WINNING **TOGETHER**

Design Guide
Fibertex Reinforcement

Fibertex
NONWOVENS

Fibertex
Reinforcement

Fibertex Reinforcement products are cost effective and offer considerable performance benefits in sub-base layers and in the construction of steep slopes.

Fibertex Reinforcements are woven products made from various polymers including PP, PET and PVA (polypropylene, polyester, and polyvinyl alcohol). They are made from high tenacity yarns ensuring high strength and low elongation. For certain applications, Fibertex Reinforcements are coated with PVC for maximum durability.

Focus on the environment

No chemical binders are used in Fibertex products or during the production process. Polypropylene is a polymer material and when incinerated it turns into carbon dioxide and water vapour, both completely harmless substances.

Concern for the environment is proved by the fact that Fibertex is among the first in the nonwoven industry to introduce an environmental management system and thereby obtaining the ISO 14001 certificate. This ensures continuous focus on efficient and financially viable management of environmental issues, which in return ensures minimal harmful effects resulting from the company's activities.

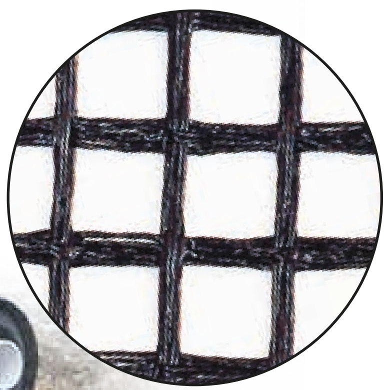
Implemented at all levels in the organisation, daily focus is on waste handling/recycling, implementation of new technologies and minimisation of waste and energy consumption.

The importance of quality

Fibertex's quality management system is certified in accordance with the most comprehensive standards set by the International Organisation for Standardisation namely DS/EN ISO 9001:2008. This means that the quality management system has been implemented and verified at all levels within the organisation.

Fibertex Reinforcements are CE marked under the EU Construction Products Directive. CE marking certifies that Fibertex's quality management system (DS/EN ISO 9001:2008) complies with the EN standards (level 2+). Fibertex Reinforcements are submitted to production control and tests in accordance with the EN standards.

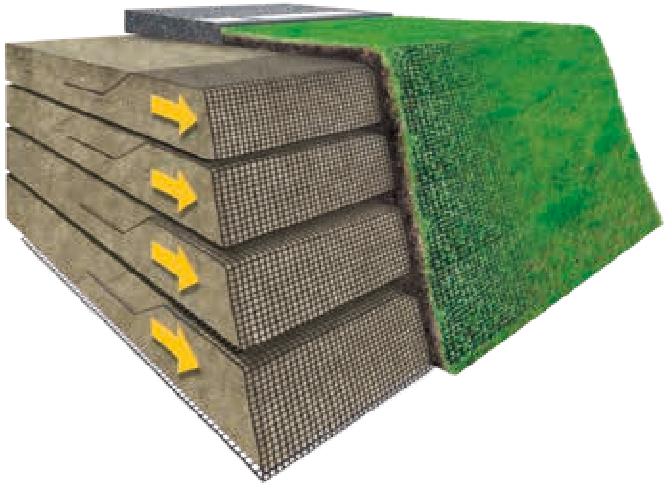
CE
1071-CPR-1846



Applications
with Fibertex Reinforcement

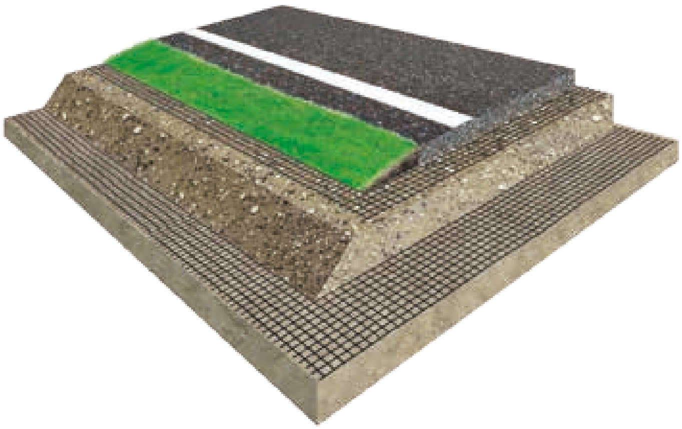
Steep reinforced slopes

Reinforcing soils with high strength and low elongation geosynthetics enables soil structures to stay stable under high loads with vertical or near-vertical surfaces. The soils are added internal shear resistance through geosynthetics, and when wrapping the geosynthetics over the surface for each layer, the horizontal forces on the vertical surface are also absorbed in the geosynthetics.



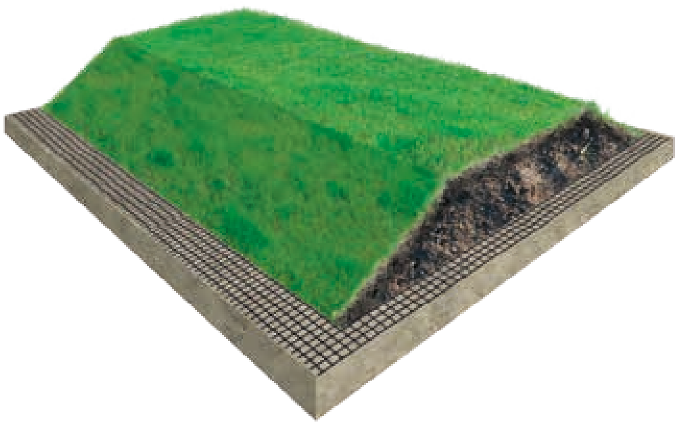
Asphalt reinforcement

Reinforcing the lower part of the asphalt layer adds internal shear resistance to the asphalt. When the underlying surface contracts and expands with the temperature and when heavy loads are applied to the asphalt the reinforcement absorbs the tensile strains and thereby prevents the asphalt from cracking.

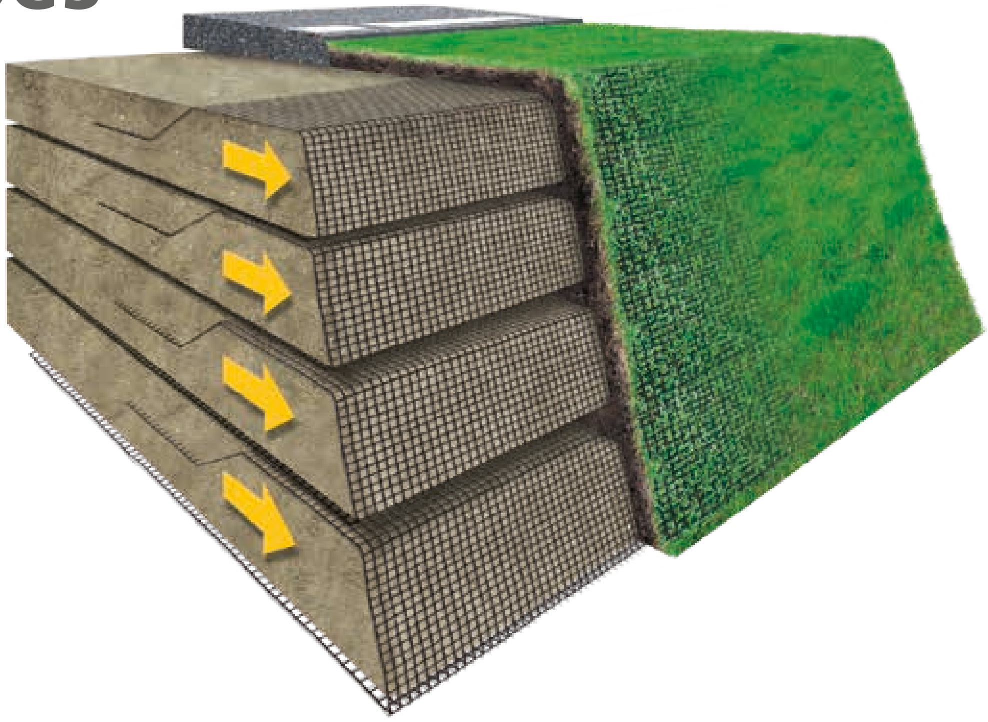


Embankments

Reinforcing the lower part of embankments prevents setting and sliding failures. The reinforcement distributes the vertical loads, and ensures horizontal stability by adding shear resistance at the base.



