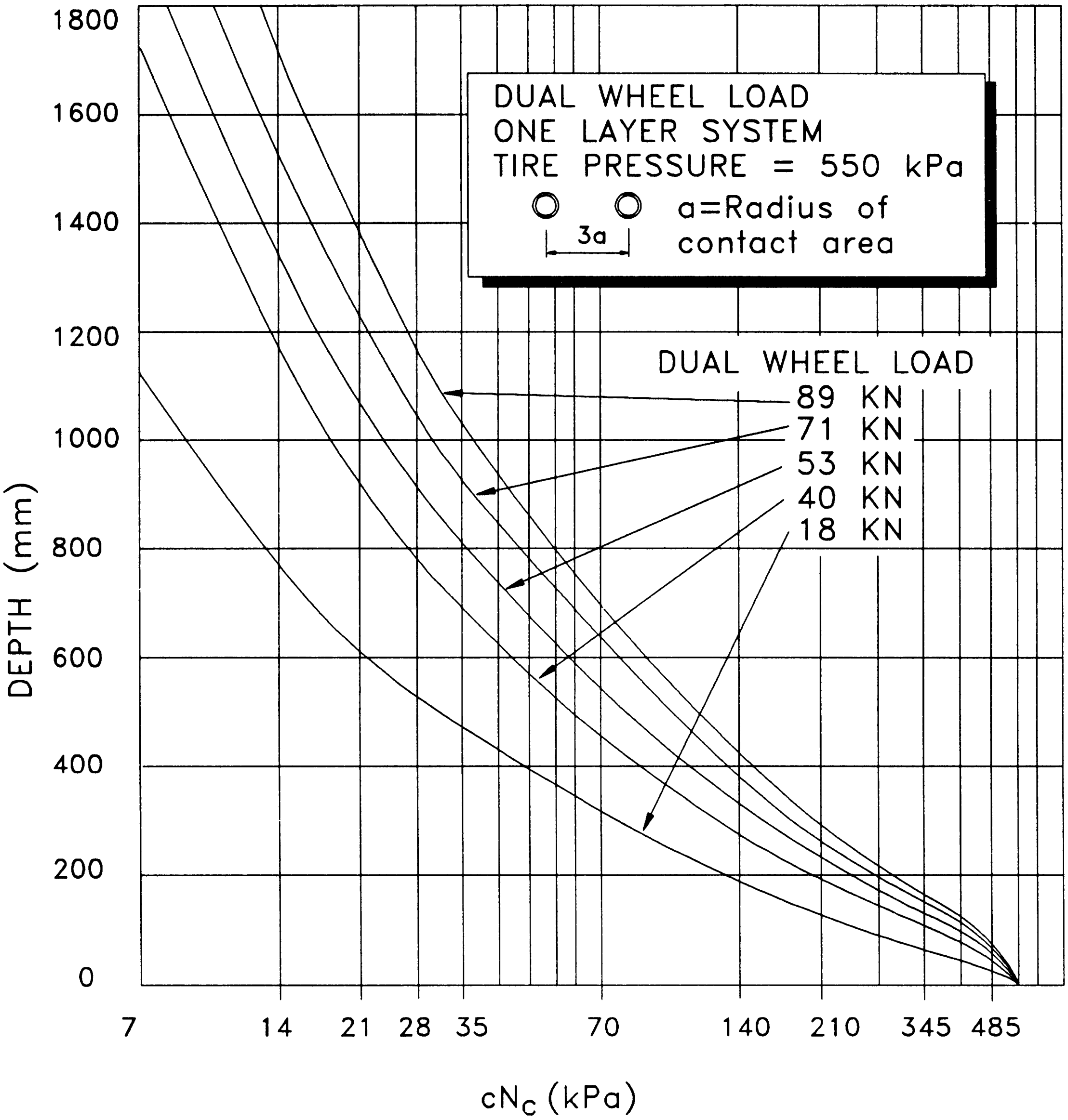


Figure 5-5 U.S. Forest Service thickness design curve for dual wheel load (Steward et al., 1977).

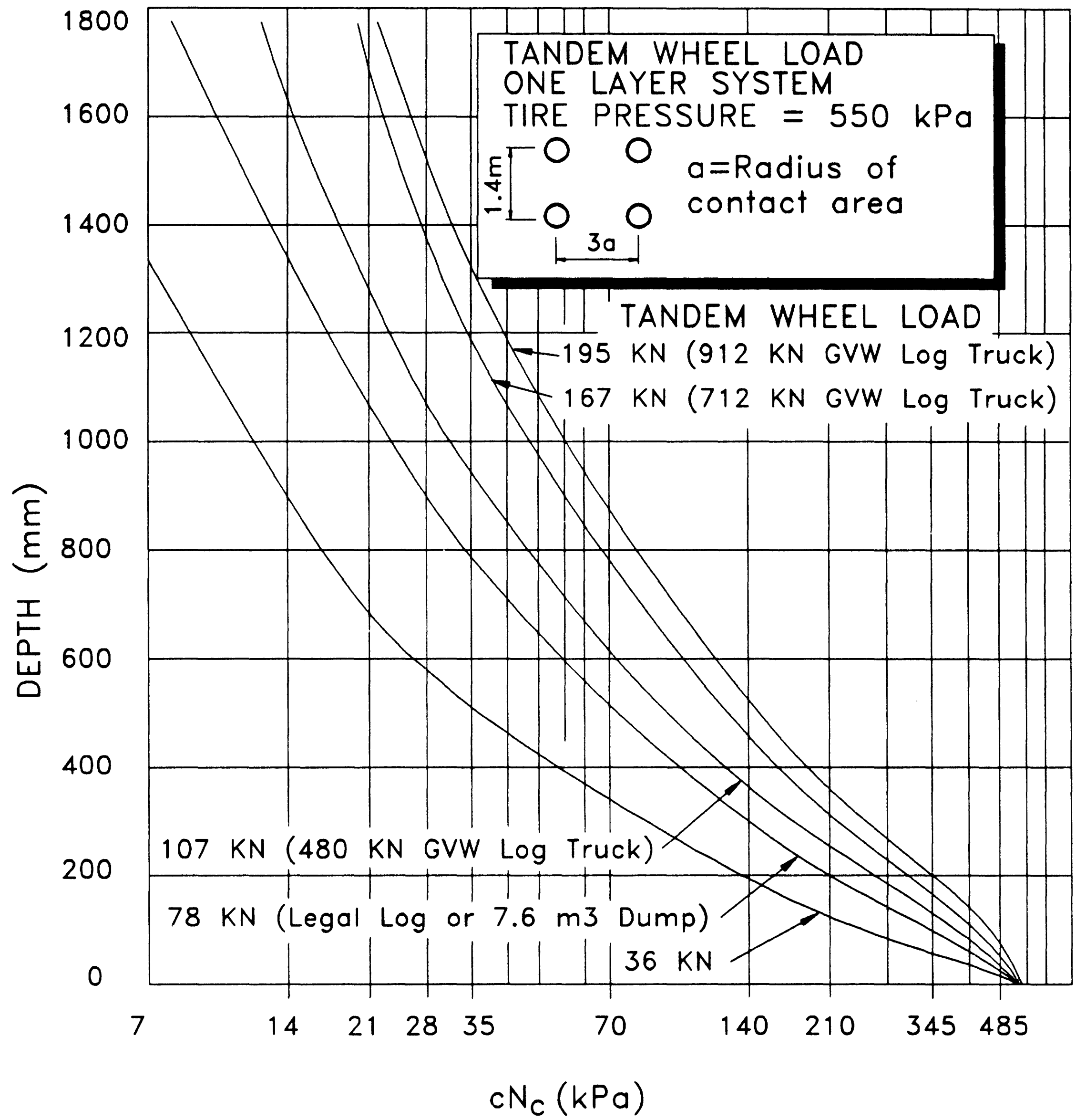


Figure 5-6 U.S. Forest Service thickness design curve for tandem wheel load (Steward et al., 1977).

