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Geotextile-encased columns (GEC) for foundation of a dike on very soft soils

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ABSTRACT: This paper presents the implementation of a new foundation system 'Geotextile-Encased Columns' (GEC) for the foundation of a dike on very soft sludge for land reclamation at the Elbe River in Hamburg, Germany. The plant site of the airplane dockyard (EADS) in Hamburg-Finkenwerder will be enlarged by approx. 140 ha for new branches of production, in particular for the production of the new Airbus A 380. The necessary area-extension is located in the 'Mühlenberger Loch' adjacent to the west of the existing plant site. The area extension is carried out by enclosing the polder with a 2,4 km long dike. The necessary dike foundations were realized by about 60000 geotextile encased sand columns with a diameter of 80 cm, which were sunk to the bearing layers at depth between 4 and 14 m below the base of the dike footing.

1 INTRODUCTION

The foundation system 'Geotextile-Encased Columns' (GEC) is a further development of well-known column foundations such as vibro displacement piles and granular piles. In contrast to conventional column foundations, encased columns can also be used as a ground improvement and bearing system in very soft soils, for example peat or sludge (undrained shear strength c_u < 15 kN/m²).

Since 1996, the new foundation system has proved its worth in many road and railway projects in Germany, the Netherlands and Sweden. In the future, GEC will be used world-wide for water and land engineering projects in very soft soils.

The fundamental suitability of the GEC system for a dike foundation on very soft soil (here sludge) for land reclamation purposes was proven at the Elbe River in Hamburg, Germany in 2001 by the contractor Josef-Möbius Bau-Gesellschaft (GmbH & Co.) in Hamburg, which owns the international patent on this new foundation system. The well-known geotextile manufacturer Huesker-Synthetics produced the geotextile for the casing. The design and development were made by the geotechnical engineering office Kempfert + Partner Geotechnik.

2 PROJECT AND SOIL CONDITIONS

The plant site of the airplane dockyard (EADS) in Hamburg-Finkenwerder will be enlarged by approx. 140 ha for new branches of production, in particular for the production of the new Airbus A 380.

The necessary area-extension is located in the 'Mühlenberger Loch' adjacent to the west of the existing plant site. The area extension is carried out by enclosing the polder (marsh or wetland) with a 2,4 km long dike. The situation is shown in figure 1. A temporary enclosure is necessary, because it is only possible to fill up the first sand layers (until 3.0 m over sea level) in the area under buoyancy. Without the sand columns there will be stability problems as the soft soils will move into the river area. Soil displacement in the river area is not allowed.

The original concept design for enclosing the area called for a 2,500 m long temporary sheet wall to depth of a 40 m with rear-anchored raking piles, to serve as a floodwall.

The value engineering concept uses the geotextile encased columns GEC as a basic foundation for the dike. After the system is installed, the dike can be constructed immediately. The temporary sheet wall is no longer necessary and the empoldering function will be served by the dike itself.

The necessary dike foundations were realized by about 60000 geotextile encased sand columns (System Möbius GEC) with a diameter of 80 cm, which were sunk to the bearing layers at depth between 4 an 14 m below the base of the dike footing.

Due to the foundation system 'Geotextile Coated Sand Columns (GEC)' the dike could be constructed on the subsoil with very small shear strength and high deformability in construction time of approx. 9 months.

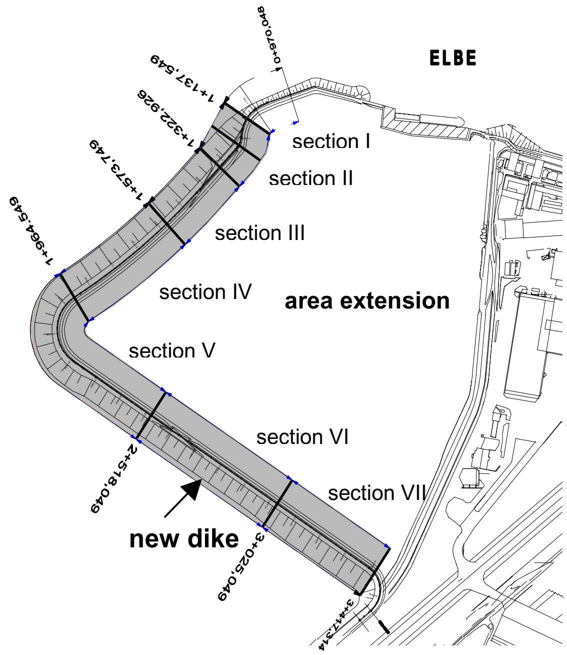

Figure 1. Concept to reclaim land by the construction of a polder

In this area, the thickness of the soft soil layer (here contaminated sludge) is between 8 to 14 m. The reclamation site is also located in mud flats with low and high tides twice a day. The undrained shear strength c_u of the soft soil is between 0.4 and 10.0 kN/m². For this reason, a conventional ground improvement with vibro displacement piles or granular piles is not possible; i.e. the c_u is much less than 15 kN/m² and the horizontal support of a not encased column cannot be maintained. Removal of the contaminated sludge would be expensive and is in any case is not permitted.

