Interactive behaviour of a flexible reinforced sand column foundation in soft soils

Comportement interactif d'une fondation de colonnes de sable flexible renforcée en sol mou

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ABSTRACT: This contribution reports on a new foundation method, which enables the design for a foundation of traffic road embankments on a soft soil or peat with very small settlement of the new embankment. By this method sand columns are inserted down to the bearing layer and reinforced with a geotextile coating. The radial supporting is strengthened by the geotextile combined with the surrounding soft ground. In this paper the bearing and deformation behaviour is shown and relevant measuring results are given.

RESUME: Cet article présente une nouvelle méthode de fondation qui rend possible une fondation de remblais de routes en sol mou ou tourbe avec peu de tassements. Par la méthode présentée, les colonnes de sable sont enfoncées dans un sol portant et renforcées d'un enrobage gèotextile. Le support radial est amélioré grâce au géotextile combiné au sol mou environnant. Dans cet article, les propriétés de résistance et de déformation de ce genre de fondation sont démontrées et les résultats de mesure essentiels sont présentés.

1 INTRODUCTION

Foundation of traffic road embankments on soft soil or peat cause unacceptable settlements in many cases. Therefore foundation is only possible by soil exchange or by improving the soil with stone columns. This contribution reports on a new foundation method, in which sand columns are inserted down to the bearing layer. The columns are coated with a sewn geotextile composite of polyester threads and a filter cloth, which guarantee the filter effect. At the same time the radial supporting of the sand columns is strengthened by the geotextile coating combined with the surrounding soft soil. Therefore the geotextile is subjected to ring tension forces. After the description of the construction procedure the components are defined, on which interaction the bearing behaviour is based. The bearing and deformation behaviour is shown and relevant measuring results are given.

2 CONSTRUCTION PROCEDURE OF SAND COLUMNS

2.1 *General background*

Meanwhile the new foundation method is built twice. The new method was first applied in widening a 6 m high railway embankment, which was built on peat and soft clay to a depth of 7 m. The 1.5 m wide sand-columns were arranged with a distance of 1.5 m in the direction of the embankment and a distance of 2.2 - 3.0 m crossways. In the second construction the foundation of a dam was on alternating sequences of peat, silt and clay. The columns were built with a diameter of 0.6 m and a distance of 1.25 m. The restrictions were the extreme time constraints, that the railway operation could be continued after a short construction period. Therefore, very low settlements of the new embankment are demanded. Succeedingly the construction steps are described.

2.2 *Dynamic driving of casings*

After the implementation of a pre-filling to carry the heavy working appliances, the casing is vibrated into the ground. There are used two different methods to drive the casing into the ground:

a) Vibrating the casing with the displacement principle.
b) Vibrating the casing and excavating the soil with a half bowl grab.

Using method a) the casing with a diameter of about 0.6 m is vibrated into the ground while the base flap is closed and displaces the soil to the sides of the casing. This method has the following advantages:

- Excavation and transportation of soil is not necessary. This is an economically reasonable aspect especially with respect to contaminated soils.
- The surrounding soft soil is subjected to compaction. This allows higher loading and higher radial support to the sand columns.

In method b), the soil is excavated with a half-round bowl grab after driving the casing. During construction, a bearing layer of about 0.50 m remains inside the casing to protect the casing against groundwater pressing into the borehole. The advantages of this method are:

- Compared with method a), a lager diameter is possible. Therefore less columns are needed and each column carries a higher loading.
- The disadvantage of this method is the missing pre-compaction of the surrounding soil. To compensate for that, the diameter of the geotextile is larger than the diameter of the borehole. By loading the sand column, it increases its diameter until the diameter of the geotextile is reached without giving any load to the coating. This causes a horizontal compaction and an increase of radial support.

2.3 *Inserting the geotextile coating*

Into the casing a hose-shaped geotextile is inserted. This is delivered from the factory and cut in length on the construction site. The geotextile consists of a geogrid (high tension strength) and a filter cloth.

2.4 *Filling of the sand columns*

Sand-gravel mixtures are used to fill the columns. The geotextile hose is fixed to the casing with prestressing-belts. To fill the sand into the casing a funnel is placed on top of the casing.

2.5 *Dynamic pulling of the casings*

The casings are pulled using vibration, which causes compaction of the sand-gravel mixture in the column.

