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Theory and practice of 'Reinforcing' steep slopes with nonwoven geotextiles

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ABSTRACT: A new design theory for geotextile reinforced earth structures is presented combining horizontal reinforcement and the effect of earth filled bags as gravity retaining wall. Beside the principle and a design example resulting in a much smaller required tensile strength of the reinforcing geotextile, two important topics are dealt with: the improvement of shear strength of the fill material by compaction and drainage in the geotextile plane, and the long-term in-soil stress-strain characteristic of nonwoven needlepunched geotextiles. Finally, some practical examples of constructed walls using a nonwoven needlepunched PP-endlessfibre geotextile are reported.

1. INTRODUCTION

Reinforcing steep slopes or earth walls by the installation of tensile resistant components is a very old construction method: Thousands of years ago, reed or willow branches have been used for this purpose, e.g. in some parts of the Great Chinese Wall. However, this system has become technically impeccable when rot-resistant materials have been used, especially various kinds of "geosynthetics".
Geogrids, woven and nonwoven geotextiles are used to "reinforce" steep slopes. The word "reinforce" is set between quotation marks, as the relatively high elongation at break of these materials, especially nonwoven geotextiles, makes it difficult to calculate these systems by conventional design procedures, and as the actual "reinforcement"-mechanism is not yet clearified.

2. DESIGN

2.1. Conventional Design Procedures

Various design methods have been developped, which are all generally based on introducing tensile forces into the calculations. The two basic methods are:

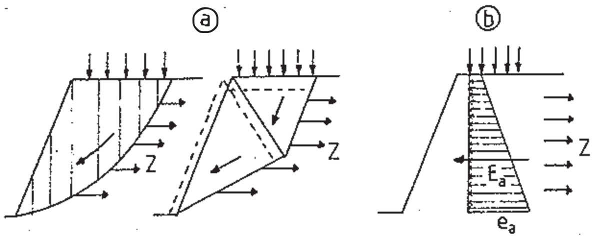


Fig. 1: Basic design procedures for reinforced slopes

a) Introducing horizontal forces into a slip circle or block sliding analysis (see Fig. 1a)
b) Taking up the horizontal earth pressure by tensile forces (see Fig. 1 b)

These methods have been modified slightly by various authors, trying to approach the design to the actual failure mechanisms as close as possible. Without any respect to technical accuracy, these methods allow a quick and safe approximate design of geotextile reinforced walls, being a highly economical alternative to other retaining structures, even when highly extensible nonwoven geotextiles with a relatively low tensile strength are used, as shown in Fig. 2 according to Studer/Meier (1986) and Chemie Linz/Polyfelt (1986).

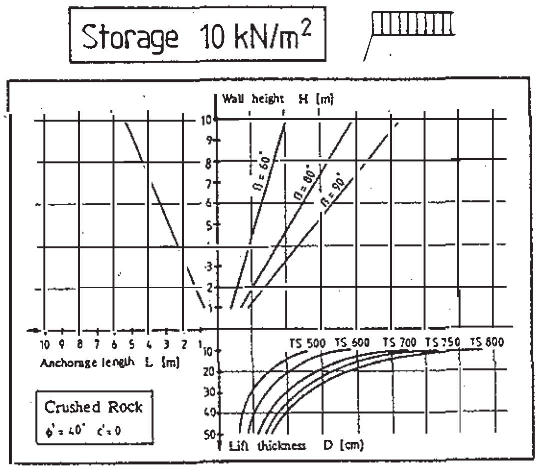


Fig. 2: Example for design charts based on conventional stability analysis acc. Chemie Linz/Polyfelt (1986)

2.2. Reflections on a New Design Theory

This theory is based on a combined functional mechanism of horizontal reinforcement and a gravity retaining structure. Without gravity retaining wall, the resulting tensile forces Z must be so high that the resulting force R from active pressure E and tensile forces Z is transfered into the basement (see Fig. 3).

