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Backanalyses of a steep slope reinforced with nonwovens

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ABSTRACT: Nonwovens can be used in earthworks as reinforcement when the material characteristics that describe the stress-strain-behaviour of the compositesystem consisting of soil and geotextile are known. Up to now calculations usually look at soil and geotextile separately. These analysis do not suit the needs calculating reinforcements with nonwovens.
A well instrumented full scale test of a steep slope reinforced with a nonwoven was the basis for backanalyses. The results at ultimate load conditions and at working conditions can be back calculated by FE-programs using in-soil parameters of the geotextiles. The parameters for nonwovens are the result of research work with short and long term tensile in-soil-tests carried out at the Technical University of Munich.

1 Introduction

Due to their low stiffness and their high elongation at breaking observed at tensile test on air nonwovens were not considered as a soil-reinforcement. Normally grids or wovens were used for soil reinforcing.

Both full scale test with steep slopes and special tensile tests showed that the load-elongation characteristics change according to the contact with the soil [1][2][3][6]. The stiffness of the compositesystem increases clearly. The aim of this research work is the examination of the stress-strain behaviour of the compositesystem of soil and geotextile and the definition of a appropriate material law. With this material law and the finite element method FEM a full scale test wall carried out at the BASt will be recalculated.

2 Load- elongation characteristics of nonwovens in contact with soil

For the examination of the load-elongation characteristics of geotextiles in contact with soil a special device was used [2][6]. In this device the specimen was built in between two soil layers. The surcharge was produced by two air bellows in the range of 20 kPa up to 200 kPa. Figure 1 shows a cross section of the device:

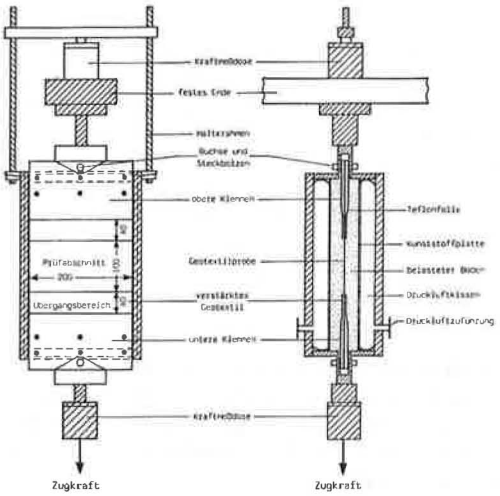

Fig. 1: cross section of the test device

In short and in long term tensile tests a number of nonwovens and wovens were examined. A mixture of sand and gravel and a silt were used as soil. In figure 2 there are test results with a needle punched nonwoven made of PES (ME-PES-270) in contact with the mixture of sand and gravel. The product has a mass per unit area of 270 g/m² and a tensile strength according to ISO 10319 of 18 kN/m.

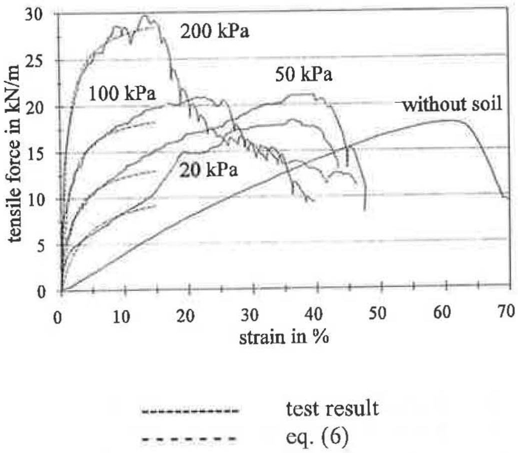

Fig. 2: test results with ME-PES-270 in contact with the mixture of sand and gravel

Figure 2 shows the clear increase of tensile strength and stiffness according to the contact to the soil and the surcharge.