STEP 9. Check geotextile drainage and filtration characteristics.

Check the geotextile drainage and filtration requirements. Use the gradation and permeability of the subgrade, the water table conditions, and the retention and permeability criteria given in Chapter 2. In high water table conditions with heavy traffic, filtration criteria may also be required. From Chapter 2, that criteria is:

$AOS \leq D_{85}$ (Wovens) (Eq. 2-3)

$AOS \leq 1.8\ D_{85}$ (Nonwovens) (Eq. 2-4)

$k_{geotextile} \geq k_{soil}$ (Eq. 2-7a)

$\psi \geq 0.1\ sec^{-1}$ (Eq. 2-8c)

STEP 10. Determine geotextile survivability requirements.

Check the geotextile survivability strength requirements as discussed in Section 5.5.

STEP 11. Specify geotextile property requirements.

Specify geotextiles that meet or exceed these survivability criteria.

STEP 12. Specify construction requirements.

Follow the construction recommendations in Section 5.12

5.7 TEMPORARY ROAD DESIGN EXAMPLE

DEFINITION OF DESIGN EXAMPLE

- Project Description: A haul road over wet, soft soils is required for a highway construction project.
- Type of Structure: temporary unpaved road
- Type of Application: geotextile separator
- Alternatives:
  - i) excavate unsuitable material and increased aggregate thickness
  - ii) geotextile separator between aggregate and subgrade
  - iii) use an estimated depth of aggregate and maintain as required

GIVEN DATA

- subgrade
  - cohesive subgrade soils
  - high water table
  - average undrained shear strength about 30 kPa or CBR = 1
- traffic
  - approximately 5000 passes
  - 90 kN single axle truck
  - 550 kPa tire pressure

- ruts - maximum of 50 to 100 mm

REQUIRED

Design the roadway section.

Consider: 1) design without a geotextile; and 2) alternate with geotextile.

DEFINE

A. Geotextile function(s):

B. Geotextile properties required:

C. Geotextile specification:

SOLUTION

A. Geotextile function(s):
   Primary - separation
   Secondary - filtration, drainage, reinforcement

B. Geotextile properties required:
   survivability
   apparent opening size (AOS)

DESIGN Design roadway with and without geotextile inclusion. Compare options.

STEP 1. DETERMINE SOIL SUBGRADE STRENGTH

given - CBR ≈ 1

STEP 2. DETERMINE SUBGRADE STRENGTH AT SEVERAL LOCATIONS

Assume that CBR ≈ 1 is taken from area(s) where the subgrade appears to be the weakest.

STEP 3. DETERMINE WHEEL LOADING

given - 90 kN single-axle truck, with 550 kPa tire pressure
- therefore, 45 kN single wheel load

STEP 4. ESTIMATE AMOUNT OF TRAFFIC

given - 5,000 passes

STEP 5. ESTABLISH TOLERABLE RUTTING

given - 150 to 200 mm

STEP 6. OBTAIN BEARING CAPACITY FACTOR

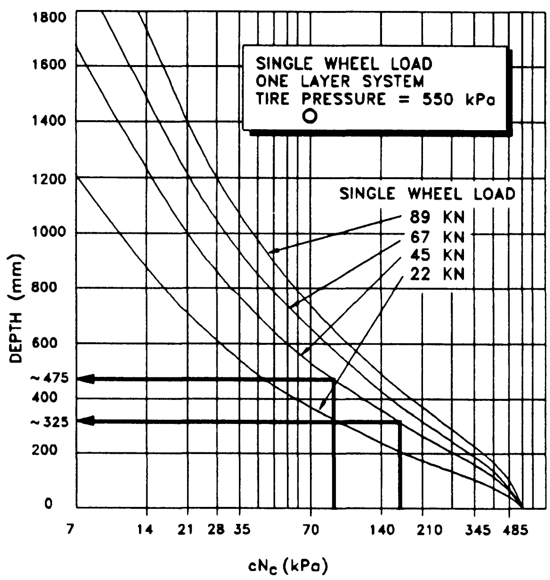
without a geotextile:
- $2.8 < N_c < 3.3$
- assume $N_c \approx 3.0$ for 5,000 passes and 50 to 100 mm ruts

with a geotextile:
- $5.0 < N_c < 6.0$
- assume $N_c \approx 5.5$ for 5,000 passes and 50 to 100 mm ruts

STEP 7. DETERMINE REQUIRED AGGREGATE THICKNESSES

without a geotextile
- $c\ N_c = 30\ \text{kPa} \times 3.0 = 90\ \text{kPa}$
- depth of aggregate ≈ 475 mm

with a geotextile
- $c\ N_c = 30\ \text{kPa} \times 5.5 = 165\ \text{kPa}$
- depth of aggregate ≈ 325 mm



STEP 8. SELECT DESIGN THICKNESS

Use 325 mm and a geotextile

STEP 9. CHECK GEOTEXTILE DRAINAGE AND FILTRATION CHARACTERISTICS

Use AOS < 0.3 mm and permittivity ≥ 0.1 sec^{-1}, per requirement of Table 5-1 since soil has > 50% passing the 0.075 mm sieve. Permeability of geotextile must be greater than soil permeability.

STEP 10. DETERMINE GEOTEXTILE SURVIVABILITY REQUIREMENTS

Use Table 5-2: with CBR = 1, dump truck contact pressure > 550 kPa, and 325 mm cover thickness, and find a **MODERATE** survivability to **NOT RECOMMENDED** rating.

Use a HIGH, or Class 1, survivability geotextile, or greater.

STEP 11. SPECIFY GEOTEXTILE PROPERTY REQUIREMENTS

From Table 5-1; geotextile separator shall meet or exceed the minimum average roll values, with elongation at failure determined with the ASTM D 4632 test method, of:

Property	ASTM Test Method	Elongation < 50%	Elongation > 50%
Grab Strength	D 4632	1400	900
Sewn Seam Strength	D 4632	1200	810
Tear Resistance	D 4533	500	350

Puncture	D 4833	500	350
Burst	D 3786	3500	1700
Ultraviolet Stability	D 4355	50% strength retained after 500 hours	

The geotextile shall have an AOS < 0.3 mm, $\psi \geq 0.1\ sec^{-1}$, and the permeability shall be ______.

