Model Tests for Analysis of the Bearing and Deformation Behaviour of Column Foundations
Essais-modèles pour l'examination de la portance et de la déformation de colonnes ballastées

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ABSTRACT: This contribution reports on large and small scale model tests on column foundations, with special analysis of the bearing and deformation behaviour of geotextile-coated sand columns under static and cyclic loads. With the model tests and test results on column foundation from literature, it is possible to make a direct comparison of the bearing and deformation behaviour between column foundation with or without coating at different foundation conditions.

RÉSUMÉ: Dans cette contribution sont présentées des essais-modèles à grande et petite échelle sur des réalisations de colonnes ballastées, dans lesquels sont surtout examinés la force portante et la déformation de colonnes, enrobés d'un manteau géotextile sous sollicitation statique ou cyclique. Par ces essais-modèles et par la contribution d'essais à travers la littérature, on peut établir une comparaison directe du comportement de portance et de déformation de colonnes ballastées avec ou sans manteau, dans de différentes qualités de sols.

1 INTRODUCTION

Today in geotechnique the experimental modeltechnique is still a good method to solve general as well as complex mechanical problems, despite of the increasing numerical possibilities. To analyze the bearing and deformation behaviour of geotextile-coated sand colums under definite boundary conditions and to prove the effectiveness of the system, large- and small scale model tests were carried out.

In contradiction to conventional stone columns geotextile-coated colums can be used for traffic embankments as soil improvement in soft soil or peat, due to the radial supporting effect of the coating combined with the surrounding soft soil. The geotextile is subjected to ring tension forces, (Kempfert et al. 1997).

With the model test results and under consideration of test results on conventional column foundation from literature, a direct comparison of the bearing and deformation behaviour between column foundation with or without coating at different foundation conditions can be made.

2 TEST DESIGN AND CONCEPT

In practice column foundations were normally arranged in different grids. The concept of the model tests is based on the `unit cell concept`, which means the consideration of a single column in an virtually infinite column grid. The influence area of this single column in a triangular grid is a hexagonal element, which can be transformed in to a circular element with equal area. Therefore an axially symmetric model is received. Figure 1 shows the outline of the simplified axially symmetric model.

Because of the general similarity principle, soilmechanical processes can be investigated in a small scale. To obtain the scaling law relationships decisive parameters of the system have to be derived with the dimensional analysis (Görtler 1975) to dimensionless products, which must have the same value in both systems. Though the strict standards at the similarity principle are difficult to fulfill (Walz 1982).

To avoid scale effects largely, first large scale model tests were carried out to analyse the fundamental relations between load, settlement, load distribution and ring tension forces in the coating. With the continuing small scale model tests the decisive parameters for the bearing behaviour and the influence on the load settlement curves are analyzed.

