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The Influence of Geotextile Permeability on the Stability of an Embankment on Weak Subsoil

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Summary:

The stability of a 3-layer-system embankment/geotextile/subsoil is strongly influenced by the geotextile permeability, and only to a lesser extent by its tensile strength, as the development of shear stresses in the subgrade is a function of the permeability of the embankment foundation. In order to quantity the influence of geotextile permeability on the consolidation process, laboratory consolidation tests have been carried out with different types of geotextiles showing a high variation in their permeability. The results showed significant differences in consolidation behaviour, and therefore the right choice of the geotextile can be of utmost importance for the embankment stability.

1. General

One of the most important applications of geotextiles is the construction of high embankments on subgrade with very low load bearing capacity, namely saturated clay, silt or peat. During the construction stage, the geotextile prevents the mixing of fill-material and subsoil and reduces the danger of local shear failures caused by the high axle loads of the construction vehicles (1). In extreme cases, the road cannot be constructed at all in an economical way without geotextiles.

Besides this separation function, a geotextile in the embankment/subgrade - interface can influence the overall stability of the structure by two parameters: tensile strength (which is however generally overrated), and permeability.

2. The influence of geotextiles on embankment stability

Very often the tensile strength of a geotextile is introduced as horizontal force in an slip circle analysis in order to increase the resisting forces and, as a result, increase the embankment stability. This procedure however is only justified if the critical slip circle intersects the embankment foundation line, that means if a toe failure (see figure 1 a) occurs. But also base failure (see figure 1 b) has to be considered in a stability analysis, a type of failure where the whole embankment sinks into the ground. In this case, a high geotextile tensile strength has no influence, and therefore in most cases the overall stability cannot be increase (or only to a small extent) by using such materials, as high strength wovens or grids. This fact has been proven by extensive computer-based research (2, 3, 4).

Consequently, one can say that the influence of geotextile tensile strength is generally overrated. On the other hand, the influence of geotextile permeability is mostly ignored. All conventional consolidation theories for the prediction of stability and consolidation behaviour (e.g. Terzaghi's theory) assume an "ideally permeable" embankment foundation to assure undisturbed rise of the pore water.

If this prerequisite is not achieved, not only the actual consolidation time is higher than calculated, but also shear stress transfers can occur in the subgrade which can influence the overall stability of the embankment in a negative way:

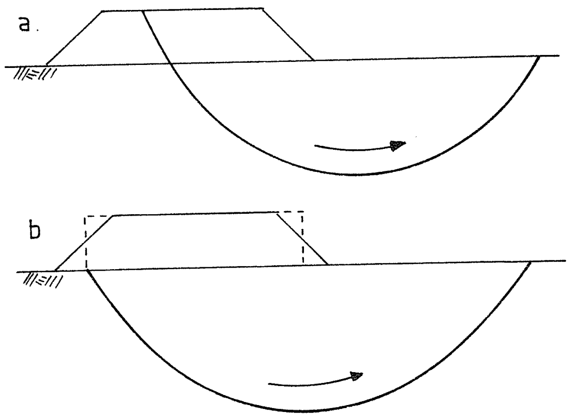


Fig. 1: Possible types of embankment failure:
a) Toe failure
b) Base failure

As can be shown using 3-dimensional consolidation theories (as opposed to the conventional 1-dimensional theories), the development of shear stresses in the subgrade is strongly influenced by the permeability of the embankment foundation (5). As an example, figure 2 shows the distribution of shear stresses at the time t in the depth z underneath an embankment for ideally permeable and impermeable foundation. On the other hand, shear stresses can increase locally, even above the initial value, as a result of the so called "Mandel-Cryer-Effect" (5). This phenomenon has also been observed in practice. Figure 3 for example shows the time dependent shear stress distribution in the case of an impermeable embankment foundation.

