Slope Protection and Retaining Walls
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LARGE-SCALE TEST ON THE BEARING BEHAVIOUR OF A WOVEN-REINFORCED EARTH WALL

GROSSVERSUCH ZUM TRAGVERHALTEN EINER STEILWAND AUS GEWEBE UND MERGEL

ESSAI A L'ECHELLE 1:1 SUR LA CHARGE ADMISSIBLE D'UN MUR DE SOUTENEMENT EN TISSE ET MARNE

A loading test on a 4,8 m high geotextile-soil-retaining wall is described. The wall consisting of Stabilenka 200 and marl was loaded by a strip load up to a maximal loading of 500 kN/m at a distance of 1,3 m behind the front edge. The wall displacements and fabric strains were measured. In spite of the high loading the failure state of the wall was not reached.

The problems of bearing capacity and deformation behaviour prediction for geotextile-cohesive soil-retaining walls are discussed, and the experiences made during constructing the wall are reported.

1. INTRODUCTION

The construction of steep walls using high-modulus fabrics and earth could be an economical alternative to conventional retaining walls. The condition for the application of these constructions in general is, that the fabrics are protected against any kind of mechanical damage, chemical action, and sunlight. The profitability depends on the boundary conditions of the construction. However it can be said that fabric-earth-constructions will be the more economical the lower the requirements on the building-material earth are, and the easier the construction itself can be carried out (1).

The requirements on the backfilling of retaining walls and other constructions concerning shear strength and compaction are high in Germany. Often these requirements require the use of earth which cannot be found in the site itself. For example the "Additional Technical Instructions and Guide-lines for earth works in road construction (ZTVE)" in general require the use of coarse-grained soil material for these purposes. The guide-lines for the application of the construction "reinforced earth" require a fill material with less than 15 % < 0,06 mm. Cohesion may not be used in the dimensioning and the stability analyses.

Concerning the bearing behaviour, earth-fabric steep walls can be compared with conventional reinforced-earth-constructions. The main difference is that the reinforcement reaches over the whole area of the backfill, and that the function of the prefabricated concrete parts as the outer boundary for the wall is taken over by the fabric itself. Of course the mechanical properties of the fabrics are completely different to those of the steel bands used for terre-armée - constructions. The placing of the fabrics into the soil over the whole area of the backfill suggests the use of soils with properties not as good as those required for the reinforced earth-constructions, and which can be found at the site itself. Because of the large contact area the forces which can be transferred from fabric to soil, are large. Therefore in such constructions good bearing capacities are to be expected. On the other hand it is up to the present almost impossible to make a correct prediction of the deformation behaviour of a steep wall under a heavy loading, when cohesive soils are used together with extensible fabrics, as compared with steel bands.

In order to study the bearing capacity and the deformation behaviour of such a geotextile-earth steep wall a 10 m long and 4,8 m high test wall was constructed in the testing pit of the Otto-Graf-Institute. The wall consisted of five layers of fabric-earth. A polyester type fabric (Stabilenka 200) was used together with cohesive filling material (weathered marl from the lower Jurassic - Lias α). The steep wall was loaded by a 1,2 x 5,2 m strip load situated near the front edge of the wall. The wall deformations and the fabric strains were measured and plotted. The test was performed by order of the firms ENKA and HUESKER; the choice of the wall dimensions, the loading boundary conditions and the type of fabric was carried out in co-operation with the specialists of these firms.

2. CHARACTERISTIC VALUES OF THE MATERIALS USED

Fabric:

polyester type Stabilenka 200		
weight	460	g/m²
average tensile strength in warp direction:	224	kN/m
average tensile strength in woof direction:	32	kN/m
average breaking elongation in warp direction:	9,3	%
average breaking elongation in woof direction:	17,3	%

Soil:

Weathered clay marl (Lias α)		
friction angle:	ϕ = 21,5	°
cohesion when compacted:	c = 40	kN/m²
average bulk weight:	2,0	t/m³
average water content:	15	%

3. TEST ARRANGEMENT AND BOUNDARY CONDITIONS

Fig. 1 shows a plan view of the steep wall in the testing pit (the loading devices are not illustrated). Fig. 2 shows a cross-section of the wall and the loading devices.