STEP 12. SPECIFY CONSTRUCTION REQUIREMENTS

See Section 5.12

5.8 DESIGN GUIDELINES FOR PERMANENT ROADWAYS

The recommended design method for using geotextiles in permanent pavements is that developed by Christopher and Holtz (1985; 1991). It is based on the following concepts:

1. Standard methods are used to design the overall pavement system (*i.e.*, AASHTO, CBR, R-value, resilent modulus, etc.).
2. **The geotextile is assumed to provide no structural support, therefore, no reduction is allowed in aggregate thickness required for structural support.**
3. Aggregate savings is achieved through a reduction in the stabilization aggregate required for construction but not used for structural support.
4. The recommended method is used to design the first construction lift, which is called the *stabilizer lift* since it sufficiently stabilizes the subgrade to allow access by normal construction equipment.
5. Once the stabilizer lift is completed, construction proceeds using standard methods.

The design method assumes that the stabilizer lift is an unpaved road which will be exposed to relatively few vehicle passes (*i.e.*, construction equipment only) and which can tolerate 50 to 75 mm of rutting under the equipment loads. The design consists of the following steps:

STEP 1. Assess need for geotextile.

Estimate the need for a geotextile based on the subgrade strength and by past performance in similar types of soils.

STEP 2. Design pavement without geotextile.

Design the roadway for structural support using normal pavement design methods; provide no allowance for the geotextile.

STEP 3. Determine need for additional aggregate.

See Figure 5-7 to determine if additional aggregate above that required for structural support is needed due to susceptibility of soils to pumping and base course intrusion. If so, reduce that aggregate thickness and include a geotextile at the base/subgrade interface. Note that a thickness reduction of approximately 50% is normally cost effective.

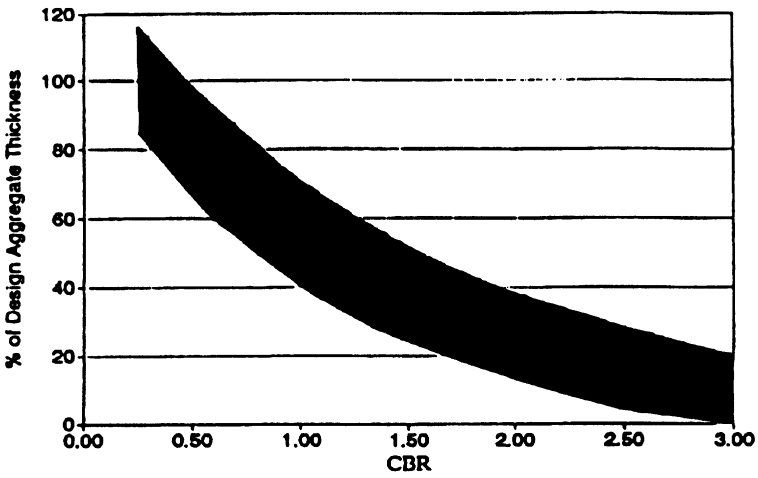


Figure 5-7 Aggregate loss to weak subgrades (FHWA, 1989; in Christopher and Holtz, 1991).

STEP 4. Determine aggregate depth required to support construction equipment.

Determine the additional aggregate required for stabilization of the subgrade during construction activities. Use a 50 to 75 mm rutting criteria for construction equipment, and refer to the procedures outlined in Section 5.6.

STEP 5. Compare thicknesses.

Compare the aggregate-geotextile system thicknesses determined in Steps 3 and 4. Use the system with the greater thickness.

STEP 6. Check geotextile filtration.

Check the geotextile filtration characteristics using the gradation and permeability of the subgrade, the water table conditions, and the retention and permeability criteria. From Chapter 2, that criteria is:

$AOS \leq D_{85}$ (Wovens) (Eq. 2-3)

$AOS \leq 1.8\ D_{85}$ (Nonwovens) (Eq. 2-4)

$k_{geotextile} \geq k_{soil}$ (Eq. 2-7a)

$\psi \geq 0.1\ sec^{-1}$ (Eq. 2-8c)

STEP 7. Determine geotextile survivability requirements.

Check the geotextile strength requirements for survivability as discussed in Section 5.5.

STEP 8. Specify geotextiles that meet or exceed those survivability criteria.

STEP 9. Follow the construction recommendations in Section 5.12.

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; Barksdale, et al., 1989; Webster, 1993) have been proposed and may also be used. If a geogrid is used, either the base material should be sufficiently well graded to provide subgrade filtration and prevent soil intrusion, or for more open bases, a geotextile filter should be used with the geogrid.

5.9 PERMANENT ROAD DESIGN EXAMPLE (Christopher and Holtz, 1991)

DEFINITION OF DESIGN EXAMPLE

- Project Description: New public street and service drive for a suburban Washington, D.C., townhouse development. State of Virginia DOT regulations apply.
- Type of Structure: Category IV street (permanent road)
- Type of Application: geotextile separator
- Alternatives: i) excavate unsuitable material and increase subgrade aggregate thickness; or ii) geotextile separator between aggregate and subgrade

GIVEN DATA

- subgrade
  - surficial soils: micaceous silts (CBR ≈ 2)
  - local areas of very poor soils (CBR ≈ 0.5)
  - low-lying topography
  - poor drainage
  - other nearby streets and roads require frequent maintenance

- traffic
  - maximum 300 vehicles per day
  - 96% passenger, 5% single-axle, 1 multiaxle
  - equivalent daily 90 kN single-axle load (EAL) applications = 10

REQUIRED

Design the pavement section.

Consider: 1) standard AASHTO design; and 2) alternate with geotextile

DEFINE

A. Geotextile function(s):

B. Geotextile properties required:

C. Geotextile specification:

SOLUTION

A. Geotextile function(s):
   Primary - separation
   Secondary - filtration

B. Geotextile properties required:
   survivability
   apparent opening size (AOS)
   permeability

DESIGN Design pavement with and without geotextile inclusion. Compare options.

STEP 1. ESTIMATE NEED FOR GEOTEXTILE

Ideal conditions for considering a geotextile; *e.g.*, low CBR, saturated subgrade, and poor performance history with conventional design.

STEP 2. DESIGN WITHOUT GEOTEXTILE

The structural design for the pavement section is based on the AASHTO Guide for Design of Pavement Structures (1977) using an equivalent design structural number for the anticipated loading and soil support conditions. (NOTES: i) AASHTO design uses English units; and ii) this case history used the AASHTO guide, 1977, which was current at time of design.)

traffic - as given

Determine structural number, SN:
   from AASHTO design charts and with 20 years, CBR = 2, EAL = 10, and Regional Factor = 2
   SN is equal to 2.9

Compute pavement thickness for structural support on a stable subgrade (*i.e.*, no fines pumped into aggregate subbase and no aggregate loss down into the subgrade):

Assume 2.5 inches asphaltic concrete surface and 8 inches aggregate base course

	surface	+	base	+	subbase
SN =	$a_1\ D_1$	+	$a_2\ D_2$	+	$a_3\ D_3$
2.9 =	0.4 *x* 2.5"	+	0.14 *x* 8"	+	0.13 *x* D_3

Therefore, D_3 = 6 inches required for subbase.

Structural design: 2.5" asphaltic concrete
8" aggregate base
6" aggregate subbase

STEP 3. ADDITIONAL AGGREGATE FOR PUMPING AND INTRUSION

By local experience in this area, and for subgrades of CBR ≤ 2, an additional 8 inches of aggregate subbase is required (stabilization aggregate).

