APPENDIX H

GEOTEXTILE DESIGN

DESIGN GUIDELINES

The widespread acceptance of geotextiles for use in engineering designs has led to a proliferation of geotextile manufacturers and a multitude of geofabrics, each with different engineering characteristics from which to choose. The design guidelines and methodology that follow help you select the right geofabric to meet your construction requirements.

UNPAVED-AGGREGATE DESIGN

Site Reconnaissance

As with any construction project, a site reconnaissance provides insight on construction requirements and potential problems.

Determine Subgrade Soil Type and Strength

Identify the subgrade soil and determine its strength as outlined in Chapter 9, FM 5-410. If possible, determine the soil's shear strength, C, in psi. If you are unable to determine C, use the nomograph in Figure H-1 to convert CBR value or CI to C.

Determine Permissible Load on the Subgrade Soil

The amount of loading that can be applied without causing the subgrade soil to fail is referred to as the *permissible stress, S.*

- Permissible subgrade stress **without** a geotextile:

$$S = (2.8)C$$

- Permissible subgrade stress **with** a geotextile:

$$S = (5.0)C$$

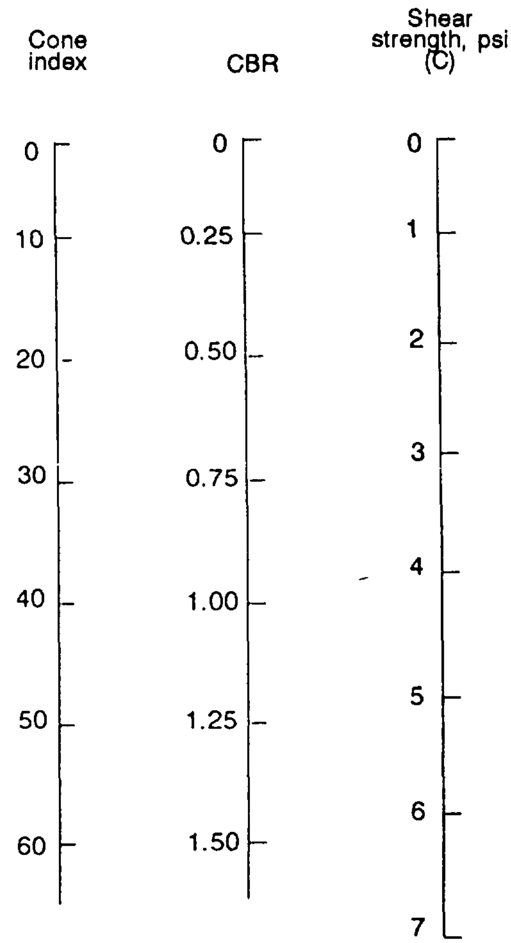


Figure H-1. Determining the soils's shear strength by converting CBR value or cone index

Determine Wheel Loads, Contact Pressure, and Contact Area

Estimate wheel loads, contact pressure, and contact-area dimensions from Table H-2. For geotextile design, single and dual wheels are represented as single-wheel loads (L) equal to one-half the axle load, The wheel load exerted by a single wheel is applied at a surface contact pressure (P) equal to the tire inflation pressure. Dual-wheel loads apply a P equal to 75 percent of the tire inflation pressure. Tandem axles exert 20 percent more than their actual weight to the subgrade soil due to overlapping stress from the adjacent axle in the tandem set,

- Estimate the area being loaded (B^2):

