Design of separation geotextiles in road structures

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Geotextile Design Criteria

For applications where geotextile separation is the dominant function, typically for paved and unpaved roads, the key criteria governing the selection and properties of geotextile are:

- Resistance to installation and construction damage,
- Adequate drainage and filtration properties of the geotextile.

For high embankment applications where geotextile reinforcement and separation are dominant functions, the geotextile must withstand construction stress damage and provide good drainage and filtration properties.

Resistance to installation and construction damage

For effective separation performance, the geotextile must not be punctured or damage during construction. During fill placement, especially when large size, sharp angular fill materials are present or when insufficient fill thickness is adopted, the geotextile is highly susceptible to puncture and damage. The latter requires that a minimum design thickness is maintained throughout the construction process.

Construction damage due to stone aggregate puncturing through the geotextile is the most critical form of damage likely to occur. Thus, the geotextile must fulfil minimum puncture resistance criteria. Geotextile performance or test criteria that presumes damage and does not ensure prevention (i.e. tear resistance) is not relevant and should not be used as the basis for design. It is more rational to design to avoid puncture by specifying minimum puncture resistance requirements than to allow damage and attempt to limit subsequent tear propagation.

To prevent the geotextile from puncturing during construction, the following influencing parameters must be evaluated to determine the anticipated puncture force:

- Initial thickness of fill above the geotextile which is a function of sub grade CBR,
- Presence of stones in the fill especially in laterite soil (i.e. > 50mm mean diameter),
- Type of constructions vehicle, wheel load and contact area and thus the pressure exerted at the elevation of the geotextile.

The puncture resistance of the geotextile can be determined based on the situation shown schematically in Figure 1. The vertical force exerted on the geotextile (which is gradually tightening around the object) is given in Equation 1.

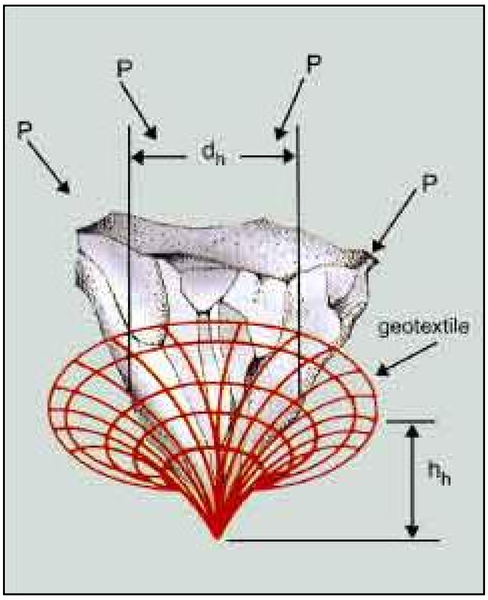


Figure 1. Stone puncturing a geotextile as pressure is applied on the stone aggregate

Equation 1

$$F_{vert} = [(\pi d_h)(h_h)\ P]$$

where,

F_{vert} = the total vertical force imposed on the geotextile adjacent to the puncture

D_h = the average diameter of the hole in the geotextile

H_h = the propagation height = dh

P = pressure exerted on the geotextile at the elevation of the sub grade

The value P can be calculated using the analysis recommended by Giroud and Noiray (1981) as shown in Equation 2.

Equation 2

$$P = \frac{p_a}{2\,(B + 2h.\tan\alpha\,)\,(\,L + 2h.\tan\alpha\,)}$$

The axle load p_a, is assumed to dissipate through the thickness of the sub base aggregate (Figure 2) where tanα may be taken as 0.6 (John, 1987). The equivalent contact area of a tire on the road surface is taken as B x L where B and L are the contact width and length of the tire respectively.

