Stability of earth Structures Reinforced by Geotextiles

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STABILITY OF EARTH STRUCTURES REINFORCED BY GEOTEXTILES

SUR LA STABILITÉ DES MUR DE SOUTÈNEMENT RENFORCÉ AU GEOTEXTILE

SYNOPSIS The stability of retaining walls or embankments can be improved by means of horizontal layers of inclusions. Several authors have analysed the method theoretically and have proposed calculation methods based on circular slip analyses. Failure occurs in a very narrow zone surrounded by rather stiff soil bodies. This failure mechanism has been studied in a special shear box using a sand-geotextile element. The long term creep of the geotextile has also been investigated in a test series including a very long lasting plane strain tensile test with constant load.

INTRODUCTION

Use of geotextiles as a reinforcing element in earth retaining structures or in embankments is rather attractive because of its low cost and uncomplicated installation. However, such structures have so far mainly been built for experimental purposes. Geotextiles have until now been used in temporary roads and some small roads situated on soft subsoils to improve the bearing capacity of the road and to separate the subsoil from the road base. The reason is, that the long term reduction in the strength of the geotextile is still an open question, which must be answered before use of geotextiles in important permanent constructions, or the allowable tensile forces should be reduced considerably making the construction too expensive.

Design of an earth retaining structure reinforced by several layers of geotextile comprises

construction of surface elements
calculation of stresses in the circular shaped geotextile membranes behind the surface elements
calculation of overlapping length and anchor length
calculation of the vertical spacing of the geotextile layers.

This paper restricts itself to the stability problem shown in the circle in Fig. 1. Since the failure takes place along a curved surface the plane of shear failure may assume different angles α relative to the horisontal layer of the geotextile. This problem also appears in the design of embankments and slopes.

The soil used in reinforced earth structures is normally sand. The failure mechanism has therefore been studied in the laboratory by performing tests with sand and a non-woven geotextile in a special shear box developed for this purpose (Fig. 5). The same phenomenon has been studied earlier in tests performed on clay-geotextile specimens (Snaith, Bell and Dubois 1979).

PROPERTIES OF THE SOIL

The sand used in all tests is a pure quarts sand with fairly angular grains, called Lund no 0. The grain size distribution is quite uniform as can be seen in Fig. 2. The void ratios in the loosest and densest state are $e_{max} = 0.82$ and $e_{min} = 0.56$. The tests are performed with a mean void ratio of 0.57. Since the sand is very dense and the stress level rather low the internal angle of friction is high. The angle of friction measured in the triaxial apparatus is $\phi = 50°$ at $\sigma_3' = 5$ kPa and $\phi = 48°$ at $\sigma_3' = 10$ kPa.
The angle of dilatation $\nu \sim 17°$.

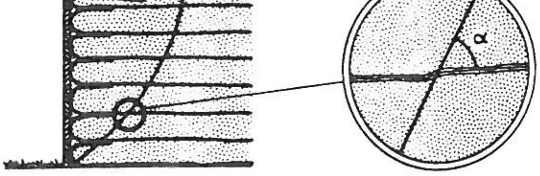

Fig. 1. Stability failure in reinforced soil.

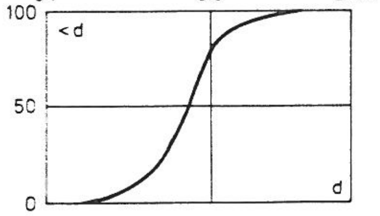

Fig. 2. Grain size distribution of sand.

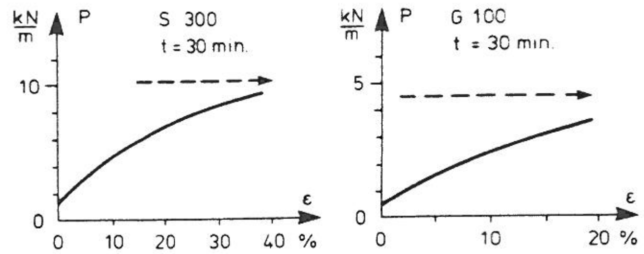

Fig. 3. Plane strain tensile tests with geotextiles.