$$B^2 = \frac{L}{P}$$

where B^2 = length of one side of the square contact area

Determine Aggregate-Base Thickness

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

Table H-1. Vehicle input parameters

Vehicle Type (Choose Category Nearest the Actual Design Vehicles)	Axles S - Single T - Tandem	Wheels S - Single D - Dual	Axle Loads (lb)	Wheel Loads[1] L (lb)	Typical[2] Tire Inflation Pressure (psi)	Contact Pressure[3] P (psi)	Wheel Contact Area B^2 (in^2)	One Side of Square Contact Area B (in)
Highway Legal Vehicles								
Haul trucks[4] - F Axle (stone, concrete)	S	S	18,000	9,000	110	110	82	9.0
R Axle	T	D	18,000	10,800	110	83	130	11.4
Tractor trailer - F Axle	S	S	18,000	9,000	120	120	75	8.7
(18 wheeler) - R Axle	T	D	18,000	10,800	120	90	120	11.0
Off Highway Vehicles[5]								
35-ton trucks - F Axle	S	S	48,000	24,000	90	90	267	16.3
(CAT 769C) - R Axle	S	D	89,200	44,600	90	68	656	25.6
Wheel loader - F Axle	S	S	24,000	12,000	50	50	240	15.5
(CAT 910) - R Axle	S	S	10,000	5,000	50	50	100	10.0
Wheel loader - F Axle	S	S	37,000	18,500	60	60	308	17.6
(CAT 930) - R Axle	S	S	14,000	7,000	60	60	117	10.8
Wheel loader - F Axle	S	S	65,000	32,000	60	60	542	23.3
(CAT 966C) - R Axle	S	S	25,000	12,500	60	60	208	14.4
Wheel loader - F Axle	S	S	136,000	68,000	85	85	800	28.3
(CAT 988B) - R Axle	S	S	55,000	27,500	85	85	324	18.0
Wheel loader - F Axle	S	S	290,000	145,000	70	70	2071	45.5
(CAT 992) - R Axle	S	S	120,000	60,000	60	60	1000	31.6
Scraper - F Axle	S	S	88,600	44,300	80	80	554	23.5
(CAT 631D) - R Axle	S	S	75,400	37,700	75	75	503	22.4
Scraper - F Axle	S	S	120,000	60,000	85	85	706	26.6
(CAT 651B) - R Axle	S	S	110,800	55,400	80	80	692	26.3

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

Table H-2. Boussinesq theory coefficients

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

- First, solve for X.

  Without a geotextile: $X = \frac{S}{(4)P}$

  With a geotextile: $X_{geotextile} = \frac{S_{geotextile}}{(4)P}$

- Using the calculated values of X and $X_{geotextile}$, find the corresponding value of M and $M_{geotextile}$ from Table H-2.

- Then solve for aggregate-base thickness H and H geotextile.

  Without a geotextile: $H = \frac{B\,(inches)}{(2)M}$

  With a geotextile:

  $$H_{geotextile} = \frac{B}{(2)M_{geotextile}}$$

The difference between H and H geotextile is the aggregate savings due to the geotextile.

Adjust Aggregate-Section Thickness for Aggregate Quality

The design method is based on the assumption that good-quality aggregate (minimum CBR value of 80) is used. If lower-quality aggregate is used, the aggregate-section thickness must be adjusted.

Table H-3, page H-4, contains typical compacted strength properties of common structural materials. These values are approximations: use more specific data if it is available. Extract the appropriate thickness equivalent factor from Table H-3, then divide H by that factor to determine the adjusted aggregate-section thickness.

Adjust Aggregate-Base Thickness for Service Life

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

2,000 passes	8%
5,000 passes	19%
10,000 passes	27%

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

A second method of determining minimum required cover above a subgrade for wheeled vehicles with and without a geotextile requires fewer input parameters. Again, use Figure H-1 to correct CBR or CI values to a C value. Determine the permissible stress on the subgrade soil (S) by multiplying C by 2.8 without a geotextile and by 5.0 with a geotextile. Select the heaviest vehicle using the road and the design vehicle for each wheel-load configuration: single, dual, or tandem. Enter the appropriate graph (see Figures H-2, H-3, or H-4, pages H-5 through H-7) at S (with and without a geotextile). Round design-vehicle wheel loads to the next higher 5,000-pound increment. Determine the intersection between the appropriate wheel-load curve and S (with and without a geotextile), then read the minimum required thickness on the left axis. Use the greatest thickness values as

Table H-3. Typical compacted strength properties of common structural materials

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

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

[2] Compressive strength at 7 days.

Note: The values listed above are general guidelines. More exact thickness equivalency factors can be determined by comparing the CBR of the available aggregate to the design CBR of 80. For example, an aggregate with a CBR of 55 would have an approximate thickness equivalency factor of 55/80 = 0.69.

the design thickness with and without a geotextile. Compare the cost of the material saved with the cost of the geotextile to determine if the use of the geotextile is cost effective.

Up to this point in the geotextile-design process, you have been concerned with general design properties for designing unpaved aggregate roads. Now you must decide which geotextile fabric best meets your project requirements.

