Landmarks in Earth Reinforcement, Ochiai et al. (eds),
© 2001 Swets & Zeitlinger, ISBN 90 2651 863 3

Practical aspects of the design of deep geotextile coated sand columns for the foundation of a dike on very soft soils

M. Geduhn & M. Raithel
Engineering office Kempfert + Partner Geotechnik, Germany

H.-G. Kempfert
Institute of Geotechnique, University of Kassel, Germany

ABSTRACT: This paper presents an investigation of a fundamental suitability of a new foundation system "geotextile coated sand columns" (GCC/GSM) to the foundation of a dike on very soft soils (sludge). This bearing system is a further development of the already known column foundations such as vibro displacement piles and granular piles. In the future, the foundation system GCC/GSM is intended to be used for water engineering projects in very soft soils.

1 INTRODUCTION

The foundation system "geotextile coated sand columns" (GCC/GSM) is a further development of the already known column-foundations such as vibro displacement piles and granular piles. In contrary to conventional column foundations, coated columns can be used as a ground improvement in very soft soils, for example peat or sludge (undrained shear strength $c_u < 15$ kN/m²). On the basis of the known procedure for calculation and dimensioning of gravel and sand columns an analytical calculation model has been developed taking the geotextile coating into account (Raithel & Kempfert 1999). The new foundation system has proved worth as regards many traffic-road and railway projects in Germany and the Netherlands. In the future, this bearing system is intended to be used for water engineering projects in very soft soils. For this reason, the fundamental suitability of the above mentioned GCC-System to a dike foundation on a very soft soil (sludge) as a basic foundation system has been investigated.

2 SMALL SCALE MODEL TESTS (SCALE 1:10)

2.1 *Model test boundary conditions*

2.1.1 *Model theory*

Because of the principle of similarity, mechanical behavor of soil can be investigated in a small scale. To obtain the scaling law relationships de-cisive parameters of the system have to be derived with the dimensional analysis to dimensionless pro-ducts, which must have the same value in both systems (model scale to true scale) (Görtler 1975). Hence these model laws are decisive:

Table 1. Decisives model laws (index m=model, n=prototype)

Term	unit	model law
Settlement	cm	$s_m = 1/\lambda \cdot s_n$
Geotextil stiffness	kN/m	$J_m = 1/\lambda^2 \cdot J_n$
Force	kN	$P_m = 1/\lambda^3 \cdot P_n$
Load	kN/m²	$\sigma_m = 1/\lambda \cdot \sigma_n$

2.1.2 *Soil mechanical parameters and geotextil*

The test soils were a very soft soil called sludge and a medium grained sand. The soil parameters are shown in table 2. The coating in the small scale model test was a synthetic material of poly-ester with a stiffness of J = 20 kN/m. The true scale stiffness of the geotextil coating is J = 2000 kN/m.

Table 2. Soil mechanical parameters

Soil type	γ / γ [kN/m³]	w [%]	φ' [°]	c' [kN/m²]	E_{oed} [kN/m²]
Sludge	6 / 16	65	34	5	1800 *)
Sand	10 / 18	0.7	38	2	28500

*) p_{ref} = 100 kN/m²

2.2 *Rotational symmetric model tests*

On basis of the present knowledge of the small scale model tests for the GCC-foundation system (Raithel 1999), 8 rotational symmetric model tests at a scale of 1:10 had been carried out under static loading. The concept of the rotational symmetric model tests was based on the "unit cell concept", which considers a single column in a virtual infinite column grid. The influence area of a single column in a triangular grid is a hexagonal element, which can be transformed into a circular element with an equivalent area. Therefore an axially symmetric model is received. According to the assumption that there is a geotextile coated columns grid of 15 % and a columns diameter of d = 0.80 m in practice, it follows in small scale model test that the ratio of the influence area A_E to the column area A_S to A_S/A_E = 50.5 cm² / 336.6 cm² = 0.15 = 15%, and the model column diameter was d = 0.08m. Because there exist almost a linear relation between settlement and column length, the length is insignificant in the model test. To analyse the bearing and deformation behavior of the foundation system a column length of 0.5 m was taken, assuming a 5 m column length and sludge thickness in nature.