For normal highway vehicles including lorries
$B = \sqrt{(pa/pt)}$ $\qquad L = 0.707B)$

For heavy construction plant with wide and double tires
$B = \sqrt{(1.414pa/pt)}$ $\qquad L = 0.5B$

where,

pa = axle load and
pt = tire pressure [typical value for construction plant = 620 kpa (Giroud et al, 1984)

The vertical force F_{vert} is resisted by the radial tension around the perimeter of the geotextile contact area (d_h). The value of the geotextile puncture strength measured in the laboratory test will not be directly compatible unless dh is equal to the diameter of the test plunger, d_p. Hence, the calculated puncture force, F_{vert} is converted into a puncture strength of geotextile, F_g using the relationship given in Equation 3a.

Equation 3a

$$\frac{F_{vert}}{D_h} = \frac{F_g}{d_p}$$

The ability of the geotextile to resist the vertical force is also dependent on the shape of aggregate puncturing the geotextile. For sharp angular aggregate, high puncture resistance of geotextile is required and vice-versa. The following shape factor, s_f of stone aggregate may be applied (Werner 1986).

Sharp aggregate, s_f varies from 2.0 to 3.0
Rounded aggregate, s_f varies from 0.8 to 1.0

Application Area	Factor of safety	
	(Koerner, 1986)	Polyfelt (Werner, 1986)
Unpaved roads	1.1 to 2.0	1.2
Embankments	1.1 to 2.0	1.2
Pavement overlays	1.1 to 1.5	1.2
Railroads	1.5 to 3.0	1.5
General earthwork fills	1.1 to 2.0	1.2

Table 1. Factor of safety against installation damage for different areas of application

Thus, the minimum required design puncture strength of a geotextile is given to Equation 3b,

Equation 3b

F_g (design) = (πd_h) (P) $(d_p) s_f$ x Factor of safety

where,

d_h = average diameter of aggregate, d50 (assumed) and,

d_p = 50mm (according to ISO 12236)

Another approach to assess indicative geotextile resistance to installation and construction damage is through geotextile resistance to installation and construction damage is through geotextile tensile strength and tensile elongation properties. To absorb or resist puncture stress, a geotextile requires either high tensile strength or high tensile elongation properties or an optimum combination of both (ref. SVG, Switzerland). Geotextiles with a low elongation can compensate the elongation requirement by having higher tensile strength characteristic and vice versa.

Table 1 shows the recommended factors of safety against geotextile installation damage for different areas of application.

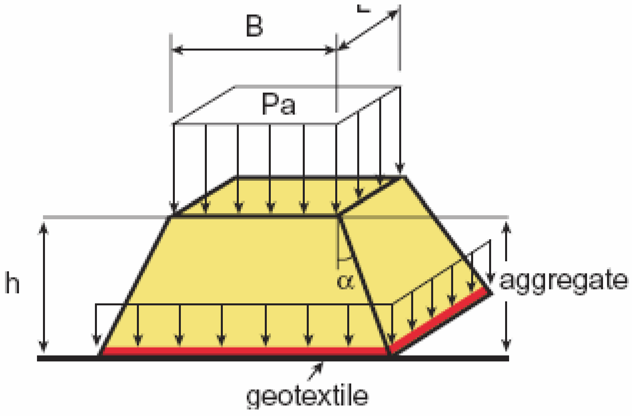


Figure 2. Axle load distribution by aggregate layer above the geotextile.

Filtration criteria

The two main criteria for evaluating geotextile filter characteristics are soil retention and permeability criteria. The geotextile must have pore size sufficiently small to retain fine soils thus prevent intermixing with the good aggregates and also the pore size must be big enough to maintain sufficient permeability to allow dissipation of pore water pressure.

The filter criteria for TenCate Polyfelt TS geotextiles in road construction are given in Table 2. This filter criteria was developed based on project specific studies and laboratory tests collected semi empirically over an observation period of more than 15 years.