TYPES OF GEOTEXTILES

There are two major types of geotextiles: woven and nonwoven. Woven fabrics have filaments woven into a regular, usually rectangular, pattern with fairly even opening spacing and size. Nonwoven fabrics have filaments connected in a method other than weaving, typically needle punching or head bonding at intersection points of the filaments. The pattern and opening spacing and size are irregular in nonwoven fabrics.

Woven fabrics are generally stronger than nonwoven fabrics of the same fabric weight. Woven geotextiles typically reach peak tensile strength at between 5 and 25 percent strain. Nonwoven fabrics have a high elongation of 50 percent or more at maximum strength.

Table H-4, page H-8, provides information on important criteria and principal properties useful when selecting or specifying a geotextile for a specific application. The type of equipment used to construct a road or airfield pavement structure on top of the geotextile must be considered. Equipment ground pressure (in psi) is an important factor in determining the geotextile fabric thickness; a thicker fabric is necessary to stand up to high equipment ground pressure (see Table H-5, page H-9).

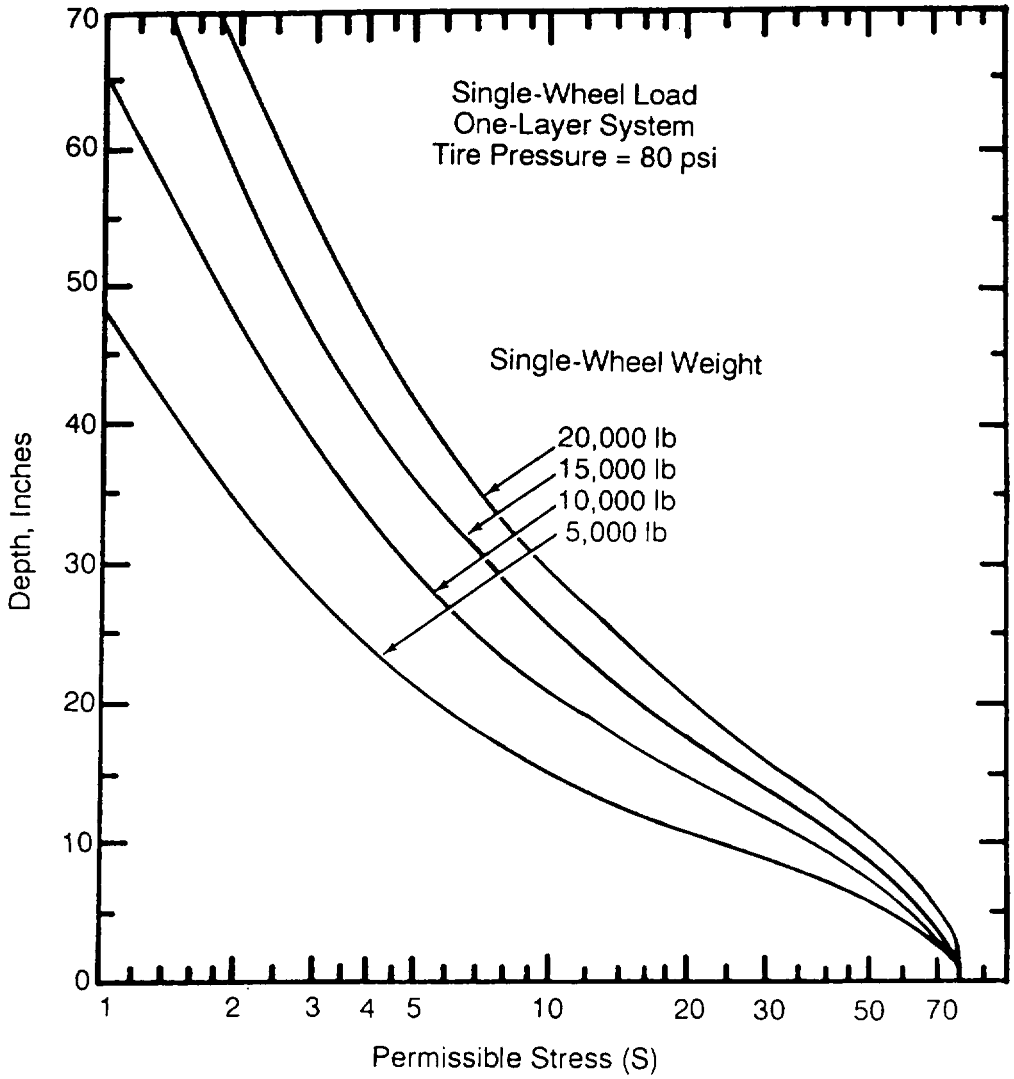


Figure H-2. Thickness design curve for slngle-wheel load on gravel-surfaced pavements