PROPERTIES OF THE GEOTEXTILE

The geotextile used are all made by Fibertex in Denmark. They are non-woven, needle-punched and thermic bonded under compression and are composed of polypropylene. The quality mainly used in the test series is the so-called S300 with a unit weight of 300 g/m^2. In a few tests a weak geotextile, G100, were used with a unit weight of only 100 g/m^2. The short term tensile strengths of S300 and G100 in plane strain is 12 and 4 kN/m, respectively.

Plane strain tensile tests have also been performed at a stress rate corresponding to that in the shear box test. The load was applied stepwise and kept constant for half an hour and after five to six steps the geotextile broke. (Fig. 3).

LONG TERM STRENGTH OF A GEOTEXTILE

In order to study the long term reduction of the strength of a geotextile stressed by a constant load a test series has been carried out in the plane strain tensile apparatus. The geotextile was loaded stepwise until failure and during a test the duration of each step was as constant as possible. But the step length t_s varied from test to test beginning with t_s = 4 min., succeding with t_s = 16, 60, 1400 and 4000 min. and ending up with a test, which is still continuing after t = 1000000 min. (2 years). The time curve is shown in Fig. 4 and the test seems now to be very near its end. In Fig. 4 is also plotted the strength of the geotextile against t_s. The relationship between the strength of the geotextile P_t and the duration of the constant load is a logarithmic function:

$$P_t = P_{max}(1 - s \cdot \log_{10} t_s)$$

P_{max} is the strength of the geotextile, when loaded with time intervals of 1 min. It is found to correspond closely to the short term tensile strength measured at the factory. The long term reduction s is 7% per decade. With an estimated life time for a retaining wall or an embankment of 20 years the strength should be reduced with 50%.

It is worth noting that this result could have been achieved even if the maximum duration of the constant load had been only one to three days. In other words, a standard method comprising tests with t = 4 min., 100 min. and 1000 - 4000 min. could be a practical tool for design purposes.

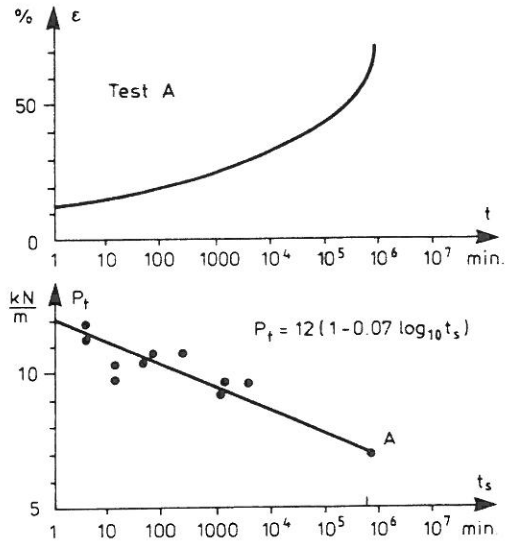

Fig. 4. Long term behaviour of geotextile S300.

THE TESTING APPARATUS

A special shear box has been developed in order to study the stabilizing effect of a geotextile embedded in sand. The sand specimens were dry and prepared by the pluvial compaction technique. The surface of the specimen was horizontal during the layering and therefore the geotextile has to be mounted horizontally, just as in practice. The sand-geotextile specimen represents an element in the backfill of a retaining wall (compare Fig. 5 and 1) or in an embankment. The sand specimen is 175 mm x 100 mm x 150 mm in size. It is situated between two circular end platens, which can be rotated in such a way that the shear surface assumes angles of 30°, 60° or 90° with the horizontal plane. Inside the two end platens some small wheels prevent deformations in the transverse direction of the geotextile. The geotextile can be fixed by two jaws corresponding to a perfect anchoring of the geotextile, or the two jaws can allow the geotextile to move freely into the sand corresponding to a very short anchor length. The sand specimen is loaded by means of weights, representing typical overburden pressures corresponding to the load of 3-5 m of