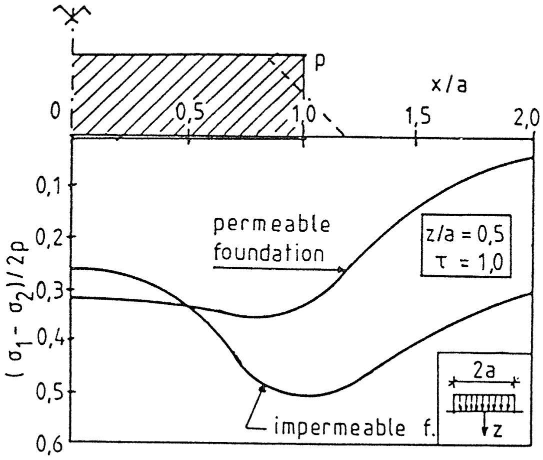


Fig. 2: Shear stress distribution acc. (4)

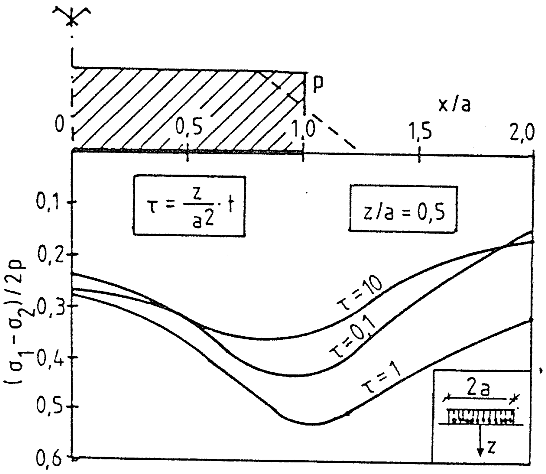


Fig. 3: Time dependent shear stress distribution acc. (4) in the case of impermeable embankment foundation

As this effect can be diminished by providing an embankment foundation as permeable as possible, it is obvious that the choice of the geotextile can have a significant influence on stability and consolidation behaviour. As a result of different manufacturing processes (e.g. mono- and multifilament wovens, slit film wovens, mechanically, thermically and chemically bonded non-wovens etc.) the geotextiles on the market show a wide range of permeability: the water discharge at 10 cm head ranges from 2 to 500 l/sec. m^2!

Generally, the permeability is a very important factor for the "reinforcement"-function of geotextiles. This has been illustrated by triaxial tests with geotextile -"reinforced" clay samples (6). Different types of geotextile have been installed horizontally in the middle of the clay sample. The tests showed that the use of "high permeability fabrics" (i.e. mechanically bonded non-wovens and geogrids) yielded much higher increases in shear strength than "low permeability fabrics" (i.e. multifilament - and slit film wovens, heatbonded non-wovens), without any regard of tensile strength! Quite on the contrary, in some cases even a decrease has been observed.

3. Consolidation tests

In order to quantify the influence of the different types of geotextile on the consolidation behaviour of saturated soils, laboratory consolidation tests have been carried out.

3.1. Test procedure

A soil sample has been installed in a steel cylinder. A layer of gravel above the samples guaranteed the free drainage of the rising pore water. Between soil and gravel the geotextile has been installed. Finally, the sample has been loaded and the time - settlement - curve has been recorded. Figure 4 illustrates the simple test device.

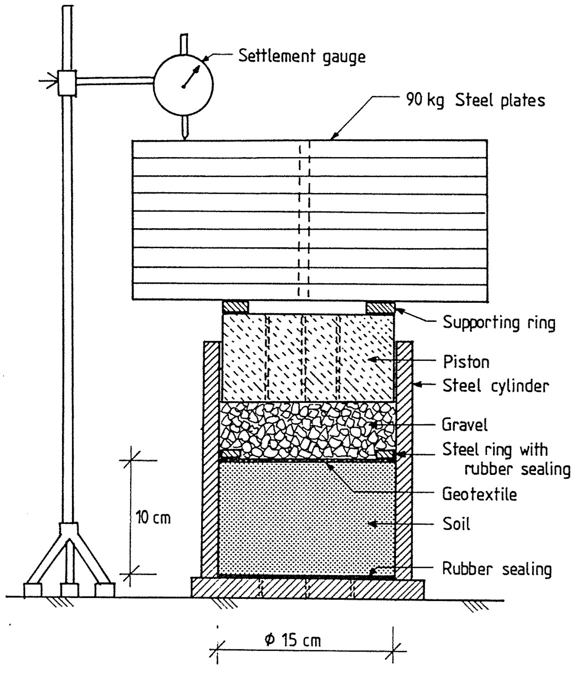


Fig. 4: Test device

The surcharge amounted to 50 kN/m^2 which correlates to a fill height of 2,5 to 3 m. In practice this value can be very often found as first fill stage of an embankment on soft subsoil.