Once the required degree of geotextile survivability is determined, minimum speification requirements can be established based on ASTM standards (see Table H-6, page H-10). When you have determined the set of testing standards, the geotextile will be required to withstand to meet use and construction requirements, you are ready to either specify a geotextile for ordering or evaluate on-hand stocks.

ROADWAY CONSTRUCTION

There is no singular way to construct madways with geofabrics. However, there are several applications and general guidelines that can be used.

SITE PREPARATION

Clear, grub, and excavate the site to design grade: fill in ruts and surface irregularities deeper than 3 or 4 inches (see Figure H-5, page H-11). Compact the subgrade if the soil CBR is greater than 1. The compaction aids in locating unsuitable materials that may damage the fabric. Remove unsuitable materials where practical.

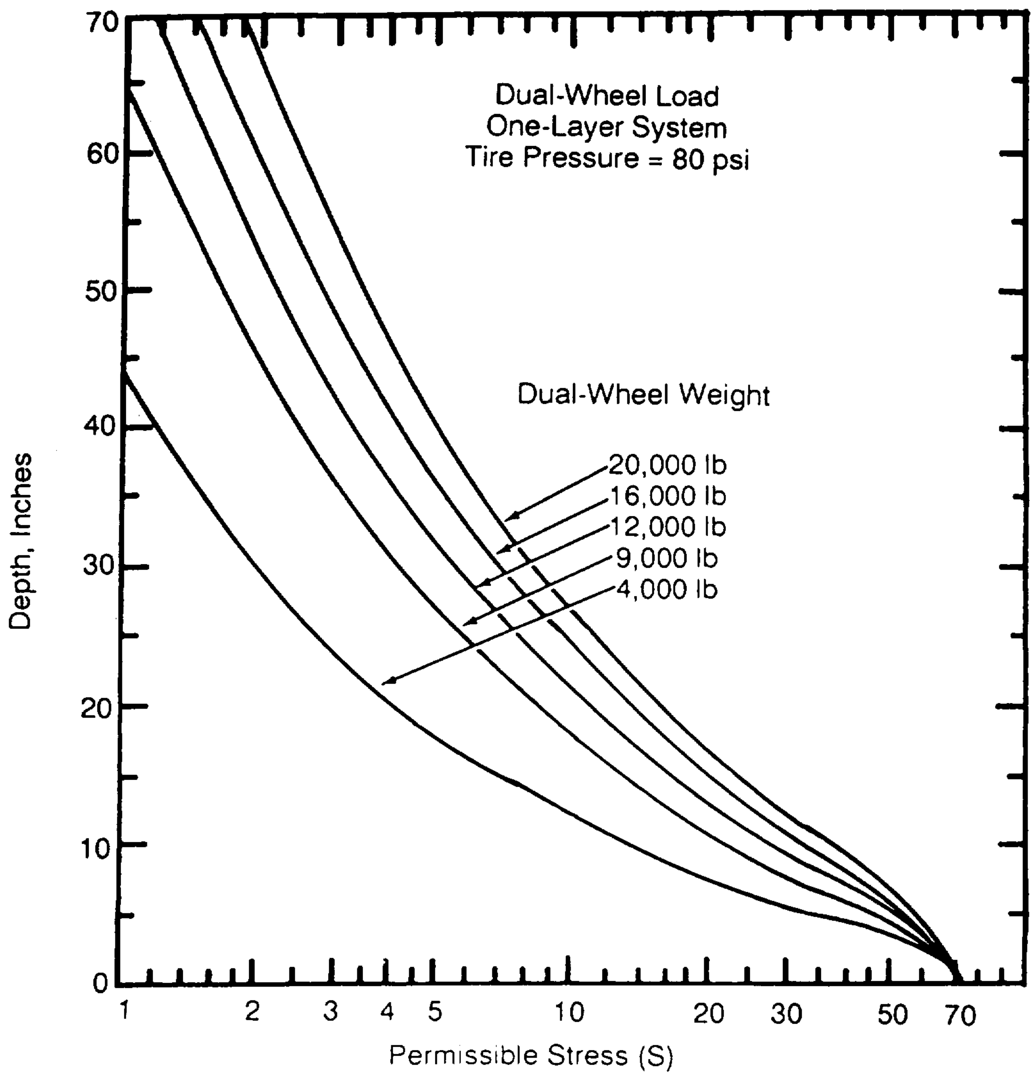


Figure H-3. Thickness design curve for dual-wheel load on gravel-surfaced pavements