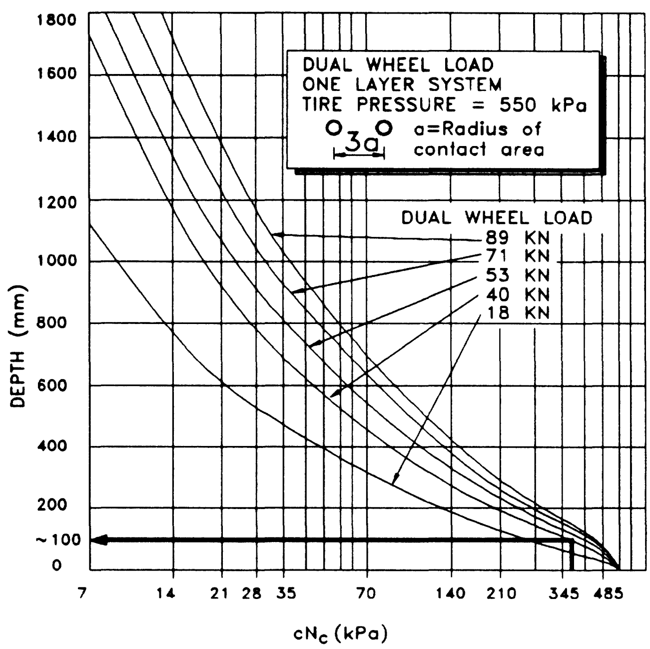
For the geotextile separator alternate, this entire stabilization layer could be eliminated. However, some very poor soils are anticipated, and some conservatism can be applied. Therefore, reduce subbase aggregate thickness to 4 inches (100 mm) with use of a geotextile separator.

STEP 4. DESIGN FOR CONSTRUCTABILITY USING A GEOTEXTILE

Use temporary road design procedures.

Assume:
CBR = 2
loaded dump trucks
< 100 passes
50 mm rut depth acceptable

Use Figure 5-5 (use 40 kN load) and
c ≈ 30 *x* CBR ≈ 60 kPa
N_c = 6
cN_c = 360 kPa
aggregate depth = 100 mm



STEP 5. COMPARE THE THICKNESSES DETERMINED IN STEPS 3 AND 4

The two thicknesses are equal; therefore, use 100 mm of stabilization aggregate with a geotextile separator. Note that the minimum thickness of aggregate for a construction haul road is 100 mm, though the contractor will likely use a greater thickness.

STEP 6. CHECK GEOTEXTILE FILTRATION CHARACTERISTICS

Use AOS < 0.3 mm per Table 5-1 because > 50% passing the 0.075 mm sieve.

Permeability of geotextile must be greater than soil permeability per Table 5-1. Estimate soil permeability and determine geotextile requirement.

STEP 7. DETERMINE GEOTEXTILE SURVIVABILITY REQUIREMENTS

Use Table 5-2, with CBR = 2, dump truck contact pressure > 350 kPa, and 150 mm cover thickness (note that 100 mm cover is limited to existing road bases, therefore 150 mm minimum compacted lift thickness is recommended), and determine that a geotextile with a **HIGH**, or Class 1, survivability rating is required.

STEP 8. SPECIFY GEOTEXTILE PROPERTY REQUIREMENTS

From Table 5-1; geotextile separator shall meet or exceed the minimum average roll values, with elongation at failure determined with the ASTM D 4632 test method, of:

Property	ASTM Test Method	Elongation < 50%	Elongation > 50%
Grab Strength	D 4632	1400	900
Sewn Seam Strength	D 4632	1200	810
Tear Resistance	D 4533	500	350
Puncture	D 4833	500	350
Burst	D 3786	3500	1700
Ultraviolet Stability	D 4355	50% strength retained after 500 hours	

The geotextile shall have an AOS < 0.3 mm, $\psi \geq 0.1\ sec^{-1}$, and the permeability shall be ______.

STEP 9. SPECIFY CONSTRUCTION REQUIREMENTS

See Section 5.12

5.10 COST CONSIDERATIONS

Estimation of construction costs and benefit-cost ratios for geosynthetic-stabilized road construction is straight-forward and basically the same as that required for alternative pavement designs. Primary factors include the following:

1. cost of the geosynthetic;
2. cost of constructing the conventional design versus a geosynthetic design (*i.e.*, stabilization

requirements for conventional design versus geosynthetic design), including
   a) stabilization aggregate requirements,
   b) excavation and replacement requirements,
   c) operational and technical feasibility, and
   d) construction equipment and time requirements;
3. cost of conventional maintenance during pavement service life versus improved service anticipated by using geosynthetic (estimated through pavement management programs); and
4. regional experience.

Annual cost formulas, such as the Baldock method (Illinois DOT, 1982), can be applied with an appropriate present worth factor to obtain the present worth of future expenditures.

Cost tradeoffs should also be evaluated for different construction and geosynthetic combinations. This should include subgrade preparation and equipment control versus geosynthetic survivability. In general, higher-cost geosynthetics with a higher survivability on the existing subgrade will be less expensive than the additional subgrade preparation necessary to use lower-survivability geosynthetics.

Research is ongoing to quantify the cost-benefit life cycle ratio of using geosynthetics in permanent roadway systems. In any case, the cost of a geosynthetic is generally $1.25/m^2 while the cost of the pavement section is generally $25/m^2. **The life extension of the roadway section will more than make up for the cost of the geosynthetic. The ability of a geosynthetic to prevent premature failure provides an extremely low-cost performance insurance.**

5.11 SPECIFICATIONS

5.11-1 Geotextile for Separation and Stabilization Applications

Specifications should generally follow the guidelines in Section 1.6. The main considerations include the minimum geotextile requirements for design and those obtained from the survivability, retention, and filtration requirements in (Sections 5.5 and 5.8), as well as the construction requirements covered in Section 5.12. As with other applications, it is very important that an engineer's representative 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 no damage to the geotextile is occurring. The following example specification is a combination of the AASHTO M288 (1997) geotextile material specification and its accompanying construction/installation guidelines.

SPECIFICATION FOR GEOTEXTILES USED IN SEPARATION AND STABILIZATION APPLICATIONS

(after AASHTO M288, 1997)

1. SCOPE

1.1 *Description.* This specification is applicable to the use of a geotextile to prevent mixing of a subgrade soil and an aggregate cover material (*i.e.*, separation application); and to the use of a geotextile in wet, saturated conditions to provide the coincident functions of separation and filtration (*i.e.*, stabilization application). In some stabilization applications, the geotextile can also provide the function of reinforcement.

1.2 *Separation.* The separation application is appropriate for pavement structures constructed over soils with a California Bearing Ratio greater than or equal to three (CBR $\geq$ 3) (shear strength greater than .pproximately 90 kPa). It is appropriate for unsaturated subgrade soils. The primary function of a geotextile in this application is separation.

1.3 *Stabilization.* The stabilization application is appropriate for subgrade soils which are saturated due to a high groundwater table or due to prolonged periods of wet weather. Stabilization is applicable to pavement structures constructed over soils with a CBR between one and three (1 < CBR < 3) (shear strength between approximately 30 kPa and 90 kPa). This specification is not appropriate for embankment reinforcement where stress conditions may cause global subgrade foundation or stability failure. Reinforcement of the pavement section is a site-specific design issue.