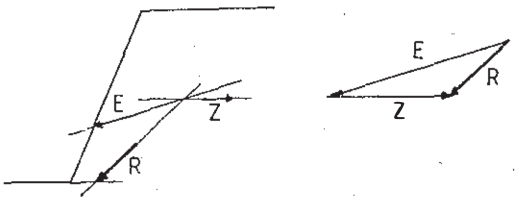


Fig. 3: Forces without gravity retaining wall

When a gravity retaining wall with the weight G is placed in front of the slope, the required tensile forces Z to transfer the resulting force R into the soil can be reduced significantly (see Fig. 4).

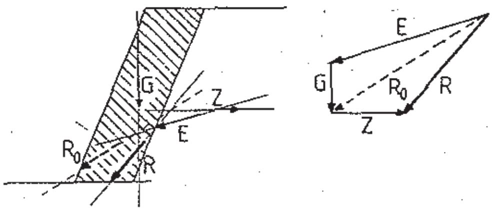


Fig. 4: Forces with gravity retaining wall

Gravity retaining walls are usually concrete walls or gabion walls. However, also flexible structures can act as a gravity retaining wall, when its internal stability is guaranteed. When looking at the construction procedure proposed for example by Chemie Linz/Polyfelt (1986) where completely closed earth filled bags are installed at the edge of the wall (see Fig. 5), it can be assumed that these "earth bags" act as a gravity retaining wall.

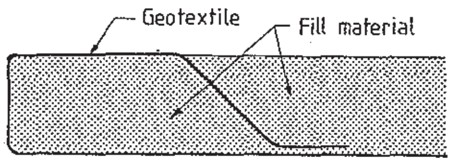


Fig. 5: "Earth bag" at the edge of geotextile reinforced wall

For checking the internal stability of the earth bag wall the following types of failure have to be considered (see Fig. 6):

a) Overturning around the edge point in every level.

b) Horizontal sliding in every level; for this type, the friction angle between soil and nonwoven needlepunched geotextiles can be assumed as $\delta = 0{,}9 \div 1{,}0 . \varphi$, whereas for heatbonded nonwovens and wovens with their smoother surface this value lies within $\delta = 0{,}6 \div 0{,}9 . \varphi$, as proven by various authors, e.g. Richards/Scott (1985).

c) Internal stability of each bag.

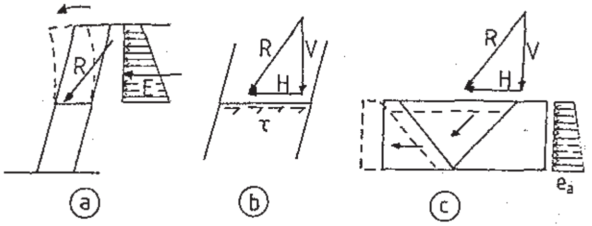


Fig. 6: Possible types of internal failure of the earth bag wall

The most critical failure type seems to be c), the internal stability of each bag. Fig. 7 shows possible configurations of the active failure zone and the involved forces.

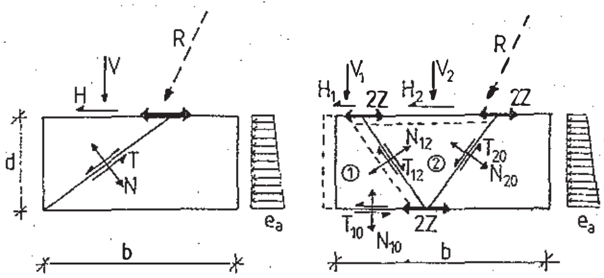


Fig. 7: Possible configurations of the active failure zone and the involved forces

Assuming the relationship between N and T as

$$T = l \cdot c + N \cdot \text{tg}\,\varphi$$

where

l ... length of slip line

c ... cohesion

φ ... friction angle

the required tensile forces can be calculated. However, there are still some open questions:

a) How are the vertical and horizontal forces from the resulting force R distributed over the width b?

b) What friction angle φ and cohesion c can be assumed?

c) What tensile strength can be introduced in the calculations?