When constructing over extremely soft soils (such as peat bogs), surface materials (such as the root mat) may be advantageous and should be disturbed as little as possible. Use sand or sawdust to cover roots, stumps, or stalks. This cushions the fabric and reduces the potential for fabric puncture. Nonwoven geotextiles are preferred when the soil surface is uneven.

LAYING OF FABRIC

The fabric should be rolled out by hand, ahead of backfilling, directly on the soil subgrade. The fabric is commonly, but not always, laid in the direction of the roadway. Where the subgrade cross section has large areas and leveling is not practical, the fabric may be cut and laid transverse to the roadway. Large wrinkles should be avoided. In the case of wide roads, multiple widths of fabric are laid and overlapped. Lap length normally depends on subgrade strength. Table H-7, page H-12, provides general guidelines for lap lengths.

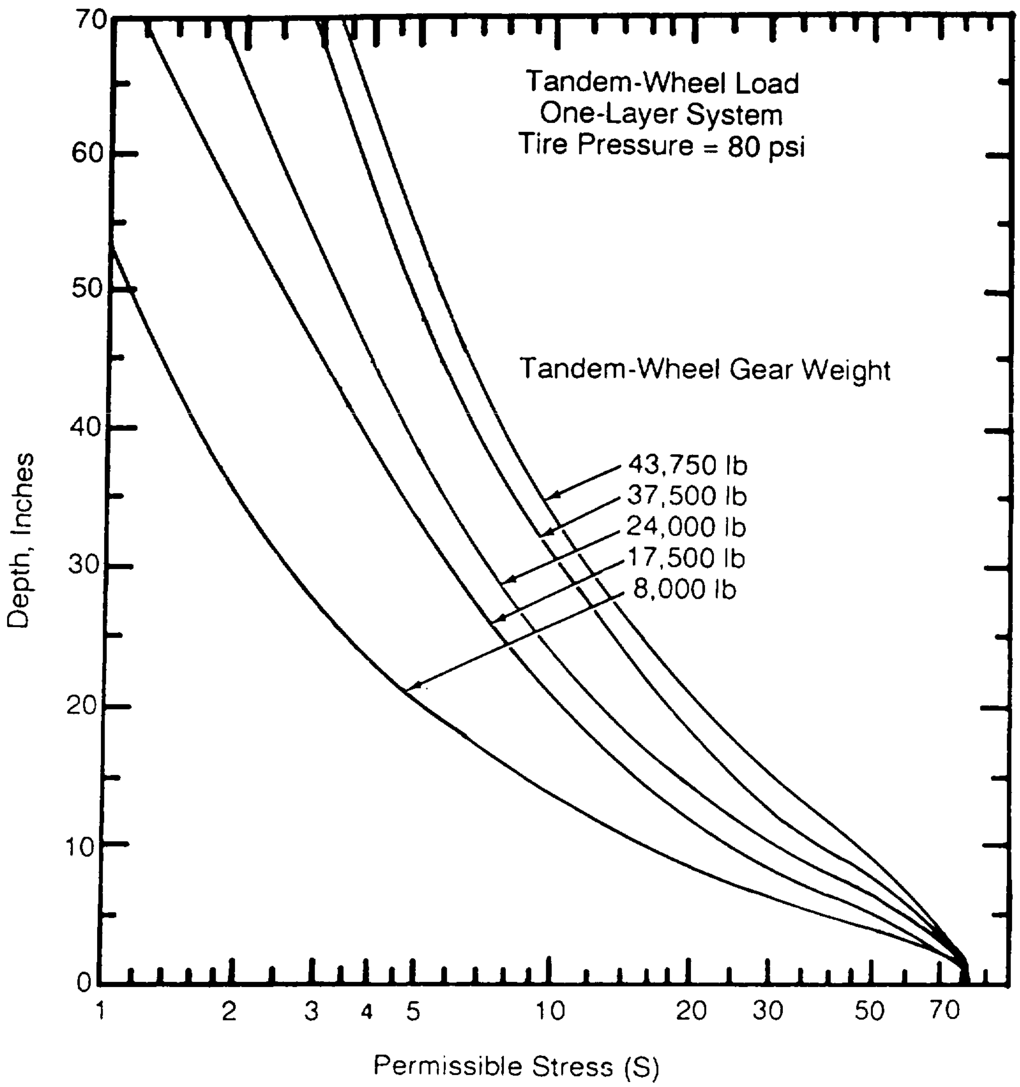


Figure H-4. Thickness design curve for tandem-wheel load on gravel-surfaced pavements

LAYING OF BASE

If angular rock is to form the base, it is common to first place a protective layer of 6 to 8 inches of finer material, Base material is then end-dumped directly onto the pre-viously spread load, pushed out over the fabric, and spread from the center using a bulldozer. Vehicles must not be driven directly on the fabric because they might puncture it. Small, tracked bulldozers (with a maximum ground pressure of 2 psi) are commonly used for spreading. The blade is also kept high to avoid driving rock down into the fabric. After spreading, com-paction and grading can be carried out with standard compaction equipment. If the roadway has side drains, they are con-structed after the pavement.

Table H-4. Geotextile evaluation

Criteria and Parameter	Property	Application			
		F	D	S	R
Design Requirements					
Mechanical strength					
Tensile strength	Wide-width strength	–	–	–	x