A 10 cm thick layer of marl was placed on the concrete floor of the testing pit and compacted. Then the shuttering for the front of the lowest fabric-soil layer was placed; the shuttering was supported against the wall of the testing pit. The fabric layer was laid out and the parts of the fabric which later should be folded back (see fig. 2) were laid over the shuttering. In order to

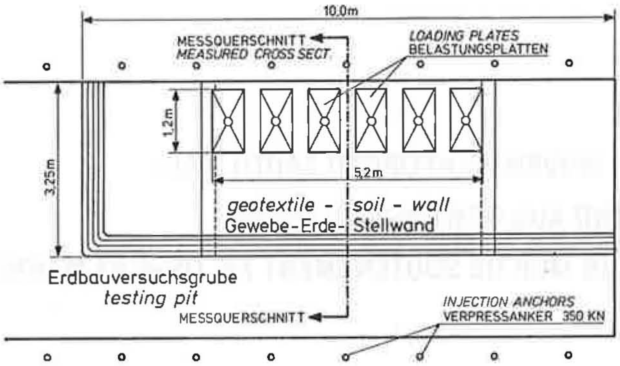

Fig. 1 - Plan view of the test steep wall (without loading devices)

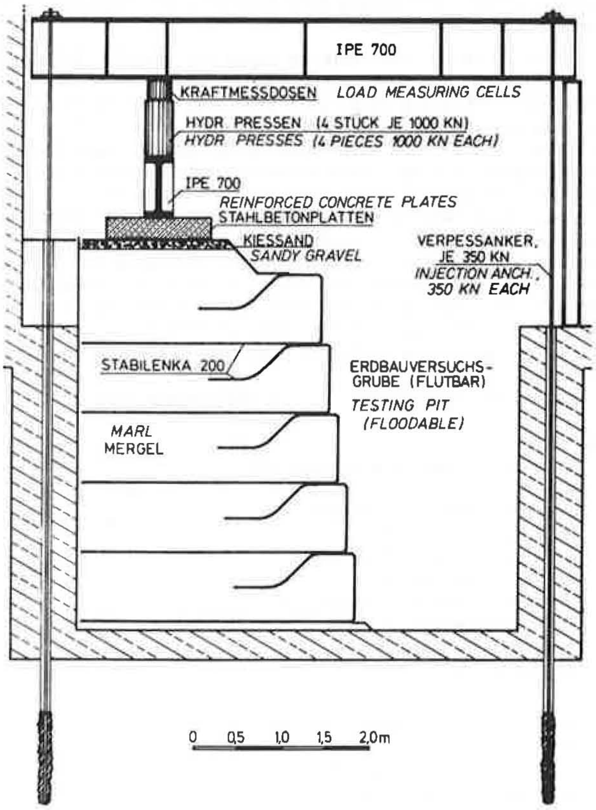

Fig. 2 - Cross-section of the wall and the loading devices

avoid displacements of the fabric during compaction, and to keep the fabric tense on the front side of the wall, it was fixed by means of squared timbers and screw clamps to the shuttering. Then the lower layer of earth of 40 cm thickness was placed and compacted in two steps of 20 cm each. The compaction was carried out using an electrical hand tamper in three crossings for each layer. So an average bulk density of 2,0 t/m³ could be reached. The upper layer of earth was placed and compacted in the same way. The fabric was folded back into the construction as shown in fig. 3. In order to avoid the impression that the front of the wall was leaning out and to facilitate the shuttering work, the following layers were set back 10 cm each, and constructed in the way described before.