Reinforcement

For high embankments where toe failure mode is dominant, a single or several layers of geotextile can be introduced at the base of the embankment as reinforcement to increase the stability of the embankment. The tensile resistance in the geotextile can be calculated using conventional Bishop's slip circle analysis. The slip circle with minimum factor of safety is determined and increased using geotextile to obtain the required safety factor (Figure 3). To determine the minimum factor of safety, slip circle analysis requires the aid of computer.
The design analysis to determine the required tensile strength in the geotextile for high embankment construction is not contained in this design manual. However, detailed design information can be obtained by contacting any TenCate Geosynthetics Europe regional office.

Influence Factors		Filter Criteria	
Fill material type	Traffic stress	Effective opening size O_{90}	Permeability kg (cm/s)
a	Medium/ heavy	O_{90} 0.10	Kg 100.ks
a	Light	O_{90} 0.11	Kg 100.ks
b	Heavy	O_{90} 0.10	Kg 100.ks
b	Medium/light	O_{90} 0.11	Kg 100.ks

Geotextile criteria
O_{90} = Effective opening size of geotextile
K_g = Permeability coefficient of geotextile
K_s = Permeability coefficient of soil

Fill material variables

Fill material	Soil characteristics
Type 'a'	: Cu < 5 and d_{50} > 50 mm
Type 'b'	: Cu > 5 or Cu < 5 and d_{50} < 50 mm

where Cu = d_{60} / d_{10} = Uniformity coefficient

Traffic load stress

Light	10 trucks / day
Medium	10 – 100 trucks / day
Heavy	100 trucks / day

Table 2. Filter criteria for TC Polyfelt TS geotextiles in road construction.

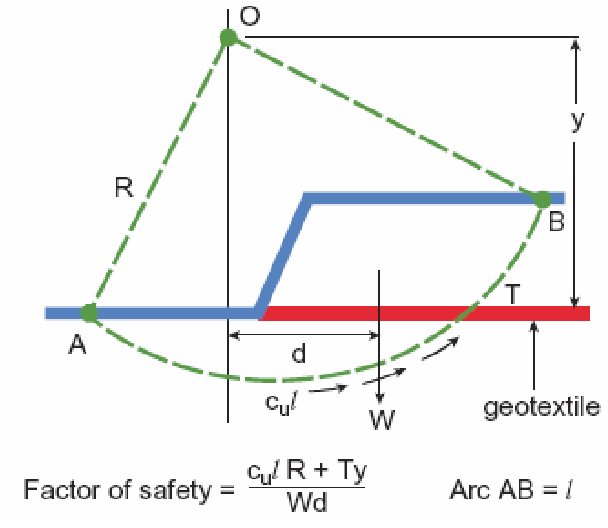


Figure 3. Analysis of geotextile reinforced embankment using Bishop's slip circle

Design Methods

Minimum fill height

In the construction of earth fill structures and roads on soft soils with CBR <3, which is typical of Asian soils, an initial layer of fill with adequate design thickness over the geotextile and weak sub grade is necessary during construction. This allows construction vehicles to access the site so that subsequent filling operations can be carried out. Any ruts occurring at this stage will be filled during subsequent sub base placement to maintain the required design thickness and ensure stability.

The minimum initial design fill height for both paced and unpaved roads is influenced by the sub grade CBR, site conditions, construction vehicle load and repetition, and can be calculated using the following methods:

- AASHTO – Polyfelt modified method
- Steward et al (1997) method

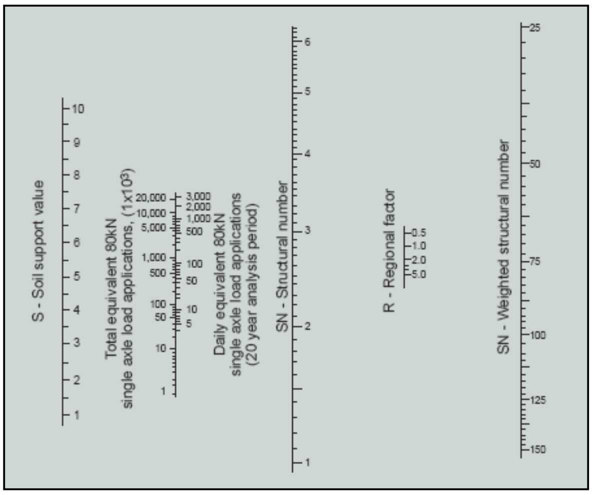


Figure 4a. Design chart for SN value for pt = 2.0 (low volume traffic).