Tensile modulus	Wide-width modulus	–	–	–	x
Seam strength	Wide width	–	–	–	x
Tension creep	Creep	–	–	–	x
Soil-fabric friction	Friction angle	–	–	–	x
Hydraulic					
Flow capacity	Permeability,	x	x	x	x
	Transmissivity	–	x	–	–
Piping resistance	Apparent opening size (AOS)	x	–	x	x
Clogging resistance	Pommetry	x	–	x	x
	Gradient ratio	x	–	–	–
Constructability Requirements					
Tensile strength	Grab strength	x	x	x	x
Seam strength	Grab strength	x	x	x	x
Bursting resistance	Mullen burst	x	x	x	x
Puncture resistance	Red puncture	x	x	x	x
Tear resistance	Trapesoidal tear	x	x	x	x

F – Filtration
D – Drainage
S – Separation
R – Reinforcement

Table H-5. Required degree of geotextile survivability as a function of cover material and construction equipment

Cover Material	6- to 12-inch Initial Lift Thickness: Low-Ground-Pressure Equipment <4 psi	6- to 12-inch Initial Lift Thickness: Medium-Ground-Pressure Equipment $\geq$4 psi, <8 psi	12- to 18-inch Initial Lift Thickness: Medium-Ground-Pressure Equipment $\geq$4 psi, <8 psi	12- to 18-inch Initial Lift Thickness: High-Ground-Pressure Equipment $\geq$8 psi	18- to 24-inch Initial Lift Thickness: High-Ground-Pressure Equipment $\geq$8 psi	>24-inch Initial Lift Thickness: High-Ground-Pressure Equipment $\geq$8 psi
Fine sand to ±2-inch-diameter gravel, round to subangular	Low	Moderate	Low	Moderate	Low	Low
Coarse aggregate with diameter up to one-half proposed lift thickness, may be angular	Moderate	High	Moderate	High	Moderate	Low
Some to most aggregate with diameter greater than one-half proposed lift thickness, angular and sharp-edge few fines	High	Very High	High	Very High	High	Moderate

NOTES:

1. **For special construction techniques such as prerutting, increase geotextile survivability requirement one level.**
2. **Placement of an excessive initial cover-material thickness may cause bearing failure of soft subgrades.**

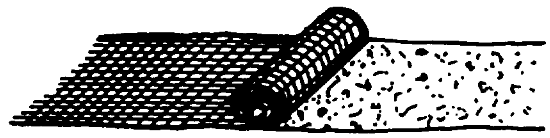
Table H-6. Minimum properties required for geotextile survivability