Steep reinforced
Slopes



Steep reinforced slopes

The design of a steep reinforced slope can be divided into five stages:

1. Calculation of the total earth pressure
2. Choice of reinforcement
3. Determination of reinforcement spacing
4. Determination of reinforcement length
5. Calculation of wrapping length

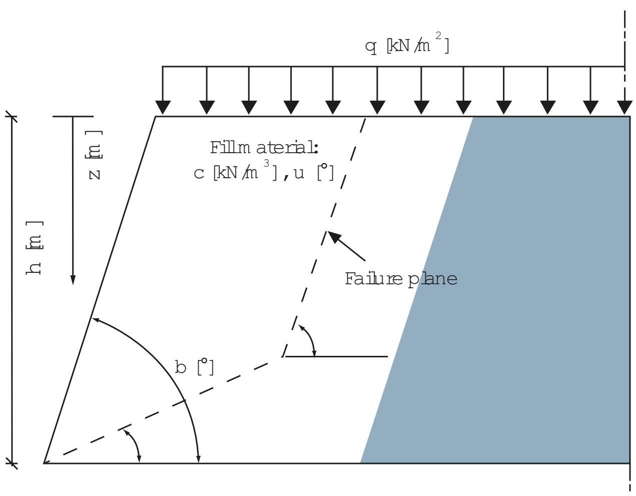


Fig 15. Reinforced slope

1. Calculation of the total earth pressure

The vertical pressure from the soil and a possible surcharge, σ_v, is used later to calculate the necessary anchoring length and is found as:

$$\sigma_{v,z} = q + \gamma \cdot z$$

Where,

$\sigma_{v,z}$ the vertical earth pressure at depth z in the slope [kN/m^2]
q the surcharge load [kN/m^2]
γ the unit weight of the fill material [kN/m^3]
z the vertical distance from the top of the slope [m]

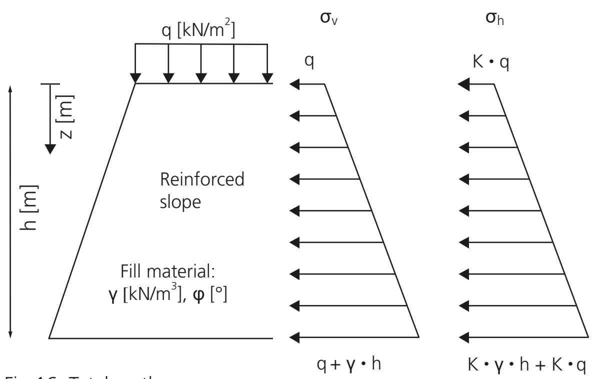
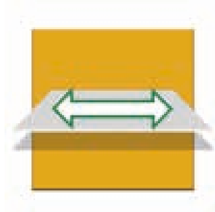


Fig 16. Total earth pressure



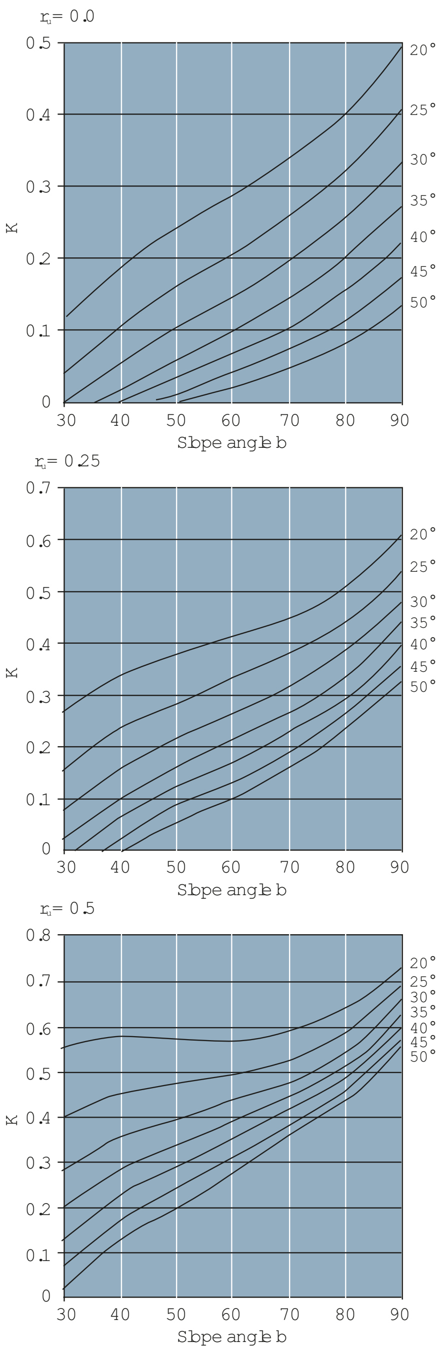


Figure: 4 Lateral earth pressure coefficient at different pore water pressure r_u [Jewel 1991]

The total lateral (horizontal) earth pressure can be calculated as a percentage of the total vertical earth pressure. This percentage is called the lateral earth pressure coefficient, K:

$$\sigma_{h,z} = \underbrace{K \cdot \gamma \cdot z}_{\text{Soil pressure}} + \underbrace{K \cdot q}_{\text{Surcharge load}}$$

Where,

$\sigma_{h,z}$	the lateral earth pressure at depth z in the slope [kN/m²]
K	the lateral earth pressure coefficient [can be read from figure 4]
γ	the unit weight of the fill material [kN/m³]
z	the vertical distance from the top of the slope [m]
q	the surcharge load [kN/m²]
φ	the angle of internal friction in the fill material [°]
β	slope angle [°]

Pore Water Pressure

$$r_u = \frac{H_{water} \cdot \gamma_{water}}{H \cdot \gamma_{soil}}$$

Where,

r_u	Pore water pressure[-]
H_{water}	Height of water table from base of the slope[m]
H	Height of the slope[m]
γ_w	the unit weight of the water [kN/m³]
γ_{soil}	the unit weight of the soil [kN/m³]

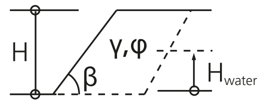


Figure: 3 Pore water pressure

2. Choice of reinforcement

Based on the calculations, a Fibertex reinforcement product is chosen, and the design long term tensile strength of the product, T_{lt}, is calculated:

$$T_{lt} = \frac{T_k}{f_c \cdot k_i \cdot k_d \cdot f_m}$$

Where,

T_{lt}	the long term tensile strength of a reinforce-ment product [kN/m]
T_k	the short term tensile strength of a product (see datasheet) [kN/m]
f_c	the creep reduction coefficient (see datasheet)
k_i	the installation damage coefficient (see datasheet)
k_d	the chemical degradation coefficient (see datasheet)
f_m	the partial material coefficient (normally set to 1.4 for material security)

Steep reinforced Slopes

3. Reinforcement Spacing

As the strength of the reinforcement in the face of the slope must always exceed the lateral earth pressure the reinforcement spacing, Sv, is calculated as:

$$\sigma_{h,z} \leq \frac{T_{lt}}{S_v}$$

Lateral earth Pressure — Reinforcement strength per unit spacing

$$S_v \leq \frac{T_{lt}}{\sigma_{h,z}}$$

Where,

S_v spacing of the reinforcement [m]

T_{lt} the long term tensile strength of a reinforcement product [kN/m]

$\sigma_{h,z}$ the lateral earth pressure at depth z in the slope [kN/m²]

As the stresses increase with the depth we have three possible approaches for designing the reinforcement spacing

- Vary the spacing distance with same reinforcement strength
- Vary the strength of the reinforcement with same spacing distance
- Vary both the spacing distance and the strength of the reinforcement

It is recommended to use only one or at most two types of reinforcement and vary the spacing distance.

