Experiences on Dike Foundations and Land Fills on Very Soft Soils

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ABSTRACT: This paper presents the land reclamation at the Elbe River in Hamburg, Germany for the necessary area-extension of the airplane dockyard (EADS) in Hamburg-Finkenwerder. The airplane dockyard (EADS) in Hamburg-Finkenwerder will be enlarged by approx. 140 ha (346-acres) for new branches of production, in particular for the production of the new Airbus A 380. The area extension is carried out by enclosing the polder with a 2.4 km long dike on very soft sludge. The necessary dike foundations were realized by about 60000 'Geotextile-Encased Columns' (GEC) with a diameter of 80 cm, which were sunk to the bearing layers with depth between 4 and 14 m below the base of the dike footing. After the enclosure of the polder the fist sand layers (until 3.0 m over sea level) filled up in the area under buoyancy.

1 INTRODUCTION

The factory 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 factory site. The area extension is carried out by enclosing the polder with a 2.4 km long dike. The situation is shown in figure 1.

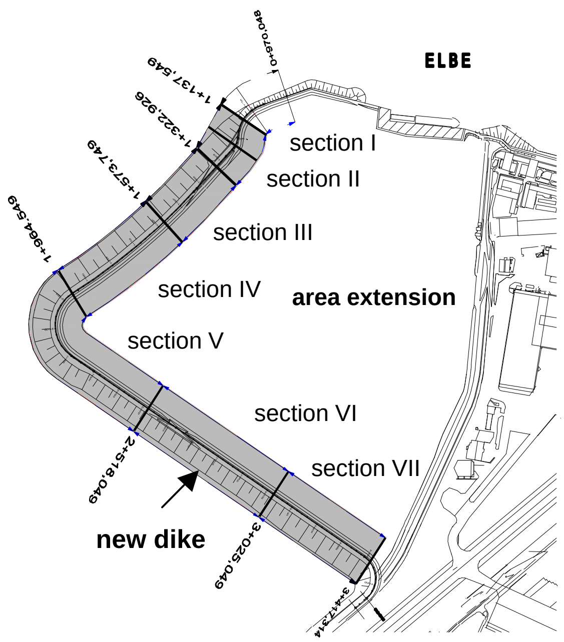

Figure 1. Concept to reclaim land by the creation of a polder

A temporary enclosure is necessary, because it is only possible to fill up the fist sand layers (until 3.0 m over sea level) in the area under buoyancy. Without doing this it will get stability problems, the soft soils would be displaced into the river area. This is not allowed.

2 CONCEPT FOR LAND RECLAMATION

The original concept design in the tender documents for enclosing the area called for a 2500 m long temporary sheet wall to depth of a 40 m with rear-anchored raking piles, to serve as a floodwall. Protected by the temporary enclosure, a constant water level was to be maintained within the area, and the first sand layers were to be filled under buoyancy. The 346-acre area was to be raised to the height of 5.5 m above sea level by a combination of sand-trickling, sand-sluicing and hydraulic filling. Following a three-year consolidation of the soft soil within the enclosure, the real flood control, a dike, was to be filled up to the height of 9 m above sea level. In the final step, the temporary sheet wall and the old existing dike line were to be removed.

The value engineering concept uses geotextile encased columns GEC as a basic foundation for the dike. After the system is installed, the dike can be filled 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 with depth between 4 an 14 m below the base of the dike footing (Figure 2). The sand columns under the base of the dike are installed by the vibro displacement method.

