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Improvement of bearing capacity for traffic areas on soft subsoil – Large scale laboratory testing

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ABSTRACT: Large scale laboratory tests have verified that the use of geosynthetic reinforcement in granular bearing layers on soft subsoil can significantly improve the bearing capacity. A two layer solution, with a geotextile and a geogrid, increases the bearing layer stiffness and hence results in a significant reduction of the deformations both for static and cyclic loading conditions.

1 INTRODUCTION

The use of geosynthetic reinforcement to improve the bearing capacity of traffic areas is an interesting but technically challenging matter. The application areas are several such as roads, railroads, airfields and hardstandings. Improvement of the bearing capacity in areas with soft subsoil may be based on a need for improved deformation and deterioration characteristics, possible reduction of bearing layer thicknesses, reduced need for expensive high quality granular materials or similar.

Variations of the load, behaviour of the bearing layer material and other effects such as climatic loads makes the picture very complex. A complete theoretical model of this comprehensive picture is not possible although some aspects can be illuminated through for example Finite Element analyses.

Existing methods for design of traffic areas are to a great extent empirical, some times supplemented with linear elastic stress analyses. New concepts, including new products in an empirically based design approach, is difficult to introduce, due to the lack of experience with the solutions.

We believe that the effects of geosynthetic reinforcement to improve bearing capacity are to a great extent related to plastic (permanent) deformations. The traditional theoretical models for traffic areas are unable to give a sufficient description of the behaviour of a geosynthetic reinforced traffic area. Furthermore they are not capable of predicting the effects of different types of reinforcement and construction solutions. In this field there is, therefore, a need to establish better understanding of the fundamental mechanisms of soil reinforcement and to develop reliable models for analyses and design methods.

SINTEF Civil and Environmental Engineering has in cooperation with the Norwegian University of Science and Technology performed an initial research project on geosynthetic reinforcement to improve bearing capacity of traffic areas on soft subsoil. The project includes large scale model tests to investigate the interaction between soil materials and reinforcement and the effects of different types of geosynthetic reinforcement and construction solutions. The project is intended to be the first step towards development of a new model for analyses and design of geosynthetic reinforced traffic areas.

2 TEST SET UP

The laboratory test programme was performed in a large test bin. The test bin consisted of an inner and an outer basin. Dimensions of the inner basin are: 12.5 m (length), 1.8 m (width) and 0.75 m (depth). The inner basin is filled with soil. The outer basin was filled with water and the water level could be varied from 0 to 0.75 m above the bottom. Free transport of water between the basins was possible through a drainage layer in the bottom. The test bin is shown in principle in Figure 1.

The test was done as a plate load test using a circular steel plate with a diameter of 150 mm loaded by a computer controlled hydraulic loading

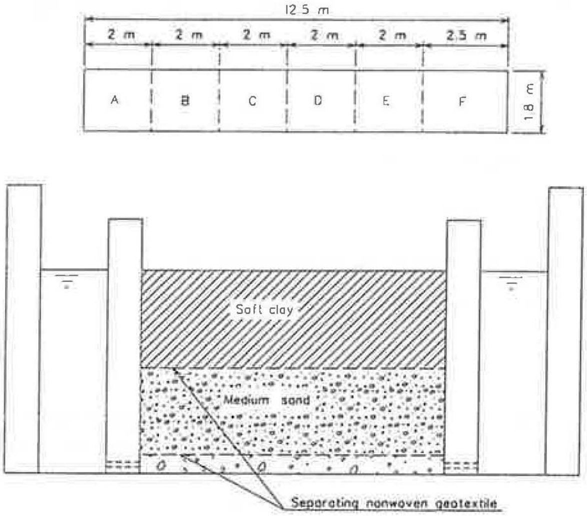

Figure 1 Test bin.

device with a maximum vertical load capacity of 1000 kN. Additional load was obtained by the use of dead weights.