2.2.1 *Results of the rotational symmetric model tests*

Figure 1 shows the settlements with and without GCC-system. Due to the interaction between cover filling, columns, geotextile and soft layer, the foundation system shows flexible and self regulating bearing behavior. The results of the static loading tests proved the self regulating bearing behavior of the system which is due to the various interactions. The factor β (β = Settlement without GCC / Settleent with GCC) of ground improvement in very soft soil amounts to β = 2.6. Comparing the results of analytical approach with the model investigations (Figure 2), it can be shown that the analytical method (Raithel / Kempfert 2000) can provide a good approximation to measured values of the settlement. The differences are due to the small scale effect caused by transferring the cohesive behavior of the soft soil. The radial support is guaranteed

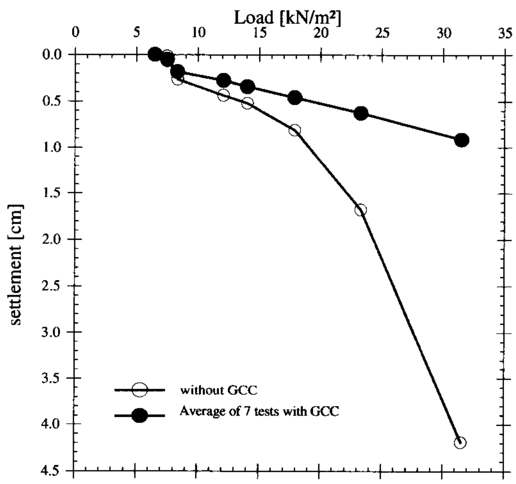

Figure 1. Settlements with and without GCC in rotational model tests scale 1:10 under static loading.

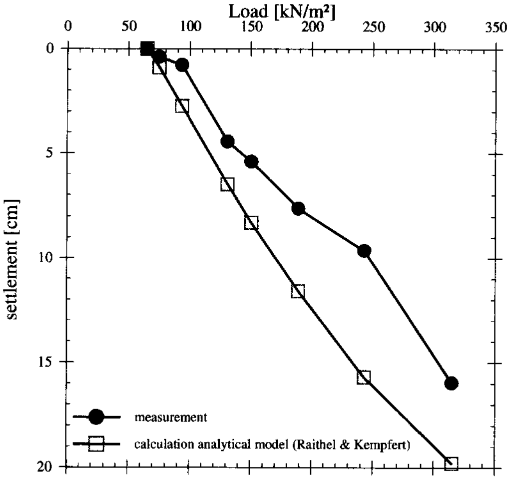

Figure 2. Comparison with the settlement in model test relating to true scale and with the analytical model calculation.

through the composite between the coating and the surrounding soft soil, because the geotextile is under ring tension force. In addition, the shear strength of the surrounding sludge were measured. Table 3 shows the results of shear strenght measurements before and after loading the GCC-system.

Table 3 shows an increase of the shear strength of the sludge after loading by an average factor of 2. Therefore, the developed foundation system GCC/GSM offers a possibility of an enormous settlement reduction, accelerates the settlement rate and improves the shear strength of the surrounding very soft soil.

2.3 *Model tests for columns installation method*

There are two construction methods in practice have: the boring method and the vibro displacement method. The vibro displacement method is more economical and ecological friendly. But the compaction of the soft soil under vibration may lead to soil

Table 3. Results of shear strength [kN/m²] measurements of the sludge before and after loading

Test number	before loading		after loading	
	c_u	q_s	c_u	q_s
1	2.4	7.0	8.0	26.0
2	4.9	7.0	10.0	19.0
3	4.1	16.0	11.0	21.0
4	7.9	15.0	16.5	26.0
5	7.8	14.0	13.0	26.0
6	7.4	25.0	10.0	26.0
7	4.0	3.0	12.0	15.0
8	4.0	4.0	5.5	7.0
mean value	5.3	11.0	11.0	21.0

deformations. Moreover, the effect of local liquefaction of the surrounding soft soil is not investigated at present. Therefore, 4 model tests for columns installation method in sludge, scale 1:10, under vibration had been carried out in a geotextile coated columns grid (A_S / A_E = 15%). Using the dimensional analysis, the measurement results of the small scale model tests and the in situ situation are directly transferable. In Table 4 characteristic values are shown for the vibro displacement method in practice and in model test.