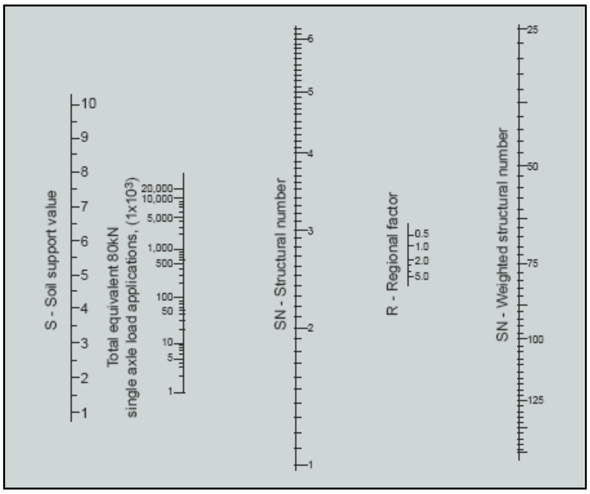


Figure 4b. Design chart for SN value for pt = 2.5 (high volume traffic).

Due to different long term performance requirements, design method for paced roads or paved earthworks cannot be adopted to design unpaved roads. This is because for paved structures, rutting is usually allowed to occur over the design life of the structure provided it does not impair service.

For sub grades stronger than CBR 3, geotextiles are rarely required for separation, although they may provide some drainage and filtration. A correlation for estimating CBR and soil strength values is given in Table 3.

Method 1: AASHTO – Polyfelt modified method

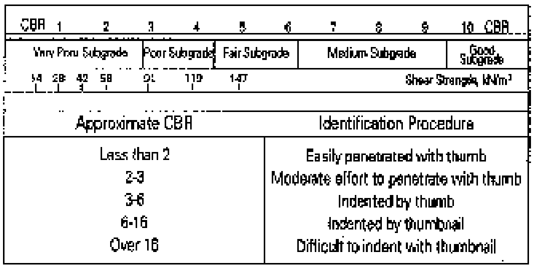
This design method is based on data developed by the American Association of State Highway and Transportation officials (AASHTO, 1972), supplemented and modified by approximately 15 years of experience with TenCate Geosynthetics Europe geotextiles in road constructions and complemented by extensive laboratory test results.
The road layer thickness is computed, based on AASHTO, as a function of the structural number (SN) and the material layer coefficient (a_j) given in Equation 4.

Equation 4

$$SN \leq \sum a_i . D_i$$

where,

SN	= structural number
$a_1, a_2, \ldots$	= material layer coefficients
$D_1, D_2, \ldots$	= thickness of respective material layers (mm)



CBR 1 2 3 4 5 6 7 8 9 10 CBR

Very Poor Subgrade | Poor Subgrade | Fair Subgrade | Medium Subgrade | Good Subgrade

14 28 42 58 91 119 147 Shear Strength, kN/m²

Approximate CBR	Identification Procedure
Less than 2	Easily penetrated with thumb
2-3	Moderate effort to penetrate with thumb
3-6	Indented by thumb
6-16	Indented by thumbnail
Over 16	Difficult to indent with thumbnail

Table 3. Correlation chart for estimating CBR and soil strength value (Koerner, 1986).

The structural number, SN required over the road sub grade for lo and high volume roads can be determined as a function of the soil support (S), number of load repetitions (W_{80kN}), regional factor (R), and terminal serviceability (pt) using Figures 4a and 4b.