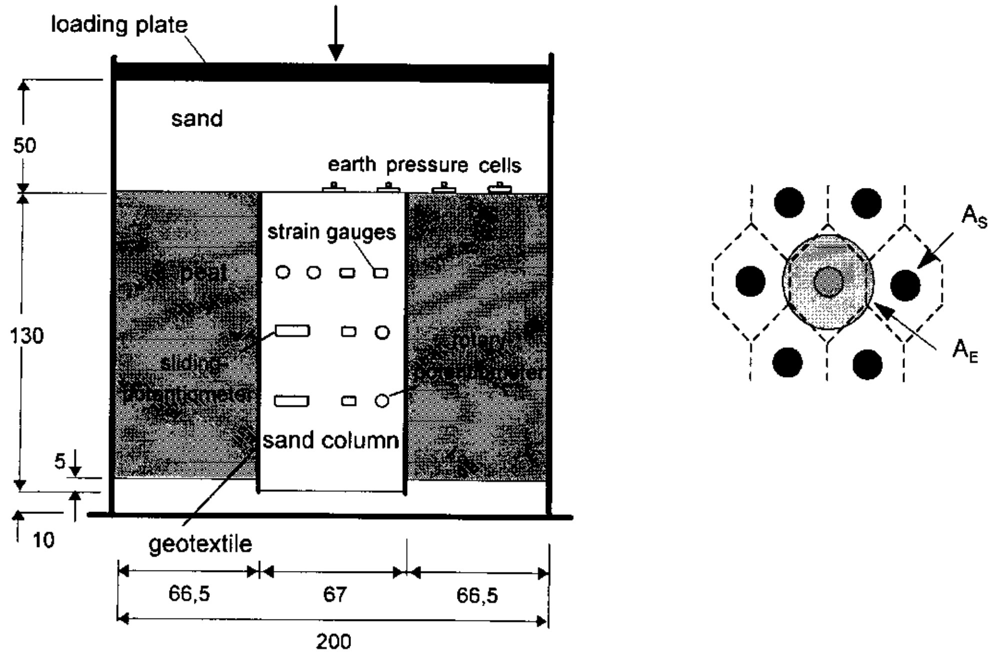

Figure 1: Large scale model test and outline of an unit cell in a grid

In the small scale model tests just the load and the corresponding settlements were measured. In the model tests with the scale 1:1 an extensive instrumentation was carried out. Measuring devices were settlement gauges, load cells, earth pressure cells for determination of the load distribution in the column head level, and strain gauges and potetiometers for the measurement of the ring tension forces. Figure 1 shows the dimensions of a large sclae model test and the location of the measurement devices.

The test soil were a slight-fibrous peat and a medium grained sand. The soilmechanical parameters are shown in table 1. The coating in the large scale model test was a sewn geotextile of polyester threads with a stiffness of J = 800 kN/m.

Table 1. Soilmechanical parameters

Soil	γ [kN/m³]	γ_{sat} [kN/m³]	w [%]	ϕ'[°]	c'[kN/m²]	ψ [°]	E_S* [MN/m²]
Sand	18	20	1	38	0	8,5	28,5
Peat	8	11	340	24	8,5	0	0,7

*Oedometric modulus at 100 kN/m².

3 FULL SCALE MODEL TESTS

First the static loading was increased up to 400 kN/m² and applied to the loading plate over the whole test area to determine the bearing capacity of one geotextile-coated sand column. The influence of a heightening of the groundwater level in the state of serviceability was examined in a second test (figure 2).

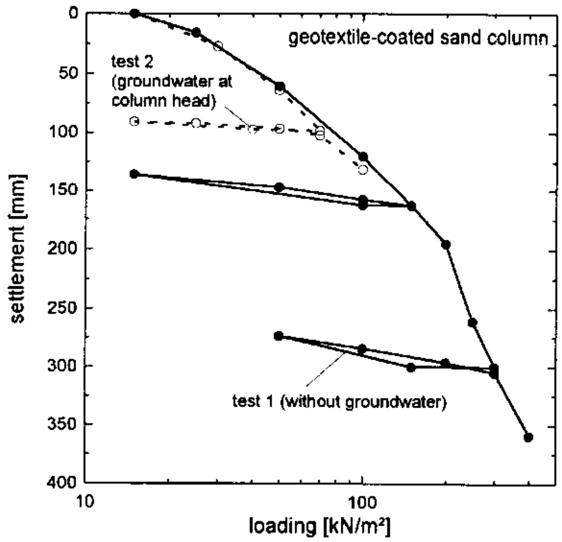

Figure 2: Measured settlements under static loading

The horizontal support of the column and therefore the bearing and deformation behaviour of the system was slightly changed by the hieghtening of the groundwater level, which can be seen in the small differences of maximal 1,0 cm at a loading of 100 kN/m². At a loading of 200 kN/m² a `crack` can be seen in the load settlement curve and in the following a significant increase of the settlement rates. This reaction can be put down to the tear of the coating. This could also be determined by the strain measurements. Though the tear of the coating cannot be treated as equivalent to the failure of the system. Because of the increase of the earth pressure in the soft soil, the high vertical pressure and the compaction of the soil a new state of equilibrium was enabled.

The cyclic loading should simulate a live load (figure 3). The first cyclic loading-sequenz had a high cyclic and a low static load increment and simulates an embankment with a low height and corresponding high live load. On the other hand the second cyclic loading-sequenz simulates a high embankment with a low cyclic and a high static load.