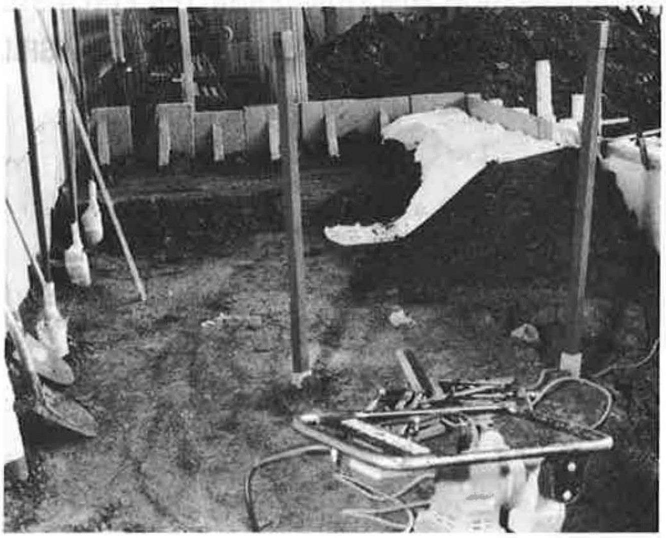

Fig. 3 - Detail of wall construction showing the fabric folded back into the construction

After the completion of the top layer a sandy gravel layer was placed in order to obtain a better load distribution (see in Fig. 2). The loading plates (reinforced concrete plates) were laid upon this gravel layer. The loading was applied using four hydraulic presses, each with a capacity of 1000 kN, using a system of steel beams as shown in fig. 4.

The reaction for the servo-controlled press forces was obtained from earth injection anchors which are installed at the periphery of the test pit. The anchors are arranged in distances of 1,4 m and have a loading capacity of 300 kN each.

The position of the loading plates with regard to the position of the fabrics must be discussed. If all rear ends of the fabric layers reach into the soil up to an (assumed) vertical plane, then the lowest bearing capacity of a fabric-soil steep wall is when the loading on the surface is arranged behind this plane, and the wall itself is not directly loaded. The failure mechanism that occurs in this case consists of two bodies in the way observed, for example, by Gaessler (2) during his studies for soil nailing (fig. 5 a). Only the lower layers are stressed by pull-out forces.

When the loading is arranged directly above the fabric layers (fig. 5 b), as was carried out in the test described here, the straining of the fabric is completely different. The wall will fail on a rupture plane which starts from the rear edge of the loading plates, and which stresses nearly all fabric layers. Simultaneously with the increase of the tensile forces in the fabric layers the normal forces on the fabric layers are increased, too, and as a result the resistance against extraction increases. The shear forces which can be transmitted between Stabilenka fabrics and different soils are known from large-scale tests under constant normal loading. So dimensioning of a steep wall for the first type of loading mentioned can be