In theory the spacing distance, should be calculated for each new layer to minimize product consumption. However, in practice it is extremely work intensive and time consuming, so normally calculation of the spacing distance is done in 4-5 intervals through out the entire construction.

Because of the face stability problems and uneven characteristics of soil the vertical spacing should never exceed 1 m. If the stresses at the top are very low, the equation will compute a higher spacing which must then be regulated to 1 m.

4. Reinforcement Length

The reinforcement length is determined by one of two different situations. The length needed for internal stability and the length needed for external stability. The greater of two reinforcement lengths will be the design anchoring length.

Internal stability

There are two internal failure possibilities

1. Internal direct sliding over reinforcement layer

2. Pullout of reinforcement

Internal direct sliding

The direct sliding on top of the reinforcement is resisted by the friction developed at the interface between the soil and top of the reinforcement. The resistant shear stress provided by friction is given by:

$$\mathbf{T}_{ds} = \sigma_{v,z} \cdot f_{ds} \cdot \tan(\varphi)$$

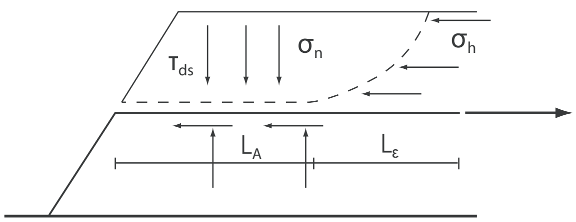
Where,

$\mathbf{T}_{ds}$ Shear stress required to resist direct sliding [kN/m²]

$\sigma_{v,z}$ The vertical earth pressure at depth z in the slope [kN/m²]

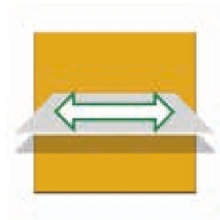
f_{ds} Factor of direct sliding (see table 1 for Fibertex reinforcement) [-]

φ The angle of internal friction in the fill material [°]



Direct Sliding over a reinforcement layer

Figure: 5.1 Internal failure mode (direct sliding)



Required length of the reinforcement after failure plane for resisting direct sliding over reinforcement

$$L_{\varepsilon,sliding} = \frac{T_{lt}}{B \cdot \tau_{ds}}$$

Where,

$L_{\varepsilon,sliding}$	Required length of the reinforcement after failure plane to resist direct sliding [m]
T_{lt}	the long term tensile strength of a reinforcement product [kN/m] (Found in section 2)
B	Width of the reinforcement in the anchorage zone [m]
τ_{ds}	Shear stress required to resist direct sliding [kN/m²]

	Gravel	Sand	Silt	Clay
f_{ds}	0.95-1.00	0.92-0.98	0.80-0.90	0.70-0.80

Table 1. Recommended factor of direct sliding for various fill materials

Pullout

Pull out of the reinforcement is resisted by the friction provided by the soil above and below the reinforcement. The resistant shear stress is calculated as:

$$\tau_p = \sigma_{v,z} \cdot f_{po} \cdot \tan(\varphi)$$

Where,

τ_p	Shear stress required to resist pullout [kN/m²]
$\sigma_{v,z}$	the vertical earth pressure at depth z in the slope [kN/m²]
f_{po}	Factor of pullout (see table 2 for Fibertex reinforcement)
φ	the angle of internal friction in the fill material [°]

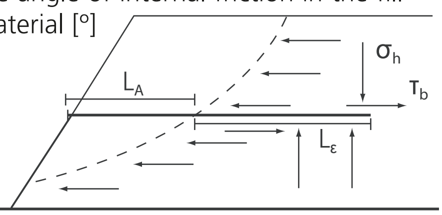


Figure: 5.2 Internal failure mode (pullout)

Required length of the reinforcement after failure plane for resisting pullout of the reinforcement

$$L_{\varepsilon,pullout} = \frac{T_{lt}}{2 \cdot B \cdot \tau_p}$$

Where,

$L_{\varepsilon,pullout}$	Required length of the reinforcement after failure plane to resist pullout [m]
T_{lt}	the long term tensile strength of a reinforcement product [kN/m] (Found in section 2)
B	Width of the reinforcement in the anchorage zone [m]
τ_p	Shear stress required to resist pullout [kN/m²]

	Gravel	Sand	Silt	Clay
f_{po}	0.90-1.05	0.75-0.95	0.70-0.90	0.60-0.85

Table 2. Recommended factor of pullout for various fill materials

Required length of the reinforcement after failure plane for internal stability is given by:

$$L_\varepsilon = \max(L_{\varepsilon,sliding}, L_{\varepsilon,pullout})$$

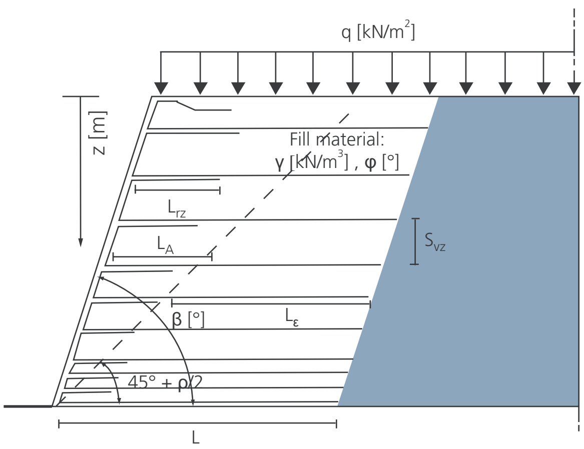


Figure: 6 Reinforcement spacing and length

Steep reinforced Slopes

Length of the reinforcement required for the internal stability

$$L_{internal} = L_{\varepsilon} + L_{A}$$

Where,

$L_{internal}$ Total Reinforcement length for internal stability [m]

L_{ε} Reinforcement length after failure plane [m]

L_{A} Reinforcement length before the failure plane [m]

$$L_A = \left[\tan\left(45 - \frac{\rho}{2}\right) - \tan(90 - \beta) \right] * H$$

ρ angle of friction for design

$$\rho = \tan^{-1}\left(\frac{\tan(\varphi)}{f_m}\right)$$

φ the angle of internal friction in the fill material [°]

f_m the partial material coefficient (normally set to1.4 for material security)

β Slope angle [°]

H Height of the slope[m]

External Stability

For calculation of external stability the surcharge load if any is converted to an equivalent soil height and added to the actual height of the slope

$$H^* = H + \frac{q}{\gamma}$$

Where,

H^* Equivalent height [m]

H Height of the slope [m]

q The surcharge load [kN/m^2]

γ the unit weight of the fill material [kN/m^3]

Knowing the pore water pressure and the slope angle, the length to height ratio can be read from the figure (7) for overall stability and direct sliding.

