Influences on the Calculatorily required Geotextile Reinforcement for Retaining Structures

R. Rüegger, D. Flum
Rüegger Systems Ltd., St. Gallen, Switzerland

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ABSTRACT: The most basic relations between geotechnical and geometrical parameters must be known to identify the deployment limits of geotextile-reinforced constructions and to understand the bearing behaviour of such systems. The forces to be absorbed by the geotextile reinforcement are decisively influenced by the characteristic values of the ground and the geometry of the terrain. In investigations based on the concept with partial safeties (EUROCODE 7, case C), a reduction of the shear parameters can soon lead to an extreme increase of the geotextile forces in the lower geotextile layers, especially in the case of a steep terrain above the construction in question. Hereby the deployment limit of such reinforced systems can be reached and the proofs of internal and external stability can hardly be established any more, if at all.

1 INTRODUCTION

Numerous dimensioning models and computer programs are now available to the engineer for the dimensioning of geotextile-reinforced constructions. Subject to identical general conditions, the results are more or less comparable as far as the forces are concerned which the geotextile reinforcement has to absorb. Differences become apparent above all when dimensioning is carried out on the basis of different safety philosophies, for example case B or case C according to EUROCODE 7. It can be highly decisive where the partial safeties are introduced and how precisely in particular the shear parameters of the subsoil and of the fill material are known. The latter have a very strong bearing on the geometry of the decisive or critical sliding surface and the forces acting in the geotextile layers which are intersected by them.

The present contribution shows the interrelations for a geometrically defined, geotextile-reinforced construction, between the forces to be absorbed by the geotextiles and the ground characteristic values of subsoil and fill material as well as the terrain inclination above the construction. It is based on results presented in the dissertation submitted by Flum [1].

2 FUNDAMENTALS AND GENERAL CONDITIONS

The investigation concerns a construction as per Fig. 1 of constant geometrical dimensions and variable ground characteristic values for subsoil and fill, with a variable inclination of the terrain.

The following general conditions apply:
- The site ground consists of soil and is homogeneous.
- There is no influence of phreatic water.
- The sliding surfaces take a linear course in sections.
- The total force Z required to stabilize the failure mechanism is evenly spread on the number of geotextile layers intersected by the decisive sliding surface.

Constant parameters

- H = 6.2 m
- h = 0.50 m
- B_{Geo} = 5.0 m (= 80% H)
- α = 70 °

Variable parameters

- Inclination of the terrain β
- Friction angle of the fill ϕ'_s
- Friction angle of the subsoil ϕ'_u
- Cohesion of the fill c'_s
- Cohesion of the subsoil c'_u
- Volume weight of the fill γ_s
- Volume weight of the subsoil γ_u

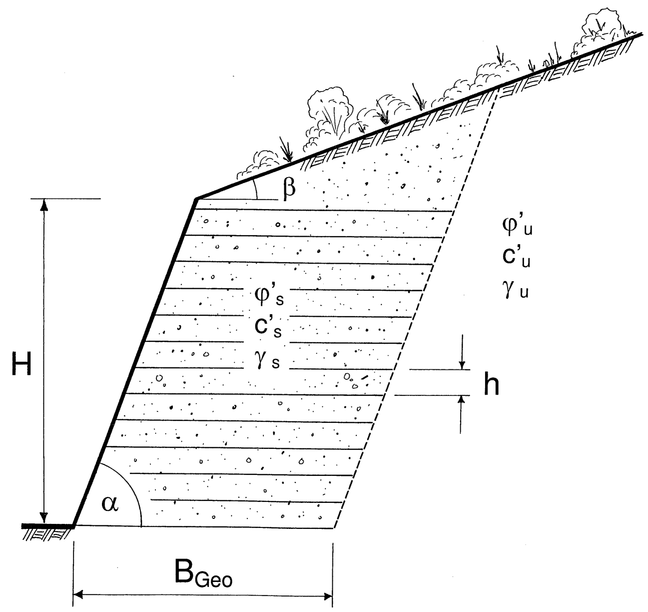


Figure 1. Example of a geotextile-reinforced structure

Investigations of failure mechanisms with curved sliding surfaces revealed that, with a substantially higher programming effort, basically the same influences would result.