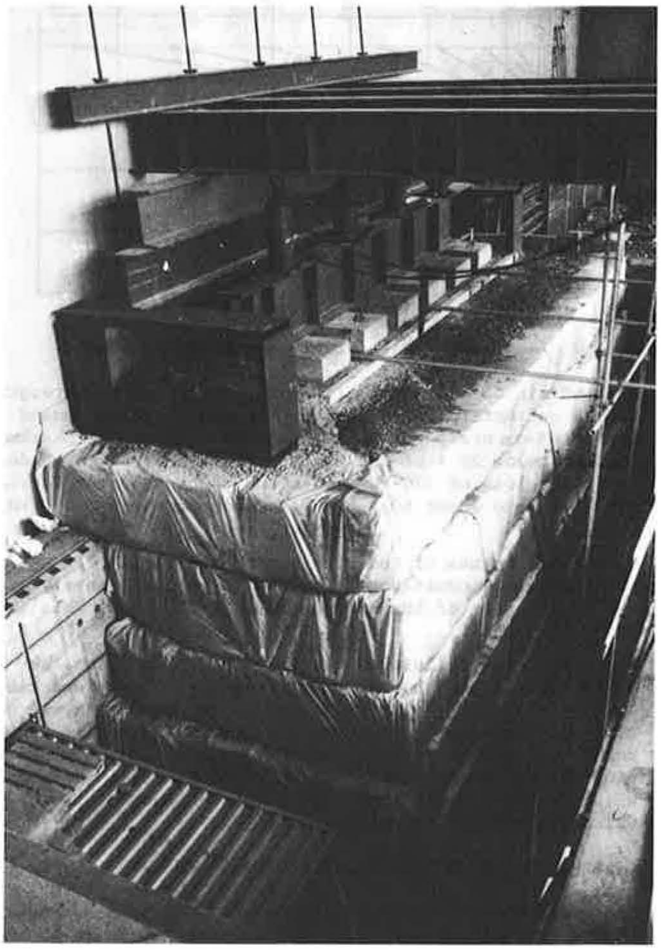

Fig. 4 - Steep wall with loading device

carried out on the basis of these test results. The bearing and deformation behaviour of a steep wall under high loading forces near the front edge is more difficult to predict, as the following test results will show.

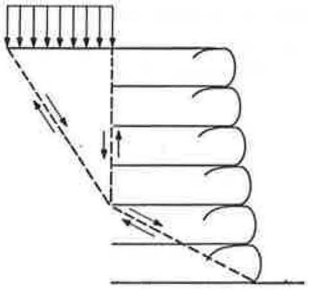

Fig. 5 a - Failure mechanism with two rigid bodies (loading behind the steep wall)

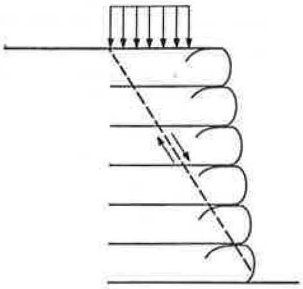

Fig. 5 b - Failure mechanism of a directly loaded steep wall

4. MEASURING DEVICES

The displacements of the front side of the wall were measured in the middle of each soil-fabric layer in horizontal direction using electrical displacement transducers. The measuring points were steel rods knocked into the front of the wall. Vertical displacements were measured in the same way. The vertical loading forces were measured using electrical load transducers between the hydraulic presses and the steel beams.

In order to record the strains of the fabric on each layer electrical resistance strain gauges were stuck to the fabric at distances of 0,5 m in the measuring profile. The gauges had a length of 10 cm. The fabric with premounted strain gauges was delivered by the producer of the fabric. Fig. 6 shows the arrangement of the measuring points.

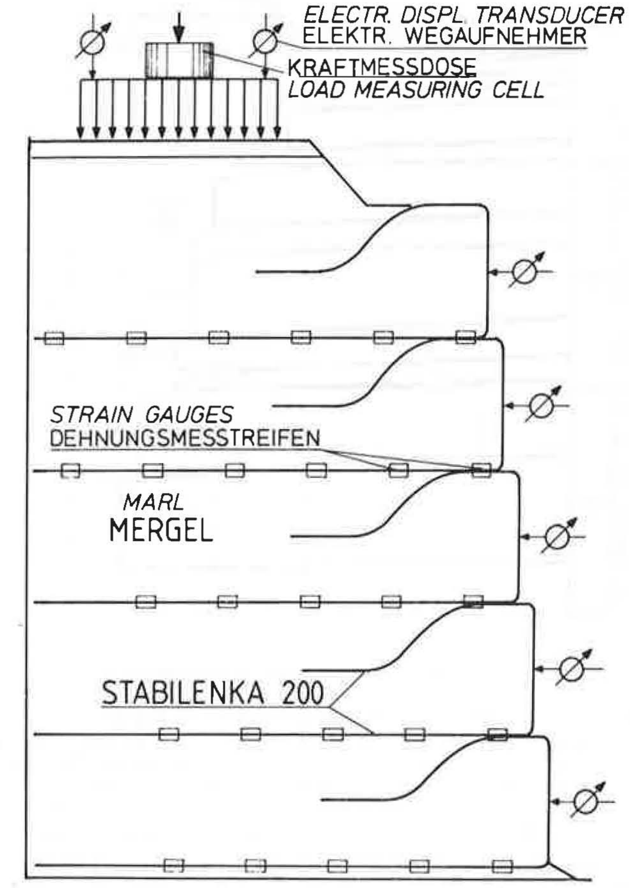

Fig. 6 - Measuring profile with the arrangement of the transducers

All values were measured, stored, and analysed using an electronic data logger.