3 MEASUREMENTS

A extensive measuring program was carried out during and after construction. Exemplary measuring results are given in the following. Figure 1 shows the settlements and the lateral displacements of sand columns in a measuring cross-section. The settlements of the new foundation are extremely small, compared to the settlements of the existing embankment of about 1.2 m to 1.5 m. The lateral displacements of sand columns occured are on a maximum scale of 10 cm, which is distinctly smaller than those from similar embankments on soft soil. This may be put down to the shear deformations and resisting effect resulting from sand columns.

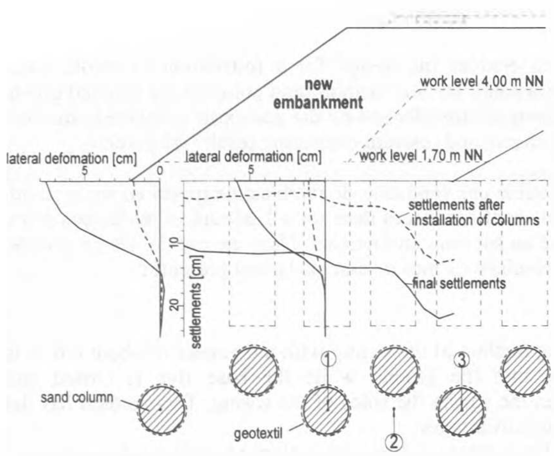

Fig. 1: foundation situation with settlements of the embankment and lateral displacements of sand columns

The behaviour of settlements and excess pore water pressure is shown in figure 2 and 3. The increase of load resulting from each step of filling leads to a short-term increase of the excess pore water pressure in the soft soil and to further settlement of the embankment. After the completion of the filling, the excess pore water pressure decreases clearly and the rate of settlements decreases very rapidly. This is due to the draining effect of sand columns, causing an acceleration of the consolidation of surrounding soft soil.

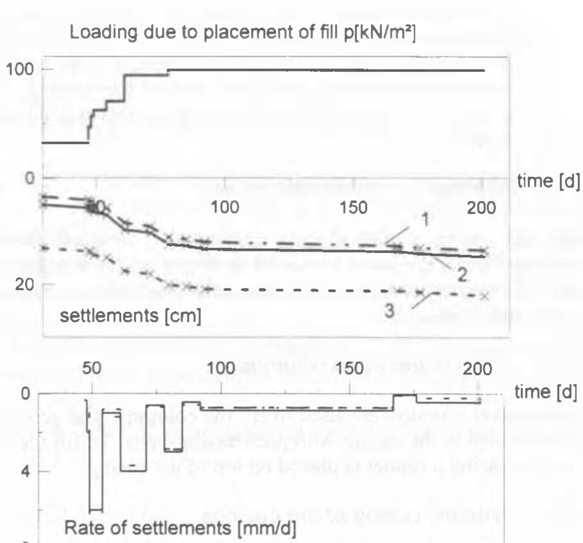

Fig. 2: settlements and rate of settlements in selected measuring points below the embankment.

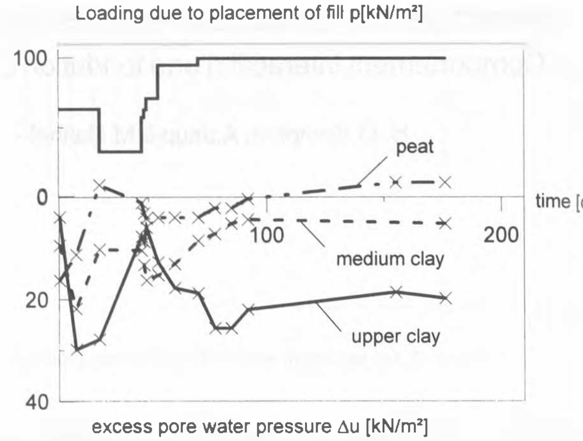

Fig. 3: Excess pore water pressure in the soft soil

4 BEARING BEHAVIOUR

The settlements of the whole system with reference to the initial values after construction are less than 20 cm. This are about 10% of foundation without sand columns. Therefore, the effect of the whole system is proved.

The foundation with geotextile-coated sand columns is a further development of the conventional technique using stone columns. By using stone columns, the supporting effect of soft ground is in some cases not sufficient. Here the radial support of the geotextile-coated sand columns is significantly raised through the ring tension forces of the geotextile. The bearing behaviour of the system is characterized by sharing the load between columns and surrounding soft soil.