The total reinforcement length required for external stability is calculated as:

$$L_{external} = \max\left[H^* \cdot (L/H)_{ds},\ H^* \cdot (L/H)_{ovrl} \right]$$

Where,

$L_{external}$ Length of the reinforcement for external stability [m]

H^* Equivalent height [m]

$(L/H)_{ds}$ Ratio of length and height required to prevent external direct sliding [can be read from figure 7]

$(L/H)_{ovrl}$ Ratio of length and height required for overall stability of slope [can be read from figure 7]

Length of the reinforcement required

$$L_{external} = \max\left(L_{internal},\ L_{external} \right)$$

Where,

L Length of the reinforcement [m]

$L_{internal}$ Total Reinforcement length for internal stability [m]

$L_{external}$ Length of the reinforcement for external stability [m]

5. Wrapping Length

Wrapping length at any depth z in the slope can be calculated by

$$L_{rz} = \frac{FS_{warp} \cdot K \cdot (z + S_v/2) \cdot S_v}{z_c \cdot f_{ds} \cdot \tan(\varphi)}$$

Where,

L_{rz} Wrapping length at depth z in the slope[m]

FS 1.2-1.4 for Fibertex Reinforcement

f_{ds} Factor of direct sliding (see table 1 for Fibertex reinforcement)

K the lateral earth pressure coefficient

φ the angle of internal friction in the fill material [°]

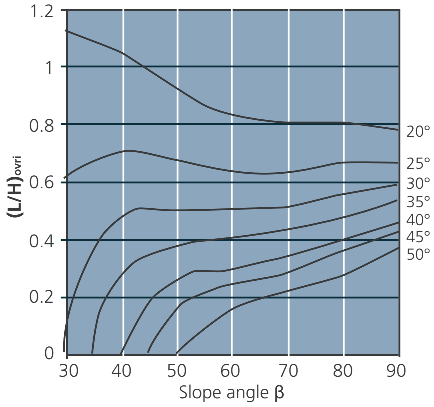
z the vertical distance from the top of the slope [m]

S_v Spacing of the reinforcement at depth z in the slope[m]

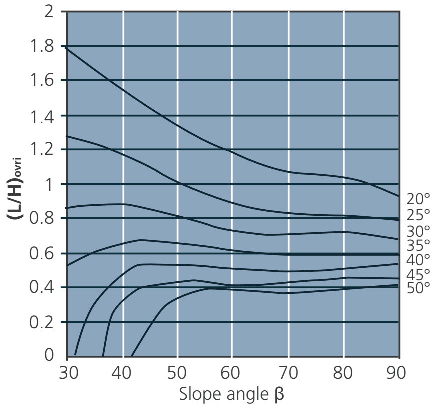
Overall Stability

Length to height ratio

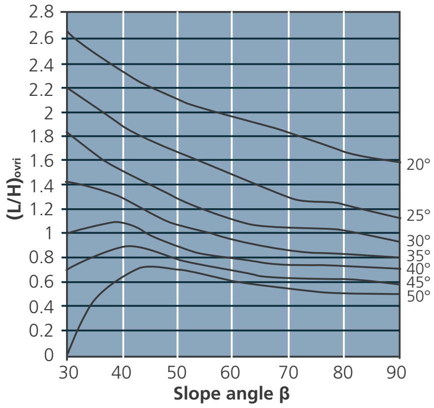
r_u= 0.00



r_u= 0.25



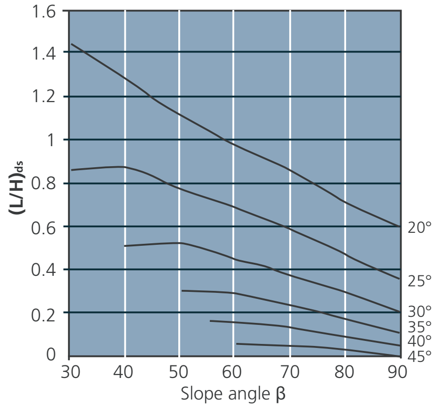
r_u= 0.5



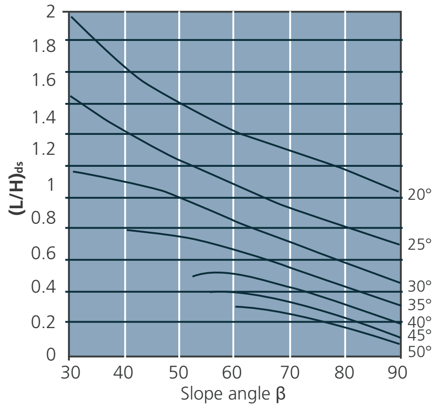
External direct sliding

Length to height ratio

r_u= 0.00



r_u= 0.25



r_u= 0.5

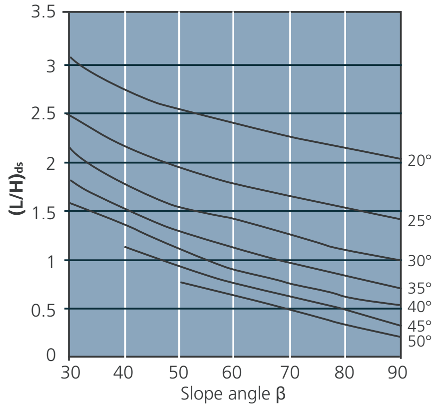
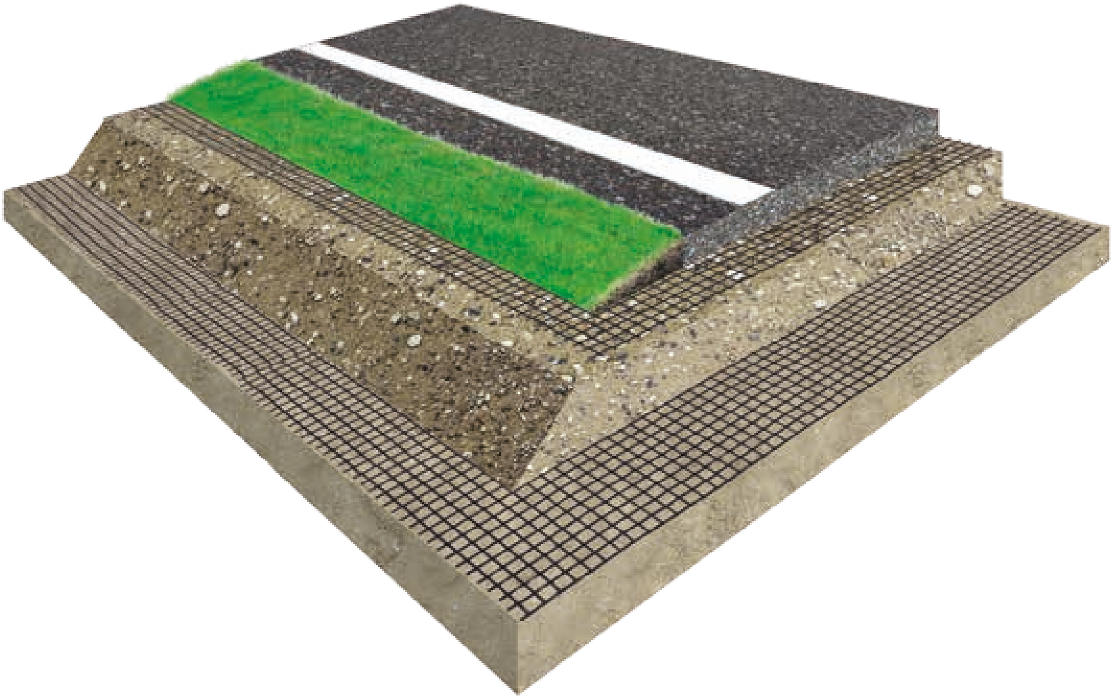


Figure: 7 The Relation between the length of reinforcement and the slope height for the overall stability and external direct sliding at different pore water pressure [Jewel 1991]

Asphalt Reinforcement



Asphalt reinforcement

The design of reinforced asphalt pavements can be divided in to three parts:

1. Design of asphalt layer

- a. Design of layer thickness

2. Design of foundation layer

- a. Calculation of equivalent wheel load
- b. Calculation of the pressure on the fill layer
- c. Determination of the fill layer depth
- d. Choice of reinforcement

3. Design checks

- a. Check for the stability of fill
- b. Check for the stability of subsoil

1. Design of asphalt layer

Asphalt reinforcement is used to prevent classical fatigue cracking of new asphalt or reflection cracking in asphalt repairs. The presence of the grid will inhibit cracking under repeated loading through control of local tensile strains and will therefore result in a lower required thickness of the layer.

a. Thickness of asphalt layer

The thickness of the asphalt layer can be read from the graph in Figure 1 when having decided the design life in terms of millions of standard axles.