5. TEST PERFORMANCE AND TEST RESULTS

The test was carried out over a period of several weeks using thirteen load steps up to a maximum load of 500 kN/m. At each load step the load was held constant until the vertical displacement of the loading plates was less than

0,02 mm/min. At ten steps the load was held constant for several days in order to determine the creep strains of the geotextile-earth wall. Upon reaching the maximum load of 500 kN/m the bearing capacity of the anchors was reached and at the same time a failure underneath the loading plates started to develop. The vertical displacements of the plates increased steadily. At the same time the front of the upper geotextile-earth layer was deformed horizontally. Due to the large deformations and the inclination of the loading plates the test had to be stopped even though the wall had not reached the failure state in the lower layers.

Fig. 7 shows a plot of the loading of the wall versus the settlement of the loading plates during the several load steps.

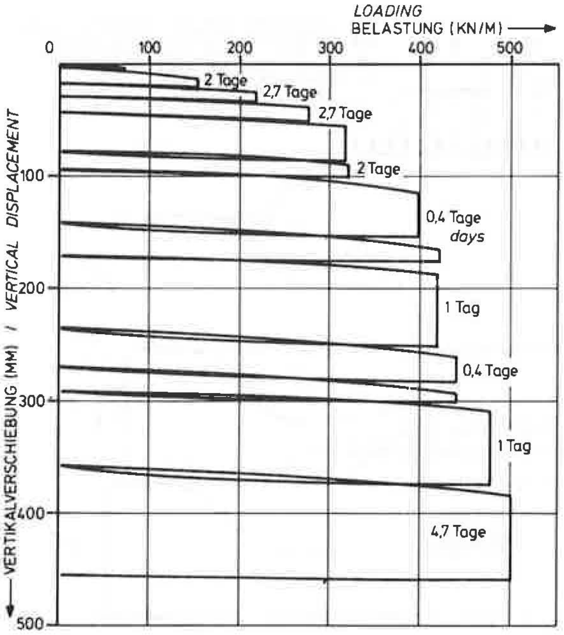

Fig. 7 - Load versus loading plate settlement

In fig. 8 the horizontal displacements of the front of the wall are shown for various load steps. One can see that up to a load of 277 kN/m the displacements decrease from the top to the bottom nearly linearly. From this load step on the upper layer is deformed more while the displacements in the lower layers decrease nearly linearly as before.

It can be assumed that without the local ground failure the horizontal displacement at the top of the wall would have reached around 100 mm under the maximum loading of 500 kN/m, which is 2,5 % of the wall height.

Fig. 9 shows the strains of the fabric for different load steps (the lower fabric layer is not shown because hardly any strains were measured here). The stress-strain diagram of a Stabilenka 200 type fabric is shown in fig. 10.

From fig. 9 it can be seen that the most intensively loaded upper geotextile layer (no. 5) had a maximum strain of around 1,3 % during the last stable load step before the ground failure occured (assuming that no appreciably higher value occured between the strain gauges, for example in a developing slip plane). During the load of 500 kN/m the large displacements destroyed the measuring cables.