The vibration will be produced from two eccentric masses which work in reverse rotation under an angular velocity. The dimensions of the test container were: length 2.0 m, width 0.8 m and height 1.3 m. The sludge thickness was 0.5 m. Figure 3 shows the top view of the principle model boundary conditions.

The deformations at the surface were measured after the columns had been installed in rows. Addition-ally, the shear strength at different depths were measured before and after 6 rows of columns had been installed.

2.3.1 *Results of the model tests for columns installation method*

During the installation of the 15% geotextile coated column grid, the following effects were observed:

1. The compaction by vibration lead to the heaving of the soft soil between the column grid and before installing the grid.
2. The heaving of the soft soil produced wave like deformations at the surface of the grid.

Table 4. Characteristic values for the vibro displacement method in practice (true scale) and in model test

magnitude		true scale	model scale
transmission	[min^{-1}]	2400.0	2400.0
static moment	[Nm]	340.0	0.34
centrifugal force	[kN]	2140.0	2.14
weight	[t]	6.0	0.006
frequency range	[Hz]	30 – 40	30 – 40

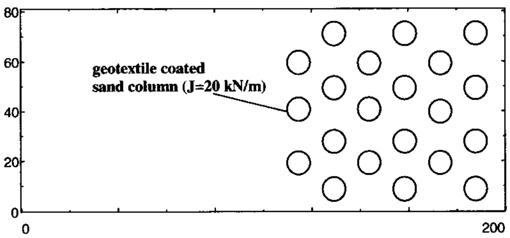

Figure 3. The top view of the principle model boundaries of the test container with finished column grid A_S / A_E = 15%.

3. An obvious liquefaction of the soft soil by the compaction energy was not observed.
4. A skew adjustment of the columns in sludge as a result of the column installation under vibrations had not been manifested.

To present the first 2 above mentioned effects clearly, a typical deformation is shown at the surface is in Figure 4.

The heaving of the surface of the sludge as shown in Figure 4 can be expressed as percentage of the column depth (ℓ = 0.50 m). Table 5 shows the results of all 4 model tests as a mean matrix value.

From Figure 4 and Table 5, it can be shown that heaving of the soft soil between the columns rows due to the compaction energy is expected to be up to 4% of the columns depth. The heave can be increase up to 8% of the columns depth by further installation of additional rows of columns. Table 6 shows the results of shear strength measurements at different depths. The shear strenght in sludge before the installation of the columns in comparison with after 6 rows of columns had been installed shows a increase by a factor of 2.5 to 4.5.

To summerise the results of the model test: the effect of liquefaction of the soft soil by the compaction energy was not observed. Further, an increase in the shear strenght of the surrounding soft soil by an average factor of 3.5 was measured, which shows the stabilization effect of the installation method.

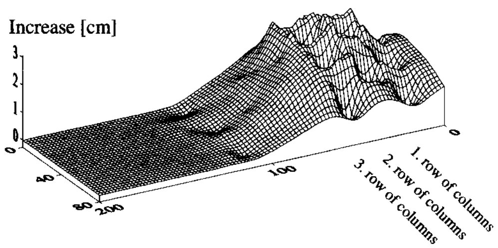

Figure 4. Heaving of the surface of the very soft soil after 3 rows of columns had been built.

Table 5. Heave [cm] at the surface of the sludge as a mean matrix value.