3 DIMENSIONING MODELS

Within the framework of the proof of the internal stability of a geotextile-reinforced retaining structure, the maximum possible tensile forces in the geotextile layers must be determined. Hereby it is necessary to investigate different possible failure mechanisms. Apart from failure bodies with steep sliding surfaces (Fig. 2) intersecting all geotextile layers, failure mechanisms with sliding surfaces extending further to the back and intersecting only a part of the geotextile layers in each case (Fig. 3) must be viewed as well.

The stabilizing force Z_i is determined by means of equilibrium considerations at the failure bodies and taking into account Coulomb's rupture condition, and evenly distributed on the geotextile layers intersected by the decisive sliding surface. The decisive sliding surface has been found when, by variation of the position of the sliding surface, the force z_i in the geotextiles is at the maximum.

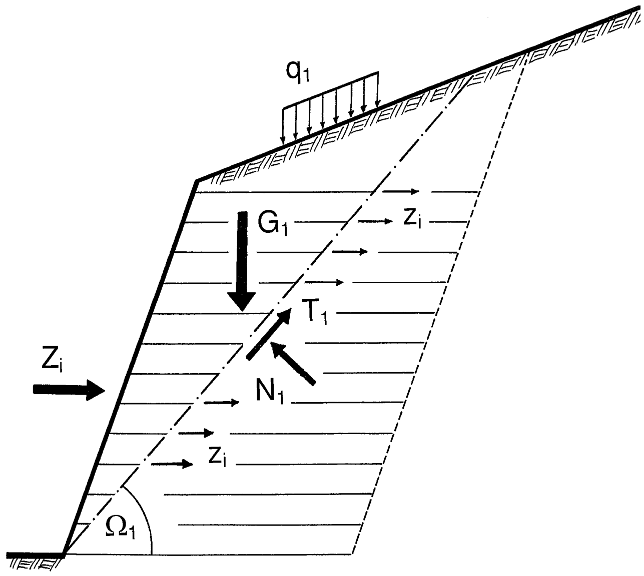
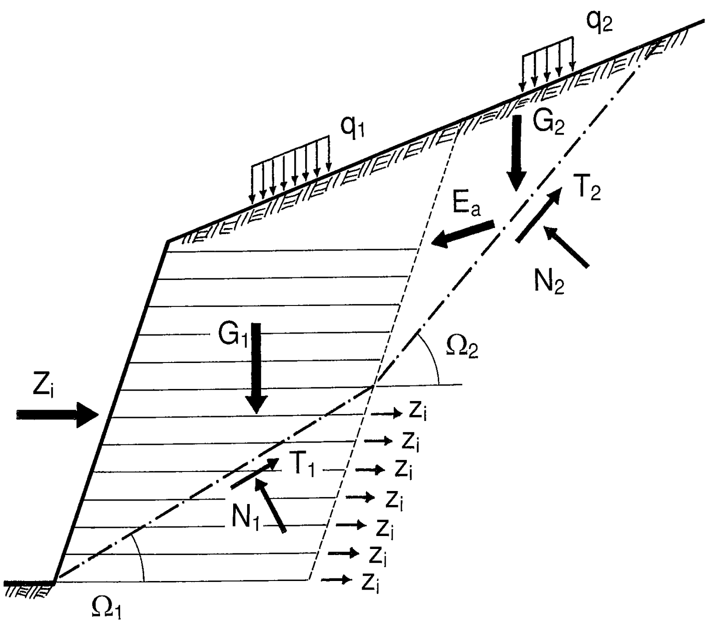


