The influence of soil and type of geosynthetics on the bearing capacity of roads

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ABSTRACT: Field experiences have shown that the use of geosynthetics improves the trafficability of unpaved roads on soft subsoil. Furthermore the height of the base course and therefore the amount of high quality geomaterials e.g. crushed gravel can be reduced. Until now the design is mainly based on empirical approaches. The height of the base course is increased until the unpaved road reaches a proper bearing behaviour or it is decided to use a certain base course height that gives conservative results. However several design approaches have been published that do not withstand the experiences gained in field. There are plenty of examinations shown throughout the literature, confirming the principle of bearing mechanism but mostly cover only individual effects. Therefore they can not be extended to an overall theory and design approach that account for all important variables. In the present research work series of loading tests on geotextile reinforced unpaved roads were carried out that aim for precise guidelines in choosing proper geosynthetics and designing a sufficient base course height that cover different requirements given by the field situation.

1 INTRODUCTION

The bearing capacity of unpaved roads is mainly influenced by the type of material used for the base course, the height, kind of installation and its compaction, the strength of the subsoil and the interaction between a reinforcement between the base course and the subsoil. In the literature lots of tests are reported where many parameters are varying throughout a test series and therefore do not allow to find a suitable design approach that is also independent from the special type of the reinforcing products used in the test series.

In an ongoing research work the influence of some parameters are picked up and examined in detail. After finite element calculations that were aimed to find decisive boundary conditions and after trying to review main parameters and their influence on the bearing capacity, small scale model tests with static and cyclic loadings in a test tank measuring 0.5 m in diameter were carried out. Based on these tests large scale model tests in a pit with 3.3 m by 5.0 m and realistic installation conditions and also static and cyclic loadings were carried out. Field tests under site conditions are planned to follow.

For this presentation some of the small and the large scale tests are chosen to be reported.

2 SMALL SCALE MODEL TESTS

2.1 *Test device*

To examine fundamental factors of a geosynthetic reinforced unpaved road a model scaled test was set up. The test device (Fig. 2.1) was designed after detailed analysis using a finite element code was carried out.

A layer of soft soil (subsoil) was inserted within a test tank owing a diameter of 50 cm. On top the soft subsoil a geosynthetics was placed and a base course was compacted by static force. Using a load piston (diameter 5 cm) a static and cyclic load respectively was applied. The settlement of the load piston and the deformations of the base course were monitored. In addition in some tests pore water pressures were measured within the soft subsoil.

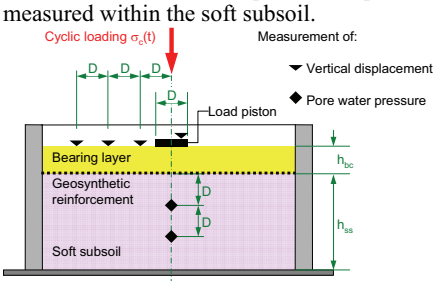

Fig. 2.1: Setup of the models scaled loading tests

2.2 *Placement of the soft subsoil*

For each loading test the fine grained soft subsoil was remoulded newly and inserted homogenous without air bubbles. The height of the soft soil layer was at least $h_{ss} = 20$ cm. The properties of the soft soil are given in Fig. 2.2. For inserting the soft subsoil it was mixed at a water content of 80 M.-% that is roughly twice the liquid limit. In the test tank the subsoil was consolidated for 2 days under a static load using a massive plate. Squeezing of the liquid soil was prevented by using o-ring sealing. The consolidation stress was varied in order to obtain a certain undrained shear strength c_u. By this method it is possible to get very homogenous density, water content and shear strength. This was checked before the loading tests by measuring the undrained strength c_u using a pocket vane and the water. The same properties in addition to the density ρ were measured also after the loading test.