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards*

T88	Particle Size Analysis of Soils
T90	Determining the Plastic Limit and Plasticity Index of Soils
T99	The Moisture-Density Relationships of Soils Using a 2.5 kg Rammer and a 305 mm Drop

2.2 *ASTM Standards*

D 123	Standard Terminology Relating to Textiles
D 276	Test Methods for Identification of Fibers in Textiles
D 3786	Test Method for Hydraulic Burst Strength of Knitted Goods and Nonwoven Fabrics, Diaphragm Bursting Strength Tester Method
D 4354	Practice for Sampling of Geosynthetics for Testing
D 4355	Test Method for Deterioration of Geotextiles from Exposure to Ultraviolet Light and Water (Xenon Arc Type Apparatus)
D 4439	Terminology for Geosynthetics
D 4491	Test Methods for Water Permeability of Geotextiles by Permittivity
D 4632	Test Method for Grab Breaking Load and Elongation of Geotextiles
D 4751	Test Method for Determining Apparent Opening Size of a Geotextile
D 4759	Practice for Determining the Specification Conformance of Geosynthetics
D 4833	Test Method for Index Puncture Resistance of Geotextiles, Geomembranes and Related Products
D 4873	Guide for Identification, Storage, and Handling of Geotextiles

D 5141 Test Method to Determine Filtering Efficiency and Flow Rate for Silt Fence Applications Using Site Specific Soil

3. PHYSICAL AND CHEMICAL REQUIREMENTS

3.1 Fibers used in the manufacture of geotextiles and the threads used in joining geotextiles by sewing, shall consist of long chain synthetic polymers, composed of at least 95% by weight polyolefins or polyesters. They shall be formed into a stable network such that the filaments or yarns retain their dimensional stability relative to each other, including selvages.

3.2 *Geotextile Requirements.* The geotextile shall meet the requirements of following Table. Woven slit film geotextiles (*i.e.*, geotextiles made from yarns of a flat, tape-like character) will not be allowed. All numeric values in the following table, except AOS, represent minimum average roll values (MARV) in the weakest principal direction (*i.e.*, average test results of any roll in a lot sampled for conformance or quality assurance testing shall meet or exceed the minimum values). Values for AOS represent maximum average roll values.

4. CERTIFICATION

4.1 The Contractor shall provide to the Engineer a certificate stating the name of the manufacturer, product name, style number, chemical composition of the filaments or yarns and other pertinent information to fully describe the geotextile.

4.2 The Manufacturer is responsible for establishing and maintaining a quality control program to assure compliance with the requirements of the specification. Documentation describing the quality control program shall be made available upon request.

4.3 The Manufacturer's certificate shall state that the furnished geotextile meets MARV requirements of the specification as evaluated under the Manufacturer's quality control program. The certificate shall be attested to be a person having legal authority to bind the Manufacturer.

4.4 Either mislabeling or misrepresentation of materials shall be reason to reject those geotextile products.

5. SAMPLING, TESTING, AND ACCEPTANCE

5.1 Geotextiles shall be subject to sampling and testing to verify conformance with this specification. Sampling for testing shall be in accordance with ASTM D 4354. Acceptance shall be based on testing of either conformance samples obtained using Procedure A of ASTM D 4354, or based on manufacturer's certifications and testing of quality assurance samples obtained using Procedure B of ASTM D 4354. A lot size for conformance or quality assurance sampling shall be considered to be the shipment quantity of the given product or a truckload of the given product, whichever is smaller.

5.2 Testing shall be performed in accordance with the methods referenced in this specification for the indicated application. The number of specimens to test per sample is specified by each test method. Geotextile product acceptance shall be based on ASTM D 4759. Product acceptance is determined by comparing the average test results of all specimens within a given sample to the specification MARV. Refer to ASTM D 4759 for more details regarding geotextile acceptance procedures.

Geotextile Requirements for Separation and Stabilization Applications

Property	ASTM Test Method	Units	Separation Application Class 2(1)		Stabilization Application Class 1(2)	
			Geotextile Elongation < 50%(3)	Geotextile Elongation ≥ 50%(3)	Geotextile Elongation < 50%(3)	Geotextile Elongation ≥ 50%(3)
Grab Strength	D 4632	N	1100	700	1400	900
Sewn Seam Strength(4)	D 4632	N	990	630	1200	810
Tear Strength	D 4533	N	400(5)	250	500	350
Puncture Strength	D 4833	N	400	250	500	350
Burst Strength	D 3786	kPa	2700	1300	3500	1700
Permittivity	D 4491	sec^{-1}	0.02(5)		0.05(5)	
Apparent Opening Size	D 4751	mm	0.60 max.		0.43 max.	
Ultraviolet Stability (Retained Strength)	D 4355	%	50% after 500 hours of exposure			

NOTES:

(1) Default geotextile selection. The Engineer may specify a Class 3 geotextile [Appendix D] based on one or more of the following:
   a) The Engineer has found Class 3 geotextiles to have sufficient survivability based on field experience.
   b) The Engineer has found Class 3 geotextiles to have sufficient survivability based on laboratory testing and visual inspection of a geotextile sample removed from a field test section constructed under anticipated field conditions.
   c) Aggregate cover thickness of the first lift over the geotextile exceeds 300 mm and aggregate diameter is less than 50 mm.
   d) Aggregate cover thickness of the first lift over the geotextile exceeds 150 mm, aggregate diameter is less than 30 mm, and construction equipment contact pressure is less than 550 kPa.

(2) Default geotextile selection. The Engineer may specify a Class 2 or 3 geotextile [Appendix D] based on one or more of the following:
   a) The Engineer has found the class of geotextile to have sufficient survivability based on field experience.
   b) The Engineer has found the class of geotextile to have sufficient survivability based on laboratory testing and visual inspection of a geotextile sample removed form a field test section constructed under anticipated field conditions.

(3) As measured in accordance with ASTM D 4632.

(4) When sewn seams are required.

(5) Default value. Permittivity of the geotextile should be greater than that of the soil ($\Psi_g > \Psi_s$). The Engineer may also require the permeability of the geotextile to be greater than that of the soil ($k_g > k_s$).

6. SHIPMENT AND STORAGE

6.1 Geotextile labeling, shipment, and storage shall follow ASTM D 4873. Product labels shall clearly show the manufacturer or supplier name, style number, and roll number. Each shipping document shall include a notation certifying that the material is in accordance with the manufacturer's certificate.

6.2 Each geotextile roll shall be wrapped with a material that will protect the geotextile from damage due to shipment, water, sunlight, and contaminants. The protective wrapping shall be maintained during periods of shipment and storage.

6.3 During storage, geotextile rolls shall be elevated off the ground and adequately covered to protect them from the following: site construction damage, precipitation, extended ultraviolet radiation including sunlight, chemicals that are strong acids or strong bases, flames including welding sparks, temperatures in excess of 71°C (160°F), and any other environmental condition that may damage the physical property values of the geotextile.

7. CONSTRUCTION

7.1 *General.* Atmospheric exposure of geotextiles to the elements following lay down shall be a maximum of 14 days to minimize damage potential.