Figure 2. Simple failure body with steep sliding surface



Figuree 3. „Two-body“ sliding mechanisme“

4 INFLUENCE OF THE INCLINATION OF THE TERRAIN β ABOVE THE RETAINING STRUCTURE

Fig. 4 graphically shows the result of the variation of the inclination of the terrain β from 0° to 30°. Hereby the ground characteristic values maintained constant amount to:

$\varphi'_s = \varphi'_u =$ 30°
$c'_s = c'_u =$ 0 kN/m^2
$\gamma_s = \gamma_u =$ 20 kN/m^3

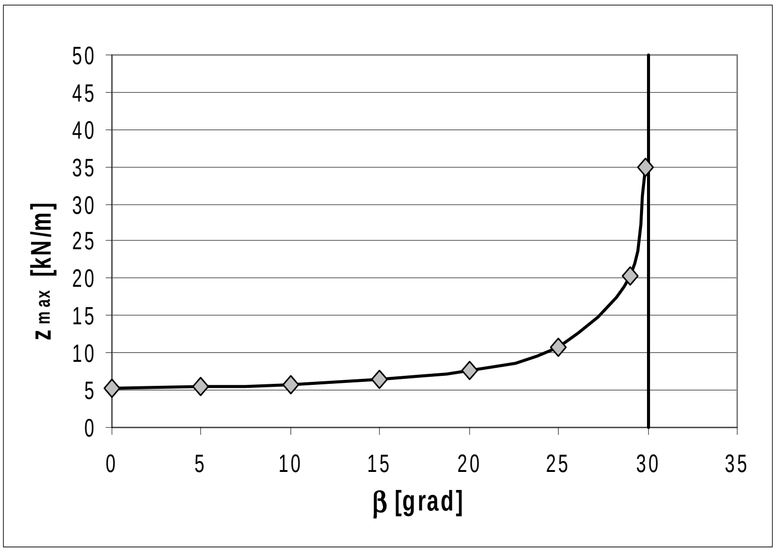


Figure 4. Influence of the inclination of the terrain β for
$\varphi'_s = \varphi'_u = 30°$, $c'_s = c'_u = 0$ kN/m^2, $\gamma_s = \gamma_u = 20$ kN/m^3

Up to an inclination of the terrain of β = 20°, the forces z_{max} increase only slightly as the terrain becomes steeper. In the area from approx. β = 25°, however, the forces z_{max} increase superproportionately and at 30° they become very large. Figs. 5 to 7 show the failure mechanisms decisive in each case for the different areas for β. These details refer to the chosen construction example in which the ratio of the width of the geotextiles to the height of the construction is 80%.

It is clearly evident that, for β > 26°, the inclination of the rear sliding surface becomes nearly parallel to the terrain surface and that, consequently, the rear failure body becomes very large. Moreover, the inclination of the front sliding surface decreases as a result of the reinforced retaining body. This means that only few geotextile layers at a lower level are intersected any more. They have to absorb a very high tensile force and transmit it to the fill. In the border area it is often the case that the sliding safety and the external safety against rupture of the terrain cannot be guaranteed any more, either.