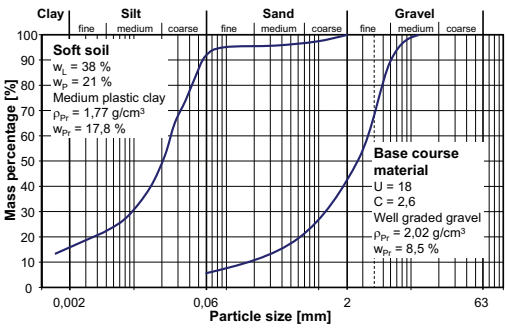

Fig. 2.2: Soft soil and base course material used in the model scaled loading test

2.3 *Geosynthetics and base course material*

To meet the geometry and forces that are adapted to the model scaled loading test a grid-like geosynthetic (GT-1) and a non-woven geosynthetic (GT-2) were choosen whose mechanical strength and stiffness are by far lower than geosynthetics that are used in proper field conditions (table 1).

Table 1: Parameters of model type "Geosynthetics"

	GT-1 (grid-like)		GT-2 (non-woven)	
Direction	md	cmd	md	cmd
Tensile strength [kN/m]	19.6	12.8	1.9	2.7
Elongating at failure [%]	2.9	2.6	18.0	33.0

After consolidation of the soft soil the geosynthetic was placed firmly on top the smooth surface of the subsoil.

The base course material (Fig. 2.2) was inserted having a homogenous water content of w = 5 M.-%. The base course was compacted to a dry density of $\rho_d = 1.85$ g/cm^3 by a loading disc under a defined load for 2 minutes. The short duration of loading ensures that there is no further consolidation and thus strength gain of the cohesive subsoil. The base course height was defined relative to the diameter of the loading piston and varies in between 0.5 D and 1.5 D.

2.4 *Test procedure*

As main output quantity used in the evaluation of the test series is the bearing capacity of the subsoil several tests were done by loading the soft subsoil itself and to vary the undrained strength c_u of the soft soil. Later test series on unreinforced and reinforced bearing layers were carried out.

There were two types of loading in the model scaled tests. First a static load increasing by a constant rate of loading was applied. The bearing capacity was defined to be the medium stress under the loading piston that was measured at a settlement of 20 mm or s / D = 0.4 respectively.

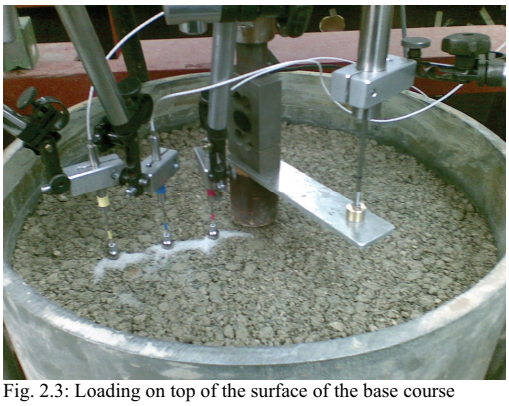

Fig. 2.3: Loading on top of the surface of the base course

Second a test series featuring a cyclic load was realised. The sinusoidal loading stress varied between 5 kPa and 105 kPa at a frequency of 1 Hz. For evaluating the test results the settlement at a certain number of cycles up to 100 000 was taken.

2.5 *Static loading tests*

Exemplarily the static bearing capacities q_s of the test series where the geosynthetic GT-2 was used are shown for different base course heights of $0.5 \cdot D$, $0.75 \cdot D$, $1.0 \cdot D$ and $1.5 \cdot D$ at an undrained shear strength of the soft soil between $c_u = 5$ kPa and 35 kPa.

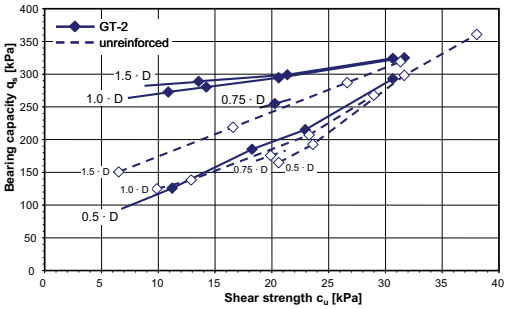

Fig. 2.4: Results of the static loading tests featuring the geosynthetic GT-2

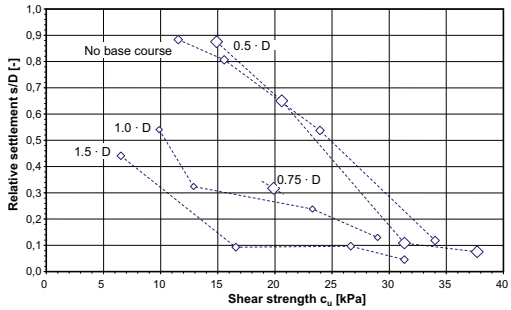

Fig. 2.5: Settlement of the load piston after 100 000 cycles, unreinforced systems