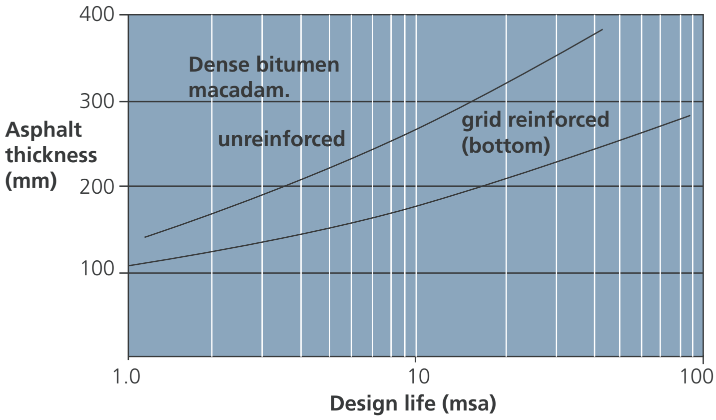


Figure: 1 Asphalt layer thickness design

2. Design of foundation layer

Foundation of a paved road can be designed as an unpaved road with small allowable rut depth.

a. Calculation of equivalent wheel load

Using the number of passes for the life of the paved structure, the equivalent wheel load is derived from the equation

$$F_e = F_p (N_p)^{.16}$$

Where,

F_e Equivalent wheel load [kN]

F_p Maximum single wheel load [kN]

N_p Number of traffic passes [-]

b. Calculation of the pressure on the fill layer

The pressure on the fill layer is given by:

$$P_f = \underbrace{\frac{F_e}{\pi * R_{af}^2}}_{\text{Due to wheel load}} + \underbrace{\gamma_a * D_a}_{\text{Due to asphalt layer}}$$

Where,

P_f Pressure on the fill layer [kN/m²]

F_e Equivalent wheel load [kN] (calculated in section 2.a)

R_{af} Radius of distributed load between asphalt layer and fill layer [m]

$$R_{af} = R + D_a * \tan\beta_a$$

R Radius of circular contact area between tire and road surface [m]

$$R = \sqrt{\frac{F_p}{\pi * P_t}}$$

F_p Average single wheel load [kN] (found in section 2.a)

P_t Wheel pressure [kN/m²]

D_a Depth of asphalt layer [m] (calculated in previous section)

β_a Load spreading angle of the asphalt layer [°] (For a good compacted asphalt layer $\beta_a = 40°$)

γ_a Unit weight of asphalt layer [kN/m³]

c. Determination of the fill layer depth

The required depth of the fill layer can be found from one of charts shown in the Figure 3. To select the correct chart, the variable

$C_u/\gamma_f R_{af}$) must be calculated

Where,

C_u Undrained shear strength of subsoil [kN/m²]

γ_f Unit weight of the fill material [kN/m³]

R_{af} Radius of distributed load between asphalt layer and fill layer [m] (calculated in section 2.b)

The value of D_f/R_{af} is then read from the graph using the variables P_f/C_f and β_f

Where,

D_f Depth of the fill layer [m]

R_{af} Radius of distributed load between asphalt layer and fill layer [m] (calculated in section 2.b)

P_f Pressure on the fill material [kN/m²] (calculated in section 2b)

β_f Load spreading angle of the fill layer [°] (For a good compacted fill material $\beta_f = 35°$)

If a chart for the particular value of $C_u/\gamma_f R_{af}$) is not available interpolation between the two nearest read values can be applied

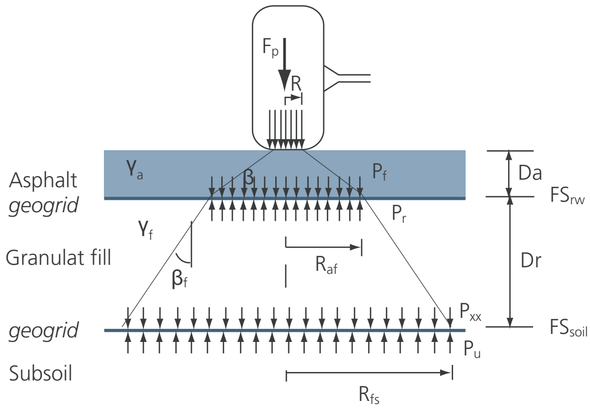


Figure: 2 Forces on the pavement

Asphalt
Reinforcement

When D_f/R_{af} is read the depth of the fill can be calculated from

$$D_f = R_{af} * \left(\frac{D_f}{R_{af}}\right)$$

Where,

D_f Depth of the fill layer [m]

R_{af} Radius of distributed load between asphalt layer and fill layer [m] (calculated in section 2.b)

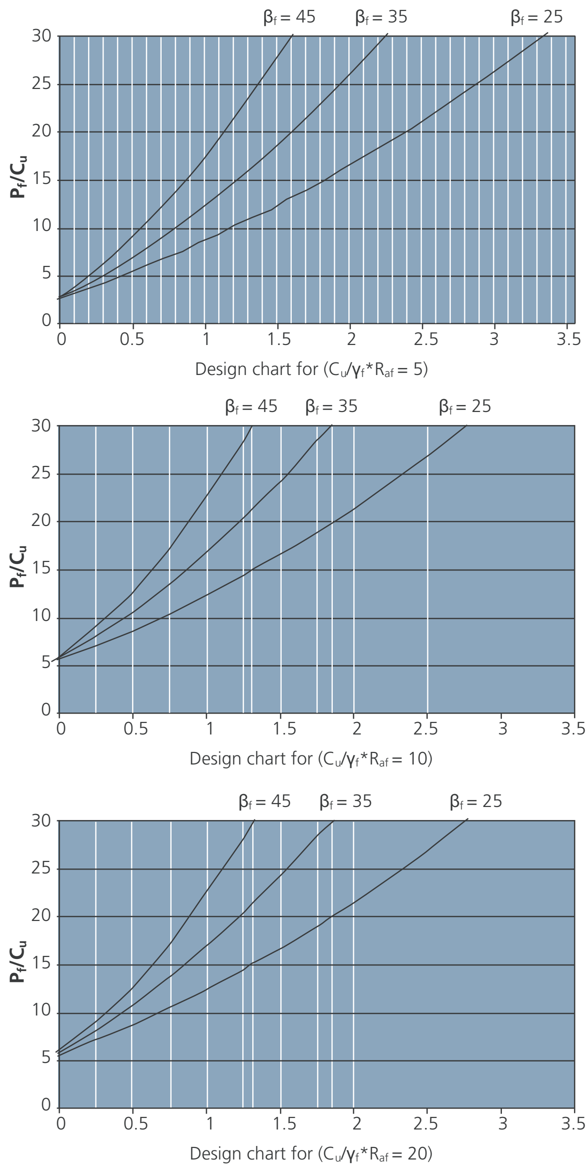


Figure: 3 Chart for designing the depth of the fill layer

d. Choice of reinforcement

The required strength of the asphalt reinforcement can be found from one of the charts shown in Figure 4. To select the correct chart, the variable must be calculated (as in section 2.c).