As soil a saturated clayey-sandy silt has been used; the grain size distribution curve is shown in figure 5. The moisture content ranged from 31,9 to 37,7 %, the soil had a semi-liquid consistency.

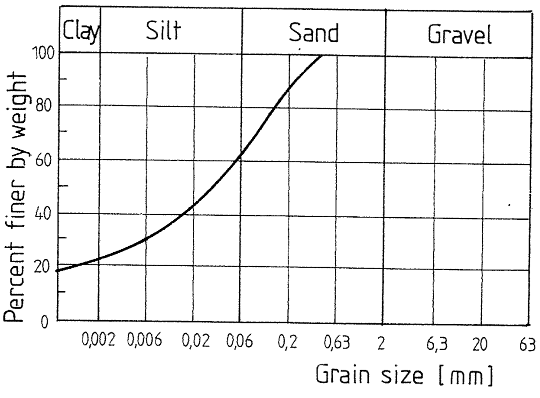


Fig. 5: Grain size distribution curve of the tested soil

No.	Type	Raw Material	Weight per unit area	Tensile Strength acc. ASTM D4595	Elongation at break	Water discharge*
1	nonwoven, mechanicall bonded	PP	200 g/m²	13.0 kN/m	50%	250 l/sec m²
2	nonwoven, heat bonded	PP/PE	230 g/m²	15.0 kN/m	30%	33 l/sec m²
3	woven, multifilament	PP	130 g/m²	300.0 kN/m	9%	25 l/sec m²
4	woven, slit film	PES/PA	590 g/m²	27.4 kN/m	47%	18 l/sec m²
5	without geotextile	-	-	-	-	-

*) at 10 cm water head, acc. manufacturers brochures

Table 1: Properties of tested geotextiles

Table 1 shows the relevant properties of the tested geotextiles. For each type, 3 tests have been carried out to achieve more accurate results.

3.2. Test analysis

Based on the section between 5 and 40 hours of the recorded time-settlement curves the final settlements s_∞ has been calculated using the graphical procedure of Asaoka (7); the principle of this procedure is illustrated in figure 6.

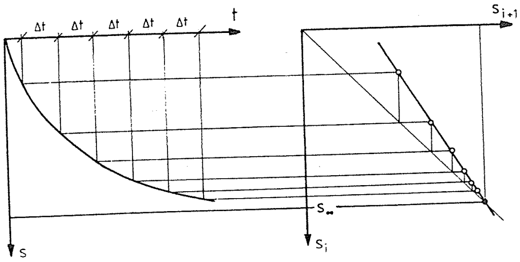


Fig. 6: Evaluation of s_∞ acc. (7)

The mathematical consolidation coefficient c_v has then been calculated using the following formula (2, 3):

$$\bar{U} = 1 - \sum_{m=0}^{\infty} \frac{2}{M^2} \cdot e^{-M^2 \cdot T_v}$$

where

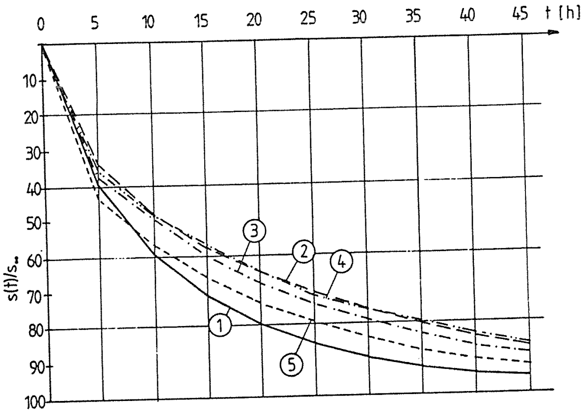
$U = s(t)/s_\infty$ (consolidation degree)
$M = \frac{1}{2} \cdot \pi \cdot (2m + 1)$
m = index variable
$T_v = c_v \cdot t/l^2$ (time factor)
$c_v = k_v \cdot E_s/\gamma_w$ (consolidation coefficient)
k_v = permeability of the soil
E_s = stiffness modulus of the soil
γ_w = unit weight of water
t = time
l = length of longest flow path = height of the soil sample

3.3. Test results

Figure 7 shows the average time-settlement-curves for each of the geotextile types. A great difference is evident between high permeability geotextiles (No. 1 - mechanically bonded non-woven) and low permeability geotextiles (No. 2 - heat bonded non-woven, No. 3 - slit film woven, No. 4 - multifilament woven). But also the tests without geotextiles (No. 5) yielded a significant increase in consolidation time: this is a result of the 2-3 cm thick mixing zone between soil and gravel; this zone shows a reduced permeability, and therefore the free rise of the porewater is disturbed.

