# MECHANICAL BEHAVIOUR OF GEOSYNTHETIC-REINFORCED LARGE SAMPLES IN A TRIAXIAL TEST

# RAPPORT SUR L'ATTITUDE DU SOL ARMÉ DE GÉOTEXTILES SOUMIS A DE LARGES ESSAIS TRIAXIAUX

# ÜBER DAS MECHANISCHE VERHALTEN VON GEOKUNSTSTOFFBEWEHRTEN GROSSPROBEN IM TRIAXIALVERSUCH

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**Summary:** The soil supporting structures reinforced with geosynthetics complete, as construction, the whole variety of classic supporting systems. In order to investigate the phenomenon of coaction betwen synthetic reinforcing and the surrounding soil, large-scale triaxial tests upon unreinforced soil (loess) have been compared with triaxial tests carried through with three different reinforcing materials.

**Zusammenfassung:** Mit Geokunststoffen bewehrte Erdstützkörper ergänzen als Bauweise die Palette der klassischen Stützbauweisen. Um das Phänomen des Zusammenwirkens der Kunststoffbewehrung mit dem umgebenden Bodenmaterial zu untersuchen, wurden großmaßstäbliche Triaxialversuche an unbewehrtem Boden (Löß) mit Triaxialversuchen, die mit drei unterschiedlichen Bewehrungsmaterialien durchgeführt wurden, verglichen.

**Résumé:** Les structures d'appui armés de géotextiles complètent, en tant que construction, toute la palette des méthodes d'appui classiques. Pour étudier le phénomène de la coopération de l'armement avec le sol environnant on a réalisé des essais triaxiaux larges sur des sols non-armés (loess) avec des essais triaxiaux réalisés sur trois matériaux d'armement différents.

Key-words: Supporting structures - geosynthetic reinforced soil - triaxial tests - larg-sclae samples - shearstrength

## 1. INTRODUCTION

In order to minimize the area required for building sites it is often advantageous to construct steep slopes. However it is necessary to ensure the stability of these expensive structures. During the last decade high tensile synthetics - so-called geosynthetics - have been developed to be used in soil structures as a sandwich system. With the help of these materials it is possible to construct steep slopes using weak soil materials (Fig. 1).

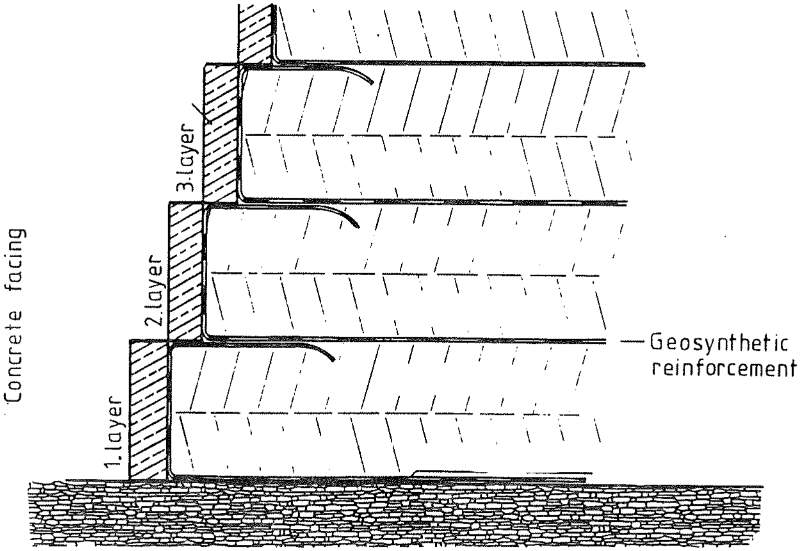


Fig. 1 Cross section of a supporting structure reinforced with geosynthetics

The mechanical behaviour of geosynthetic reinforced slopes is that tension forces which cannot be carried by the soil are taken over by the geosynthetics. This is analogeous to the action in reinforced concrete. The design of such structures generally assumes riged bodies which cannot represent the actual behaviour [1].