To determine the SN value, the equivalent soil support value of the sub grade and the total or daily load repetitions for the design period are required to determine the unweighted structural number. This unweighted structural number is used with the selected regional factor to determine the design SN applicable to the overall structure. The thickness of aggregate above the sub grade without geotextile can then be determined using Equation 4.

Figure 5 shows the correlation between the soil support value, S and CBR of the sub grade obtained from Utah Department of Highways. The regional factor may be estimated by analyzing the climate conditions that may influence the sub grade strength. Based on AASHTO Road Rest information, values that may be used as guide for such an analysis appropriate for Asian conditions are given in Table 4. The typical material layer coefficients are given in Table 5.

The influence of TC Polyfelt TS geotextile on the soil support and the design life of the adjusted road structure are given in Figure 6 and 7 respectively.

Having obtained the modified soil support value, S_g, and the design traffic load repetitions, $W_{80kN(g)}$ the modified structural number can be obtained in the same manner from Figures 4a or 4b. Using the regional factors and material coefficients given above, the thickness of the unpaved road with geotextile separator can be determined A direct cost comparison can be made in the reduction of aggregate thickness with and without TenCate geotextile.

For unpaved roads it is recommended to add approximately 75mm to the final fill thickness to compensate for long term aggregate surface loss caused by traffic and surface water runoff Experience has shown that construction of roads over very poor sub grades (<CBR1) often is not possible without the use of a geotextile. In such instances contamination of the bottom layer of the sub base is in the order of 100-150 mm or greater.

Climatic condition	Regional factor, R
Sub grade material (dry season)	0.2 – 1.5
Sub grade material (wet season)	4.0 – 5.0

Table 4. Regional factor, R.

Material layer	a_i
Asphalt surface course	0.44
Crushed stone base course	0.14
Sandy gravel sub base course	0.11
Sand or sandy-clay	0.05 – 0.10

Table 5. Typical material layer coefficients.

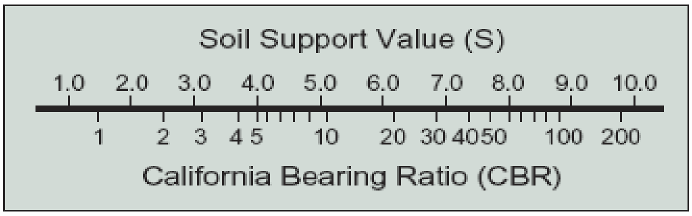


Figure 5. Correlation between soil support value and CBR (Utah Dept. of Highway)

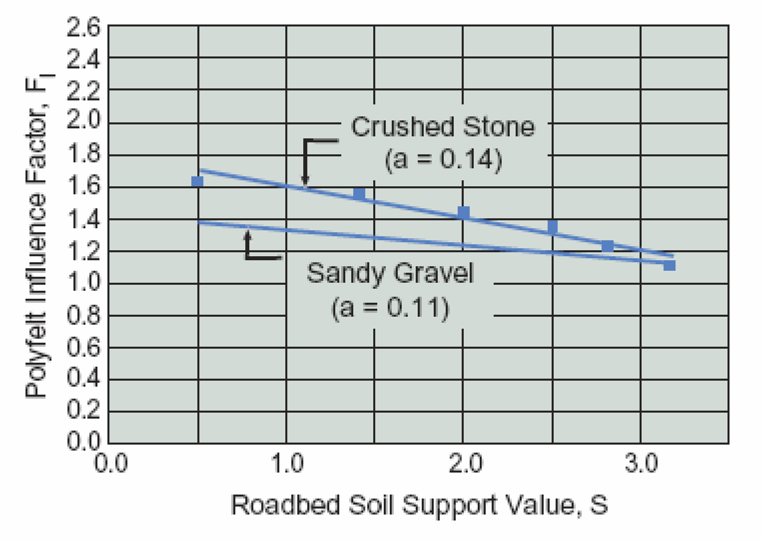


Figure 6. Influence of TCGE geotextile on the soil support. Modified soil support, Sg= F_1 x S