Figure 2 shows the undrained shear profile of the soft soil and one typical ground composition in this projekt (oedometric modulus for a stress level σ_{ref} = 100 kN/m²).

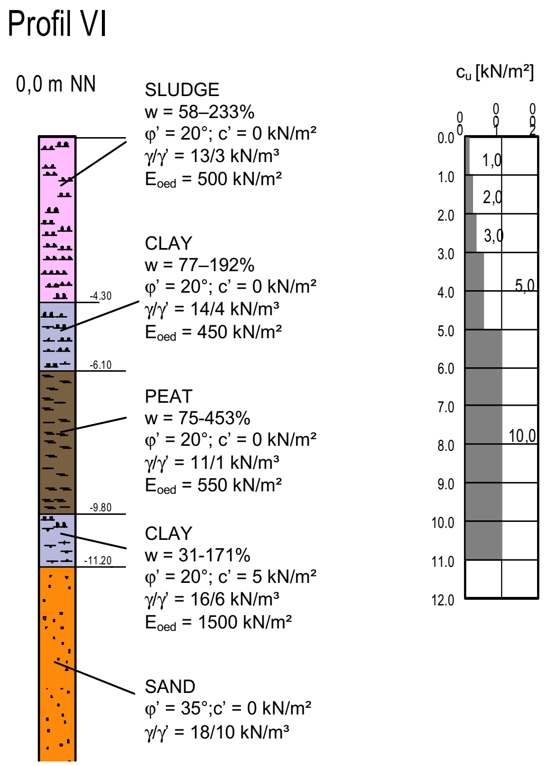

Figure 2: Soil Conditions (example)

3 BEARING SYSTEM GEC AND CALCULATION MODEL

The GEC are arranged in a regular column grid. The diameter of both the column and the geotextile is 0.8 m. The distance between the columns' centers is normally between 1.7 and 2.4 m.

Based on the unit cell concept, a single column in a virtual infinite column grid can be considered. A_C designates the column area. A_E is the influence area of a hexagonal element of a single column in a triangular grid, which can be transformed into a circular element with an equivalent area. Figure 3 shows the unit cell concept described above.

As opposed to conventional column foundations, geotextile-encased columns can be used as a ground improvement method and as a bearing system for very soft soils, because radial support is guaranteed by the geotextile.

With a non-encased column, the horizontal support of the soft soil must be equal to the horizontal pressure in the column. With a geotextile-encased column, the horizontal support of the soft soil can be much lower, due to the radial supporting effect of the geotextile casing. The columns act simultaneously as a vertical drains, but the main effect is the transport of the load to a deeper bearing layer. To carry the high ring tension forces, these geotextile casing are manufactured seamlessly.

There is horizontal stress in the column $\sigma_{h,c}$ due to the vertical stress $\sigma_{v,c}$ over the column head. There is also horizontal earth pressure $\sigma_{h,tot}$ due to the vertical stress $\sigma_{v,s}$ over the soft soil as well as the horizontal support of the casing.

Figure 3 shows the calculation model.