Many structures constructed using geosynthetic reinforcing show that they are conservatively designed and new design methods have been looked for which describe the failure mechanism in a better way [1], [2], and [3]. Triaxial tests on large samples (height 160 cm, diameter 80 cm) reinforced with geosynthetics at the third points of the height were compared with those of an unreinforced sample. The soil used was a fine grained cohesive loess [4]. The grain size analysis is shown in Fig. 2.

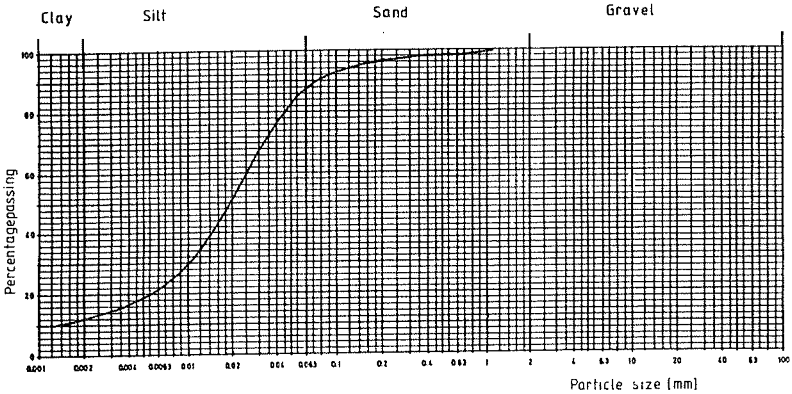


Fig. 2 Particle size distribution

2. DESIGN

Based on experience obtained with the construction systems "reinforced soil" [4] and "soil nailing" [5] it is assumed that in the limit state failure takes place in a plane wedge system. The slip surfaces which are assumed divide the construction into an active and a resisting part. The reinforcement cut by the slip planes anchors the slipping body to the resisting body.

By varying various parameters (angle of friction, slip planes etc.) at limit equilibrium the maximum tensile forces are calculated. These tensile forces have to be carried by the reinforcement. The allowable forces in the reinforcement are determined as the short term tensile strength according to DIN 53857. These values are modified by a factor of safety and other reduction factors. These reduction factors take into account damage during placing, chemical environment and ageing. In addition the pull out resistance in the soil has to be determined [1]. The parameters needed in this iterative design method are

Soil parameters:

| | | |
|---|---|---|
| Density | $\gamma$ | ~ 18 - 20 $kN/m^3$ |
| angle of friction | $\phi$ | ~ 15 - 40 ° |
| cohesion | $c$ | generally 0 |

Geosynthetic parameters:

Short time tensile strength $Z$ [kN/m]

Reduction factors: dependent on the products for environment, long time behaviour and placing

Geometry of the construction:

Height $H$ [m]

Slope $\beta$ [°]

External loads

Traffic and other external loads $b \cdot q$

Internal forces

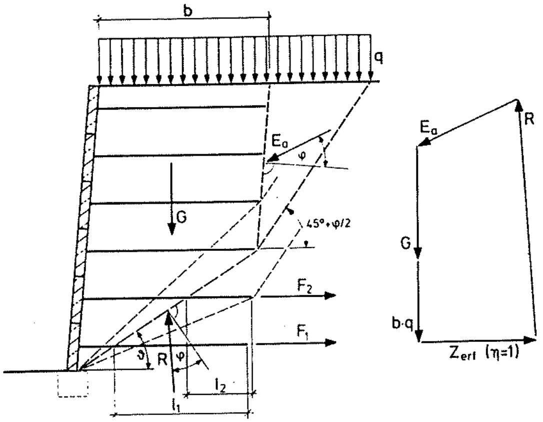
Weight of slipping body $G$

Earth pressure from second body $E_a$

Frictional force on slip plane $R$

Tensile force at limit equilibrium $Z_{erf}$ of the forces $G$, $b \cdot q$, $E_a$ and $R$

Fig. 3 shows the polygon of forces at limit equilibrium.



$$\eta = \frac{1}{Z_{erf}} \sum F_i \geq 2{,}0 \qquad (F_i = 2 \cdot \sigma_{i(ver)} \cdot l_i \cdot \tan \varphi_r \; ; \quad F_i < \text{zul } F)$$

Fig. 3 Cross section of a geosynthetic reinforced construction with acting forces and force polygon

## 3. NEW CONCEPTS

Large scale loading tests have shown that the above mentioned design methods are very conservative. In reality the structures are built out of a new material which is capabile of carrying large loads. The behaviour of this new material is not yet completely understood and the present state of knowledge must be compared with the start of reinforced concrete design. On the way to finding a design method which takes into account deformation characteristics of reinforced soil, cylindrical samples reinforced with different geosynthetics were compared with an unreinforced soil.