3 Derivation of a material law

This test results have to be transformed into a material law to be used in FE-calculations, in analytical approaches or practical design. This law has to take into account the influence of the soil and the soil surcharge. The first step was to find an equation which describes the load-elongation of one tensile test in soil. Up to an elongation of $\varepsilon = 10$ % the correlation of eq. (1) is quite good:

$$Z(\varepsilon) = \frac{\varepsilon}{a+b\varepsilon} \qquad (1)$$

Z is the tensile force in kN/m, a and b are variables. For each test one have to determine these variables with an non-linear regression analyses. The results of these analyses could be combined with the expression (2) and (3).

$$a(P)=\frac{c_a}{d_a+P} \qquad (2)$$

$$b(P)=\frac{c_b}{d_b+P} \qquad (3)$$

Thus eq. (1) could be extended by the influence of the soil surcharge:

$$Z(\varepsilon, P)=\frac{\varepsilon}{(\frac{c_a}{d_a+P})+(\frac{c_a}{d_a+P})\varepsilon} \qquad (4)$$

The results of eq. (4) are plotted in figure 2. Material law (4) and the test results agree very well. The geotextile-stiffness as a tangent deformation modulus is defined as:

$$V_T = \frac{dZ}{d\varepsilon} = \frac{d}{d\varepsilon}(\frac{\varepsilon}{a+b\varepsilon}) \qquad (5)$$

Eq. (5) and eq. (4) could be transformed in eq. (6):

$$V_T(Z,P)=\frac{(1-Z(\frac{c_b}{d_b+P}))^2}{(\frac{c_a}{d_a+P})} \qquad (6)$$

With eq. (6) the geotextile-stiffness could be calculated in dependence of the surcharge and of the stress. For the ME-PES-270 the following variables are determined:
$c_a = 6.213$
$d_a = -0.843$
$c_b = 9.556$
$d_b = 88.88$

Eq. (6) could be used with FE-calculations or in design approaches. In a similar way it is possible to calculate the time dependent elongations of the long term tensile tests.

4 FEM- model of the test wall

For the backanalyses the FE-Program MISES 3 was used. This program allows the calculation of two and three dimensional structures. For the soil isoparametric elements with eight nodes was used. The Mohr-Coulomb yield criterion was applied to this elements. Because of the viscoplastic model the stresses could occasionally exceed the yield surface. These stresses cause viscoplastic strain and were reduced by repetitive resolutions of the equation system. The geotextiles are modelled by elastic bar-elements with three nodes.

As a speciality this program offer an interface element called "thin-layer-joint-element" [6]. This element was used for the conjunction between geotextile and soil. The shear stiffness is independent of the normal stiffness thus slippage between geotextile and soil may occur. Furthermore it is possible to feed interface shear parameters examined in direct shear tests. Figure 3 shows a scheme of the composite system consisting of soil and geotextile.