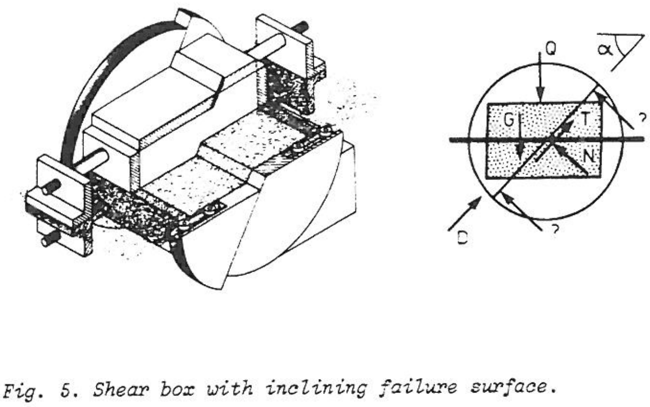

Fig. 5. Shear box with inclining failure surface.

sand. It is possible to prevent horizontal movements between the upper pressure head and the end platens in order to study the effect of the movements in the sliding soil mass. The sand-geotextile specimen was sheared at a deformation rate of 0.12 mm/min. The maximum shear deformation was 28 mm. Fig. 5 also shows the principle of calculation. The known quantities are the dead load of weights Q, the weight of the sand and the moving part of the apparatus G, the external shearing force D producing shear deformations. Unknown quantities are the shearing force T in the failure surface and the force N normal to the failure surface. T is easily calculated from

$$T = (Q + G)\sin\alpha - D$$

but N remains unmeasured.

A test series includes four test types

1. Dummy tests.
2. Sand tests without any geotextile.
3. Tests with fixed geotextile.
4. Tests with movable geotextile.

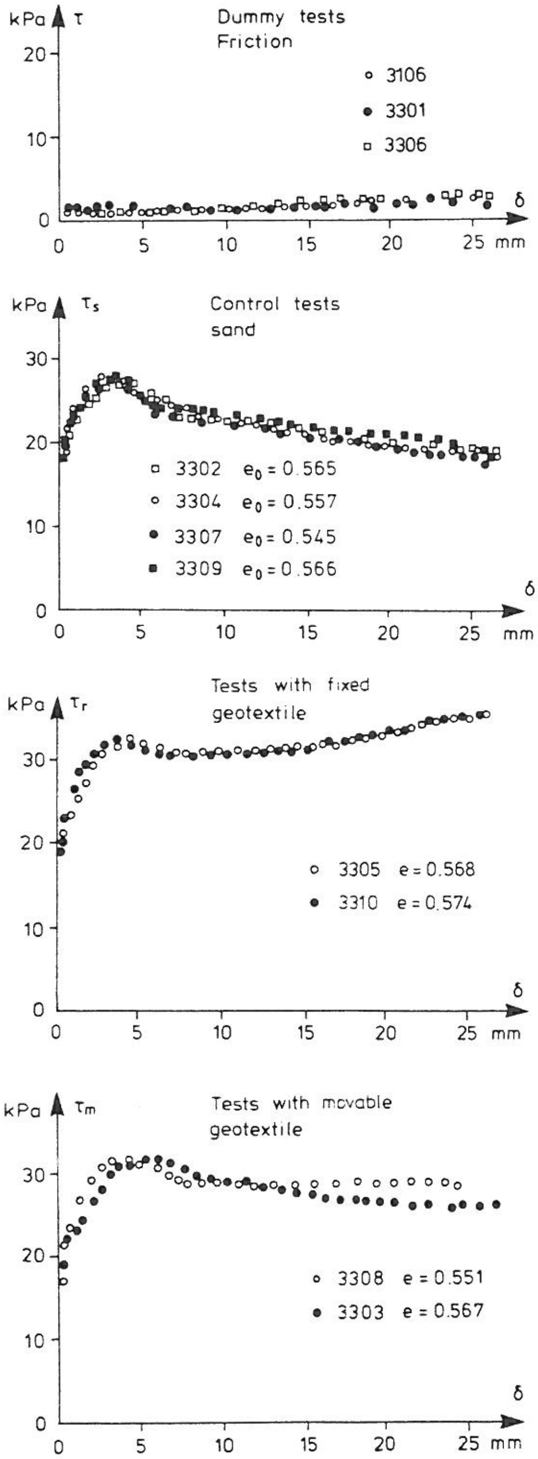

Fig. 6. Tests with α = 30° and $\sigma_n \approx$ 40-45 kPa.