The test results show that for low base course heights (0,5 · D) there is little improvement of the bearing capacity independent of the used geosynthetic. For base course heights larger than 0.75 · D and especially for low subsoil strengths the bearing capacity rises clearly. For the applied loading in the model scaled test the gain in bearing capacity is little for higher undrained strengths of the subsoil from c_u = 30 kPa and more.

An enlargement of the base course height with layers h_{bc} > 1.0 · D gives no further increase of the bearing capacity. Table 2 is showing the bearing capacity at an undrained strength of c_u = 20 kPa and the factor of strength gain due to the non-woven geosynthetic GT-2.

Table 2: Static loading, bearing capacity q_s at c_u = 20 kPa

Height of bearing layer h_{bc}	Bearing capacity q_s		
	Unreinforced	Reinforced GT-2	Factor of increase
0.5 · D	155	195	1.3
0.75 · D	175	255	1.5
1.0 · D	185	290	1.6
1.5 · D	240	300	1.3

2.6 *Cyclic loading tests*

Under the same conditions (subsoil strength, base course height and used geosynthetics) as the static loading tests series of cyclic loading tests were conducted.

The results shown in this paper are based on the relative settlement s / D measured at the load piston after 100 000 cycles. For the unreinforced bearing layers the test results are given in figure 2.5. Similar to the behaviour in the static loading tests the unreinforced systems are showing a reduction of the settlement if the base course height is 0.75 · D or more.

Using a base course height of 0.5 · D the bearing capacity is equal to the one that is measured on the soft subsoil itself. In this case the use of geosynthetics in between the soft subsoil and the base course the leads to a considerable reduction of the settlement under cyclic loading (Figure 2.6).

The application of the rigid grid-like GT-1 results in a further settlement reduction compared to the more flexible and soft non-woven geosynthetic GT-2. The influence of reinforcement based on the geosynthetics decreases continuously up to an undrained subsoil strength of c_u = 30 kPa.

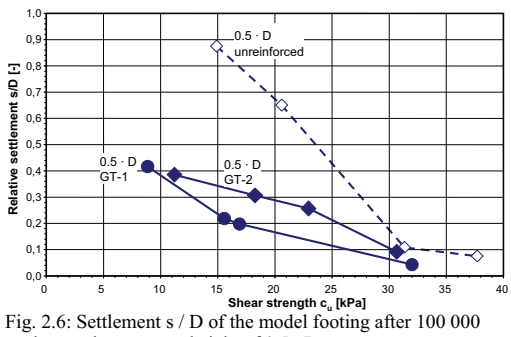

Fig. 2.6: Settlement s / D of the model footing after 100 000 cycles at a base course height of 0.5 · D

Table 3: Comparison of the results at c_u = 20 kPa, h_{bc} = 0.5 · D

System	Height of base course h_{bc}	Relative settlement s / D	Settlement reduction
unreinforced	0.5 · D	0.67	-
reinforced GT-1	0.5 · D	0.17	75 %
reinforced GT-2	0.5 · D	0.29	57 %

Table 3 sums up the relative settlement s / D for a base course height of h_{bc} = 0.5 · D and a subsoil strength of c_u = 20 kPa. At this base course height and subsoil strength the effectiveness of a geosynthetic layer in the model scaled test is at maximum. It is becoming apparent that even a geosynthetic having a low tensile strength (GT-2) is leading to a reduction in settlement of 57 % compared to the un-

reinforced case. The stiffer grid-like geosynthetic GT-1 is even reducing the settlement by 75 %.