The soil consisted of 3 layers. A 50 mm thick drainage layer of gravel overlaid by 250 mm of sand and on top a 300 mm soft clay. The clay was stirred mechanically to obtain homogenous conditions in the test bin. The undrained shear strength of the clay was measured by vane borings and was in average 2.5 kPa.

The plate loading tests were performed on a bearing layer of 150 mm of crushed rock, grain size 11-16 mm, carefully placed on top of the soft clay. The bearing layer was given three different layouts along the test bin, each of them covering one third of the test bin.

In the sections A and B a nonwoven separating geotextile was placed between the soft clay and the bearing layer. The geotextile was a spunbonded needle punched polyester nonwoven with nominal unit weight 180 g/m^2.

In the sections C and D a woven geotextile for separation and reinforcement was placed between the soft clay and the bearing layer. The geotextile was a multifilament polyester woven geotextile with a nominal short time failure strength of 70 kN/m in both machine and crossways directions.

The sections E an F were similar to section C and D with the addition of a reinforcing geogrid placed in the granular masses, 50 mm above the clay. The grid was a woven geogrid of polyester coated with PVC with mesh size 30x30 mm and a nominal short time failure strength of 50 kN/m in both machine

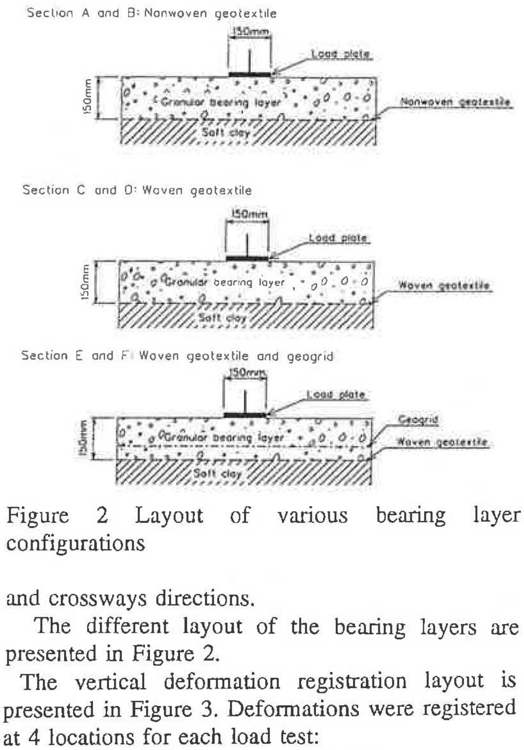

Figure 2 Layout of various bearing layer configurations

and crossways directions.

The different layout of the bearing layers are presented in Figure 2.

The vertical deformation registration layout is presented in Figure 3. Deformations were registered at 4 locations for each load test:

- S0, directly on the loading plate
- S1, at the top of the geotextile on top of the clay, under the centre of the loading plate, measuring the deformations relative to S0, (compression of the bearing layer)
- S2, at the geotextile on top of the clay, 200

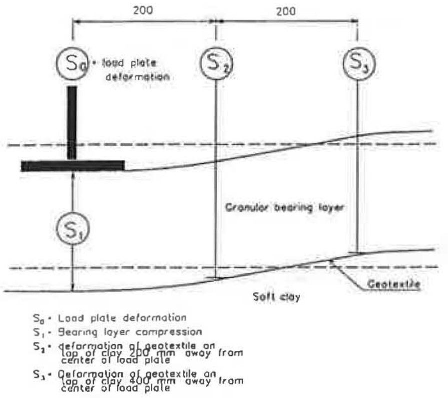

Figure 3 Vertical deformation registration layout

mm from the centre of the load plate
- S3, at the geotextile on top of the clay, 400 mm from the centre of the load plate

In section F, the horisontal movement of the geosynthetics was measured by connecting steel wires, protected by PVC-hoses, to the geotextile and the geogrid. The wires were attached at three locations:

- under the centre of load plate,
- 150 mm and 300 mm away from the centre of the load plate

The horisontal movement of particles in the bearing layer were measured 50 and 150 mm away from the centre of the load plate at three levels:

- just above the geotextile (on top of the clay)
- just above the geogrid (50 mm above the clay)
- 50 mm above the geogrid (100 mm above the clay)

Pore pressure build-up in the clay was measured 100 mm under the clay surface below the centre of the load plate. For section A, the pore pressure gauge was located at the same depth, but at a horisontal distance of 200 mm from the centre of the load plate.