It is valid: $s_{Sand\ column} \leq s_{Soil}$

and $Q_E \cdot A_E = Q_S \cdot A_S + Q_{Soil} \cdot (A_E - A_S)$

where
Q_E = acting total load
Q_{soil} = long-term stress, acting on the surrounding soil
Q_S = stress, acting on sand-columns at the end of soil consolidation

The total settlements of sand column are composed of the subsoil settlements, shear deformation of the columns combined with bulging without volume change, as well as the compressibility of the columns. The settlements of the soft soil is caused by the high compressibility of the layer.

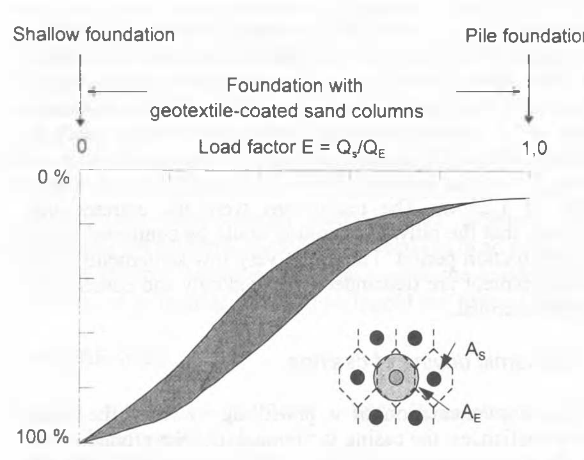

Fig. 4: Interactive effect between load factor and settlement

Compared with the surrounding soft soil, sand-columns behave as significantly stiffer elements. Therefore, a load concentration over sand-columns result from arch action. Arising from the definition of load factor $E = Q_S/Q_E$ (Q_S = part of the load acting on column, $Q_E = Q_S + Q_{Soil}$ = total load in the influencing area of the column) the diagram from above describes the acting way of the foundation system.

The load factor E depends on many parameters. The most important of them are given:

- Stiffness of the soft soil around the columns
- Stiffness of the column material
- Grid distance of the columns
- Stiffness of gotextile
- Stiffness of seam
- Permeability of soft soil
- Surcharge

In addition to the well-known interaction between building (embankment) and ground, a lot more factors interacting with each other have to be considered, in order to model the behaviour of this foundation system. This are:

1. Interaction between column and bottom pressure
2. Interaction between column and earth pressure
3. Interaction between geotextile and column
4. Interaction between geotextile and earth pressure
5. Interaction among columns

The interactive influences are shown schematically in figure 5 and will be explained in the following.

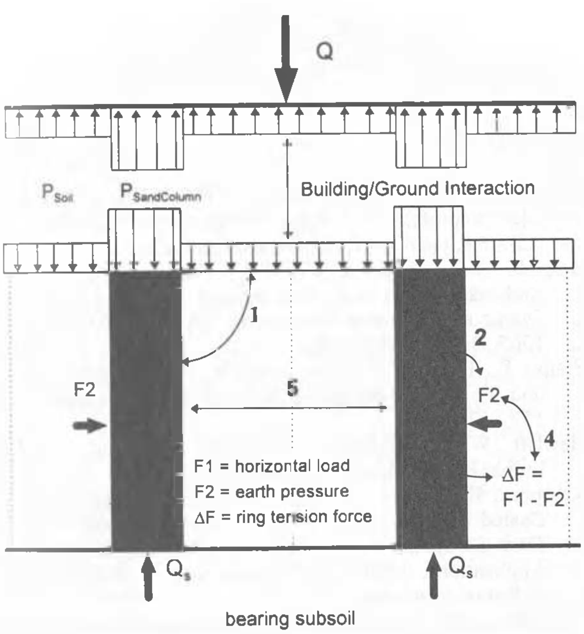

Fig. 5: Interactive influences

The load distribution between column and surrounding soil depends mainly on the stiffness ratio. The axial deformation of the column is mostly caused through shear deformation without volume change, which results in the enlargement of column diameter. This bulging is not consistant along the column.

If the column begins to yield, the load carried by the column is transferred partially to the surrounding soft soil and the settlements of the soil increase. Time-dependent load distribution appears, as the settlements of soft soil according to the theory of consolidation. In the procedure of consolidation, the sand column can be seen as vertical drainage. This interactive effect between the deformation of columns and the settlements of soft soil finally gives a time- and load-dependent equilibrium state.