Required Degree of Geotextile Survivability	Grab Strength [1] lb	Puncture Strength [2] lb	Burst Strength [3] psi	Trap Tear [4] lb
Very high	270	110	430	75
High	180	75	290	50
Moderate	130	40	210	40
Low	90	30	145	30

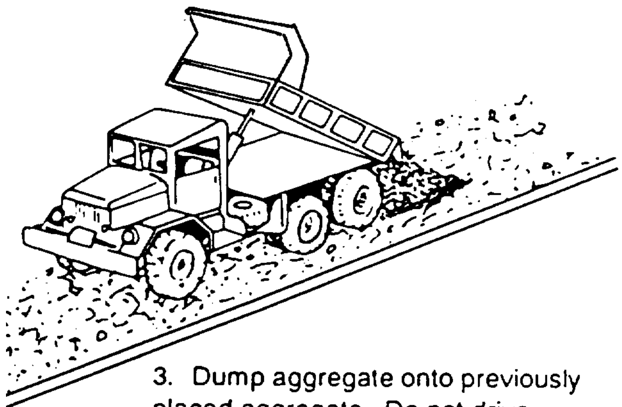
[1] ASTM D 4632
[2] ASTM D 4833
[3] ASTM D 3786
[4] ASTM D 4533, either principal direction

Note: All values represent minimum average roll values (for example, any roll in a lot should meet or exceed the minimum values in this table). These values are normally 20 percent lower than manufacturer-reported typical values.

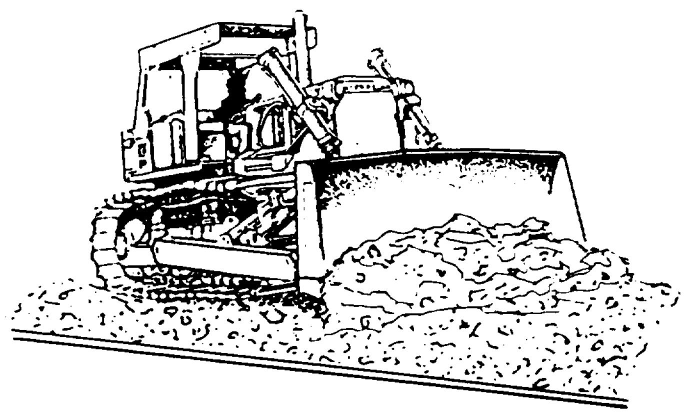
1. Prepare the ground by removing stumps, boulders, and so forth; fill in low spots.



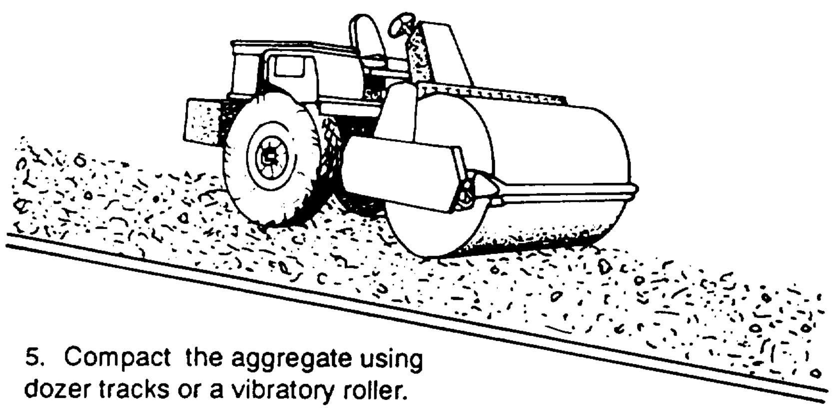
2. Unroll the geotextile directly over the ground to be stabilized. If more than one roll width is required, overlap the rolls. Inspect the geotextile.



3. Dump aggregate onto previously placed aggregate. Do not drive directly on the geotextile. Maintain at least 6 to 12 inches cover between the truck tires and the geotextile.



4. Spread the aggregate over the geotextile to the design thickness.



5. Compact the aggregate using dozer tracks or a vibratory roller.

Figure H-5. Construction sequence using geotextiles

Table H-7. Recommended minimum overlap requirements

CBR	Minimum Overlap
> 2	1 – 1.5 feet
1 – 2	2 – 3 feet
0.5 – 1	3 feet or sewn
< 0.5	Sewn
All roll ends	3 feet or sewn