Row of column	1	2	3	4	5	6
build in 1. row	1.7	1.1	0.6	0.2	0.2	0.1
build in 2. row	1.9	2.4	1.4	0.6	0.3	0.1
build in 3. row	1.9	2.6	2.6	1.8	1.0	0.4
build in 4. row	1.9	2.6	3.3	3.4	3.2	1.0
build in 5. row	1.9	2.7	3.5	4.0	3.7	2.4
build in 6. row	1.9	2.7	3.5	4.3	3.7	3.7
increase [%] *)	3.8	5.4	7,0	8.6	7.4	7.4

*) reference to the column depth (ℓ = 0.50 m)

Table 6. Results of shear strength c_u [kN/m²] measurements in the sludge at different depths before and after the installation of sand columns

depth [cm]	10	25	40
c_u before GCC	1.7	1.7	1.6
c_u after GCC	5.9	4.5	7.2

3 TRUE SCALE TESTS

At present the foundation of a dike on very soft soils by using the foundation system "geotextile coated sand columns" (GCC/GSM) will be realized at the river "Elbe" in Germany (Hamburg). Hence, an investigation by a true scale test in a german harbour was conducted by the company "Möbius Bau-Gesellschaft GmbH & Co." (Möbius, unpupl.). 30 geotextile coated sand columns with a diameter of d = 0.80 m in a columns grid of 20% were installed. The columns depth was ℓ = 5.0 m on average. The vibro displacement method was chosen from a off-shore pontoon. The soil parameters of the very soft soil are comparable with the model test soil shown in table 2. During the manufacturing of the 20% geotextile coated column grid, the following effects were observed:

- The compaction by vibration leads to the heaving of the soft soil between the columns grid. It was estimated up to 2-4% of the columns depth.
- A skew adjustment of the columns in sludge as a result of the column installation under vibrations had not been manifested.
- An obvious liquefaction of the soft soil by the compaction energy could not be disco-vered. The average factor of the increase in the shear strenght is 1.5.

The investigation in the true scale tests confirms the results of the small scale model tests. Based on the true scale tests and the model tests (scale 1:10) results the foundation system GCC/GSM is practicable for water engineering projects in connection with very soft soils, e.g. sludge.

4 SUMMARY

On basis of the present knowledge of small scale model tests for the foundation system "geotextile coated sand columns" (GCC/GSM) two kinds of model tests at a scale 1:10 had been carried out in very soft soil. The 8 rotational symmetric model tests under static loading proven the possibility of an enormous settlement reduction, acceleration of the settlement rate and increase in the shear strength of the surrounding very soft soil. It can be shown that by using the analytical model a good approximation of the settlement measurements can be obtained. The radial support is guarantee through the comfined effect of the coating and the surrounding soft soil, because the geotextile is under ring tension force. On the basis of interaction between cover filling, columns, geotextile and soft soil layer, the foundation system shows flexible and self regulating bearing behavior. The 4 columns installation method model tests under vibrations show that the compaction by vibration leads to the heaving of the soft soil between the columns grid. An effect of liquefaction of the soft soil by the compacting energy was not be observed. Rather an increase in the shear strength of the surrounding soft soil with an average factor of 3.5 was measured, which shows the stabilisation effect of the installation method. A skew adjustment of the columns in sludge as a result of vibrations has not been manifested. Moreover, an investigation in the true scale test confirms the above mentioned results of the small scale tests. From the results of the true and small model test, it can be concluded that the new foundation system "GCC/GSM" can be practicably applied for water engineering projects on very soft soils.

REFERENCES

Görtler, H. 1975. *Dimensionsanalyse.* Ingenieurwissenschaftliche Bibliothek. Berlin. Springer Verlag.

Möbius, 2000. Geokunststoffummantelte Sandsäulen System Möbius (GSM) im Wasserbau. Unpublished.

Raithel, M. & Kempfert, H.-G. 1999. *Bemessung von geokunststoffummantelten Sandsäulen.* Bautechnik 76. Heft 11: 983-991.

Raithel, M. 1999. *Zum Trag- und Verformungsverhalten von geokunststoffummantelten Sandsäulen.* Schriftenreihe Geotechnik. Universität Gh Kassel. Heft 6. Juli 1999.

Raithel, M. & Kempfert, H.-G. 2000. *Calculation Models for Dam Foundations with Geotextile Coated Sand Columns.* An International Conference on Geotechnical & Geological Engineering GeoEng 2000. Melbourne.