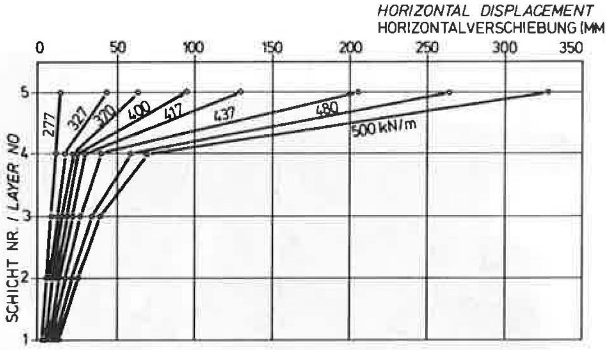

Fig. 8 - Horizontal wall displacement versus load

At a strain of 1,3 % only 15 % of the short term strength of the geotextile is activated. The producers recommend for long-term steep wall constructions to keep the maximum loading below 25 % of the maximum tensile strength. Under the strip load of 370 kN/m near the front edge the fabric was loaded to about 60 % of this recommended load (50 kN/m).

Using test values of the strain gauges a field of equal strains can be constructed for the moment immediately after application of the maximum load of 500 kN/m. This is shown in fig. 11.

The start of a failure of the wall on a slip plane, as depicted in fig. 5 b, is clearly visible. It is remarkable that the degree of utilization of the fabric layers decreases considerably from the top toward the bottom. The reason is, probably, that there is an additional compaction of the cohesive backfilling under the high loading which causes a settlement trough in the upper fabrics, which strains the geotextile additionally.

6. PROBLEMS OF ESTIMATING THE LOADING CAPACITY

The loading capacity of the steep wall had been estimated before the test using different methods. According to the rigid-body-assumption the wall should have failured due to a tensile failure in the second geotextile layer from the bottom. The test has shown that these considerations were wrong, and that the bearing capacity had been considerably underestimated. Certainly many further investigations are necessary until a generally valid statement on the bearing behaviour of steep walls of the type tested here will be possible. Until this achieved, an estimation of the loading capacity for similar systems in practice will have to start from the assumption of a rigid failure body.

The following assumptions can be made:
The stress propagation under the strip load takes places under an angle of

$$0{,}5\ \left[\left(\frac{\pi}{4}+\frac{\phi}{2}\right)+\frac{\pi}{4}\right]$$

which corresponds to a slightly modified "primitive" assumption. The failure plane begins at the rear edge of the loading area, and has a dip angle of

$$\frac{\pi}{4}+\frac{\phi}{2}$$

to the horizontal plane (fig. 12). According to these assumptions graphical solutions can be carried out for the failure body loaded by the load P, as shown in fig. 12.