At subsoil strengths higher that $c_u = 30$ kPa the influence of both base course height and geosynthetic reinforcement is decreasing obviously ($\Delta(s / D) < 0.1$). This is clearly given by the small values of s / D that are shown in table 4.

Table 4: Results of the cyclic loading tests using the non-woven geosynthetic GT-2

Subsoil strength c_u	Base course height h_{bc}	Relative settlement s / D
10	0.5 · D	0.40 *)
10	1.0 · D	0.20 *)
10	1.5 · D	0.15 *)
20	0.5 · D	0.28
20	1.0 · D	0.16
20	1.5 · D	0.13
30	0.5 · D	0.10
30	1.0 · D	0.06
30	1.5 · D	0.04

*) extrapolated values

3 LARGE SCALE MODEL TESTS

3.1 *Test setup*

Unpaved roads reinforced by geosynthetics are built mainly for temporary site traffic and for roads with lower priority such as rural roads and forest trails. This situation was simulated by using a large scale test within a pit having an area of 3.3 m by 5.0 m by placing the subsoil, the geosynthetic reinforcement and the base course as shown in figure 3.1.

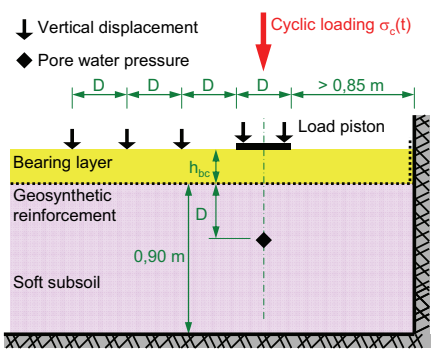

Figure 3.1: Large scale static and cyclic loading tests

By a circular and rigid steel plate (diameter D = 300 mm) a static and cyclic load was applied on top of the bearing layer. The resulting settlements that are time and cycle dependent were registered as well as the varying pore pressure in the soft subsoil.

The test setup and the location of the transducers are shown in figure 3.1.

3.2 *Subsoil material, preparation and installation*

The material used for the soft subsoil is a clay with low plasticity that is a by-product of a nearby plant producing aggregates for road construction. This clay was delivered in a very homogenous quality having nearly constant water content. The plasticity and the grain size distribution are shown in figure 2.2. The clay was installed in 3 layers with a water content of 18 M.-% each compacted by a roller (1500 kg) with stamp feet. The full height of the subsoil was about 0.9 m.

After the compaction the density ρ and the water content w were determined in a grid 1 m by 1 m as well as the undrained shear strength c_u (vane shear test). The tests showed a very low span of the results of the shear strength c_u and of the water content.

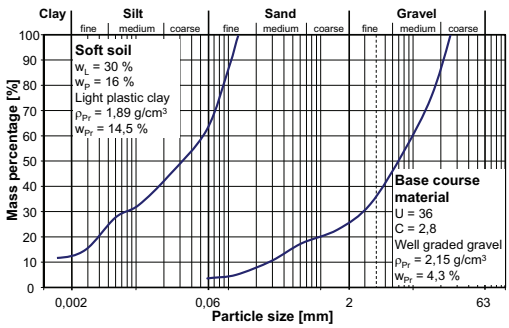

Fig. 3.2: Soils used in the large scale model tests

Fig. 3.3: Subsoil installation for the large scale tests

3.3 *Geosynthetics and base course material*

The reinforcement layers were a non-woven (GT-3), a geogrid (GT-4) and a compound material (GT-5), consisting of the previously mentioned products (GT-3 and GT-4, table 5).

Table 5: Parameters of Geosynthetics used in large scale tests

	Tensile strength [kN/m]		Elongation at failure [%]	
Direction	md	cmd	md	cmd
Non-woven GT-3	6.5	10.0	50	30
Geogrid GT-4	40.0	40.0	8	8
Compound material GT-5	40.0	40.0	8	8

The base course material was a well graded gravel that was installed in different heights between 0.5 · D (150 mm) and 1.5 · D (450 mm, figure 3.2). The water content of the base course was 5 M.-% for each test setup and the dynamic compaction was done in 4 passes with a 140 kg vibratory plate.