3 TEST PROGRAMME

The test programme included a static and a cyclic loading programme for each of the bearing layer configurations. All the static loading tests, at sections A, C and D, were completed before the dynamic testing programme was started.

The static loading was applied in load steps of 1 kN (56.6 kPa) with 1 minute interval between the steps. Stop criterion for the load was a maximum vertical deformation of 150 mm.

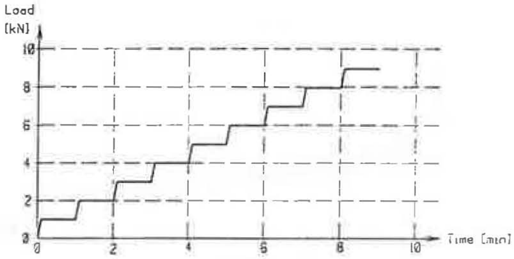

Figure 4 Static loading sequence

Unloading was done in one step. The static loading programme is presented in principle in Figure 4.

The cyclic loading was performed at sections B, D and F, starting with a static load sequence of two load steps up to 2 kN (113 kPa), followed by unloading to 0 kN. Immediately after unloading, a sinusoidal cyclic loading with a frequency of 1 Hz was applied with load amplitudes and intended number of cycles as shown in Figure 5. For some of the tests the intended number of cycles were not reached due to exceedence of the maximum deformation criterion.

4 TEST RESULTS

An extract of the test results are presented in this paper. A distinct failure could not be identified directly from the load deformation curves. A failure criterion must hence be based on an evaluation of the vertical deformations. Generally the measurements provided reliable results although some were disturbed or interrupted due to large deformations.

4.1 Vertical deformations

For the static load, the load-deformation curves for section A (separating nonwoven) and section C (reinforcing woven geotextile) are almost identical up to load step 4 kN (226 kPa). With increasing