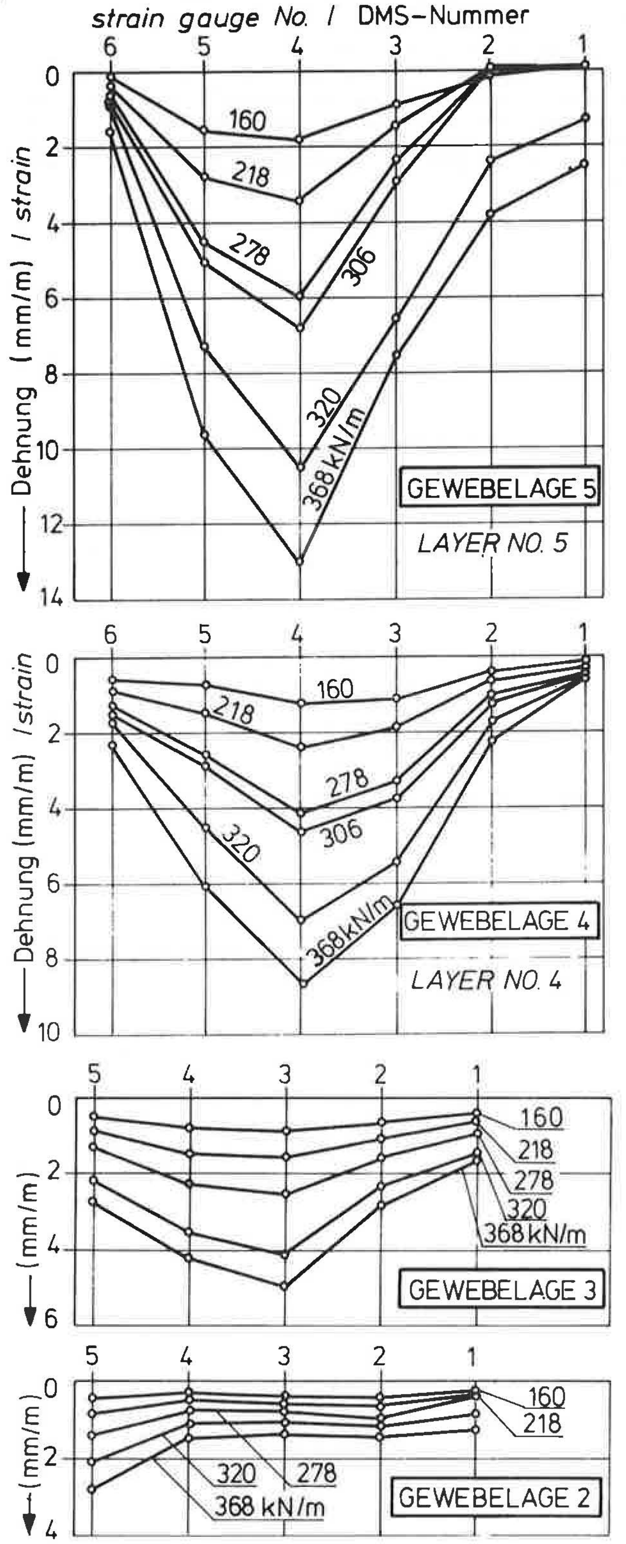

Fig. 9 - Strain distribution in the fabrics at different load steps

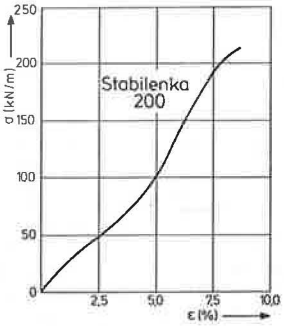

Fig. 10 - Stress-strain diagram of Stabilenka 200

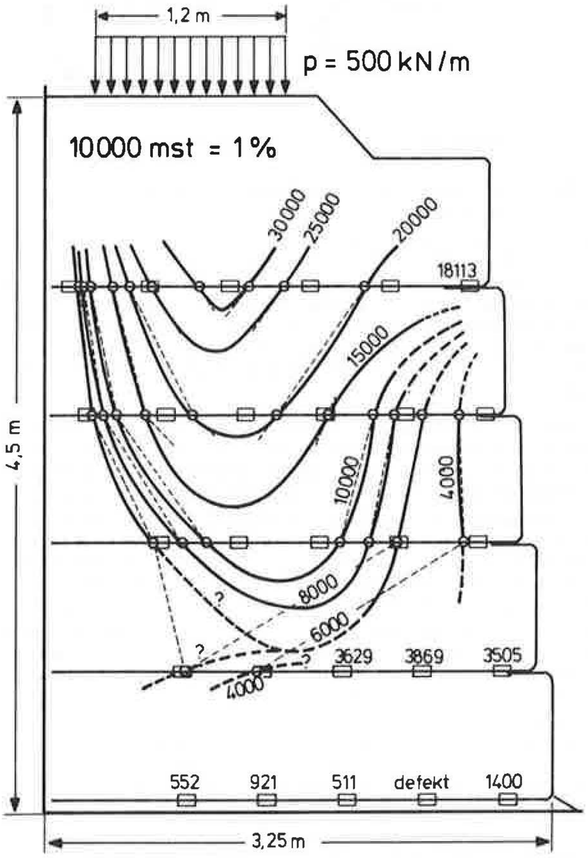

Fig. 11 - Field of equal fabric strain under the maximum loading of 500 kN/m

On the sliding wedge which cuts the geotextile layers no. 1 to 4 all acting forces (dead weight G, loading P, fabric tensile forces S 1 to S 4, cohesion c, and friction force R) are applied. The tensile forces in the geotextile S 1 ...n are applied in relation to the normal forces acting on the geotextile behind the slip plane assuming $\phi_{soil-soil} = \phi_{soil-fabric}$

