Design of separation geotextiles in road structures
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.

Equation 1
\[ F_{vert} = \left[ (\pi d_h h_h) P \right] \]
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 = \( d_h \)
- \( P \) = pressure exerted on the geotextile at the elevation of the sub grade

Figure 1. Stone puncturing a geotextile as pressure is applied on the stone aggregate
The value $P$ can be calculated using the analysis recommended by Giroud and Noiray (1981) as shown in Equation 2.

**Equation 2**

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

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

For normal highway vehicles including lorries

$$B = \sqrt{(pa/pt)} \quad L = 0.707B$$

For heavy construction plant with wide and double tires

$$B = \sqrt{(1.414pa/pt)} \quad L = 0.5B$$

where,

$pa = \text{axle load and}$

$pt = \text{tire pressure [typical value for construction plant = 620 kpa (Giroud et al, 1984)]}$

The vertical force $F_{\text{vert}}$ is resisted by the radial tension around the perimeter of the geotextile contact area ($dh$). 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, $dp$. Hence, the calculated puncture force, $F_{\text{vert}}$, is converted into a puncture strength of geotextile, $F_g$ using the relationship given in Equation 3a.

**Equation 3a**

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

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

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

**Equation 3b**

$$F_g(\text{design}) = (\pi d_h) (P) (d_p) s_f \times \text{Factor of safety}$$

where,

$$d_h = \text{average diameter of aggregate, } d_{50} \quad (\text{assumed})$$

$$d_p = 50 \text{mm (according to ISO 12236)}$$

Another approach to assess indicative 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.

<table>
<thead>
<tr>
<th>Application Area</th>
<th>Factor of safety</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(Koerner, 1986)</td>
</tr>
<tr>
<td>Unpaved roads</td>
<td>1.1 to 2.0</td>
</tr>
<tr>
<td>Embankments</td>
<td>1.1 to 2.0</td>
</tr>
<tr>
<td>Pavement overlays</td>
<td>1.1 to 1.5</td>
</tr>
<tr>
<td>Railroads</td>
<td>1.5 to 3.0</td>
</tr>
<tr>
<td>General earthwork fills</td>
<td>1.1 to 2.0</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Influence Factors</th>
<th>Filter Criteria</th>
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<tbody>
<tr>
<td>Fill material type</td>
<td>Traffic stress</td>
</tr>
<tr>
<td>a</td>
<td>Medium/heavy</td>
</tr>
<tr>
<td>a</td>
<td>Light</td>
</tr>
<tr>
<td>b</td>
<td>Heavy</td>
</tr>
<tr>
<td>b</td>
<td>Medium/light</td>
</tr>
</tbody>
</table>

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

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 subgrades 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 \( a_i \) given in Equation 4.

**Equation 4**

\[
SN \leq \sum a_i \cdot D_i
\]

where,

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

![Design chart for SN value for pt = 2.0 (low volume traffic).](image)

![Design chart for SN value for pt = 2.5 (high volume traffic).](image)

Table 3. Correlation chart for estimating CBR and soil strength value (Koerner, 1986).
The structural number, SN required over the road sub grade for low and high volume roads can be determined as a function of the soil support (S), number of load repetitions ($W_{80N}$), 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, $W_{80N(g)}$, 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.

<table>
<thead>
<tr>
<th>Climatic condition</th>
<th>Regional factor, R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sub grade material (dry season)</td>
<td>0.2 – 1.5</td>
</tr>
<tr>
<td>Sub grade material (wet season)</td>
<td>4.0 – 5.0</td>
</tr>
</tbody>
</table>

Table 4. Regional factor, R.

<table>
<thead>
<tr>
<th>Material layer</th>
<th>$a$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asphalt surface course</td>
<td>0.44</td>
</tr>
<tr>
<td>Crushed stone base course</td>
<td>0.14</td>
</tr>
<tr>
<td>Sandy gravel sub base course</td>
<td>0.11</td>
</tr>
<tr>
<td>Sand or sandy-clay</td>
<td>0.06 – 0.10</td>
</tr>
</tbody>
</table>

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, $S_g = F \times S$

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

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

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.

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<table>
<thead>
<tr>
<th>Ruts (mm)</th>
<th>Traffic (Passes of 80kN equiv. axle)</th>
<th>Bearing Capacity Factor, ( N_c )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without Geotextile</td>
<td>(&lt; 50)</td>
<td>(&gt; 1000)</td>
</tr>
<tr>
<td></td>
<td>(&gt; 100)</td>
<td>(&lt; 100)</td>
</tr>
<tr>
<td>With Geotextile</td>
<td>(&lt; 50)</td>
<td>(&gt; 1000)</td>
</tr>
<tr>
<td></td>
<td>(&gt; 100)</td>
<td>(&lt; 100)</td>
</tr>
</tbody>
</table>

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

1. AASHTO Interim Guide For Design of Pavement Structure (1972). Published by the American Association of State Highway and Transportation Officials.

2. Broxson, I. and Eriksson, L. (1986). Long-term properties of geotextile and their function as a separator in road construction, 3rd. Int. Conf. on Geotextiles, Vienna,