EXPERIMENTAL RESULTS

The tests carried out until now are grouped into six test series, including tests with α = 30°, 60° and 90° and vertical loads $\sigma_n \sim$ 40-45 kPa and 80-85 kPa. A test series includes as a minimum four test types and ten tests: Dummy tests without sand and geotextile, control tests with sand, tests with movable geotextile and tests with fixed geotextile. A test series with α = 30° and $\sigma_n \sim$ 40-45 kPa is shown in Fig. 6.

Dummy tests

The friction between the different parts of the apparatus which pass over each other during the test is minimized by using rubber membranes and silicone grease. The lasting friction is measured in special tests without sand and geotextile as shown in Fig. 6 or after a normal test in an uncleaned apparatus.

Control tests

Tests performed with sand specimens serve as control tests. The angle of internal friction can be calculated and compared with results from triaxial tests. However, it is a little complicated since the two quantities measured is a normal stress on a horizontal surface and a shear stress in another surface inclining α degrees, as indicated in Fig. 7.

First τ_s can be plotted against σ_n as shown in Fig. 7. Proportionality between τ_s and σ_n can be obtained by adding the attraction $c\cot\phi$ = 11 kPa to all values of σ_n.

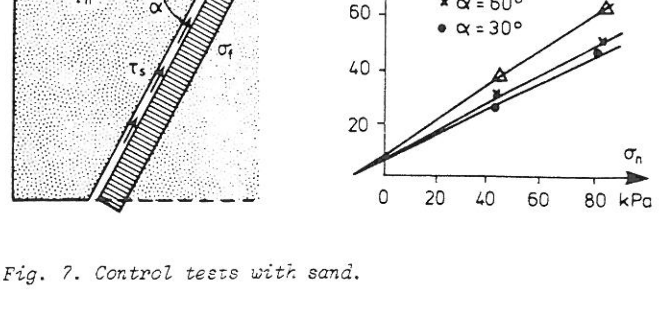

Fig. 7. Control tests with sand.

Assuming homogeneous stress distribution in the specimen the Mohr's circle can be used to illustrate the problem (Fig. 8). The inclining surface is the plane of zero extension, which is represented by the point F. The angle ν in Fig. 8 is the angle of dilatation. The point representing the horizontal surface is found by turning F 2α clockwise. For a fixed value of α and τ_s/σ_n ϕ depends on the choise of ν as shown in Fig. 8. The intersection between the curves with different values of α gives $\phi = 54^\circ$ and $\nu = 14^\circ$. This agrees well with triaxial test results mentioned earlier in this paper, taking into account the differences between plane and axisymmetrical states. The apparent cohesion is 8 kPa and may be effected by testing technique.

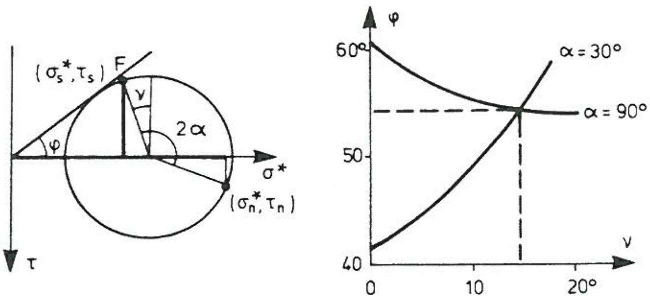

Fig. 8. Determination of strength properties of sand.

Tests with fixed geotextiles

The maximum reinforcing effect is obtained when the ends of the geotextile don't move. As observed in Fig. 6 the shearing resistance of sand τ_s decreases during the test while the shearing resistance of sand with fixed geotextile τ_r is slightly increasing. The improvement factor τ_r/τ_s is then increasing during the test.

Values of τ_r and τ_s are shown in Fig. 9, corresponding to a shear deformation δ = 10 mm. It is seen, that the sand-geotextile element acts as a frictional material with an increased internal friction, but with the same cohesion as that of the sand.