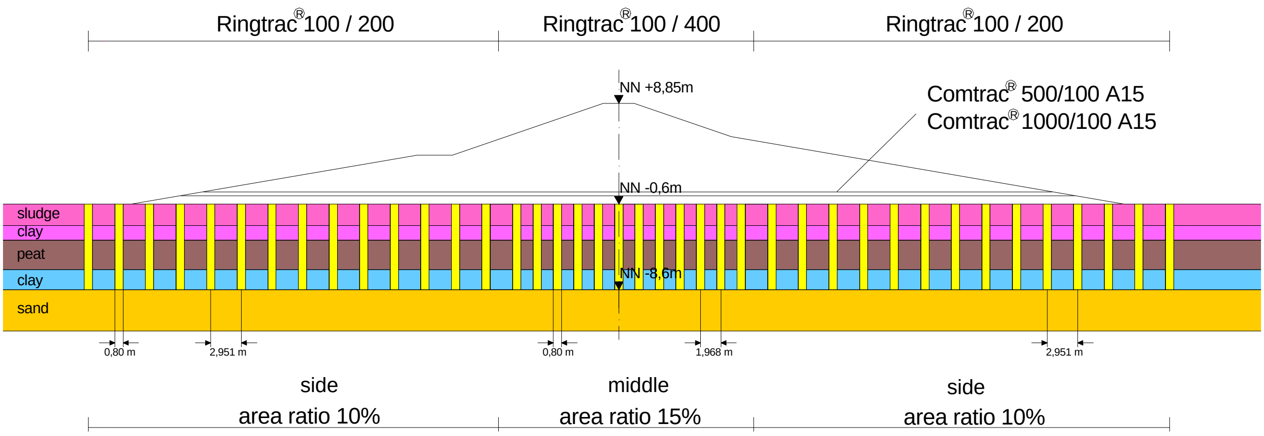

Figure 2. Cross section of the value engineering concept

In comparison with the original concept, this solution saves a considerable amount of sand, due to both the steeper slope (1:6 against 1:20) and a large reduction in settlement.

In addition, with the GEC solution, it was possible to do the foundation work <u>and</u> bring the dike up to the floodproof height of 7 meters above sea level within only eight months.

So the foundation and ground improvement system GEC

- eliminated 35000 tons of steel, since a sheet wall was not necessary
- saved 150000 m² of tidal mud flat reclamation
- used 1100000 m³ less sand to fill up the dike (steeper slope, large settlement reductions).
- produced very little noise pollution (12 vibro displacement machines reached a noise level of 50 dba at a distance of 1000 m)
- shortened construction time for the dike from 3 years to 8 months
- effected a dramatic settlement reduction and a high settlement acceleration similiar to that of vertical drains.

3 SOIL CONDITIONS

In this area, the thickness of the soft soil layer (here especially 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 in 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, because the c_u is much less than 15 kN/m² and the horizontal support of a not encased column is not guaranteed. Removal of the contaminated sludge would be expensive and is in any case not permitted.

Figure 3 shows the undrained shear profile in the soft soil and one typical ground composition in this project in section VI (oedometric modulus for a stress level σ_{ref} = 100 kN/m²).

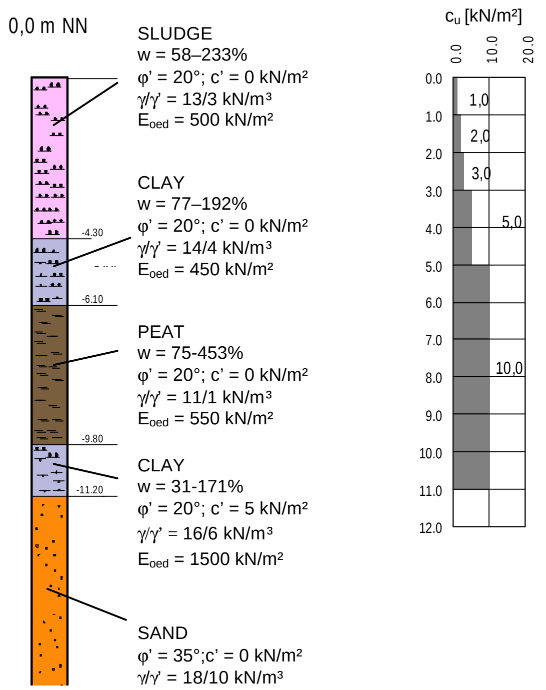

Figure 3. Soil conditions (example)

4 GEOTEXTILE ENCASED COLUMNS (GEC)

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.

To implement the GEC system, we use a regular column grid. The diameter of both the column and the geotextile is 0.8 m. The distance between the columns 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 triangular grid, which can be transformed into a circular element with an equivalent area.