The passive earth pressure to the column depends on the load carried by the soft soil and increases during load redistribution. As a result of increase of passive earth pressure the column is better supported than before. Correspondingly, more load can be carried by the column. The part of the loading carried by the surrounding soft soil decreases further, as well as the support from passive earth pressure (interaction between columns and earth pressure). In addition, the effect of the geotextile coating on the column should be taken into consideration, because the column is considerably stabilized through ring tension forces in the geotextile. Similarly, the mobilizing of these ring tension forces is also dependent on the interaction between column and geotextile.

The ultimate bearing capacity is reached if the lateral load from the column cannot be carried further. By investigating the ultimate bearing capacity, it should be taken into consideration that the passive earth pressure cannot be fully mobilized. Through the ring tension forces in the geotextile the deformation of a column may be reduced significantly. Therefore the deformation-dependent soil resistance cannot reach the values of the limiting state, but possibly values in the range of earth pressure at rest (interaction between geotextile and earth pressure).

Until now, only the behaviour of an individual geotextile-coated sand-column and the surrounding soft soil has been looked at. In fact, the neighbouring columns interact with each other. Therefore a sand-column can be loaded so far, until the overload is transfered to the neighbouring columns. Then, slope or base failure may occure, if the bearing capacity of the column group is reached.

It should be pointed out, that the bearing behaviour can be influenced by the construction method. This should be taken into account in the analysis. For example, in the second engineering project the soil is compacted among the sand columns while the columns are built. Because of this, the soil can therefore carry more load and give higher lateral support to the columns. In this case, the self compaction of soil should be judged, and soil parameters adapted.

5 CALCULATION METHOD

The calculation method concerning the new combined foundation system was developed by considering several limit states:

a) Ultimate limit state - EC 7, case 1C - (stability of the embankment)

The whole system behaves as slope and ground failure problem. The sand columns are included in the calculation by concerning their real shear strength. The radial supporting of the sand columns by the geotextile is taken into consideration only on a little scale. This limit state can be investigated by using similar analysing and numerical methods.

b) Ultimate limit state - EC 7, case 1B - (design of the geotextile)

The calculation of the bearing and deformation behaviour leads to a three-dimensional problem. To simplify this problem, the limit state is split up in two seperate models. By the examination of a single column and the use of an axial symmetric calculation model the ring tension forces for the design are given (chapter 6).

c) Serviceability limit state - EC 7, case 2 - (settlement calculation)

This limit state can be investigated by using numerical methods. To investigate the deformation behaviour of the total system a cross model is used.

6 CALCULATION OF THE RING TENSION FORCES

For the calculation of the ring tension forces the following idealized boundary conditions are required:

- The columns are inserted down to the bearing layer.
- Limitation of the influence area of a single column. Due to radial consolidation an axial symmetric calculation model is used.
- The immediate and secondary consolidation settlements can be ignored
- The soil properties were not changed by the construction of the columns, or this changing is considerated seperatly.

In this axial symmetric calculation FE-model a single column with the surrounding soft soil in the influence area, according to the column grid, is reflected. The results of a parameter study with various influence areas, stiffnesses of the soft ground, column diameters and loadings are shown in the figures 6 and 7. The ring tension forces in the geotextile are given dependent on several parameters.

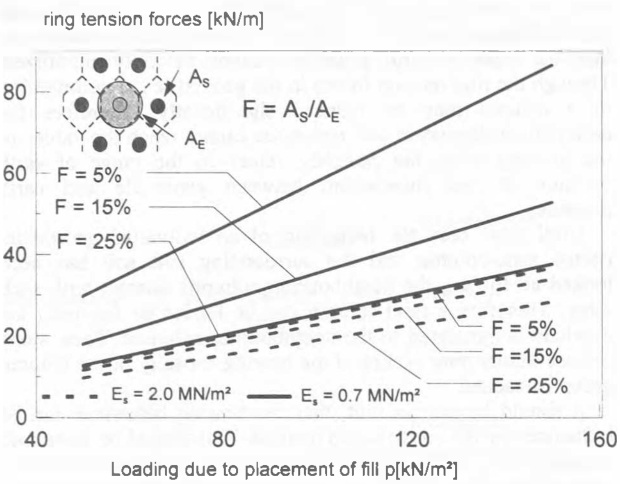

Fig. 6: Ring tension force in the geotextile by a column diameter of 0.6 m.