The improvement factor τ_r/τ_s is also shown in Fig. 9 and compared with test results from [6]. The improvement factor depends on the intersection angle α. It is interesting to notice that the plane of principal tensile strain is horizontal for $\alpha = 45 + \nu/2 \approx 52^\circ$, theoretically causing maximum of improvement.

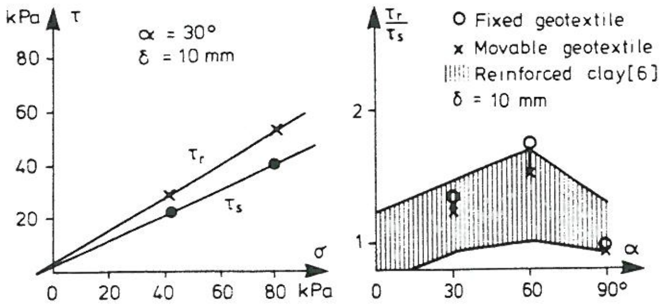

Fig. 9. Comparison between tests with sand, tests with reinforced sand and tests with reinforced clay.

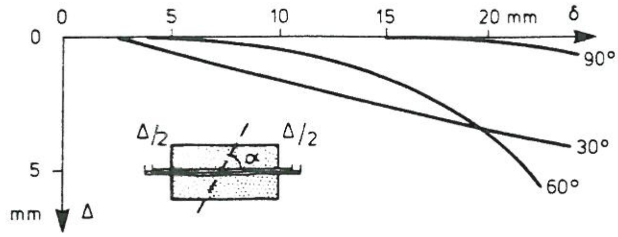

Fig. 10. Retraction of movable geotextile.

Tests with movable geotextiles

The minimum reinforcing effect is obtained if the anchor length is very small, for instance if the overlapping length between two textiles is too short. Tests with an anchor length of half the length of the sample result in a minimum improvement factor (Fig. 9). The difference between the improvement factors for fixed and movable geotextiles increases when δ exceeds 10 mm.

The movement of the geotextile into the sample is shown in Fig. 10. At $\alpha = 30^\circ$ the movements begin after a shear deformation δ of 2 mm, for $\alpha = 60^\circ$ after δ = 8 mm and for $\alpha = 90^\circ$ the movements are very small even after 20 mm. In agreement with these observations the test series shows that the improvements for $\alpha = 30^\circ$ takes place almost from the beginning; but for $\alpha = 60^\circ$ the improvement begins after δ = 2-3 mm.

These tests show that even if the anchor length is very short the geotextiles still improves the soil. A possible failure plane near the border of the reinforced zone will then be forced to take place outside the reinforced zone.

INTERACTION BETWEEN SAND AND GEOTEXTILE

When the shearing resistance of sand beneath shallow foundations or behind smooth retaining walls is exceeded the failure takes place in failure zones of considerable extent. It is possible to place the geotextiles inside the failure zone, most conveniently orientated in the direction of principal tensile strain (McGown et al. 1978), although the most practical location is horizontal. In this case the effect of reinforcement can be measured in triaxial tests with horizontal layers of geotextile (Broms 1977) or in the unit cell (McGown and Andrawes 1977).

This paper deals with instability of a normal retaining wall or embankment. The failure takes place in very narrow failure zones surrounded by rather stiff soil bodies and is normally assumed to follow a circle or a logarithmic spiral. The failure mechanism around the geotextile is rather complicated as shown in Fig. 11. During failure

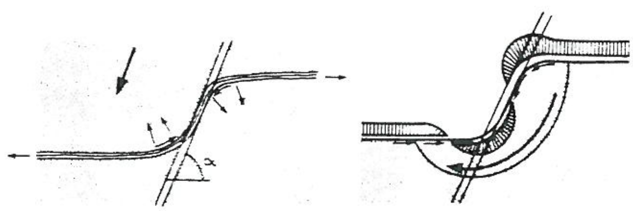

Fig. 11. Local instability near intersection point.

the geotextile is forced into the direction of the failure plane. At point A the bending of the geotextile increases the normal shear stresses between geotextile and sand and reduces the tensile forces in the geotextile outside the failure area. When the failure plane is very steep the necessary anchor length is reduced essentially. (Fig. 10 $\alpha = 90°$). At point B the bending reduces the stresses between the geotextile and the sand below. If the geotextile and the sand above is removed, it results in a sand slope loaded with the interaction forces from the geotextile. The removed part can be seen by turning Fig. 11 upside down. The slope may during the overall stability failure be unstable and the rotation of the geotextile reduced.