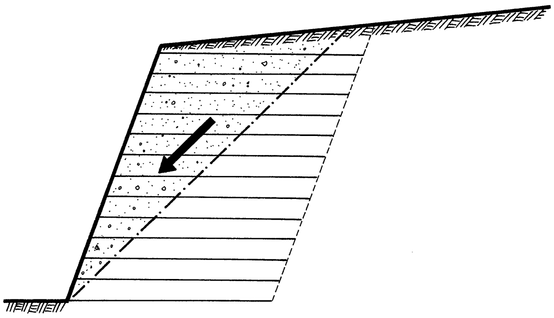


Figure 5. β = 0°...11°

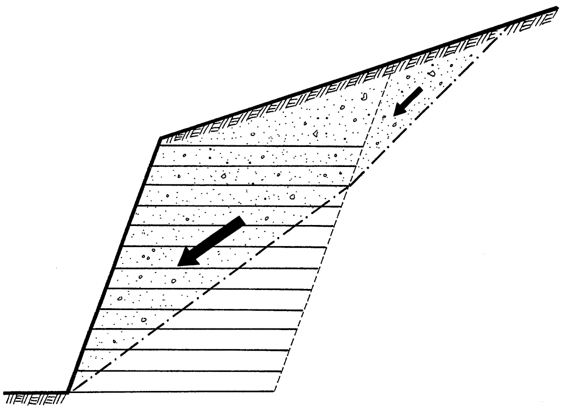


Figure 6. β = 0°...11°

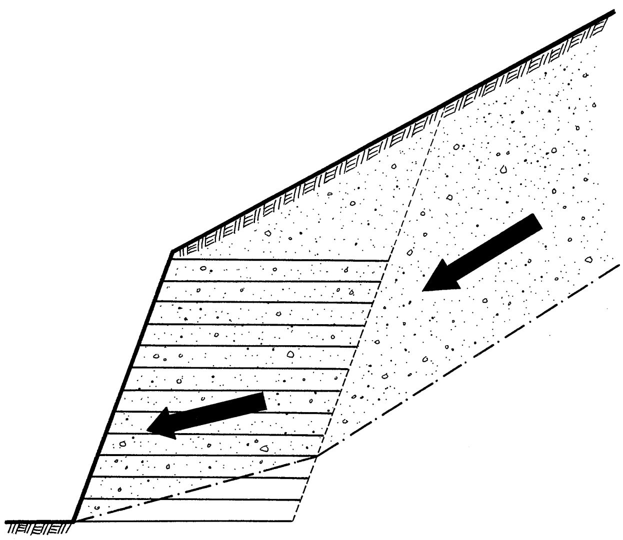


Figure 7. β = 26°...30°

5 INFLUENCE OF THE FRICTION ANGLE

5.1 *Subsoil*

The position of the area with superproportional growth of the forces in Fig. 4 depends directly on the size of the friction angle of the environment. Theoretically, the force z_{max} becomes very large for $\varphi'_u = \beta$ and c' = 0 kN/m^2. In this case the superproportional growth starts at approx. $\varphi'_u = (\beta - 5...7°)$.

The friction angle of the environment is given from nature and is usually not influenced by the build-up of a geotextile-reinforced construction. The extent of φ'_u and accordingly the range of the superproportional growth of the forces, therefore, is predefined project-specifically.

5.2 *Fill*

The friction angle within the fill is responsible to a decisive degree for the level of the forces in the intersected geotextile layers. Two curves with a different φ'_s are shown in Fig. 8. A reduction of the friction angle in the fill from 30° to 25° in this case causes an increase of the forces z_{max} in the intersected geotextiles

- at β = 5° by a factor of 1.7,
- at β = 20° by a factor of 1.9 and
- at β = 24° by a factor of 2.5.

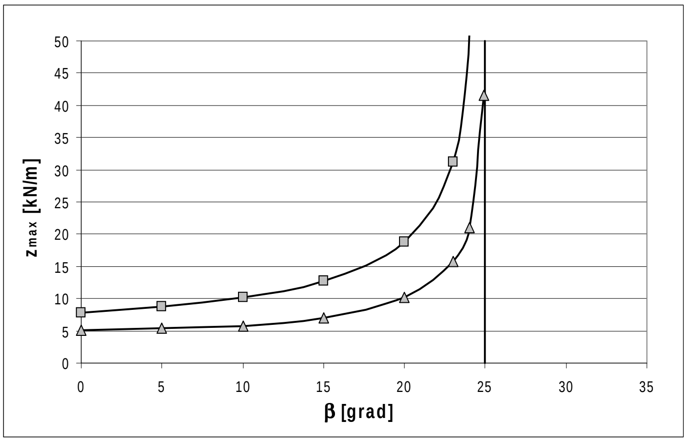


Figure 8. Influence of the friction angle of the fill φ'_s

Geotechnical parameters of the upper curve:

$\varphi'_u = \varphi'_s = 25°$
$c'_u = c'_s = 0\ kN/m^2$,
$\gamma_u = \gamma_s = 20\ kN/m^3$

Geotechnical parameters of the lower curve:

$\varphi'_u = 25$, $\varphi'_s = 30°$
$c'_u = c'_s = 0\ kN/m^2$,
$\gamma_u = \gamma_s = 20\ kN/m^3$

When building a geotextile-reinforced construction, the value of the friction angle of the fill φ'_s is influenced to a major extent by the fill material and the placement quality (compaction). If a poor fill material with a low shear resistance is applied, the individual geotextile layers soon have to absorb forces of twice the level as compared to the expert placement of a suitable fill material with impeccable compaction.

5.3 *Reduction of the friction angle*

According to the concept with partial safeties, starting from characteristic geotechnical parameters and using partial safety factors, the dimensioning values of the ground characteristic values are determined and then used for the static calculations. According to EUROCODE 7, case C, the partial safeties are usually:

- for friction angle: $\gamma_\varphi = 1.25$,
- for cohesion: $\gamma_c = 1.60$,
- for volume weight: $\gamma_\gamma = 1.00$.

In the range of $\varphi' = 28...35°$, the friction angle of the environment and of the fill is reduced by 5...6° through the introduction of a partial safety of $\gamma_\varphi = 1.25$ ($\varphi'_d = \arctan(\tan \varphi'_k / \gamma_\varphi)$).

Due to this reduction of φ'_u, the range of the superproportional growth of the forces z_{max} moves to the left by approx. 5...6°. If the amount of the reduced friction angle of the environment is nearly equal to the inclination of the existing terrain surface β and the cohesion amounts to 0 kN/m^2, the forces in the geotextile layers intersected by the decisive sliding surface become very high.

If the "two-body sliding mechanism" is decisive, the reduction of φ'_u causes additionally a shifting of the decisive sliding surface to the rear. The rear, non-reinforced failure body becomes accordingly bigger and presses onto the front, reinforced body with a comparativly higher force. Depending on the situation, only a few geotextile layers are intersected any more by the decisive sliding surface. These layers have to absorb the entire occurring forces.

The reduction of the friction angle φ'_s in the reinforced body causes the β-z_{max}-curve to be shifted upwards (cf. Fig. 8). The forces z_{max} consequently become higher.

6 INFLUENCE OF THE COHESION

So far, the cohesion in the reinforced range and in the underlaying subsoil were put at a constant 0 kN/m^2. What, however, is the β-z_{max}-relationship when taking into account a cohesion of e.g. $c'_u = c'_s = 5.0$ kN/m^2? When do which failure mechanisms become decisive and how high become the forces z_{max} in the geotextile layers?

Fig. 9 shows two curves which vary in the amount of cohesion. The cohesion of the upper curve amounts to $c'_u = c'_s = 0$ kN/m^2, the one of the lower curve to $c'_u = c'_s = 5$ kN/m^2. The friction angles are considered uniformly with 30° and the volume weights with a constant 20 kN/m^3. In this investigated example, an increase of the cohesion from $c'_u = c'_s = 0$ to 5 kN/m^2 has the following influences:

- In the range $\beta = 0°...15°$ the maximum possible forces in the geotextiles are roughly halved. At $\beta = 25°$ a ratio of approx. 1:3 results, at $\beta = 29°$ one of approx. 1:5.

- The lower curve within the range of the superproportional growth shows a clearly smaller curvature radius. The critical range clearly shifts to the right. With a cohesion c = 0 kN/m^2, the curve at $\beta = \varphi'_u = 30°$ tends towards infinity. By the introduction of a cohesion of c = 5 kN/m^2, the vertical asymptotic line is shifted to $\beta = 34.1°$. Consequently the excessively steep rise is no longer at $\beta = \varphi'_u$!