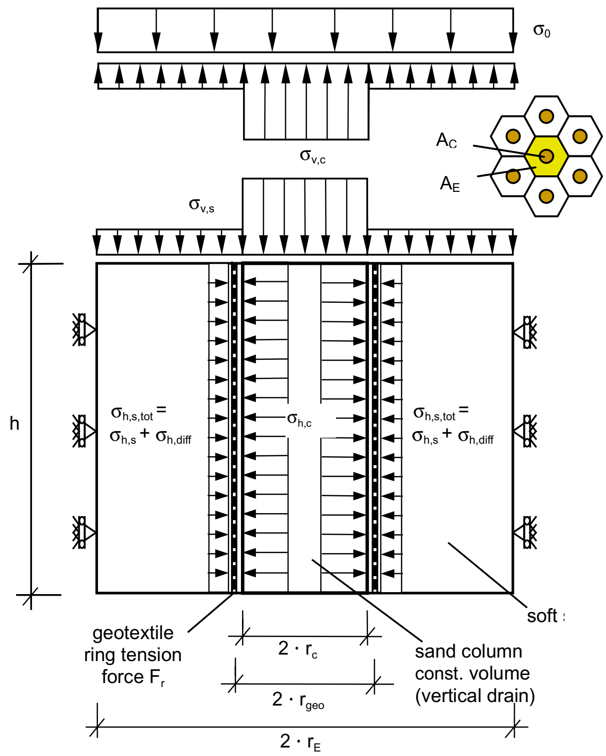

Figure 3. Calculation Model

This creates a difference in horizontal stress $\sigma_{h,diff}$, which results in ring tensile forces F_R in the geotextile casing. The horizontal support depends also on the vertical pressure over the soft soil $\sigma_{v,s}$, which can be much smaller. As a result we get a stress concentration above the column head and a lower vertical pressure over the soft soil and therefore a large settlement reduction.

On the basis of the familiar procedure for calculation and dimensioning of gravel and sand columns, an analytical calculation model has been developed which takes the geotextile casing into account Raithel & Kempfert (1999). More details are shown in Raithel (1999) and also in Raithel & Kempfert (2000).

The derived equations can be solved by iterative process.

4 DESIGN RESULTS

The sand-filled columns are encased by the seamless, circular-woven geotextile Ringtrac®, which is made of polyester threads. On the basis of the above-described analytical calculation model and additional FEM-calculations, the grids in table 1 were designed with more than 60000 columns using different types of Ringtrac®.

The stiffness of the geotextile casing was between J = 1700 and 2800 kN/m. The maximum high tensile force of the geotextile varied between 100 and 400 kN/m over the cross section of the dike. The length of the columns depended on the depth of the soft soil along the dike line, which varied between 4 and 14 m.

For this project, the ratio of the column area A_C to the influence area A_E (A_C/A_E) was between 0.10 and 0.20 = 10% to 20%.

As a result of the stability calculations, a geocomposite with a high tensile strength (maximum high tensile force 500-1000 kN/m) in the dike base, perpendicular to the dike centerline is needed, to accelerate the construction of the dike and to obtain a high degree of stability in the initial stage of construction. It was also necessary to increase the stability if the area behind the dike was to be raised to a height of 5 to 8 m above sea level. The factor β (β = settlement without GEC / settlement with GEC) of ground improvement in soft soil amounts to about β = 2.5 to 4. Similar values for the ground improvement factors β could also seen in model tests.

More details are shown in Kempfert et al (1999). The main calculation results for the design of the dike foundation are shown in table 1.

Table 1. Calculation results

Dike-section	Part	High [mNN]	Grid A_C/A_E [%]	ca. number of columns	Settle-ment [cm]
II	middle side	+9,25 +5,50	17 10	4.400	50 47
III	middle side	+8,90 +5,50	15 10	5.700	41 39
IV	middle side	+8,90 +5,50	15 10	8.000	70 65
V	middle side	+8,90 +5,50	15 10	17.000	109 106
VI	middle side	+8,90 +5,50	15 10	12.000	95 88
VII	middle side	+8,90 +5,50	20 15	9.800	169 146

5 GEOTEXTILE-ENCASED COLUMN INSTALLATION

Normally, there are two installation methods in practice. With the excavation method, an open steel pipe is driven to the natural foundation and its contents are removed by soil auger.

The vibro displacement method, which is more economical, is commonly used. A steel pipe with two base flaps (which close upon contact with the soil) is vibrated down to the bearing layer, displacing the soft soil. The geotextile casing Ringtrac® is installed and filled with sand. At this stage, the sand in the column is loose. After drawing up the pipe under vibration a geotextile-encased column filled with sand of medium density is produced.

Figure 4. Installation by vibro displacement from offshore pontoon

With both economy and ecology in mind, the vibro displacement was used for the entire Hamburg project. However, the soft soil surface along the planned dike line varied between 0.8 above sea level to 2.5 m below sea level. Therefore, different construction methods were necessary to install the GEC foundation for the dike.

The majority of the columns were installed using equipment operating from offshore pontoons (110 × 11 m) to better tolerate the tidal fluctuation (3.5 m water level difference), as shown in figure 4. At low tide, work continued with the pontoons resting directly on the soft soil. After installation, the column heads were stabilized by filling sand between the columns. Notably, no tidal erosion was observed.

Figure 5 shows a finished column following vibro withdrawal of the steel pipe (open base flaps).