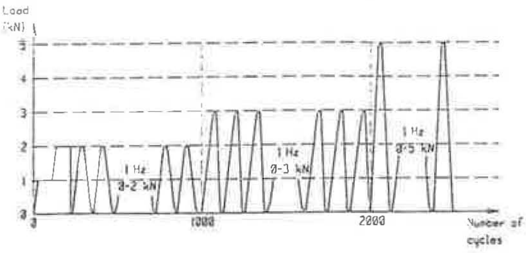

Figure 5 Cyclic loading sequence

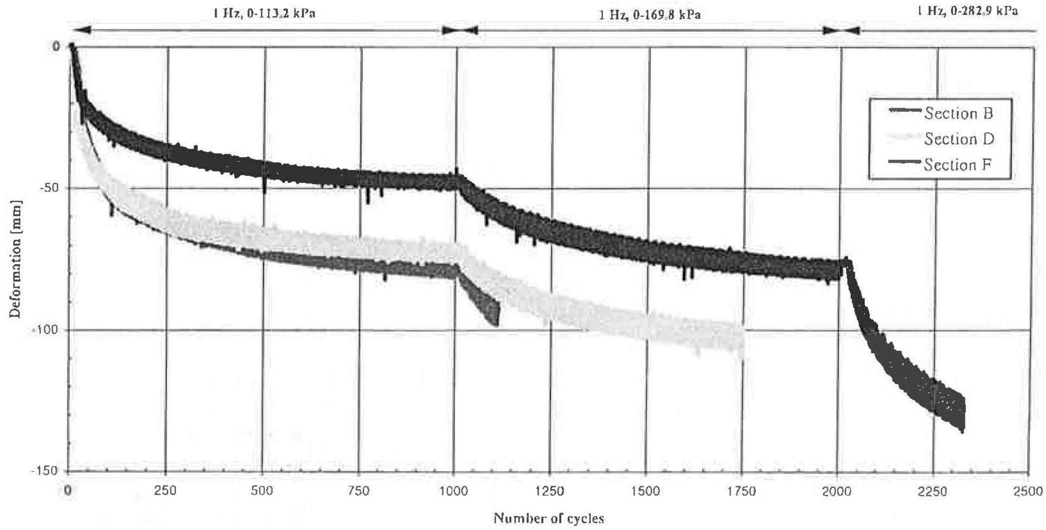

Figure 6 Vertical deformation of load plate, cyclic sequence

load, section A has larger deformations than section C. The maximum deformation criterion is reached at 5 kN (283 kPa) for section A and 6 kN (339 kPa) for section C. Section E (with the two layer solution) has less deformation than the other sections for the same amount of load and the maximum deformation criterion is reached for a load of 9 kN (509 kPa).

For the cyclic load sequence the vertical deformation of the load plate is presented in Figure 6.

The deformations of section B and D start quite similar, but in section B the deformation is about 10 mm larger with increasing number of load cycles. In comparison, the deformations in section F for the same load conditions, are significantly lower for the whole loading sequence. It is worthwile to notice that the same level of deformation (50 mm for load amplitude 0-2 kN) is reached after 100 cycles in section B and 1000 cycles in section F.

Profiles of the vertical deflection of the geotextile are presented in Figure 7. These profiles correspond to the measured deformations after 1000 cycles of load 0-2 kN + 100 cycles of load 0-3 kN for all the sections. There are significant difference in the deflection bowl between the multi-layer solution and the others. The maximum vertical deformation of the multi-layer solution was about 40 % less than for the non woven solution. The deflection bowl of the multi- layer solution is significantly shallower and the influence radius has increased about 25 % compared with the non woven solution.

4.2 Horisontal displacement

The measurements of the horisontal displacement of the geogrid and the grain adjacent to the grid show that the displacements are almost coinciding, except at the early phase of the cyclic loading. Based on the grain movement 150 mm away from the centre of the load plate, a displacement profile is presented in Figure 8. The absolute numbers are not corrected for the effects of wire curvature due to the vertical deformation. It can be seen that the lateral outward movement of the particles is less in the levels close to the geogrid.

4.3 Pore Pressure Measurements

The pore pressure measurements indicate that the increase in pore pressure is directly related to the applied loads for all the tests. The increase is less for the multi layer solution than for the other solutions for the same load.

5 EVALUATION OF RESULTS

The test results have shown that geosynthetic reinforcement increase the bearing capacity of the soft subsoil and have also shown significant differences between different solutions.

The differences in deformation between the separating non woven geotextile and the woven reinforcing geotextile is only visible at high loads

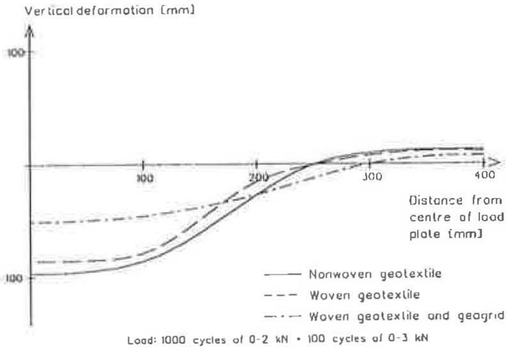

Figure 7 Geotextile deflection profiles

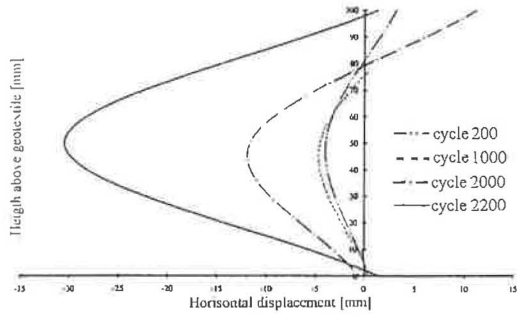

Figure 8 Horisontal displacement of granular particles 150 mm away from the load plate