7.2 *Seaming.*

a. If a sewn seam is to be used for the seaming of the geotextile, the thread used shall consist of high strength polypropylene, or polyester. Nylon thread shall not be used. For erosion control applications, the thread shall also be resistant to ultraviolet radiation. The thread shall be of contrasting color to that of the geotextile itself.

b. For seams which are sewn in the field, the Contractor shall provide at least a 2 m length of sewn seam for sampling by the Engineer before the geotextile is installed. For seams which are sewn in the factory, the Engineer shall obtain samples of the factory seams at random from any roll of geotextile which is to be used on the project.

b.1 For seams that are field sewn, the seams sewn for sampling shall be sewn using the same equipment and procedures as will be used for the production of seams. If seams are to be sewn in both the machine and cross machine directions, samples of seams from both directions shall be provided.

b.2 The seam assembly description shall be submitted by the Contractor along with the sample of the seam. The description shall include the seam type, stitch type, sewing thread, and stitch density.

7.3 *Site Preparation.* The installation site shall be prepared by clearing, grubbing, and excavation or filling the area to the design grade. This includes removal of top soil and vegetation.

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 and compacted using normal procedures.

7.4 *Geotextile Placement.*

a. The geotextile shall be laid smooth without wrinkles or folds on the prepared subgrade in the direction of construction traffic. Adjacent geotextile rolls shall be overlapped, sewn or joined as required in the plans. Overlaps shall be in the direction as shown on the plans. See following Table for overlap requirements.

Overlap Requirements

SOIL CBR	MINIMUM OVERLAP
Greater than 3	300 - 450 mm
1 - 3	0.6 - 1 m
0.5 - 1	1 m or sewn
Less than 0.5	Sewn
All Roll Ends	1 m or sewn

a.1 On curves the geotextile may be folded or cut to conform to the curves. The fold or overlap shall be in the direction of construction and held in place by pins, staples, or piles of fill or rock.

a.2 Prior to covering, the geotextile shall be inspected by a certified inspector of the Engineer to ensure that the geotextile has not been damaged (*i.e.*, holes, tears, rips) during installation. Damaged geotextiles, as identified by the Engineer, shall be repaired immediately. Cover the damaged area with a geotextile patch which extends an amount equal to the required overlap beyond the damaged area.

b. The subbase shall be placed by end dumping onto the geotextile from the edge of the geotextile, or over previously placed subbase aggregate. Construction vehicles shall not be allowed directly on the geotextile. The subbase shall be placed such that at least the minimum specified lift thickness shall be between the geotextile and equipment tires or tracks at all times. Turning of vehicles shall not be permitted on the first lift above the geotextile.

NOTE: On subgrades having a CBR values of less than 1, the subbase aggregate should be spread in its full thickness as soon as possible after dumping to minimize the potential of localized subgrade failure due to overloading of the subgrade.

b.1 Any ruts occurring during construction shall be filled with additional subbase material, and compacted to the specified density.

b.2 If placement of the backfill material causes damage to the geotextile, the damaged area shall be repaired as previously described in section 7.4.a.2. The placement procedures shall then be modified to eliminate further damage from taking place. (*i.e.*, increased initial lift thickness, decrease equipment loads, etc.)

NOTE: In stabilization applications, the use of vibratory compaction equipment is not recommended with the initial lift of subbase material, as it may cause damage to the geotextile.

8. METHOD OF MEASUREMENT

8.1 The geotextile shall be measured by the number of square meters computed from the payment lines shown on the plans or from payment lines established in writing by the Engineer. This excludes seam overlaps, but shall include geotextiles used in crest and toe of slope treatments.

8.2 Slope preparation, excavation and backfill, bedding, and cover material are separate pay items.

9. **BASIS OF PAYMENT**

9.1 The accepted quantities of geotextile shall be paid for per square meter in place.

9.2 Payment will be made under:

Pay Item	Pay Unit
Separation Geotextile	Square Meter
Stabilization Geotextile	Square Meter

5.11-2 Geogrid Reinforcement

An AASHTO, or other standard setting organization, geogrid specification for reinforcement of pavement structures is, presently, not available. Nor was a widely accepted, typical state agency specification for geogrid reinforcement located for inclusion in this manual (though several agency's do have a geogrid reinforcement specification). A typical, generic type material specification for geogrid reinforcement for pavements will be difficult to develop because of: the proprietary nature (i.e., current product patents) of biaxial geogrids; the absence of generic design procedure; a lack of understanding of the mechanistic benefits of geogrid reinforcement; lack of a clear definition of the function(s) of the geogrid in pavement reinforcement application; lack of side-by-side product performance testing; lack of performance documentation; and inability to measure contribution of geogrid reinforcement to pavement structure with non-destructive testing methods.

Agencies which are using geogrids in pavements have typically initiated use after the following considerations:

1. Define purpose and applicability geogrid reinforcement. For example, geogrid reinforcement may be used to minimize over excavation over soft subgrades, to reduce or minimize aggregate base course thickness, to extend pavement life (i.e., analysis period), or a combination of these.
2. Define function(s) of geosynthetic, and assess applicability of geogrids.
3. Construct and monitor a demonstration project to examine performance of candidate geogrid reinforcement(s) versus the agency's conventional construction technique.
4. With satisfactory performance, write a material specification which either lists prequalified products or lists key property requirements.
5. Monitoring of additional projects to confirm anticipated performance, and construction of additional demonstration projects to confirm performance of new products, as needed.

Thus, a geogrid pavement reinforcement specification may list prequalified products or key property requirements. Key property requirements may include definition of some, or all, of the following properties: aperture size; percent open area; tensile modulus (initial, or 2% or 5% secant); rib junction strength; rib junction efficiency; rib thickness; flexural rigidity; and secant aperture stability. See Webster (1993) for a description of the aperture stability test procedure, and applicability of results to their test program.

A geogrid reinforcement specification should allow use of other geogrid products that either: (i) meet the physical properties defined by the key property requirements; or (ii) by demonstrating performance equivalency through full-scale laboratory testing, in-ground testing of pavements, and prior projects.

5.12 INSTALLATION PROCEDURES

5.12-1 Roll Placement

Successful use of geotextiles in pavements requires proper installation, and Figure 5-8 shows the proper sequence of construction. Even though the installation techniques appear fairly simple, most geotextile problems in roadways occur as the result of improper construction techniques.

If the geotextile is ripped or punctured during construction activities, it will not likely perform as desired. If the geotextile is placed with a lot of wrinkles or folds, it will not be in tension, and, therefore, cannot provide a reinforcing effect. Other problems occur due to insufficient cover over the geotextile, rutting of the subgrade prior to placing the geotextile, and thin lifts that exceed the bearing capacity of the soil. The following step-by-step procedures should be followed, along with careful observations of all construction activities.