$C_u/\gamma_f R_{af})$

Where,

C_u Undrained shear strength of subsoil [kN/m²]

γ_f Unit weight of fill material [kN/m³]

R_{af} Radius of distributed load between asphalt layer and fill layer [m] (calculated in section 2.b)

The value of D_f/R_{af} is then read from the graph using the variables P_f/Cu, β_f and φ_f

Where,

D_f Depth of the fill layer[m]

R_{af} Radius of distributed load between asphalt layer and fill layer [m] (calculated in section 2.b)

P_f Pressure on the fill material [kN/m²] (calculated in section 2b)

C_u Undrained shear strength of subsoil [kN/m²]

β_f Load spreading angle of the fill layer [°]

φ_f angle of friction in the fill material [°]

If a chart for the particular value of $C_u/\gamma_f R_{af})$ is not available interpolation between the two nearest read values can be applied.

When $T_{req}/C_u R_{af})$ is found the required tensile strength of the reinforcement can be calculated from

$$T_{req} = R_{af} \cdot C_u \cdot \left(\frac{T_{req}}{R_{af} \cdot C_u}\right)$$

Where,

T_{req} Required tensile strength of the reinforcement [kN/m]

R_{af} Radius of distributed load between asphalt layer and fill layer [m] (calculated in section 2.b)

C_u Undrained shear strength of subsoil [kN/m²]

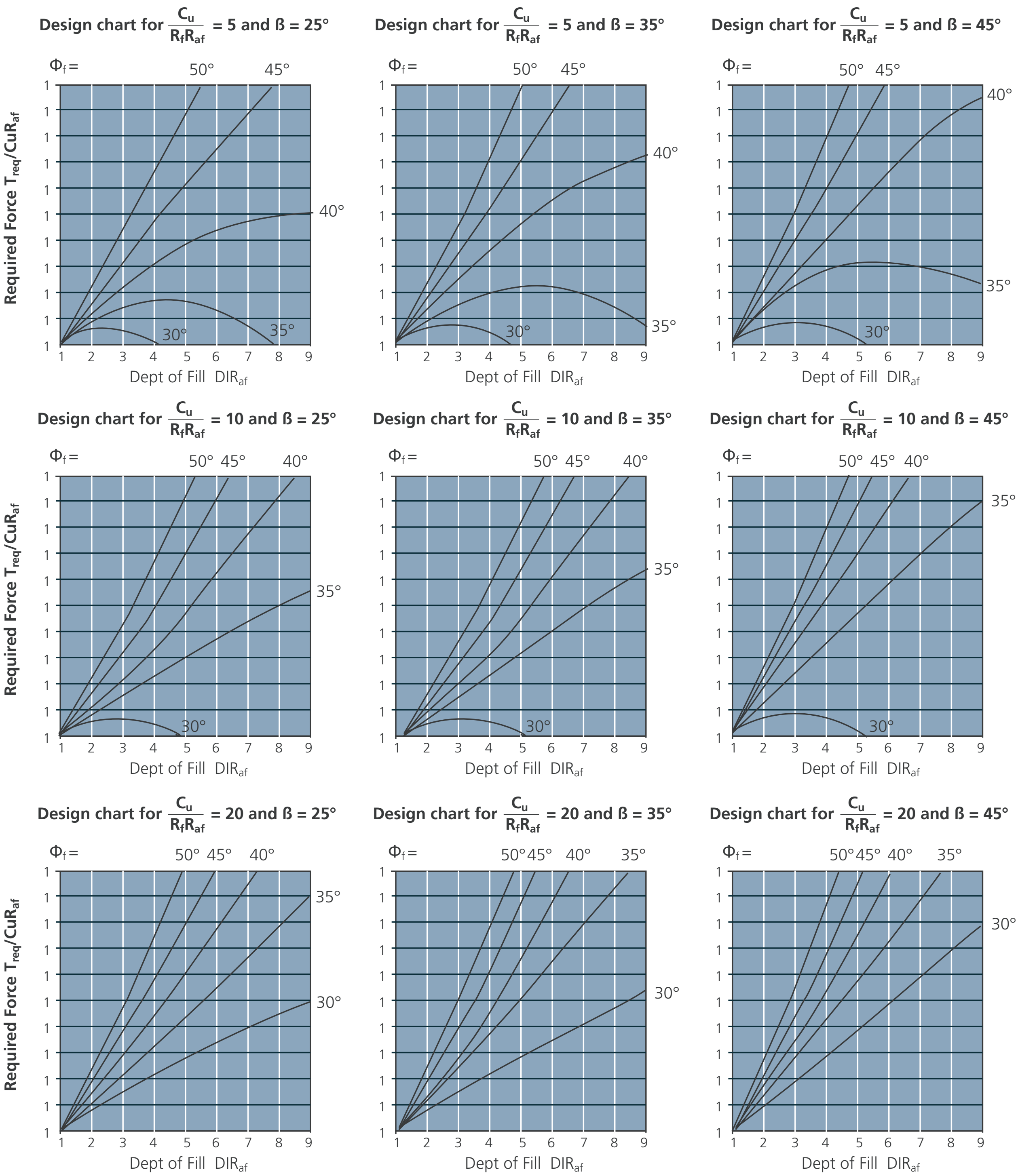


Figure: 4 Charts for tensile force in reinforcement

Asphalt Reinforcement

3. Design Checks

a. Stability of fill

The stability of the fill can be checked by calculating the factor of safety for bearing failure.
The factor of safety is calculated as the bearing capacity of the fill divided by the actual pressure applied to the fill (calculated in section 2b.)

The Bearing Capacity of the fill is found as:

$P_y = 0.6 \cdot R_{af} \cdot \gamma_f \cdot N_\gamma$

Where,

P_y Bearing capacity of fill layer [kN/m²]

R_{af} Radius of distributed load between asphalt layer and fill layer [m] (calculated in section 2.b)

γ_f Unit weight of the fill material [kN/m³]

N_γ Bearing capacity factor for a rough base footing [-]
$N_\gamma = 2 \cdot R_{af} \cdot (N_q + 1).(\tan)\ \varphi_f$

N_q Bearing capacity factor for the fill material [-]

$$N_q = \frac{1+\sin\varphi_f}{1-\sin\varphi_f} * e^{\pi * \tan\varphi f}$$

φ_f Internal angle of friction of the fill material [°]

0.6 is the shape factor for an axial symmetry.

$$FS_{fill} = \frac{P_y}{P_f}$$

Where,

FS_{fill} Factor of safety for the stability of fill [-] (Normally greater then 1.2 for material security)

P_y Bearing capacity of the fill layer [kN/m²]

P_f Pressure on the fill layer [kN/m2] (calculated in section 2b)

If the desired factor of safety is reached, the fill will be able to bear the proposed pavement.
Otherwise either,

- increase the load spreading angle in the asphalt layer by,
  - increasing the thickness of the asphalt layer or
  - using a different type of asphalt

or,

- increase the angle of friction in the fill layer

by,

  - increasing compaction
  - using a different fill material

b. Stability of subsoil

The stability of the subsoil can be checked by calculating the factor of safety for bearing failure.
The factor of safety is calculated as the bearing capacity of the subsoil divided by the applied pressure on the subsoil

The bearing capacity of the subsoil is found as:

$$P_u = N_c * C_u * \left(\frac{R_{fs}}{R_{af}}\right)$$

Where,

P_u Bearing capacity of the sub soil [kN/m²]

N_u Bearing capacity factor for the subsoil [-] (5.69 for reinforced structures)

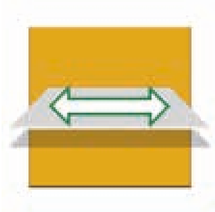
C_u Undrained shear strength of the subsoil [kN/m²]

R_{fs} Radius of distributed load between fill material and subsoil [m]
$R_{fs} = R_{af} + D_f \cdot \gamma_f \cdot \tan\beta_f$

R_{af} Radius of distributed load between asphalt layer and fill layer [m] (calculated in section 2.b)