Figure 5. Installed column after drawing the steel pipe under vibration

A further GEC construction method was used for numerous road and railway projects in Germany, the Netherlands and Sweden. The vibro displacement machine rested on top of the installed columns, with mats under the 120-ton unit to facilitate load distribution. This land construction method is shown in Figure 6.

Figure 6. The well-tested vibro displacement method on land.

The displacement of the soft soil leads to an uplifting of the soft soil within and around the columns grid. The heaving produced wavelike deformations at the surface of the grid. The lifting was measured at up to 3-8 % of the column depth. This effects duplicated those produced in scale model tests Geduhn & et al. (2001) conducted before the start of this project. The measurement results of the scale model tests were directly transferable to those made at the actual site.

Liquefaction of the soft soil by compaction energy was not observed. Measurements showed an increase in the undrained shear strength of the soft soil surrounding the columns.

Figure 7 shows one result of the measurements of the depth of the soft soil before and immediately after installation of the columns. Further, an increase by a factor of 2 in the shear strength of the surrounding soft soil was measured, which shows the additional stabilizing effect of the installation method.

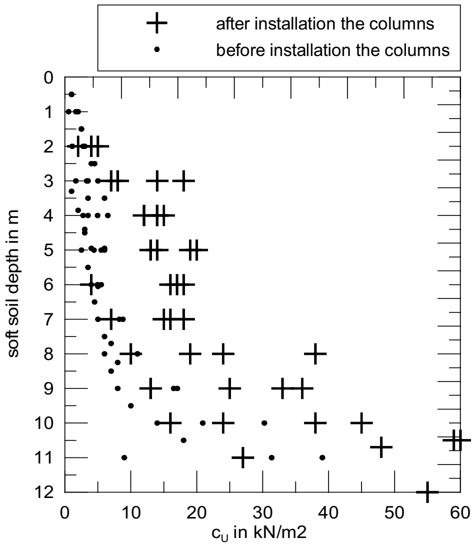

Figure 7. Increase of the undrained shear strenght in the soft soil between the columns in comparison before and after installation the columns

6 MEASUREMENTS

Due to the different soil conditions along the dike length 7 measurement cross sections are necessary.

In a typical measurement cross section 4 groups with one earth pressure gauge and one water pressure gauge above the soft soil layer, as well as two piezometers in the soft soil are placed. In each cross section a horizontal and two vertical inclinometers for the examination of the deformation behaviour are used.

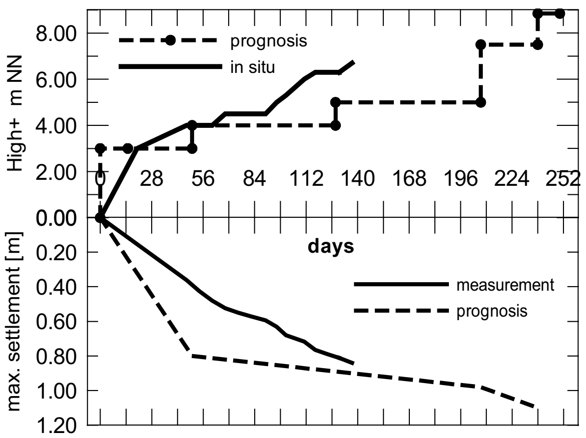

Figure 8: Measured settlements in section VI

On the basis of the measurements it can be shown, that the real soil conditions are better than the soil parameters in the tender documents, especially with regard to the consolidation behaviour.

Due to high effectiveness of the foundation system, the dike could be constructed in approx. 9 months to about 7 m height. Therefore after 39 weeks, the necessary safety corresponding to high water could be reached. In figure 6 the measured values of the settlements in dike section VI are shown.

7 SUMMARY

The plant site of the airplane dockyard (EADS) in Hamburg-Finkenwerder will be enlarged by approx. 140 ha for new branches of production, in particular for the production of the new Airbus A 380. The necessary area enlargement is located in the 'Mühlenberger Loch' adjacent to the west of the existing factory site. The area enlargement is carried out by enclosing the polder with a 2,4 km long dike.

The necessary dike foundations were realized by about 60.000 geotextile encased sand columns (System Möbius GEC) with a diameter of 80 cm, which were sunk to the bearing layers at depth between 4 and 14 m below the base of the dike footing.

Due to the foundation system 'Geotextile Encased Sand Columns' (GEC) the dike could be constructed on the subsoil with very small shear strength and high deformability in a construction time of approx. 9 months.

The foundation system 'Geotextile-Encased Columns' (GEC) was successfully used to found a dike in very soft soil for the purpose of land reclamation. Figure 9 shows the dike.

Figure 9: Dike and polder

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