1. The site should be cleared, grubbed, and excavated to design grade, stripping all topsoil, soft soils, or any other unsuitable materials (Figure 5-8a). If moderate site conditions exist, *i.e.*, CBR greater than 1, lightweight proofrolling operations should be considered to help locate unsuitable materials. Isolated pockets where additional excavation is required should be backfilled to promote positive drainage. Optionally, geotextile-wrapped trench drains could be used to drain isolated areas.
2. During stripping operations, care should be taken not to excessively 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, do not excavate surface materials so you may take advantage of the root mat strength, if it exists. In this case, all vegetation should be cut at the ground surface. Sawdust or sand can be placed over stumps or roots that extend above the ground surface to cushion the

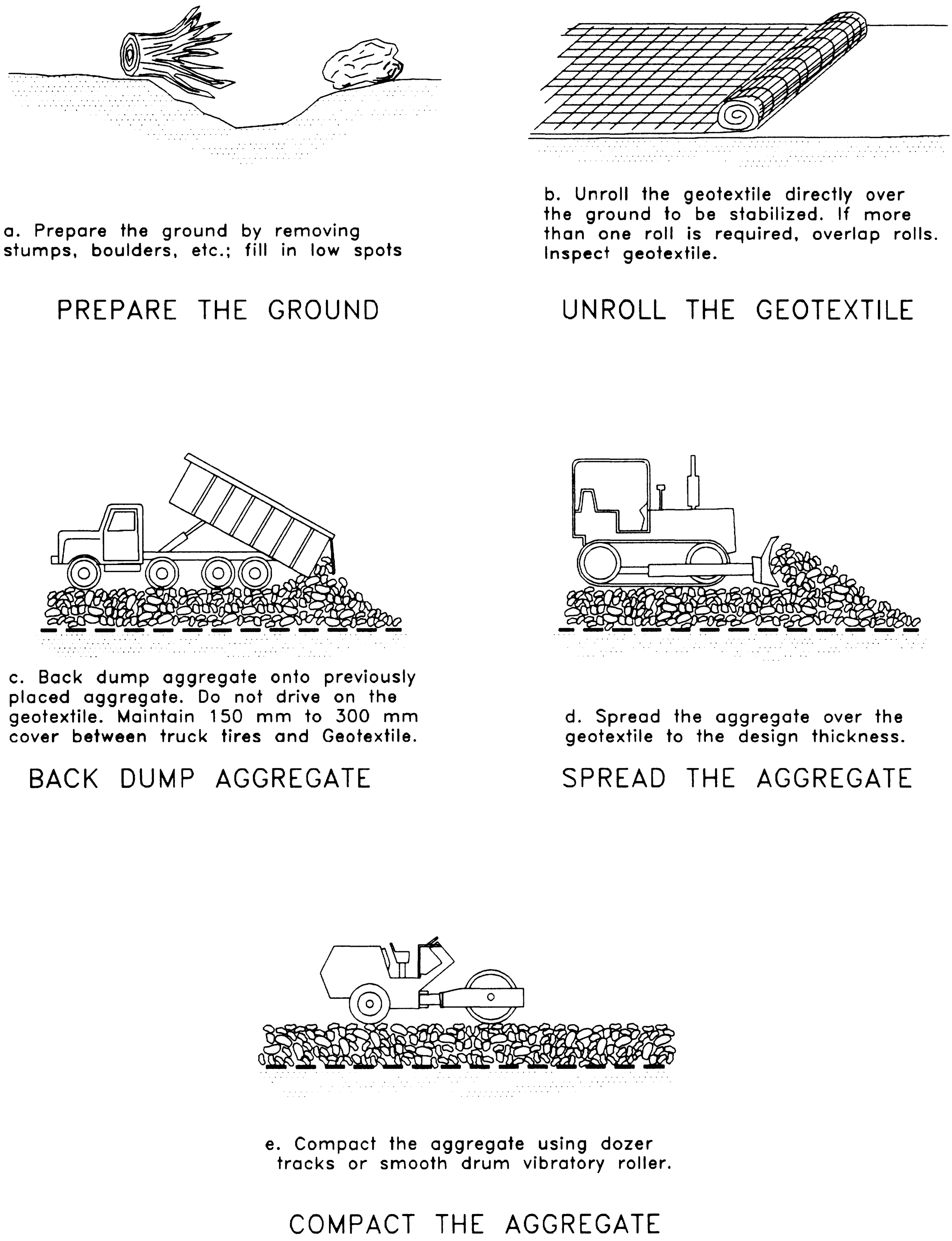
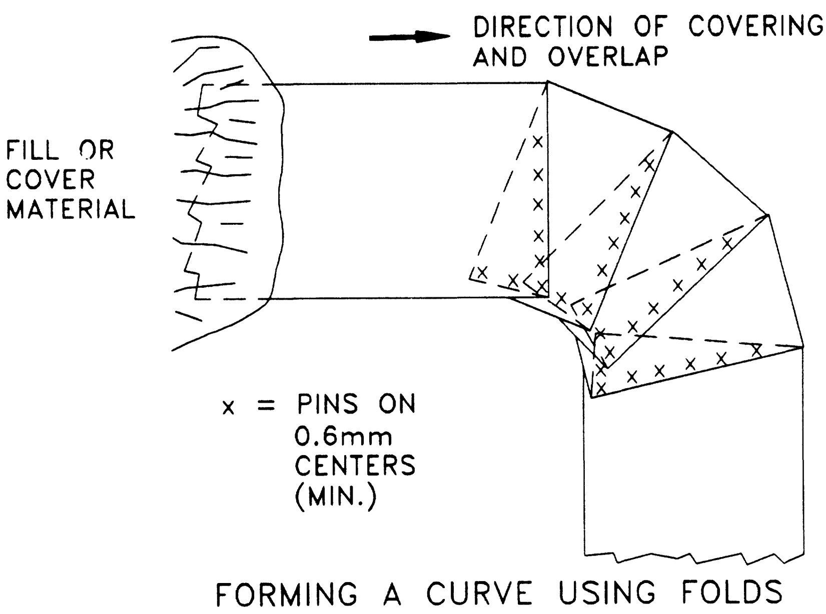


Figure 5-8 Construction sequence using geotextiles.

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 5-8b). Field operations can be expedited if the geotextile is pre-sewn to design widths in the factory so 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 joined as required. (Specific requirements are given in Sections 5.12-2 and 5.12-3.)
5. For curves, the geotextile should be folded or cut and overlapped in the direction of the turn (previous fabric on top) (Figure 5-9). Folds in the geotextile should be stapled or pinned approximately 0.6 m on centers.
6. When the geotextile intersects an existing pavement area, the geotextile should extend to the edge of the old system. For widening or intersecting existing roads where geotextiles have been used, consider anchoring the geotextile at the roadway edge. Ideally, the edge of the roadway should be excavated down to the existing geotextile and the existing geotextile sewn to the new geotextile. Overlaps, staples, and pins could also be utilized.
7. Before covering, the condition of the geotextile should be checked for excessive damage (*i.e.*, holes, rips, tears, etc.) by an inspector experienced in the use of these materials. If excessive defects are observed, the section of the geotextile containing the defect should be repaired by placing a new layer of geotextile over the damaged area. The minimum required overlap required for parallel rolls should extend beyond the defect in all directions. Alternatively, the defective section can be replaced.
8. The base aggregate should be end-dumped on the previously placed aggregate (Figure 5-8c). 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 to 300 mm, or to the design thickness if less than 300 mm, prior to compaction (Figure 5-8d). At no time should traffic be allowed on a soft roadway with less than 200 mm (150 mm for CBR $\geq$ 3) of aggregate over the geotextile. Equipment can operate on the roadway without aggregate for geotextile installation under permeable bases, if the subgrade is of sufficient strength. 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 so rutting in the initial lift is limited to 75 mm. If rut depths exceed 75 mm, it will be necessary to decrease the construction vehicle size and/or weight or to increase the lift thickness. For