D_f Thickness of the fill layer [m]

β_f Load spreading angle of the fill layer [°]



The pressure on the subsoil P_{es} is found as:

$$P_{es} = \frac{F_e}{\pi * R_{fs}^2} + \gamma_a * D_a + \gamma_f * D_f$$

Where,

P_{es}	pressure on the subsoil [kN/m^2]
F_e	Equivalent wheel load [kN] (calculated in section 2a)
R_{fs}	Radius of distributed load between fill material and subsoil [m] $R_{fs} = R_{af} + D_f \cdot \gamma_f \cdot \tan \beta_f$
R_{af}	Radius of distributed load between asphalt layer and fill layer [m] (calculated in section 2.b)
D_f	Thickness of the fill layer [m]
β_f	Load spreading angle of the fill layer [°]
γ_a	Unit weight of asphalt layer [kN/m^3]
D_a	Thickness of asphalt layer [m]
γ_f	Unit weight of fill material [kN/m^3]

The factor of safety can then be calculated as:

$$FS_{soil} = \frac{P_u}{P_{es}}$$

Where,

FS_{soil}	Factor of safety for the stability of the subsoil [-]
P_{es}	Equivalent pressure on the subsoil [kN/m^2]
P_u	Bearing capacity of the subsoil [kN/m^2]

If the desired factor of safety is reached, the subsoil is mechanically stable.

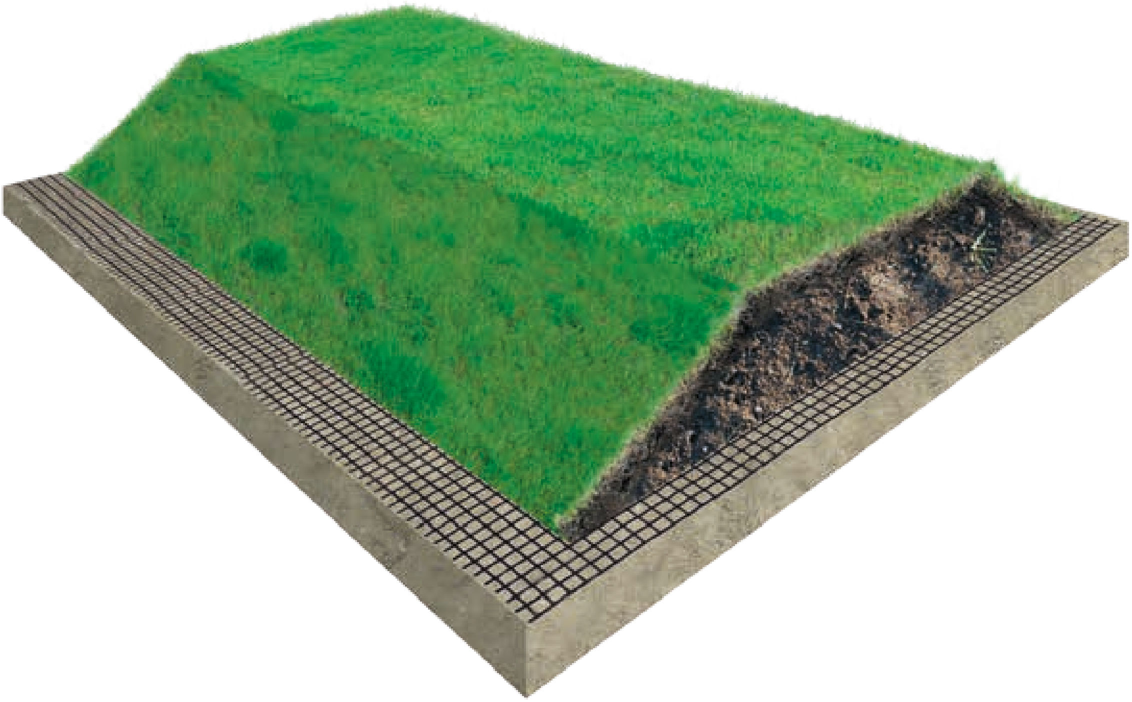
Otherwise either,

- increase the load spreading angle by,
  - increasing the thickness of the fill material, or by
  - increasing the compaction of the fill material, or by
  - using a different fill material

or,

- increase the Cu value of the subsoil by artificial consolidation.

Design of Embankment



Design of Embankment

The design of an embankment can be divided into two stages, check for the bearing capacity of the foundation soil and if the bearing capacity is sufficient then design of the embankment.

1. Checking the bearing capacity of foundation soil

a. Calculation of equivalent footing width
b. Calculation of bearing capacity of foundation soil
c. Calculation of applied stresses
d. Calculation of the factor of safety for bearing failure

2. Designing the Embankment

a. Calculation of restoring and overturning moment
b. Fixing the slip circle
c. Calculation of required reinforcement strength

1. Checking the bearing capacity of foundation soil

The equivalent footing width is used to calculate the bearing capacity of the foundation soil with the chosen embankment on top. After the bearing capacity of the chosen embankment is calculated the stresses that are actually applied are found and the two are compared to get a factor of safety.

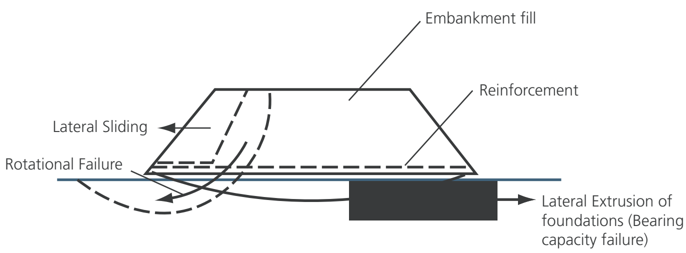


Figure: 1 Typical Failure mode for an embankment *a. Calculation of equivalent footing width*

Equivalent footing width is used for changing the non uniform vertical load distribution on the footing of embankment to uniform vertical load distribution for the calculation of bearing capacity.

$$B = b + 2n(H - h^*)$$

Where,

$$h^* = \frac{C_u(2+\pi)}{\gamma}$$

B	Equivalent footing width of embankment [m]
b	Embankment crest width [m]
n	Cotangent of the slope angle [-]
H	Height of Embankment [m]
C_u	Undrained shear strength of soil beneath the footing [kN/m²]
γ	Embankment fill unit weight [kN/m³]

b. Calculation of bearing capacity of foundation soil

A bearing capacity factor is multiplied to the soil strength depending on the dimensions of the overlaying embankment

$$q_u = N_c * C_u$$

$$\text{for } \frac{B}{D} < 2 : N_c = 2 + \pi$$

$$\text{for } \frac{B}{D} \geq 2 : N_c = \pi + .5\left(\frac{B}{D} + 2\right)$$

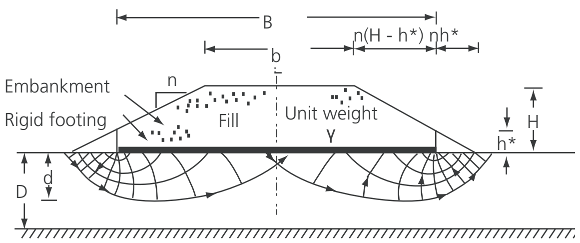


Figure: 2 Embankment on soft soil

Where,

q_u	Bearing Capacity [kN/m²]
N_c	Bearing capacity factor [-]
C_u	Undrained shear strength of soil beneath the footing [kN/m²]
B	Equivalent footing width of Embankment [m]
D	Depth of the soft soil [m]

c. Calculation of applied Bearing Stress

The vertical pressure applied by the fill material on the foundation soil is found by:

$$q_a = \frac{\gamma\left[b * H + n\left(H^2 - (h^*)^2\right)\right]}{B}$$

Where,

$$h^* = \frac{C_u(2+\pi)}{\gamma}$$

q_a	Applied stress [kN/m²]
γ	Embankment fill unit weight [kN/m³]
b	Embankment crest width [m]
H	Height of Embankment [m]
n	Cotangent of the slope angle [-]
B	Equivalent footing width of embankment [m]

Calculation of the factor of safety for bearing failure.

$$FS_b = \frac{q_u}{q_a}$$

Where,

q_a	Applied bearing stress by the fill [kN/m²]
q_u	Bearing Capacity of foundation soil [kN/m²]
FS_b	Factor of safety for bearing capacity [-]

Design of Embankment

Recommended factor of safety for bearing capacity is 3.