- Up to β = 25°, the case "simple failure body with steep sliding surface" is decisive for c' = 5 kN/m^2. Only for β > 25° does the decisive sliding surface in the reinforced body no longer intersect all geotextile layers and the "two-body sliding mechanism" becomes decisive. By the introduction of a cohesion c' > 0 kN/m^2 the decisive sliding surface through the reinforced body becomes generally steeper in comparison with case c' = 0 kN/m^2. The total weight of the failure body decreases. The maximum forces in the geotextile layer become smaller.

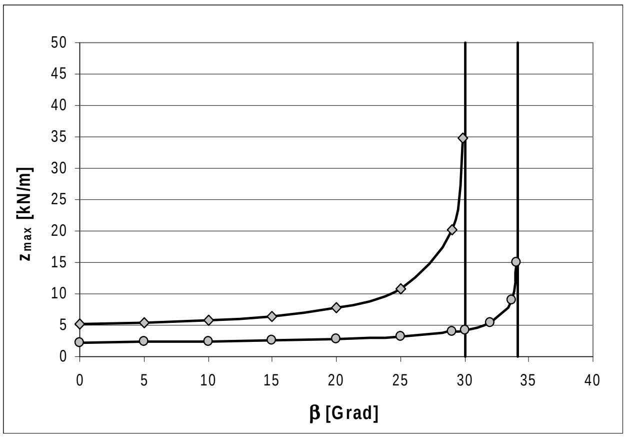


Figure 9. Influence of the cohesion $c'_s = c'_u$

Geotechnical parameters of the upper curve:

$\varphi'_u = \varphi'_s = 30°$
$c'_u = c'_s = 0\ kN/m^2$,
$\gamma_u = \gamma_s = 20$ kN/m^3

Geotechnical parameters of the lower curve:

$\varphi'_u = \varphi'_s = 30°$
$c'_u = c'_s = 5\ kN/m^2$,
$\gamma_u = \gamma_s = 20\ kN/m^3$

If the cohesion c' > 0 kN/m^2, the maximum forces z_{max} to $\beta = (\varphi'_u + \Delta)$ can be absorbed by means of common reinforcement geotextiles. In the investigated example, parameter Δ amounts to approx. 3...4° and is substantially influenced by the extent of the cohesion and the friction angle.

If, due to weathering, loosening due to frost-thawing cycles or the influence of water, the cohesion drops to nearly c' = 0 kN/m^2 and $\beta >= \varphi'_u$ applies, the retaining forces required for an equilibrium become very high. Too high to be absorbed with geotextiles. The consequence may be a failure of the retaining structure in the area of the lower geotextile layer, but under certain circumstances also sliding on the bottom or a proper rupture of the terrain.

According to EUROCODE 7, case C, the partial safety correction value for the cohesion γ_c is 1.60. If the extent of the effectively existing (long-term) cohesion is substantially overestimated or if it decreases significantly as a result of environmental influences, the ratio of the forces occurring in the assumed as against those in the effectively existing condition will be substantially above 1.60 in most cases. Hereby the introduced partial safety of 1.60 feigns a safety which is only illusory!

If a (prudently chosen) cohesion c' > 0 kN/m^2 is introduced, it must be guaranteed that this cohesion exists over the entire life span of the retaining structure and that it is not reduced by corresponding external influences.

7 INFLUENCE OF THE VOLUME WEIGHT

Fig. 10 presents graphically the results from the variation of the volume weight γ, assumed as being identical for both the fill and the subsoil, for a terrain inclination $\beta = 20°$. Hereby the friction angle and the cohesion of the fill are equal to the friction angle and the cohesion of the subsoil.

The force z_{max} in the geotextiles depends in linear manner on the volume weight. The position and gradient of the curves are influenced directly by the size of the friction angle and the cohesion. The curves become steeper as the friction angle gets smaller.

The geotechnical parameters of the middle and bottom curve in Fig. 10 vary only in the cohesion. By increasing the cohesion from 0 kN/m^2 to 5 kN/m^2 in this example, the middle curve is shifted parallel downwards by approx. 5 kN/m.
If the volume weight $\gamma = \gamma_s = \gamma_u$ is varied and if φ' and c' are kept constant, the same decisive sliding surface will always result. This means that the volume weight has no influence on the position of the decisive sliding surface.

