

Embankment foundation on geotextile-coated sand columns in soft ground

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ABSTRACT: This contribution reports on the technical experiences with geotextile-coated sand columns used in the foundation of an approximately 6m high railway embankment based on a soft ground of clay-peat layer up to 7m. The sand columns (1.5m in diameter) have been coated with a sewn geotextile composite of polyester threads and a filter cloth. The bearing behaviour of the columns is influenced by the mobilized soil reaction in the soft layers in combination with the occurring ring tensile forces in the geotextile. Details on the execution of the foundation are given and measuring results concerning strain, forces and deformations in the geotextiles and foundation elements are presented.

1. INTRODUCTION

The foundation of traffic road embankments on soft soil or peat is normally treated by exchanging soft soils or by improving soil with sand columns. By using sand columns, the supporting effect of soft ground is in some cases not sufficient. In this paper, a new foundation method is reported, in which sand columns are inserted into bearing layer and the radial supporting of sand columns is strengthened by using geotextile coating combined with surrounding soft ground. In this case, the geotextile is loaded by ring tension forces.

This method was first applied in widening a 6m high railway embankment, which was built on a soft subsoil consisting of clay and peat with a thickness of 7m. One of the constraining conditions of this construction was that the widening of the embankment should be finished within one month.

The railway operation on the new embankment should be started again after a construction period of about 4 months. Therefore, it was demanded on the foundation method that only very small settlements of the new embankment were allowed after the completion of filling.

2. GROUND CONDITIONS AND FUNDAMENTALS OF THE FOUNDATION METHOD

2.1 *Ground and soil parameters*

Fig. 1 shows the existing and planned foundations with soil layers and parameters. The existing embankment has a very low stability. The soft ground conditions can be discerned from the settlement basin of the existing embankment, which has a maximum settlement between 1.2m and 1.5 m.

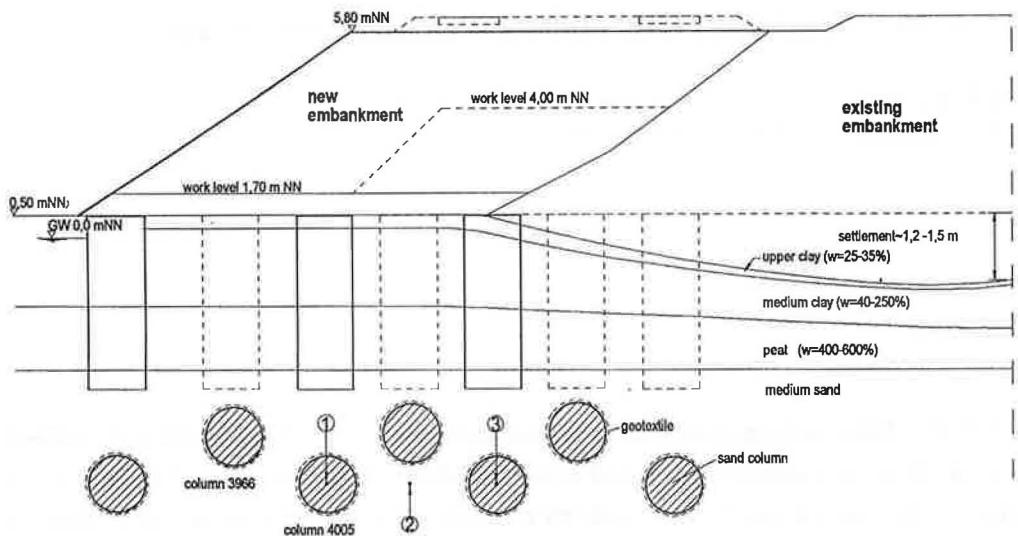


Fig. 1 Soil conditions and location of foundations

2.2 Construction procedure of sand columns and filling

The geotextile-coated sand columns were arranged in a form of column grid having an axial distance of 2.2m to 3.0m in the direction of embankment profile and 1.25m in the longitudinal direction. In the first step, a pre-filling of 1.2m thickness with sand acting as the first working level was carried out on the existing ground surface from NN+0.5m to NN 1.7m. Then, the rows of sand columns were constructed from this working level. These sand columns should not reach into the toe of the slope of the existing embankment. The sand columns, which were not constructed in the first step, were built in a following step with the help of the second working level about 3.50 m above the existing ground surface. The division of the column construction into two working steps proved to be necessary to prevent the stability failure of the existing railway embankment under dynamic loading resulting from the driving of casings.