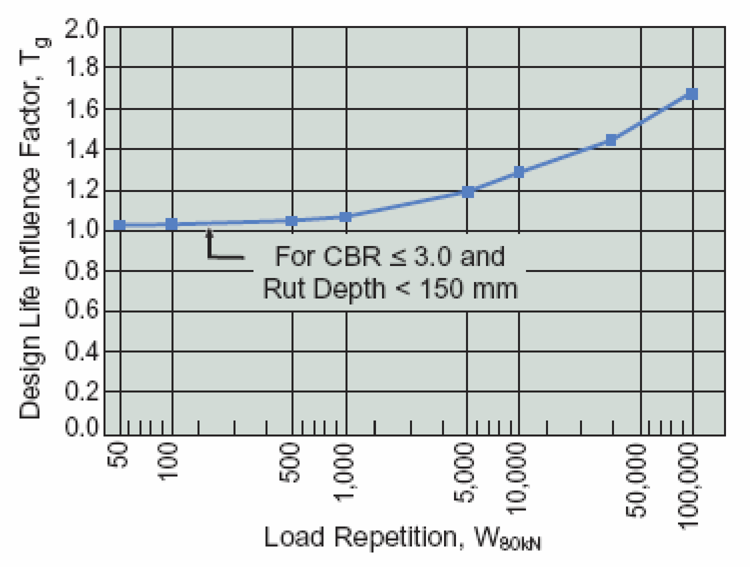


Figure 7. Influence of TCGE geotextile on the design life of road. Adjusted load repetitions, $W_{80kN(g)} = W_{80kN}/Tg$

Method 2: Steward et al (1977) method

This method, developed by Steward, Williamson and Mohney (1977) for the U.S. Forest Service (USFS), is based on both theoretical analysis and empirical (laboratory and field) tests and is suitable for low volume unpaved roads design.

This method considers the amount of rutting that would occur under a given stress level acting on the sub grade due to traffic loading, both with and without a geotextile separator. Steward et al (1977) presented this stress level in terms of classical bearing capacity factors as given in Table 6.

This method is applicable for:

- Number of vehicle passes up to 10000
- Cohesion less aggregate layer compacted to CBR 80
- Sub grade shear strength with CBR <3

The undrained shear strength of the soil, c in kN/m^2 can be obtained from CBR test using Equation 5.

Equation 5

$$c \text{ in } kN/m^2 = 28 \times CBR$$

Having determined the rut depth, bearing capacity factor (N_c), and type of wheel load anticipated during construction, the required aggregate thickness (mm) with and without a geotextile separator can be obtained from Figures 8, 9 or 10.

This method considers the amount of rutting that would occur under a given stress level acting on the sub grade due to traffic loading, both with and without a geotextile separator. Steward et al (1977) presented this stress level in terms of classical bearing capacity factors as given in Table 6.

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

Table 6. Bearing capacity factors for different ruts and traffic conditions both with and without geotextile separator (Steward et al. 1977)