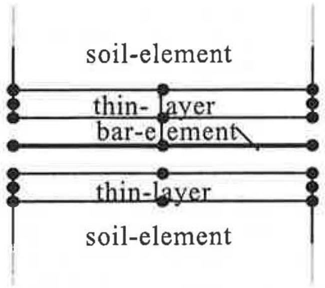

Fig 3: Scheme of the composite system consisting of soil and geotextile

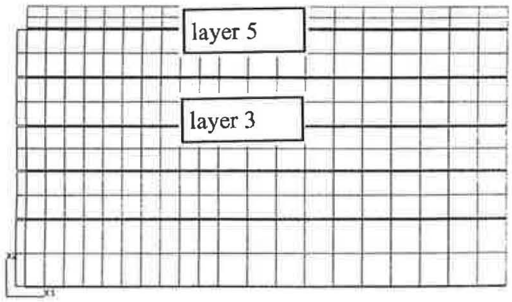

Fig. 5: FEM-model of the reinforced wall

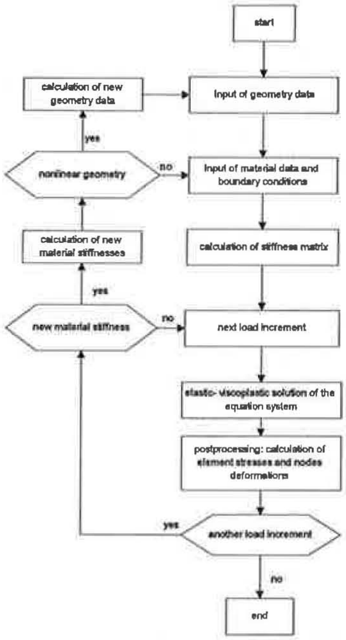

Fig. 4: sequence of FE-calculation

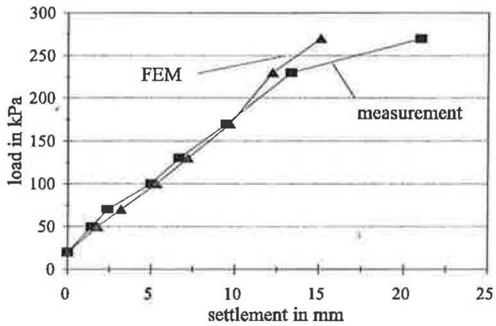

Fig. 6: load settlement behaviour

The stiffnesses of the geotextile elements were calculated with eq. (6) in dependence of surcharge and the tensile force at each place in the wall. Thus the stiffness matrix is not constant while the calculations. According to the full scale test the surcharge was increased incrementally. In figure 4 a scheme of FE-calculation sequence is shown.

5 FE- results and comparison with the test wall

The test-wall built with sand had a height of about 3m. The wall was reinforced with the nonwoven ME-PES-270 and the surcharge was increased until break [5]. Figure 5 shows the simulating FE-model with 530 elements.

In the following figures the FEM-results are compared with the measurements of the full scale test wall. In figure 6 is the load-settlement behaviour of the surcharge device represented. In figure 7 the strain distributions along the geotextiles are plotted. The lines are the FEM-results, the bigger symbols represents the test wall measurements. Figure 8 shows the horizontal face displacement of the wall for surcharge 20 kPa and 230 kPa.

The comparison shows that the FEM-results agree very well with the performance of the test wall. This good agreement especially of the geotextile strains are enabled by the accurate and examination of the load-elongation characteristics of nonwovens in contact with soil

6 Conclusions

The load-elongation characteristics of nonwovens are influenced by the soil and the surcharge of the system. In-soil-tests with a number of nonwovens and wovens were carried out to examine the influ-

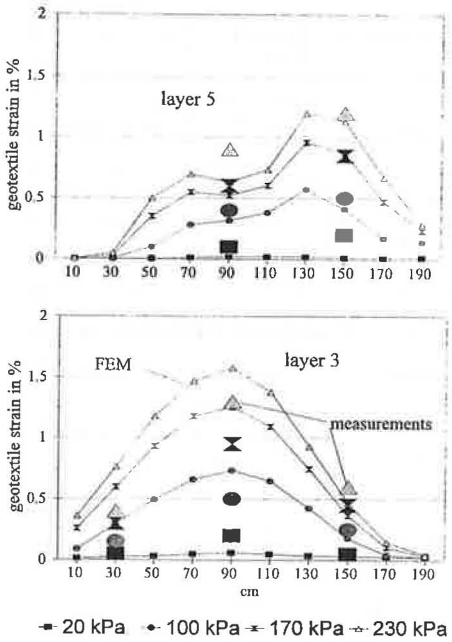

Fig. 7: strain distribution of the geotextiles

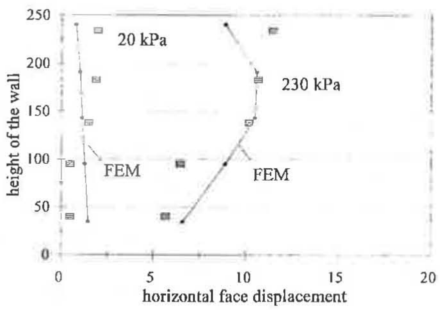

Fig. 8: horizontal face displacement

ence of the soil. These test results were used to derivate a material law for the geotextile stiffness in dependence of the soil and the surcharge. An existing FEM-program was extended with this material law and used to recalculate a full scale test wall reinforced with a nonwoven. The FE-results are in good accordance with the measurements of the test wall. This research work leads to a better understanding of the "soil-geotextile-system".The testing of nonwovens without soil gives no suitable design-parameters for practical work. The presented method to get them from in-soil-tests allows the calculation of the behaviour at working conditions of nonwoven reinforcements as well as the ultimate strength of the reinforced soil structure.

7 References

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