3.4 *Cyclic loadings*

Table 6 is showing the parameters for the different test setups. The variation was in the reinforcement, the height of the base course and the shear strength of the subsoil.

Table 6: Test parameters examined in the cyclic loading tests

reinforce-ment	shear strength of subsoil c_u [kPa]	base course height h_{bc}	cyclic loading $\sigma_{c,max}$ [kPa]
none	30	0.5 · D	350
none	30	0.5 · D	450
none	30	1.0 · D	450
none	30	1.0 · D	550
none	30	1.5 · D	550
GT-3	30	0.5 · D	350
GT-3	30	0.5 · D	450
GT-3	30	1.0 · D	450
GT-3	30	1.0 · D	550
GT-3	30	1.5 · D	550
GT-3	60	0.5 · D	350
GT-3	60	0.5 · D	450
GT-3	60	1.0 · D	450
GT-3	60	1.0 · D	550
GT-3	60	1.5 · D	550
GT-4	30	0.5 · D	350
GT-4	30	0.5 · D	450
GT-4	30	1.0 · D	450
GT-4	30	1.0 · D	550
GT-4	30	1.5 · D	550
GT-5	30	0.5 · D	350
GT-5	30	0.5 · D	450
GT-5	30	1.0 · D	450
GT-5	30	1.0 · D	550
GT-5	30	1.5 · D	550

The cyclic loading defined by $\sigma_{c,max}$ (figure 3.4) was applied with values of 350 kPa, 450 kPa and 550 kPa. Since no large deformations occurred during the test up to 100 000 cycles were applied with a frequency of 0.3 Hz. To get information about the differences between bearing behaviour under static and cyclic loading both types of loadings were conducted. Results of static loading are not shown in this work.

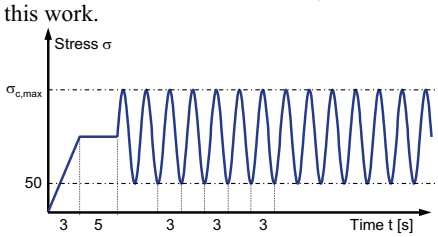

Fig.3.4: Cyclic loading

In this report four test series are discussed consisting of an unreinforced system and systems with the reinforcement layers GT-3, GT-4 and GT-5. The base course heights varied between 0.5 · D and 1.0 · D and the cyclic loading $\sigma_{c,max}$ between 350 kPa and 550 kPa. The figures 3.5 to 3.8 show the settlement normalized by the diameter of the loading plate (s / D) plotted against the number of cycles.

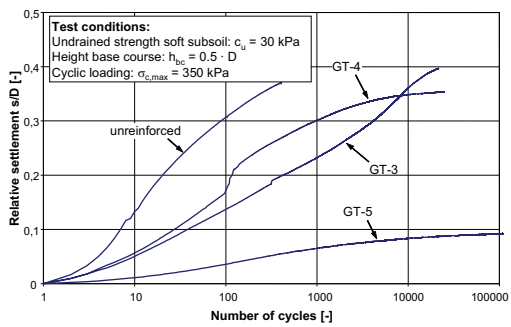

Figure 3.5: Cyclic loading $\sigma_{c,max}$ = 350 kPa, c_u = 30 kPa, h_{bc} = 0.5 D

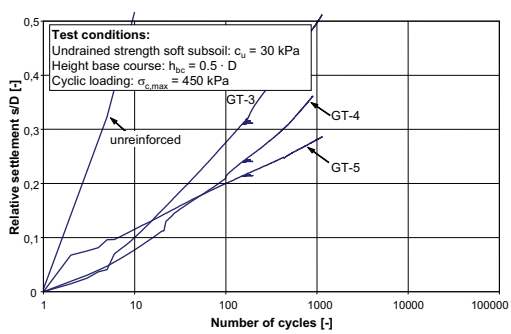

Figure 3.6: Cyclic loading $\sigma_{c,max}$ = 450 kPa, c_u = 30 kPa, h_{bc} = 0.5 D