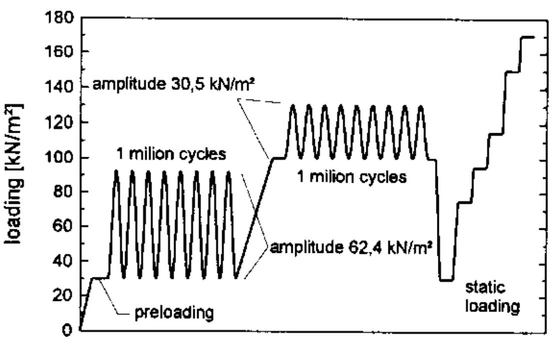

Figure 3: load diagramm

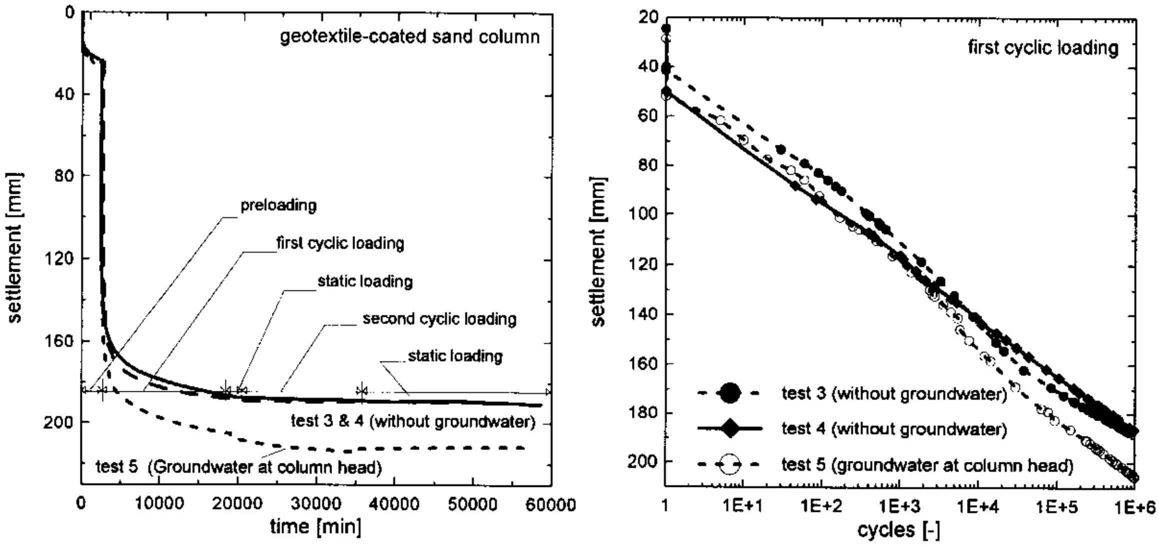

Figure 4: Settlements in linear and half logarithmic graph

At a cyclic loading of the system there are much higher settlements compared to static loading at the same loading level. A decisive factor for that is the relation between the cyclic loading amplitude and the static loading. The settlements occur during the first cyclic loading sequenz very quickly and indicate a linear course in the half logarithmic graph (figure 4). Even with a higher stress level during the second cyclic loading sequenz further settlements were very low because of the high cyclic preloading.

4 SMALL SCALE MODEL TESTS

At most soilmechanical model tests exists the following power law between the load P and the deformation u (d_i = geometrical dimension; P_0 = reference load)

$$\frac{u}{d_i} = a \cdot \left(\frac{P}{P_0}\right)^{\alpha} \tag{1}$$

If the exponent α is constant the results are straight lines in a double logarithmic graph with the gradient α and the axis segment a. Such a dimensionless graph of the results is not sufficient for the transposition of the model test results to prototypes, if the deformation behaviour of the soils depend on the stress level. This can be recognized, as the straight lines are parallel with different axis segments if the model tests are carried out in variable scales. The existance of a scale effect and the quantitative effect of the stress level can be recorded by a model-family.

The small scale model tests should be used for the examination of the change of the test results depending on the geometrical parameters. It can be assumed, that the percentage deviation between the test results with different geometrical conditions is independent of the stress level or the scale effects.

At a constant area ratio of 12 % (corresponding to the full scale model tests) first the model scale was varied, using a coating with a stiffness that satisfies the scaling law. The model scales were 1:6,5; 1:11,5 and 1:13. By the model family no visible scaling effect could be recognized. For the analysis of the effectiveness model tests without a column and with and without coating were carried out (figure 5).

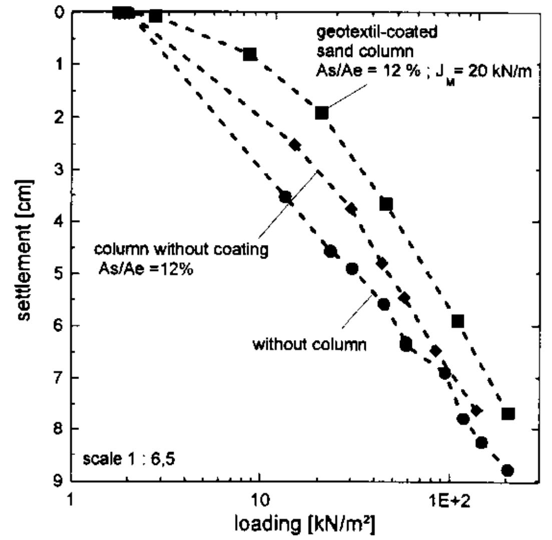

Figure 5: Settlements without column, without coating and geotextile-coated sand column (scale 1:6,5)