STABILIZATION BY GEOTEXTILES

The development of the additional shear force ΔT produced by the geotextile can be studied in the shear box as already shown in Fig. 6. The results of extensive test series are shown in Fig. 12 a) and b), whereas Fig. 12 c) and d) show results from a few more tests carried out to obtain further information.

Fig. 12 a) and b) show ΔT corresponding to a movement of δ = 10 mm and 20 mm respectively. The stabilization is evidently a friction phenomenon. The strength of the geotextile limits the value of ΔT but does not normally influence its actual value.

Tests with sand in its loosest state can be seen in Fig. 12 c), and shows some reduction of ΔT. It is also observed in tests with more extensible geotextile (Fig. 12 d)). The reduction is of course expectable, but it seems to be very small, only 10-20%. If further investigations show the same tendency, it should then be possible to use such results as shown in Fig. 12 over a wide range of sand densities and geotextile modules.

CONCLUSIONS

The stability of a slope, a retaining wall or an embankment can be improved by horizontal layers of geotextiles. The spacing of the layers depends on the long term creep strength of the geotextile and the interaction between geotextile and soil which takes place in a narrow failure zone surrounded by rather stiff soil bodies.

The long term creep strength has been studied in a plane strain tensile apparatus, showing that the strength is a logarithmic function of time. After a loading period of 2 years the strength is reduced to 60% of its initial strength specified by the factory.

The interaction between soil and geotextile in a narrow failure zone has been studied in a special shear box developed for this purpose. The main result is that the reinforcing mechanism is a frictional phenomenon as shown in Fig. 12. It means that the local influence of a geotextile is proportional to the overburden pressure until the additional shearing force ΔT reaches its maximum value at a certain depth, where the strength of the geotextile is fully utilized. The strength of the geotextile limits the size of the reinforcing construction, but the improvement of the soil has to be taken into account by calculating the additional mean shear stress between every two layers, and then determine higher angles of internal friction in the soil-geotextile elements.

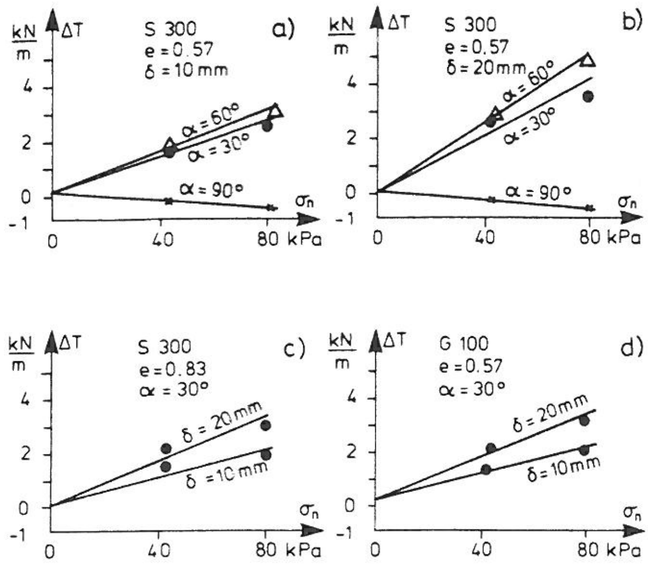

Fig. 12. Shear force introduced by fixed geotextile.

Strength improvement of a dense sand like that mainly used in this study is not possible in practice. The imposed deformations in the geotextile are bigger than the peak strength deformation in the sand. The improvement caused by geotextiles is then followed by a reduction in the strength of the sand. In the tests which correspond to a heavily reinforced sand the strength of the sand-geotextile system nearly kept its strength during shearing (Fig. 6).

Strength improvement of a loose sand is easy, since the strength of both the sand and the geotextile still increases continuously even after large deformations.

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