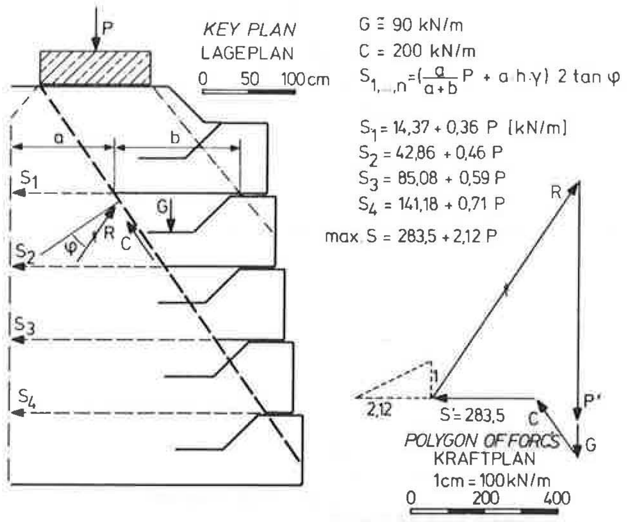

Fig. 12 - Graphical solutions for the retaining wall

From these calculations the determination of the fabric tensile force follows

$$\max S_{total} = S_1+S_2+S_3+S_4 = S'+2{,}12\ P$$

S' is the part due to the dead weight of the backfilling. Every increase in P increases the sum of the fabric tensile forces with the factor 2,12, and it can be seen that failure due to collective pull-out of the geotextiles cannot occur on this wall (the force polygon cannot be completed).

The tensile forces cannot become larger than the tensile strength of the fabric (200 kN/m). From the relations for S 1 to S 4 it follows that, under assumption of a rigid body displacement and without taking the fabric strain into consideration, layer no. 4 should fail first at a load of P ≅ 83 kN/m, which is obviously in contradiction to the test result. Even if it is taken into consideration that for the test wall the assumption of plane strain conditions is too disadvantageous because of the fabric which projected over the ends of the strip load the above statement remains true. It will be the aim of further investigations to develop a dimensioning method which will take into consideration the behaviour of extensible fabrics and compressive soils, and which probably will allow predictions to be made of the deformations.

7. EXPERIENCES DURING THE CONSTRUCTION OF THE STEEP WALL

During the construction of the wall it became evident that it was nearly impossible to compact the areas behind the fabrics at the front side in such a way that the geotextiles were stressed after removing the shuttering. They remained unstressed in spite of the use of different methods of compaction. The single soil layers stood free because of the cohesion. Even during the loading only in higher load steps stressing in the upper layers became visible. From this it may be concluded, that the fabric covering of the wall front does not contribute very much to the bearing capacity, which can also be demonstrated soilmechanically. Due to the unstressed fabrics the wall does not look attrative. The construction and support of the shuttering was not easy even in the laboratory. In practice it will be necessary to find methods which make shuttering of front side at the wall unnecessary, or at least easier.

The stress of the geotextile layers is heavily influenced by the compaction method and compaction direction. Also the unaccustomed work with the material "geotextile" is in the practical realization of geotextile-soil-constructions a factor which makes demands on the personal in a way outside the area of experience of conventional earth works.

(1) Wichter, L., "Geotextil-Erde-Steilwand als Dauerbauwerk", Die Bautechnik, Vol 62, H. 9, Sept. 1985, S. 289-291

(2) Gäßler, G., "Die Anwendung des statistischen Sicherheitskonzeptes auf verankerte Wände und vernagelte Wände", Vorträge Baugrundtagung, Deutsche Gesellschaft für Erd- und Grundbau, Essen, 1981