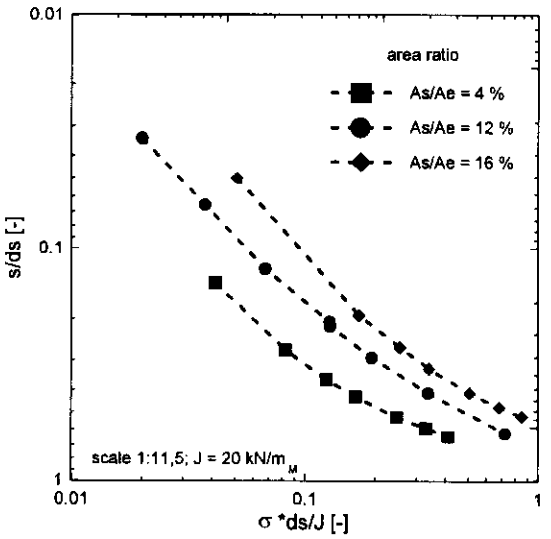

Figure 6: Influence of the area ratio (d_S = column diameter, J = geotextile stiffness)

It can be seen, that by using a coating a significant reduction of the settlements can be achieved. In the following the area ratio was varied by using different diameters of the test cylinder. Figure 6 shows, as expected, that, apart from the stiffness of the geotextile by same soil conditions the reduction of the settlements is determined by the area ratio. The functions in figure 6 can be approximated through straight lines in the double logarithmic scale.

5 COMPARISON WITH TEST RESULTS GIVEN IN LITERATURE

For examination of the effectiveness of coated columns and not coated columns, the results of the model tests and one field test measurement (A_S/A_E = 30%; J = 2000 kN/m) was compared with the results of tests (field tests and model tests for columns without coating) given in literature. Although all test conditions are not comparable, the calculated settlement ratios β (settlement without columns/settlement with columns) in the range of working stresses are combined and shown in figure 7 depending on the area ratio.

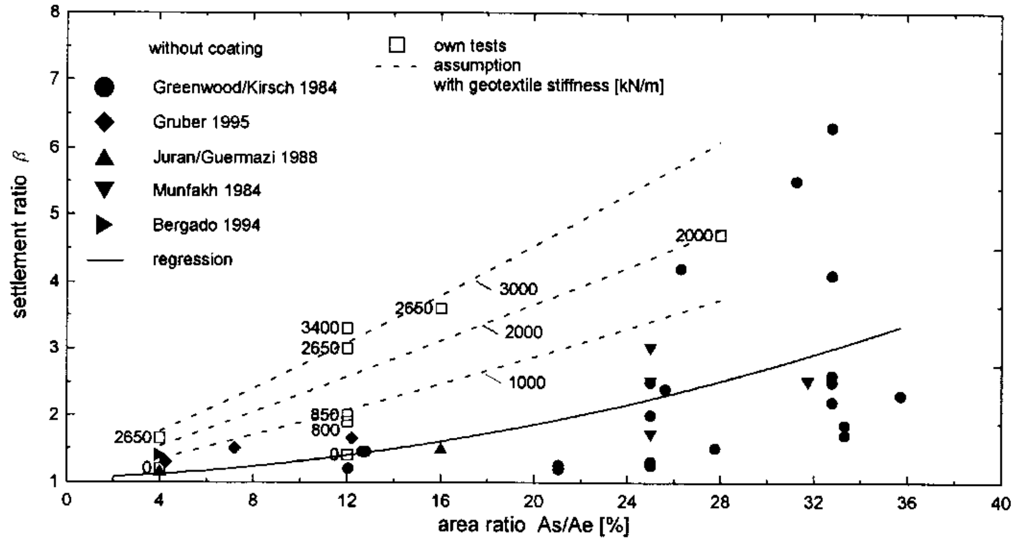

Figure 7: Settlement ratio for column foundations depending on the area ratio A_S/A_E

The settlement ratios of the geotextile-coated sand columns are generally higher than a regression curve for columns without coating. The dashed lines are assumtions based on the model test results. By increase of the geotextile stiffness an expansion of the settlement ratios is shown.

6 SUMMARY

With the large- and small scale model tests an analysis of the bearing and deformation behaviour of stone- and sand columns with- or without coating was carried out. By the model tests and the results of column tests given in literature could be shown, that by use of a coating a further reduction of the settlements in comparison to columns without coating can be achieved.

The results of the model tests shall be used to optimise planning and dimensioning of column foundations for soil improvement and to develop an analytical or numerical calculation and design model for geotextile-coated sand columns.

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