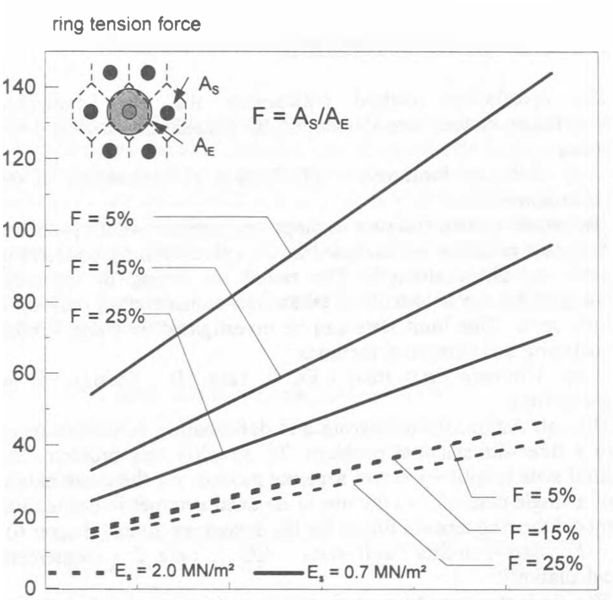

Fig. 7: Ring tension force in the geotextile by a column diameter of 1.5 m.

This parameter study is based on the two used column diameters of 0.6 and 1.5 m. The distance between the columns in the grid is considered by a column influence area factor $F = A_S/A_E$, which was established at 5, 15, and 25%. This means a influence radius of 1.34, 0.77 and 0.60 m by a column with 60 cm diameter. For the geotextile built-in, a stiffness parameter of coating was assumed to be $EA \cong 1900$ kN/m. The seam reduces the stiffness. The calculation is based on real shear parameters, due to the fast decrease of the excess pore water pressures. The loading was simulated by activation of the dead weight. This corresponds to the real construction, in which the sand columns are loaded by the embankment.

The calculation is performed in several steps:

i) primary state before construction
ii) loading resulting from prefilling without the effect of geotextile
iii) activation of column geotextile
iv) further construction stages

To summarize, the stiffness of the the surrounding soft soil is the most important parameter for the value of ring tension forces in the geotextile.

7 CONCLUSIONS

The new foundation method 'geotextile-coated sand columns' was successfully carried out as designed. The measurements made during the construction confirmed the assumed bearing and deformation behaviour. The settlements and the excess pore water pressures decrease very fast.

In connection with the measuring results and the experiences from construction, it may be seen however that some problems concerning the bearing and deformation behaviour remain to be solved. In order to obtain further results and to examine the usability of the constructed embankments, series of long-term measurements in the cross sections described above are planned. Further on large-scale model tests with static and cyclic loading are planned. In general, the knowledge and the calculation method concerning the new foundation method is so far developed, that the satisfactory prediction of deformation and loading for similar engineering projects can be made.

REFERENCES

Asaoka A., Matsuo M., Kodaka T. 1994: Bearing Capacity of Clay Improfed with Sand Compaction Piles. *Proc. XIII ICSMFE*, pp 763 - 766. Balkema, Rotterdam.

Bergado D.T., Long P.V 1994: Numerical Analysis of Embankment on Subsiding Ground Improved by Vertical Drains and Granular Piles. *Proc. XIII ICSMFE*, pp 1361 - 1365. Balkema, Rotterdam.

Franke E., Lutz B., El-Mossallamy Y. 1994: Pfahlgründungen und die Interaktion Bauwerk/Baugrund. *Geotechnik* 17, pp 157 - 172.

Hewlett W.J., Randolph M.F 1988: Analysis of Piled Embankments. *Ground Engeneering*, Vol. 21.

Kempfert, H.-G 1996: Embankment Foundation on Geotextile-Coated Sand Columns in Soft Ground. *Proceedings of the First European Geosynthetics Conference*; Geosynthetics: Applications, Design and Construction, pp 245 - 250. Balkema, Rotterdam.

Priebe H.J. 1995: Die Bemessung von Rüttelstopfverdichtungen. *Bautechnik* 72, Heft 3, pp 183 - 191.

Soyez, B. 1987: Bemessung von Stopfverdichtungen. *Baumaschine und Bautechnik BMT*, pp 170 - 186.