Calculations have shown that question a), the stress distribution over the width b, is of utmost importance for the stability. In concrete retaining walls, the stresses from the resulting force R is distributed triangularly, as shown in Fig. 8a. In the case of earth filled bags, the stiffness modulus of the bags is equal to that of the surrounding soil, therefore a part of the resulting force R is taken up by the soil (see Fig. 8b).

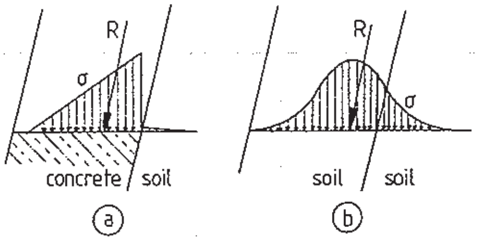


Fig. 8: Distribution of the resulting force R

The following sections 2.3. and 2.4. deal with questions b) and c).

As an example, the retaining wall illustrated in Fig. 9 has been designed. According Schulze/Simmer (1977) the active earth pressure coefficient λ_a can be calculated as

$$\lambda_a = \frac{\cos^2(\varphi+\alpha)}{\cos^2\alpha \cdot \cos(\delta-\alpha)\left[1+\sqrt{\frac{\sin(\varphi+\delta)\cdot\sin(\varphi-\beta)}{\cos(\alpha-\delta)\cdot\cos(\alpha+\beta)}}\right]^2}$$

with $\alpha = 10°$, $\beta = 0°$ and $\delta = \varphi = 30°$ this leads to $\lambda_a = 0{,}227$, resulting in the earth pressure distribution illustrated in Fig. 9.

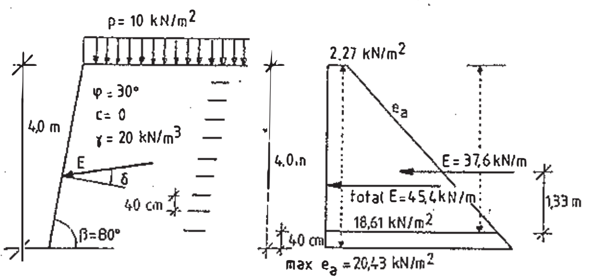
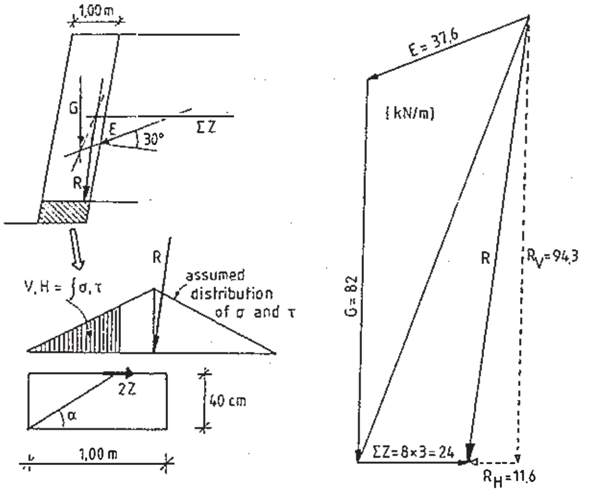


Fig. 9: Design example: given data and earth pressure

According to the different design methods, the following calculatory tensile strengths Z are required:

a) slip circle analysis acc. Chemie Linz/Polyfelt (1986) by using the design charts and taking into account the used factors of safety (1,3 for soil parameters, 3,0 for geotextile tensile strength) --> Z = 7,0 kN/m
b) by taking up total earth pressure:
   $Z = \text{total } E/n = 45{,}4/9 = 5{,}0$ kN/m
c) by taking up maximum earth pressure:
   $Z = \max e_a \,.\, d = 20{,}43 \,.\, 0{,}40 = 8{,}2$ kN/m
d) acc. "earth bag wall theory" described in this paper --> Z = 3,0 kN/m