and large deformations. An increase in the maximum static load of about 20 % was obtained by the woven geotextile compared to the non woven. The cyclic loading showed that the woven geotextile provided larger resistance to cyclic deformations compared to the non woven. This was especially visible at large load levels and high number of cycles. This indicates that the reinforcing mechanism for the woven geotextile is mainly related to the "tensioned membrane effect" /4/ which requires quite large deformations.

The two layer solution gave a significant reduction of the displacement of the load plate compared with the other solutions. This reduction is clear both for the static and the cyclic loads and is visible also at small loads and deformations. The total deformations were reduced about 80 % compared with the non woven solution for the same load level. The number of load cycles required to obtain a comparable level of deformation is 10 times higher for the two layer solution than for the nonwoven solution.

The amount of increase in the pore pressure, correlated with the deflection profile of the subsoil

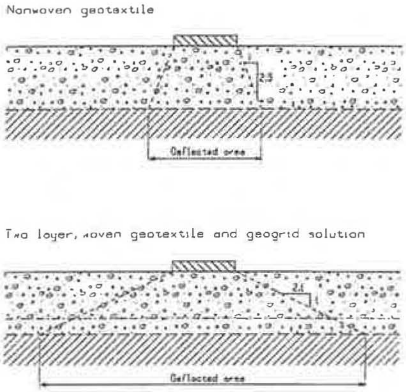

Figure 9 Load distribution for non woven geotextile and two layer solution

surface, show that the two layer solution provides a stiffer bearing layer, giving a larger deflection area with less maximum deflection. The radius of the deflection area is increased for the two layer solution compared with the non woven solution. The results indicate that the load spreading, which can be illustrated by an equivalent load spreading angle, is significantly increased in the two layer solution, Figure 9.

The measurements of the movement of the grain particles, as presented in Figure 8, indicates that the geogrid provides a lateral restraining of the materials. This is also verified by the measurements of the compression of the bearing layer which is significantly less for the two layer solution compared with the others.

6 CONCLUSIONS AND RECOMMENDATIONS

The large scale laboratory tests have verified the beneficial effects of geosynthetic reinforcement to improve the bearing capacity of granular bearing layers on soft subsoil.

The beneficial effects of the woven reinforcing geotextile are only visible at large deformations but results in an improved ultimate bearing capacity of about 20 % compared with the separating non woven geotextile. The beneficial effect is believed to be mainly related to the tensioned membrane effect.

The two layer solution with a woven geotextile in the bottom and a geogrid in the granular masses, results in significant improvement of the deformation characteristics. Compared to the unreinforced solution the vertical deformation is reduced about 80% for the same amount of load and the ultimate bearing capacity is about doubled. For the cyclic loading the number of load cycles to obtain a defined level of deformation is ten times higher for the two layer solution compared with the non woven solution.

The two layer solution provides a stiffer bearing layer resulting in an increased load spreading and a reduced degreee of mobilisation of the subsoil.

An increase in overall stiffness of the bearing layer may give several positive effects. The potential for reduction of vertical deformations of traffic areas due to reduction of horisontal movement of bearing layer material and by plastic deformations of the subsoil are obvious. It may also provide other beneficial options. Some possible applications are :

- reduction of differential settlements of embankments on soft subsoil (railway embankments, road widening etc.)
- reduction of traffic induced vibrations on soft subsoil (e.g high speed trains)

The development of models for analysing the mechanisms and effects of geosynthetic reinforcement is crucial to improve the understanding and to use this to achieve better construction solutions.

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