The construction of sand columns was carried out in the following steps:

- Dynamic driving of casings by means of a tube having a diameter of 1.5m
- Soil excavation within the casing by using half-bowl grab to about 0.50 m into the sand layer. The remaining part of the middle sand beneath the bottom of the excavation within the casing, which has a thickness of about 1m, plays a role as stopper against the pressing of groundwater into casing, so that the further construction can be carried out under dry condition.
- Inserting of a sixfold sewn geotextile, which is made up of composite of polyester threads and a filter cloth. This coating has a diameter of 1.58m larger than that of casing. The geotextile tubes were cut in length and sewed in the construction site.
- The columns were then filled with fine to middle sand. In this procedure, the geotextile tube was fixed with pre-stressing belts. A funnel was placed upon the casing and the sand was filled into

the column.

e. Pulling of the casing with vibration.

After the construction of sand columns, the densities of the column material in situ (sand with uniformity coefficient of $U \approx 2.9$) were estimated by using dynamic penetration tests. They had a value of $D = 0.3$ to 0.5 under groundwater condition. Based on the results of triaxial tests, the angle of internal friction of the sand columns was evaluated to be 32° . After this constructing stage, the pre-fills built in the second step were removed to NN +1.2 m, and a mineral sealing material with a thickness of 0,3 m was filled on it. Then, the embankment was further filled up to the final level in seven steps within a period of only four weeks. From the triaxial tests on sand samples from the embankment, the angle of internal friction was determined to be 35° .

2.3 *Design of foundation and geotextiles*

The calculation method concerning the new foundation technic was developed by considering two limit states, namenly the stability of the embankment and the bearing behavior of the combined foundation system, respectively.

a) Limit state 1

The whole system behaves as slope and ground failure problem. This can be therefore investigated by using similar analysing methods. In the calculation, the sand columns are included in the calculation by considering their shear strength. The effect of geotextile on the stability is taken into consideration only on a littel scale. The horizontal geogrid placed at the working level of NN +1.7m is not included in the calculation of slope stability.

b) Limit state 2

The loads arising from the filling are directly

carried by sand columns, which are supported by the surrounding soft soil. Accordingly, a combined bearing system is formed, which leads to the improvement of the soft ground. This combined foundation system is self-adjusted in such a way that the loading from the filling can be partly transferred to the surrounding soft soil, if the stiffness of sand columns decreases as a result of plastic yielding. At the same time, the soil resistance stabilizing the sand columns may rise to a certain extent. Besides, the coating geotextile works as filter element and the tension force is transmitted through it.

3. MEASUREMENTS

In order to examine the calculation method developed and prove the suitability of the new foundation method, the observation supported by a measuring program was carried out according to ENV 1997-1 (EC 7). Through this procedure, it should be proved that no critical situation concerning the stability of embankment may appear in all construction stages.

The following elements were built into a measuring corss-section and the corresponding measurements were made:

- vertical inclinometers measuring the horizontal displacements of sand columns;
- horizontal inclinometers measuring the settlement basin above and between sand columns;
- porewater pressure gauge measuring the development of excess pore water pressure of soft soil between sand columns;
- stress gauge measuring the vertical stress in soil above and between sand columns.

Fig. 2 illustrates the embankment settlements and horizontal displacements of sand columns in the

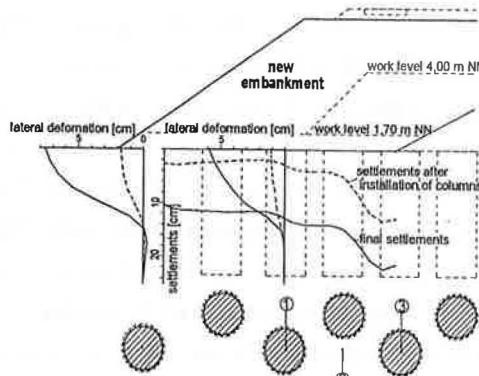


Fig. 2 Embankment settlements and lateral deformations of geotextile coated sand columns

selected cross section. It can be seen from this figure that the horizontal displacements of sand columns occurred are on a maximum scale of 10cm, which is distinctly smaller than those from similar embankments on soft soils. This may be put down to the shear deformations and resisting effect resulting from sand columns.