If the desired factor of safety is reached, the foundation soil will be able to bear the proposed embankment and calculation of the reinforcement can be done.

If not, then either a lower factor of safety would have to be accepted or improvement of the foundation soil would be needed.

2. Designing the Embankment

The required tensile strength of the reinforcement for designing the embankment can be determined by considering the global stability analysis of desired embankment.

$$FS_g = \frac{\text{Re storingMoments}}{\text{OverturningMoments}}$$

a. Calculation of restoring and overturning moment

The restoring moment (RM) is the mechanism that works against the failure. It is provided by the mobilized shear strength along the failure surface in the foundation soil and the tensile force in the reinforcement.

The overturning moment (OM) is the mechanism that causes the failure it is an effect of the horizontal earth pressure from the embankment fill and the self weight of embankment fill applied to the foundation soil.

$$RM = \underbrace{Z_r * T_g}_{\text{Due to Reinforcement}} + \underbrace{C_u * R^2 * \theta}_{\text{Due to shear strength of foundation}}$$

$$OM = \underbrace{\frac{1}{2} * K_a * \gamma * H^2 \left(Z_c - \frac{H}{3} \right)}_{\text{Due to horizontal earth pressur}} + \underbrace{\sum_{i=1}^{m} W_i \left(x_i - x_c \right)}_{\text{Due to self weight of fill material}}$$

$$K_a = \frac{1 - \sin\varphi}{1 + \sin\varphi}$$

Where,

RM	Restoring Moments [kN-m]
Z_r	Vertical distance of the reinforcement from the center of slip circle [m]
T_g	Limiting tensile force developed in the reinforcement [kN/m]
C_u	Undrained shear strength of soil beneath the footing [kN/m²]
R	Radius of the slip circle [m]
θ	Angle made by the slip circle to the center [°]
OM	Overturning Moments [kN-m]
K_a	Coefficient of active earth pressure [-]
γ	Embankment fill unit weight [kN/m3]
H	Height of Embankment [m]
Z_c	Z coordinate of the slip circle center [m]
W_i	Weight of the embankment fill in region i [kN]
m	number of regions [-]
x_i	x coordinate of center of mass in region i [-]
x_c	X coordinate of the slip circle center [-]
φ	the angle of internal friction in the fill material [°]

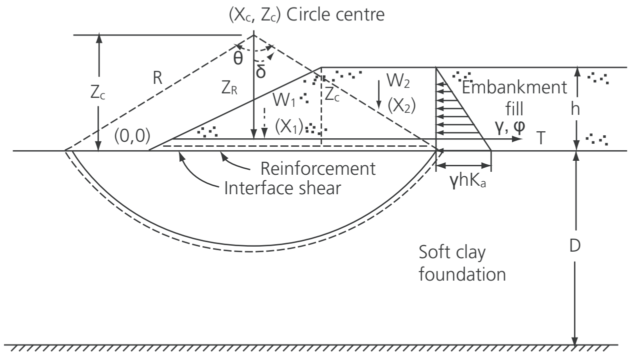
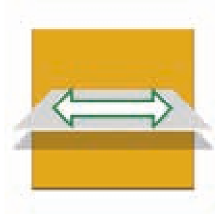


Figure: 2 Embankment on soft soil



b. Fixing the slip circle

This method can be easily implemented in the form of a computer program, which can search for a slip circle giving the lowest factor of safety of the desired embankment. Once the slip circle is fixed then all the values related to geometry (R, θ, X and Z coordinates) are fixed.

Recommended factor of safety for global stability is 1.5.

c. Calculation of required reinforcement strength

The limiting force developed in the reinforcement

$$T_g = \min\left(T_s, T_p, T_{lt}, T_a\right)$$

Where,

T_s	Required reinforcement strength to resist shear failure [kN/m]
T_p	Required reinforcement strength to resist pullout [kN/m]
T_{lt}	the long term tensile strength of a reinforcement product [kN/m]
T_a	Required reinforcement strength required to maintain allowable strain [kN/m]

1. Calculation for T_s

Sum of thrust force in fill and clay fill interface shear

$$T_s = \underbrace{\frac{1}{2} * K_a * \gamma * H^2}_{\text{Thrust force In fill}} + \underbrace{\delta * C_u \left[x_c + R * \sin\left(\frac{\theta}{2}\right) \right]}_{\text{Shear at clay fill interface}}$$

Where,

T_s	Required reinforcement strength to resist shear failure [kN/m]
K_a	Coefficient of active earth pressure [-]
γ	Embankment fill unit weight [kN/m^3]
δ	coefficient of friction at clay fill interface [-]
C_u	Undrained shear strength of soil beneath the footing [kN/m^2]
x_c	X coordinate of the slip circle center [-]
R	Radius of the slip circle [m]
θ	Angle made by the slip circle to the center [°]

2. Calculation for T_p

$$T_p = 2 \int_0^{x_c + R\sin(\theta/2)} \sigma_n dx$$

Where,

T_p	Pullout strength of reinforcement [kN/m]
σ_n	Normal stress acting on the reinforcement [kN/m^2] $\sigma_n = \gamma * z$
z	the vertical distance from the surface of the slope [m]
x_c	X coordinate of the slip circle center [-]
R	Radius of the slip circle [m]
θ	Angle made by the slip circle to the center [°]

3. Calculation for Tlt

Allowable reinforcement force governed by strength,

$$T_{lt} = \frac{T_k}{f_c * k_i * k_d * f_m}$$

Where,

T_{lt}	the long term tensile strength of a reinforcement product [kN/m]
T_k	the short term tensile strength of a product (see datasheet) [kN/m]
f_c	the creep reduction coefficient (see datasheet)
k_i	the installation damage coefficient (see datasheet)
k_d	the chemical degradation coefficient (see datasheet)
f_m	the partial material coefficient (normally set to 1.4 for material security)

4. Calculation for T_a

Allowable reinforcement force governed by allowable strain ε_a, T_a

$$T_a = J * \varepsilon_a$$

Where,

T_a	Reinforcement force governed by allowable strain [kN/m]
J	Secant stiffness of reinforcement over the range (0-ε_aa) (Can be found from stress strain curve)
ε_a	Allowable tensile strain in the reinforcement [-]

Facts about Fibertex

The Fibertex Group is a market leading manufacturer of needlepunch nonwovens for industrial and technical applications. Headquartered in Aalborg, Denmark, with production in Denmark, the Czech Republic, France, the USA, Turkey, South Africa and Brazil Fibertex is globally represented. Since its foundation in 1968, Fibertex has continuously expanded and today manufactures nonwovens for customers all over the world for many different applications.

The Fibertex way

The Fibertex supply chain ensures that we do our utmost to fulfil our customers demands. This process is an efficient management tool, it helps us to maintain our superior level of technical support, R&D, logistics, production and quality in all areas. We strive to provide an unparralled service to our customers from initial contact to delivery and after-sales service.

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Fibertex Nonwovens A/S
Svendborgvej 16
DK-9220 Aalborg
Denmark
Tel. +45 96 35 35 35
Fax +45 98 15 85 55
fibertex@fibertex.com
www.fibertex.com

Fibertex
NONWOVENS