Fig. 10 shows the principles and assumptions of the design acc. d). The single rupture of the lowest bag is assumed to be the most critical type of failure.



$$\eta = \frac{(V\cos\alpha - H\cdot\sin\alpha)\cdot \operatorname{tg}\varphi + 2Z\cos\alpha}{V\cdot\sin\alpha + H\cdot\cos\alpha}$$

$$Z = 3{,}0\ \text{kN/m} \Longrightarrow \min\eta = 1{,}01$$

Fig. 10: Principles, assumptions and results of the design-example

Based on the simplifying assumptions illustrated in Fig. 10, a computer program has been developped for designing reinforced earth walls according to this new method.

2.3. Shear Strength Characteristics of the Geotextile Wrapped Soil

The actual shear strength situation inside the earth bags can be stated as higher than in the surrounding soil. The reasons for this can be found in various factors:

a) A better compactability:
   As shown by Tatsuoka et al (1986) and Werner/Resl (1986) the friction between soil and nonwoven geotextile reduce the lateral movement of the soil grains, resulting in a better compaction and thus in an increase of shear strength.
b) The introduction of a 3-dimensional state of stresses, leading to much higher allowable shear stresses, acc. Werner/Resl (1986)
c) The drainage function of the geotextile:
   Especially with cohesive fill material the drainge function is of great importance, in order to drain off pore water during compaction and consolidation as well as seapage water caused by rainfall or by groundwater flow, see Tatsuoka et al (1986).
   The positive effect of the drainage function has also been demonstrated by Fabian/Fourie (1987) in traxial tests, where various types of geotextiles have been installed horizontally in the middle of the soil sample. The tests have shown that "high

permeability geotextiles" (needlepunched nonwovens) show a higher increase in shear strength as "low permeability geotextiles" (heatbonded nonwovens, wovens), which show in some cases even a decrease! Therefore the lower tensile strength of needlepunched nonwovens seems to be overcompensated by their transmissivity.

2.4. In-Soil Tensile Strength of the Geotextiles

The question which tensile strength should be inserted into the stability calculations is influenced by 3 factors:
a) Factor of safety
b) Stress-strain-curve in soil confinement
c) Long-term behaviour

ad a)
When needlepunched nonwovens are used as reinforcing elements, a factor of safety FS = 3,0 is recommended, e.g. by Studer/Meier (1986) and Chemie Linz (1986), as long as a more detailed analysis of the functional mechanisms is not possible.

ad b)
The stress strain characteristic of needlepunched nonwovens is characterized by slippage and straightening of the fibres and fibre obliquity, acc. Hearle (1972). Due to the interlocking effect between soil and geotextile (see Fig. 11) the fibre slippage is reduced and therefore higher strength and lower elongation are yielded compared with the standard tensile test where the geotextile is examined without soil confinement, as proven by Fock/McGown (1987), and illustrated in Fig. 12.

Additionally, the stiffness of the geotextile is increased by preloading during compaction, acc. Studer/Meier (1986).

ad c)
As the load is sustained over a long period of time, the long-term behaviour is of importance for the stability of the structure. Many authors are concerned about the different long-term behaviours (i.e. creep) of the different raw materials, namely polyester and polypropylene, which is undenieable testing the geotextile without soil confinement. Fock/McGown (1987) however have shown that embedded in soil creep is no relevant factor even when polypropylene fabrics are used (see Fig. 13).

3. PRACTICAL EXPERIENCE

Numerous projects have been carried out using a nonwoven needlepunched PP-endless-fibre geotextile with the brand-name "Polyfelt TS". The construction was done according the recommendations by Chemie Linz/Polyfelt (1986) and as illustrated in Fig. 14.