The settlement basin under the widening part of the embankment (see Fig. 2) can be divided into the portions from the pre-filling and from the filling after the construction of sand columns. The first has a very inhomogeneous distribution having the values from 3 to 25cm, while the second behaves almost as a homogenous distribution having the same value of about 8cm for 3.7m filling thickness, i.e. about 2cm per filling meter. Compared with the settlements of the existing embankment (about 1.2m to 1.5m), these settlements can be seen as extremely small. Furthermore, the settlements of the foundation using geotextile-coated technic decrease with time rapidly (see Fig. 3).

The bearing model assuming the loading adjustment from soft soil into sand columns is confirmed by the measuring results of vertical stress in the old ground surface. If an arch-acting factor or

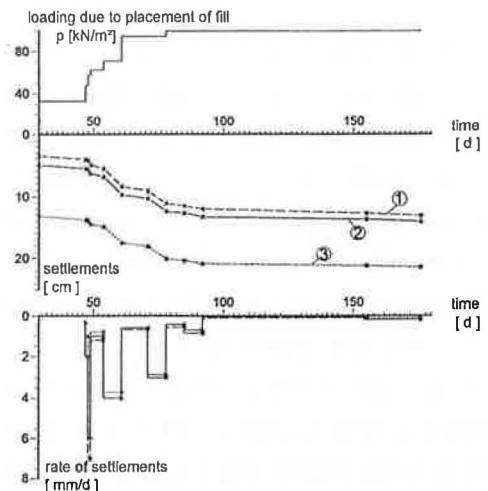


Fig. 3 Settlements and rates of settlement versus time in the selected measuring points below the embankment

loading factor of sand column is defined as

$$E = \frac{Q_s(\text{load carried by the sand column})}{Q(\text{total load on sand column and neighbouring soil})},$$

then the value of E can be evaluated between 0.4 and 0.6 according to the Fig. 4. With the increasing of load, the factor E decreases from higher value down to 0.4. This demonstrates a load-readjustment from sand column to surrounding soft soil.

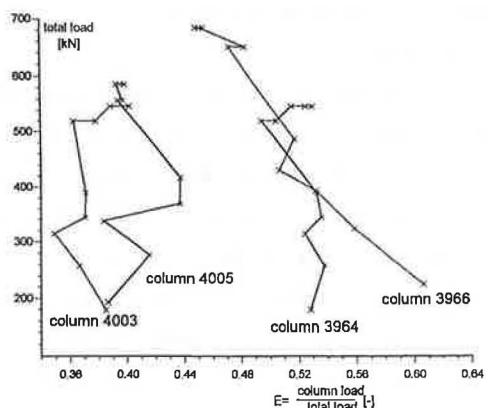


Fig. 4 Measured loads and loading factor of sand column

The increase of load resulting from each step of filling leads to the short-term increase of excess porewater pressure in soft soil. After the completion of filling, excess porewater pressure decreased clearly in all measuring points. This can be put down to the draining effect of sand columns as expected, which leads to the acceleration of the consolidation of soft soil. In Fig. 5, the measured curves of excess porewater pressure depending on time are presented. The measuring data obtained during the construction of sand columns show a little increase of excess porewater pressure. This could be observed only in the measuring points that lay directly beside the sand columns being constructed. After the construction of sand columns, excess porewater pressure decreases correspondingly. Arising from these results, it can be concluded that no considerable excess porewater pressures endangering the stability of embankment are to be expected due to the driving of steel tube.