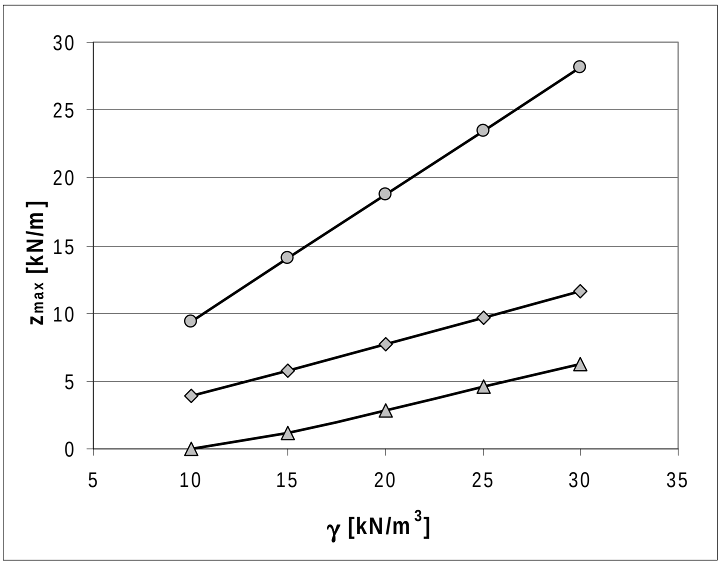


Figure 10. Influence of the volume weight $\gamma_s = \gamma_u$ for $\beta = 20°$

Geotechnical parameters of the top curve:

$\varphi'_u = \varphi'_s = 25°$
$c'_u = c'_s = 0$ kN/m^2,

Geotechnical parameters of the middle curve:

$\varphi'_u = \varphi'_s = 30°$
$c'_u = c'_s = 0$ kN/m^2,

Geotechnical parameters of the bottom curve:

$\varphi'_u = \varphi'_s = 30°$
$c'_u = c'_s = 5$ kN/m^2,

Due to the linearity between the volume weight and the force z_{max}, the maximum forces z_{max} are also increased by the factor x if γ is increased by a factor x. According to EUROCODE 7, case B, the dimensioning value of the volume weight is determined by multiplication of the characteristic value with the partial safety correction value $\gamma_\gamma = 1.35$. As a result of this artificial increase of the volume weight, the forces z_{max} in the geotextiles also increase by the factor 1.35. Hereby the position of the decisive sliding surface remains unchanged.

It makes little sense, furthermore, to allocate a partial safety factor of 1.35 to a parameter whose size is fairly accurately known or can be determined. A partial safety factor of 1.35 for the volume weight means that the volume weight could deviate from the characteristic value by up to 35%, which is surely not possible with a careful investigation and determination of the size of the ground characteristic values.

8 FINAL REMARKS

Care is recommended in principle for constructions in steeper terrain, and more detailed clarifications of the actual subsoil circumstances, possible hillside water, etc. are an absolute must.

The knowledge of the fundamental interrelations between geotechnical and geometrical variables, and the ability to assess the influences of the ground characteristic values are the basis to estimate the deployment possibilities of retaining structures in geotechnology, irrespective of whether a geotextile-reinforced retaining structure or a nailed wall is concerned.

Retaining structures in geotechnics should nowadays be dimensioned according to the concept with partial safeties (for example according to EC 7, case C) as a matter of principle. Hereby the uncertainties in establishing the ground characteristic values are directly covered by means of partial safety correction values. The position of the sliding surfaces is decisively influenced by the reduction of the friction angles and the cohesion, and the really critical cases are investigated.

If case B according to EC 7 is stubbornly applied to all failure mechanisms with sliding surfaces through the reinforced body as per the EBGEO [3] guidelines, the most critical cases are never even considered under certain circumstances.

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