The design was in all cases based on conventional design methods, as basically described in section

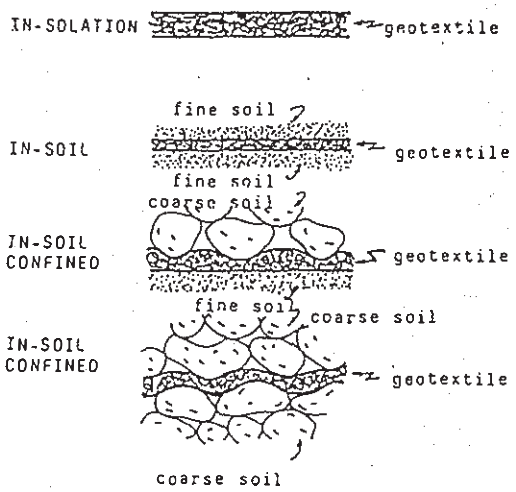


Fig. 11: Influence of in-soil confinement

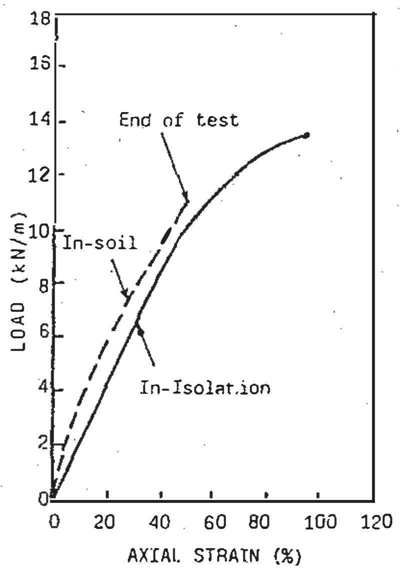


Fig. 12: Load strain curves in isolation and in-soil

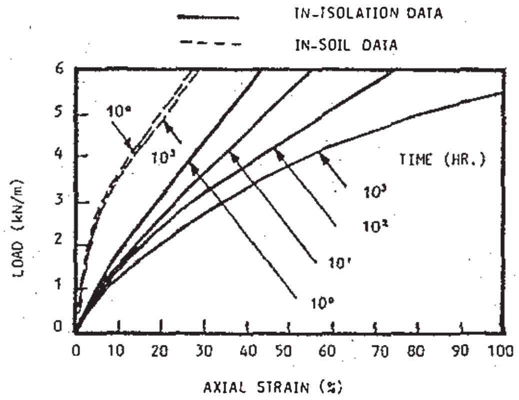


Fig. 13: Isochronous load-strain curves for a needlepunched PP-nonwoven, acc. Fock/McGown (1987)