4. VERIFICATION OF THE MEASURED RESULTS

4.1 Calculation model

The test results from the sand column No. 4005 and also partly from the sand column No. 4003 were analysed by using an axial symmetric calculation model based on finite element method. Elastic and elasto-plastic calculations were carried out respectively. Table 1 includes the used material parameters for the elasto-plastic model according to mohr-coulomb fracture criterion. Based on the low excess porewater pressures and the rapid decay of the settlements observed, the calculation for the final state was approximately performed by using effective

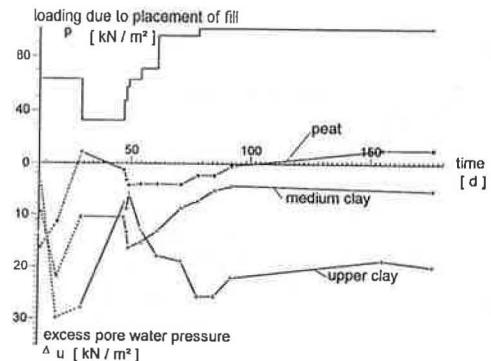


Fig. 5 Excess pore water pressures in the soft soil and between sand columns

shear parameters. From these calculations, the largest ring tension forces in the geotextile could be expected. For the geotextile built-in, a stiffness parameter of coating was assumed to be $EA \approx 1.900$ kN/m.

The calculations were performed in several steps:

- primary state before construction
- loading resulting from pre-filling without the effect of geotextile
- activation of column geotextile
- further construction stages of filling.

4.2 Results

A comparison between the measured and calculated settlements is shown in Fig. 6. From this, it can be seen that the elastic calculation provides

Table 1: Material parameters used for elasto-plastic calculations

Soil type	γ/γ_r [kN/m³]	G [MN/m²]	v [-]	φ' [°]	c' [kN/m²]
Embankment	18/20	10	0.33	35.0	1
upper clay	16/16	0.67	0.40	17.5	15
medium clay	15/15	0.5	0.40	17.5	10
peat	11/11	0.15	0.33	17.5	5
sand/column	18/20	7.5	0.33	32.0	1

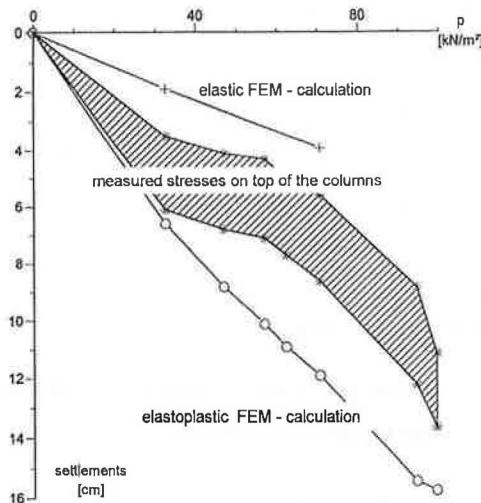


Fig. 6 Comparsion of the measured settlements with the results from FEM-calculation

unsatisfactory results due to so-called silo effects. In comparision with this, the elasto-plastic calculations lead to the better results. Considering the longer standing time and the consolidation of soft soil, the results measured and calculated may come closer further.

The ring tension forces calculated are approximately 30 kN/m. This value is smaller than that from the design calculation including the traffic loading in the section 2.3.

The comparison of measured and calculated vertical stresses in the heads of sand columns and in soft soil between sand columns show a satisfactory agreement. In this case, the best results are also achieved by using elasto-plastic model. Compared with the results calculated, the sand columns measured in situ behave slightly softer. The local yielding of sand columns occurred can be considered in the calculation by using a reduced material stiffness.

5. CONCLUSIONS AND PROSPECT

For the first time, the new foundation method of „geotextile coated sand columns“ was applied in widening an existing railway embankment and the construction was successfully carried out as planned. The measurements made during the construction confirmed the assumed bearing and deformation behaviour of this combined foundation system. No critical situation was observed during all construction stages. The settlements measured *in situ* decrease rapidly.

In general, the calculation method concerning the stability and deformation behaviour of the new foundation system is already so far developed, that the satisfactory prediction of deformation and loading for the similar engineering projects can be made.

In connection with the interpretation of the measuring results and the experiences from the construction discussed above, it may be seen however that some problems concerning the bearing and deformation behaviour of the foundation system, especially long-term behaviour, remain to be solved. In order to obtain further observing results and to examine the usability of the constructed embankment, a series of long-term measurements in the cross-section described above and further tests under cyclic traffic loads are planned.