## 4. TRIAXIAL TESTS

First of all a cylindrical sample of loess (diameter 80 cms, height 160 cms) with a water content of 18 % was prepared. Fig. 4 shows a sketch of the testing equipment.

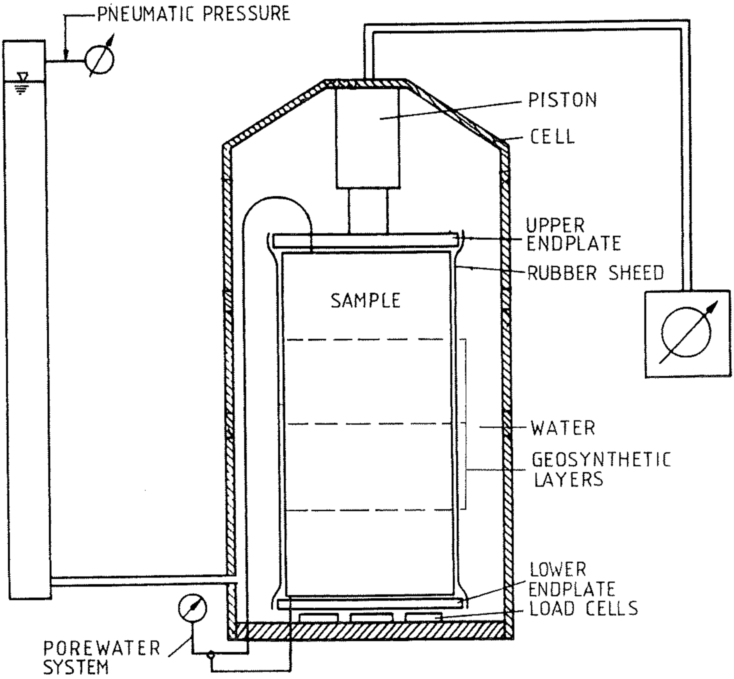


Fig. 4 Testing equipment for a cylindrical sample of loess (Diameter of the sample 80 cm, height 160 cm)

It consists of a pressure cell with a hydraulic piston in the top. The sample is placed between this piston and the base of the cell. On the top and bottom of the sample metal plates are placed to apply the deviator load. The sample is enclosed in a rubber membrane which is sealed to the end plates. The cell is filled with water and a cell pressure $\sigma_3$ is applied using air pressure. The test is carried out using a servo-hydraulic system which deforms the sample axially at a rate of 1 mm/min. The axial load is measured using load cells in the base of the cell.

The tests were carried out at three different constant cell pressures of 0,5 bar, 1,0 bar and 1,5 bar. The results of the tests are shown in the Mohr-Coulomb diagram in Fig. 5.

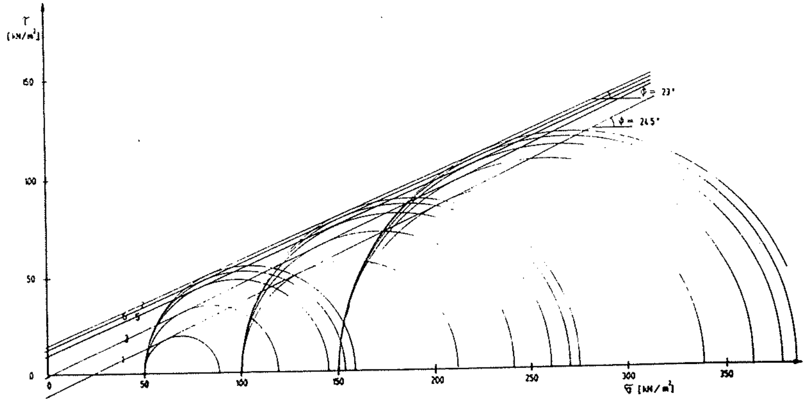


Fig. 5 Mohr-Coulomb diagram of tests with loess carried out in the testing equipment of Fig. 4