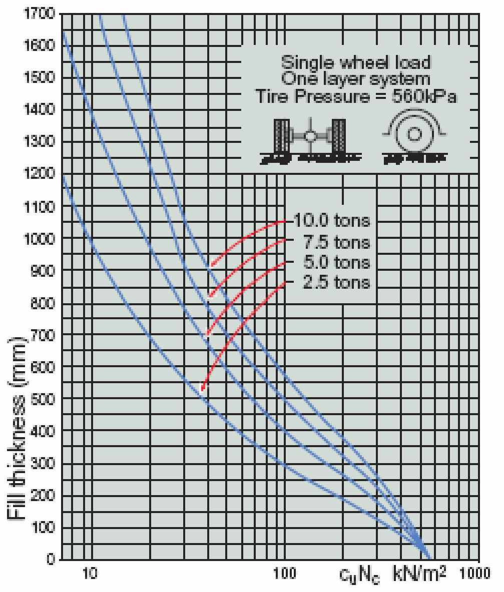


Figure 8

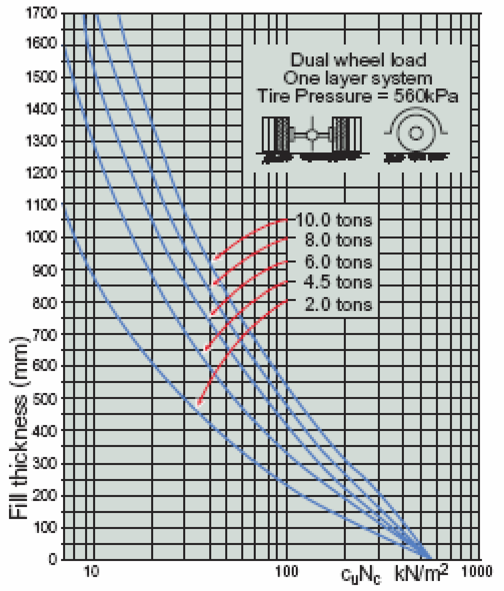


Figure 9

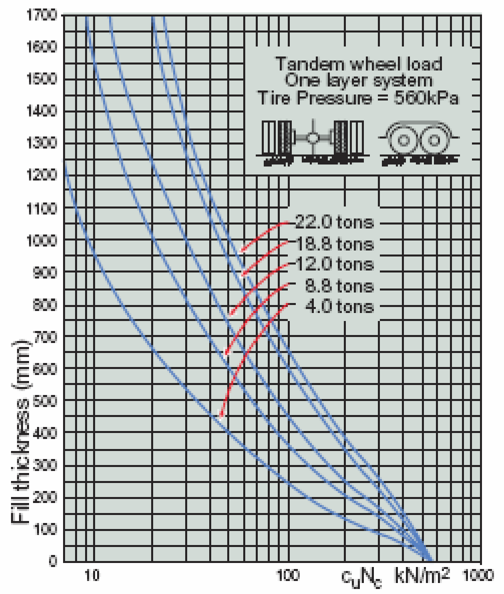


Figure 10

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a_1, a_2, a_3	road material layer coefficients
B	contact width of tire
c/c_u	soil cohesion/undrained soil cohesion
C_u	uniformity coefficient of soil d_{60}/d_{10}
d_{10}	soil grain size at which 10% by weight is finer
d_{50}	average diameter of stone aggregate
d_{60}	soil grain size at which 60% by weight is finer
d_h	average diameter of hole in the geotextile due to stone puncturing the geotextile
d_p	diameter of piston plunger for laboratory puncture test
D_1, D_2, D_3	thickness of road material layer
F_g	minimum initial height of backfill above the geotextile
F_I	Polyfelt influence factor on soil support value
F_{vert}	total vertical force imposed on the geotextile adjacent to the puncture area
h	minimum required design puncture strength of geotextile
h_h	propagation height/depth of stone puncturing the geotextile
k_g	permeability coefficient of geotextile
k_s	permeability coefficient of soil
L	contact length of tire
N_c	bearing capacity factor
O_{90} (D_w)	effective opening size of geotextile obtained from wet sieving according to Franzius Institute, Hanover
P_a	axle load of vehicle
P_t	tire pressure of construction plant
Pt	traffic volume terminal serviceability
P	pressure exerted on the geotextile at the elevation of the sub grade
R	regional factor
s_f	shape factor of stone aggregate
S	soil support value
S_g	modified soil support value
SN	structural number
T	tensile force of geotextile
T_g	design life influence factor due to TCGE geotextile
W	weight of embankment fill under consideration
W_{80kN}	traffic load repetition (equivalent standard axle load)
$W_{80kN(g)}$	adjusted traffic load repetition (equivalent standard axle load)
α	angle of axle load distribution through initial fill layer above the geotextile