Figure 8 shows the graphic representation of the calculated consolidation coefficient c_v; the following average values has been yielded by the different geotextile types:

No. 1 - mech. bonded non-woven $c_v = 7{,}76.10^{-8}$ m²/sec
No. 2 - heat-bonded non-woven $c_v = 4{,}78.10^{-8}$ m²/sec
No. 3 - slit film woven $c_v = 5{,}31.10^{-8}$ m²/sec
No. 4 - multifil woven $c_v = 4{,}87.10^{-8}$ m²/sec
No. 5 - without geotextile $c_v = 6{,}29.10^{-8}$ m²/sec



The final settlements S_∞ ranged between 4mm (at a water content of 32%) and 9mm (at a water content of 38%).

Fig. 7: Time - settlement curves:
1 - mechanically bonded non-woven
2 - heatbonded non-woven
3 - slit film woven
4 - multifilament woven
5 - without geotextile

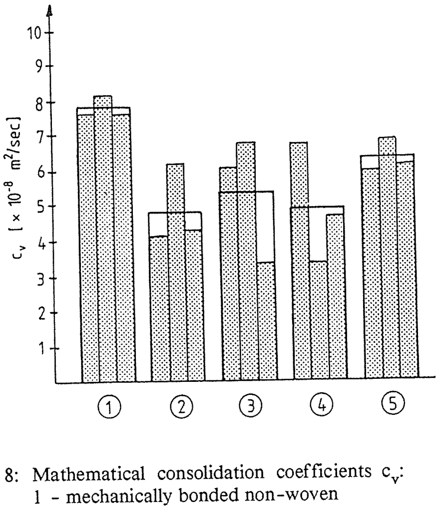


Fig. 8: Mathematical consolidation coefficients c_v:
1 - mechanically bonded non-woven
2 - heatbonded non-woven
3 - slit film woven
4 - multifilament woven
5 - without geotextile

The required time t to achieve a certain value of consolidation degree U increases when the consolidation coefficient c_v decreases; therefore, compared with mechanically bonded non-wovens (No. 1), the consolidation times for the other geotextile types increase by the following factors:

No. 2	- heat-bonded non-woven	+ 62 %
No. 3	- slit film woven	+ 46 %
No. 4	- multifil. woven	+ 59 %
No. 5	- without geotextile	+ 23 %

Taking into account the shear stress situation in the subsoil underneath an embankment as mentionned in section 2, it is obvious that these significant differences can have a great influence on the shear stress development and thus on the overall stability of the embankment. To what extent these factors are influenced, can only be predicted by complicated computer-based 3-D-consolidation calculations.

Another interesting factor is the great variation of results for geotextiles No. 2, 3 and 4, as can be seen in figure 8. The filtration behaviour of these products (heat-bonded non-wovens and wovens) cannot be predicted and controlled, due to their 2-dimensional structure with small opening size, which is very prone to clogging, whereas mechanically bonded non-wovens show excellent filtration behaviour as a result of their 3-dimensional porous fibre structure.

A better filtration behaviour of mechanically bonded materials in roads construction has also been observed at large-scale laboratory tests carried out by the Technical University of Munich/FRG (8). Heat-bonded materials and slit film wovens tend to build up a "filter cake" resulting in a blocking of the fabrics.

4. Conclusion

For the type selection of geotextiles to be installed at the embankment/subgrade - interface not only the separation function, but also the filtration function has to be taken into account. A high geotextile permeability should be provided in order to guarantee the free rise of the pore water and thus to achieve a quick and troublefree consolidation of the subsoil. In this respect, mechanically bonded non-wovens show a better performance than other product types, such as heat-bonded nonwovens and all types of wovens.

The authors are aware that the results cannot be directly transfered to all cases, but it is undeniable that these unfavourable effects can occur, and that they have to be taken into account. In order to predict the stability and consolidation behaviour of on embankment on weak subgrade as accurately as possible, a maximum permeability embankment foundation should be provided, and this can be achieved by the choice of an appropriate geotextile type.

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