The soil has an angle of friction of 23° and a cohesion of 15 kN/m². Tests on the reinforced samples using various geosynthetics at the third points (see Fig. 4) were carried out. The following geosynthetics were used:

Table 1

| Trial | Type of product | Material | Tensile strength [kN/m] |
|---|---|---|---|
| B | non-woven | polyester | 35<br>(in the direction of needling) |
| C | geogrid | polypropylen | 35 |
| D | woven | Polyester (warp)<br>Polyamid (weft) | 200 (warp)<br>50 (weft) |

The test were carried out in the same way as those on the unreinforced sample.

## 5. TEST RESULTS

Fig. 6 shows the result of the tests on all types of geosynthetics and for all cell pressures.

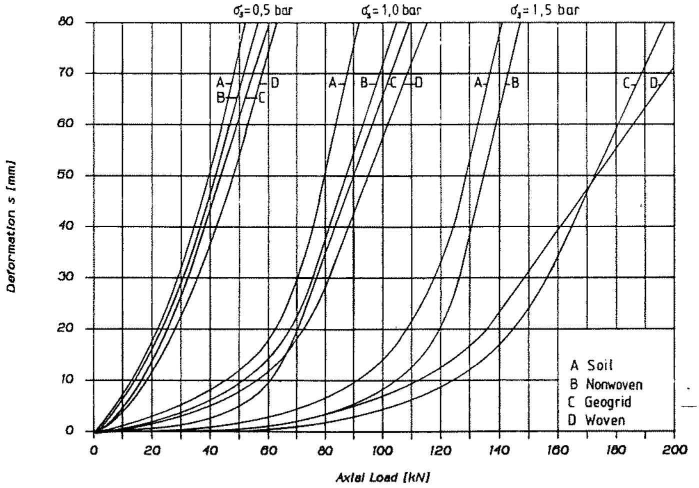


Fig. 6 Results of the tests on all types of geosynthetics for the different cell pressures

The higher deviator loads in the reinforced samples can be clearly seen. Typical Mohr-Coulomb diagrams for a non-woven geosynthetic are shown in Fig. 7.

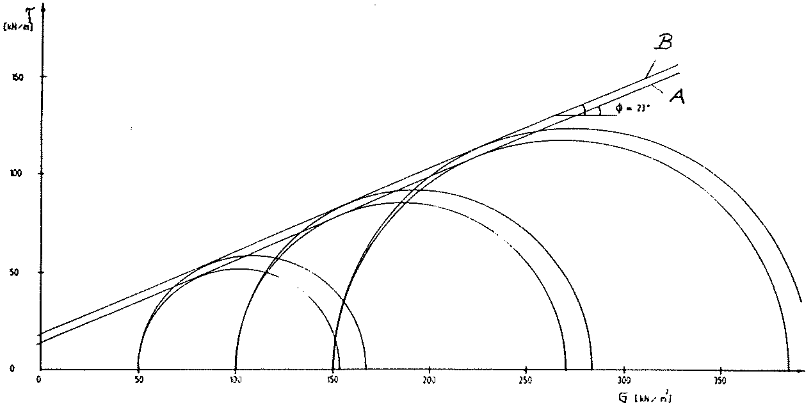


Fig. 7 Typical Mohr-Coulomb diagram for a non-woven geosynthetic (B) in comparison with loess (A)

The shear parameters for all the geosynthetics tested are shown in the following table.

Table 2

| Trial | Type of product | Angle of friction [°] | Cohesion c [kN/m$^2$] |
|---|---|---|---|
| A | - | 23 | 15 |
| B | non-woven | 23 | 18 |
| C | geogrid | 29 | 8 |
| D | woven | 31 | 8 |

The evaluation of the shear parameters was carried out at equal deformation states for all samples. Changes in angle of friction and cohesion were dependent on the geosynthetic used. All products produced increases in the shear strength.

## 6. FUTURE DEVELOPMENTS

The reinforcing effect of geosynthetics in a loess soil was investigated in large triaxial tests. It was shown that increases in the shear parameters occured with the three geosynthetics used.

However the rotational symmetry in the triaxial test only partly describes the real plane strain states in steep slopes.

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