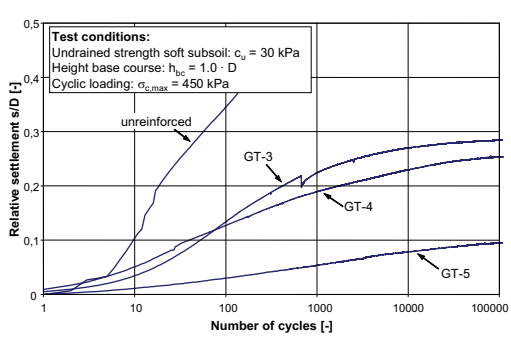

Figure 3.7: Cyclic loading $\sigma_{c,max}$ = 450 kPa, c_u = 30 kPa, h_{bc} = 1.0 D

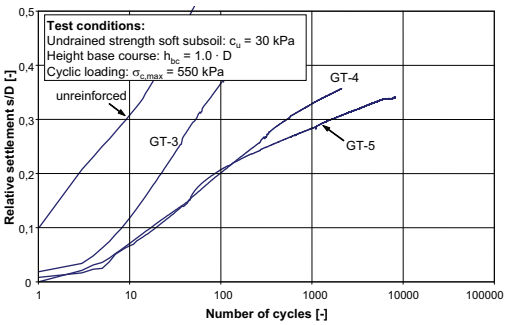

Figure 3.8: Cyclic loading $\sigma_{c,max}$ = 550 kPa, c_u = 30 kPa, h_{bc} = 1.0 D

Figures 3.5 to 3.8 show that at a small base course height ($h_{bc} = 0.5 \cdot D = 150$ mm) and a moderate loading ($\sigma_{cmax} = 350$ kPa; figure 3.5) there is hardly no difference between the products GT-3 and GT-4 but a visible difference of the performance of those products to the unreinforced system. There is a significant settlement reduction by using product GT-5.

Increasing the load ($\sigma_{cmax} = 450$ kPa; figure 3.6) by keeping all other boundary conditions constant leads to increasing deformations of the compound product GT-5 as well. All products behave very similar under a higher load and low base course height.

Keeping this loading (450 kPa) and increasing the base course height ($h_{bc} = 1.0 \cdot D = 300$mm; figure 3.7) shows again the benefit of the compound material. The difference between the other two products (GT-3 and GT-4) is negligible.

This changes by a further increase in the cyclic loading ($\sigma_{cmax} = 550$ kPa; figure 3.8). Keeping the other conditions constant, the non-woven (GT-3) fails after a small number of cycles. The stiffer products GT-4 and GT-5 show a better behaviour and similar deformations at low numbers of cycles. This changes with higher numbers of cycles where the compound material presents a slightly better behaviour than the geogrid alone.

A summarizing graph showing the settlements at a cycle number of n = 1000 with most of the tests meanwhile carried out is given in figure 3.9.

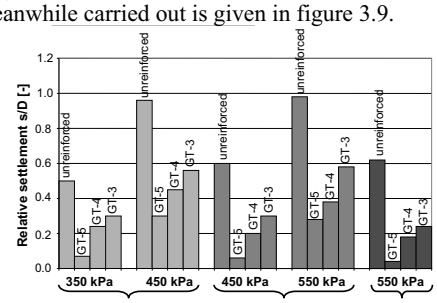

Figure 3.9: Summary of relative settlement (s/D) after n = 1000 cycles at an undrained shear strength c_u = 30 kPa of the subsoil

4 CONCLUSION

Within the actual research work about 60 small scale and about 40 large scale tests were carried out under static and cyclic loading following strict boundaries according to soil installation and loading conditions. The tests are in good concordance with experiences gained in situ on real sites and will be referred to other field and laboratory tests (e.g. Cuelho et al.; Perkins et al.; Christopher, et al., Floss, et al., Laier / Bräu) in the next steps. Also the results will lead to a calibration of finite element calculations that were done in the beginning of this research work. The evaluation of the test results will be continued and presented in the final report of this research project. Afterwards additional large scale tests with different types of geosynthetics are planned.

5 ACKNOWLEDGMENT

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6 LITERATURE

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