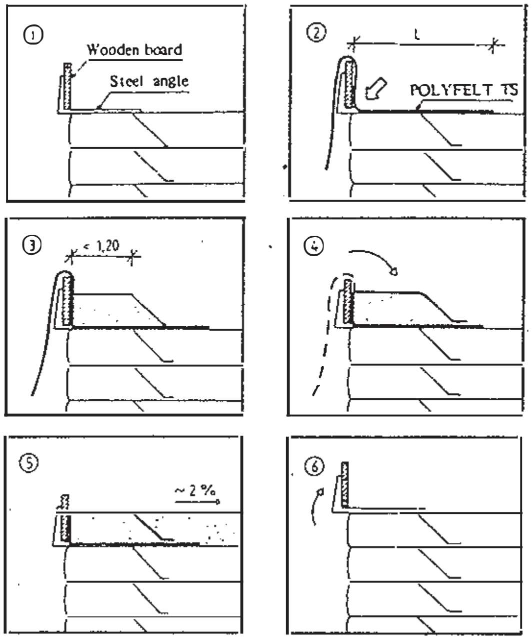


Fig. 14: Construction procedure

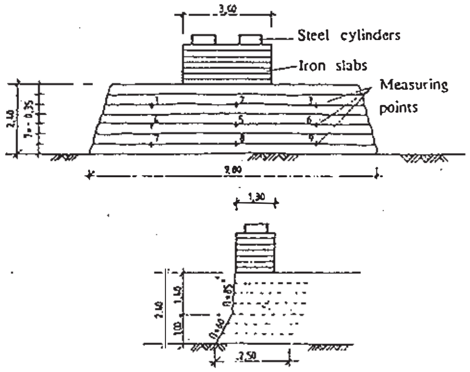


Fig. 15: Test embankment acc. Werner/Resl (1986)

2.1. This may lead to an overdesign, as shown in section 2.2., and Werner/Resl (1986), where a test embankment showed a factor of safety FS = 0,67, calculated with conventional methods, and no sign of failure, high deformations or creep have been observed (see Fig. 15).

Nevertheless, the economical benefits have been undenieable:
- low material costs
- low transportation costs
- the in-situ material can be used as fill material
- easy installation with unskilled workers and no heavy equipment.

When the retaining wall has to fulfill its function permanently and not only temporary (Fig. 16), a UV-

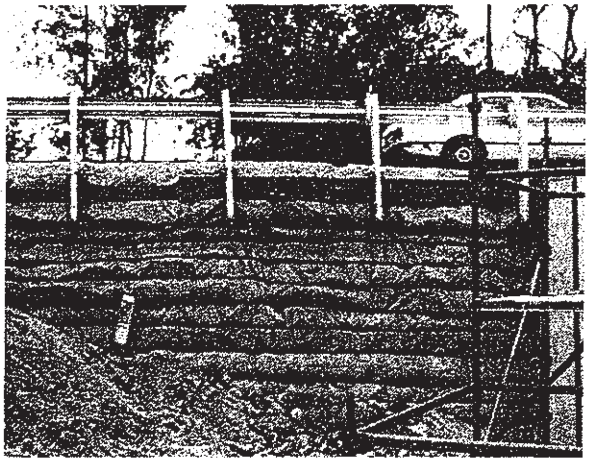


Fig. 16: Temporary retaining wall, Queensland/Australia

Fig. 17: UV-protection by planting, Steyr/Austria

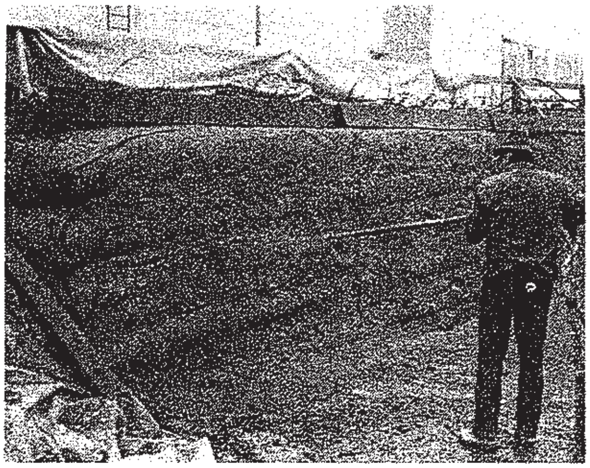


Fig. 18: UV-protection by shotcreting; storage yard, Linz/Austria

protection has to be provided. Possible methods are planting (Fig. 17), shotcreting (Fig. 18), non-constructive brick walls etc.

4. CONCLUSION

Even geotextiles with low modulus offer an economical method of "reinforcing" steep slopes in spite of their relatively low tensile strength. The described stability mechanism combining horizontal reinforcement and "earth bags" as a gravity retaining wall tries to give a more detailed approach to the actual stress situation. An example showed that the required tensile strength is up to 65 % lower than calculated with conventional design methods.

Additional mechanisms, especially the increase of shear strength of the geotextile wrapped soil due to compaction and drainage in the plane of the fabric have to be more closely analyzed in future research.

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