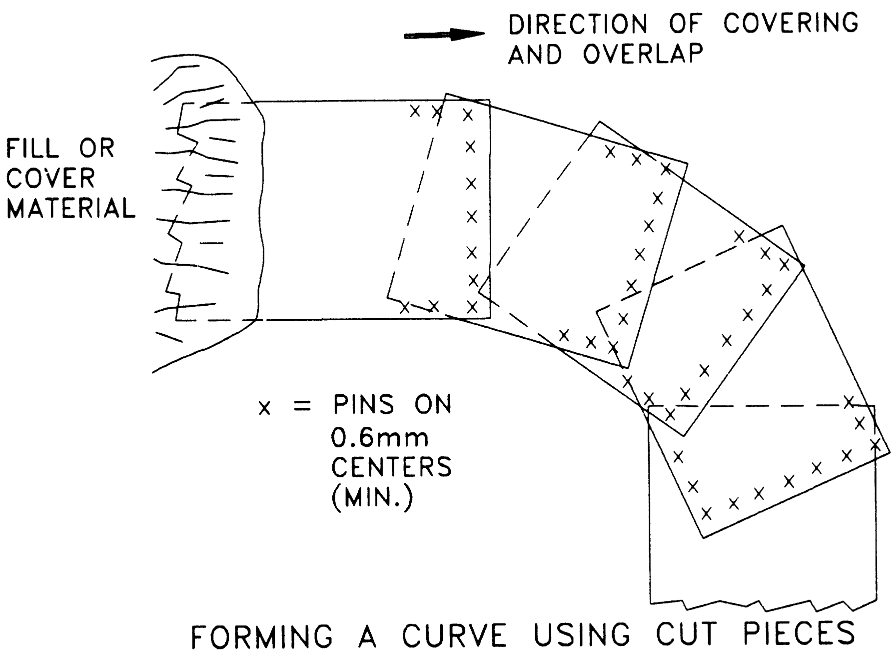


Figure 5-9 Forming curves using geotextiles.

example, it may be necessary to reduce the size of the dozer required to blade out the fill or to deliver the fill in half-loaded rather than fully loaded trucks.

10. The first lift of base aggregate should be compacted by *tracking* with the dozer, then compacted with a smooth-drum vibratory roller to obtain a minimum compacted density (Figure 5-8e). For construction of permeable bases, compaction shall meet specification requirements. For very soft soils, design density should not be anticipated for the first lift and, in this case, compaction requirements should be reduced. One recommendation is to allow compaction of 5% less than the required minimum specification density for the first lift.
11. Construction should be performed parallel to the road alignment. Turning should not be permitted on the first lift of base aggregate. Turn-outs may be constructed at the roadway edge to facilitate construction.
12. On very soft subgrades, if the geotextile is to provide some reinforcing, pretensioning of the geotextile should be considered. For pretensioning, the area should be proofrolled 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 to prestress the geotextile-aggregate system in key areas.
13. Any ruts that form during construction should be filled in, as shown in Figure 5-10 to maintain adequate cover over the geotextile. In no case should ruts be bladed down, as this would decrease the amount of aggregate cover between the ruts.
14. All remaining base aggregate should be placed in lifts not exceeding 250 mm in loose thickness and compacted to the appropriate specification density.

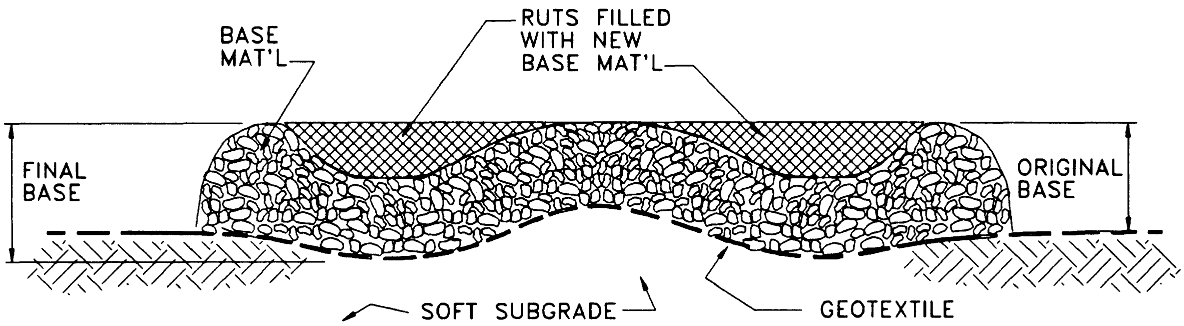


Figure 5-10 Repair of rutting with additional material.

5.12-2 Geotextile 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 joint. The amount of overlap depends primarily on the soil conditions and the potential for equipment to rut the soil. If the subgrade does not rut under construction activities, only a minimum overlap is required to provide some pullout resistance. 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 5-4.

TABLE 5-4
RECOMMENDED MINIMUM GEOTEXTILE OVERLAP REQUIREMENTS

CBR	Minimum Overlap
> 2	300 - 450 mm
1 - 2	600 - 900 mm
0.5 - 1	900 mm or sewn[1]
< 0.5	sewn[1]
All roll ends	900 mm or sewn[1]
NOTE: 1. See Section 5.12-3.	

The geotextile can be stapled or pinned at the overlaps to maintain their position during construction activities. Nails 250 to 300 mm long should be placed at a minimum of 15 m on centers for parallel rolls and 1.5 m on centers for roll ends.

Geotextile roll widths should be selected so overlaps of parallel rolls occur at the roadway centerline and at the shoulders. Overlaps should not be placed along anticipated primary wheel path locations. Overlaps at the end of rolls should be in the direction of the aggregate placement (previous roll on top).

5.12-3 Seams

When seams are required for separation applications, they should meet the same tensile strength requirements for survivability (Table 5-1) as those of the geotextile perpendicular to the seam (as determined by the same testing methods). Seaming is discussed in detail in Section 1.8. All factory or field seams should be sewn with thread as strong and durable as the material in the fabric. *J-seams* with interlocking stitches are recommended. Alternatively, if bag-type stitches, which can easily unravel, or butt-type seams are used, seams should be double-sewn with parallel stitching spaced no more than 5 to 10 mm apart. Double sewing is required to safeguard against undetected missed stitches. The geotextile strength may actually have to exceed the specifications in order to provide seam strengths equal to the specified tensile strength.

For certain geogrids, overlap joints, tying or interlocking with wire cables, plastic pipe, hog rings, or bodkin joints may be required. Geotextile seam strength requirements should also be applied to overlapped or mechanically fastened geogrids. Consult the manufacturer for specific recommendations and strength test data.

5.13 FIELD INSPECTION

The field inspector should review the field inspection guidelines in Section 1.7. Particular attention should be paid to factors that affect geotextile survivability: subgrade condition, aggregate placement, lift thickness, and equipment operations.

5.14 SELECTION CONSIDERATIONS

For a geotextile to perform its intended function as a separator in a roadway, it must be able to tolerate the stresses imposed on it during construction; *i.e.*, the geotextile must have sufficient survivability to tolerate the anticipated construction operations. Geotextile selection for roadways is usually controlled by survivability, and the guidelines given in Section 5.5 are important in this regard. As mentioned, the specific geotextile property values given in Table 5-2 are minimums. For important projects, you are strongly encouraged to conduct your own field trials, as described in Section 5.5.

5.15 REFERENCES

References quoted within this section are listed below. Additional discussion on recent roadway research is presented in Appendix G. Detailed lists of specific ASTM and GRI test procedures are presented in Appendix E. The Koerner (1994) is a recent, comprehensive textbook on geosynthetics and is a *key* reference for design. This and other *key* references are noted in bold type.

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