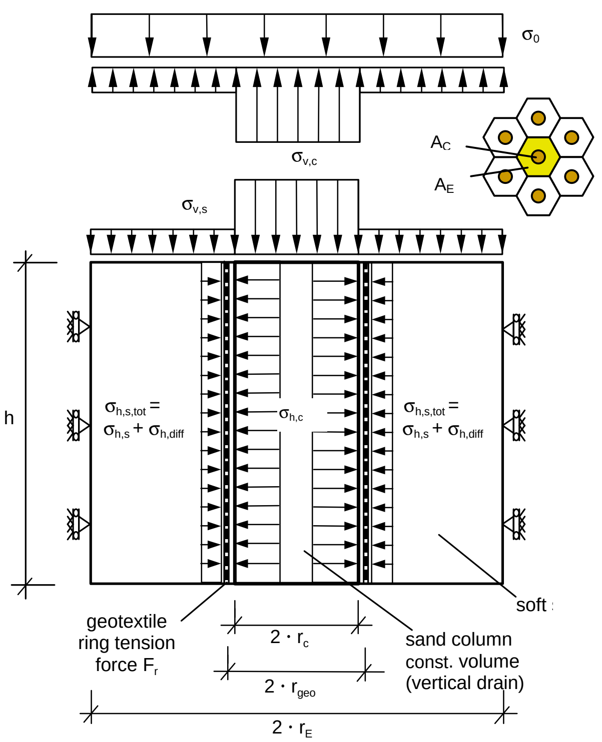

Figure 4. Calculation Model

On the one hand, there is horizontal stress in the column $\sigma_{h,c}$ due to the vertical stress $\sigma_{v,c}$ over the column head. On the other hand, there is 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.

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. 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. Figure 4 shows the calculation model.

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, for which it is advisable to use a calculation program.

5 DESIGN OF THE DIKE FOUNDATION

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 the geotextile casing Ringtrac®. The stiffness of the geotextile casing was between J = 1800 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 thickness 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%.

Table 1. Calculation results

Dike-section	Part	High [m above sea level]	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

As a result of the stability calculations, we needed a geocomposite with a high tensile strength (maximum high tensile force 500-1000 kN/m) in the dike base perpendicular to the dike line, to accelerate the filling of the dike and to obtain a high degree of stability in the initial stage of construction.

The factor *ß* (*ß* = settlement without GEC / settlement with GEC) of ground improvement in soft soil amounts to about *ß* = 2.5 to 3.5. This values for the ground improvement factors *ß* 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.

6 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 more 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 the pipe under vibration (the two base flaps open automatically, s. Figure 6) a geotextile-encased column filled with sand of medium density remains.

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.

Figure 5. Vibro displacement method from pontoon lying on soft soil.

The majority of the columns was installed using equipment operating from offshore pontoons (110 × 11 m) to better contend with tidal fluctuation (3.5 m water level difference. At low tide, work continued with the pontoons resting directly on the soft soil, as shown in Figure 5. After installation, the column heads were stabilized by filling sand between the columns. Notably, no tidal erosion was observed.

Figure 6 shows a finished column following vibro withdrawal of the steel pipe (open base flaps).

Figure 6. 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 stood 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 7.

Figure 7. 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 column grid. The heaving of the soft soil produced deformations at the surface of the grid. The lifting was measured at up to 3-8 % of the column depth.

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 8 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.

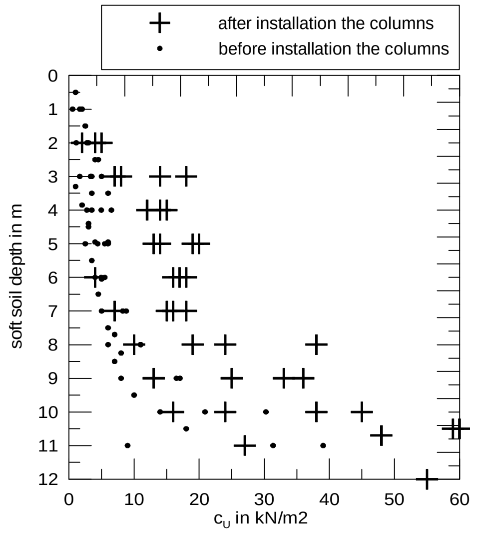

Figure 8. Increase of the undrained shear strenght in the soft soil between the columns in comparison before and after installation the columns

7 MEASUREMENTS OF DIKE BEARING AND DEFORMATION BEHAVIOUR

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- and one water pressure gauge above the soft soil layer, as well as two piezometers in the soft soil are placed.

In addition in each cross section a horizontal and two vertical inclinometers for the examination of the deformation behaviour are used.

On the basis of the measurements it can be shown, that the real soil conditions are better in opposite to the documented 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 a building time of approx. 9 months about 7 m height (in spite of hardly avoidable time deficits in the initial phase).

Therefore after 39 weeks the necessary high water safety could be reached. In figure 9 the measured values of the settlements in the dike section VI are shown.

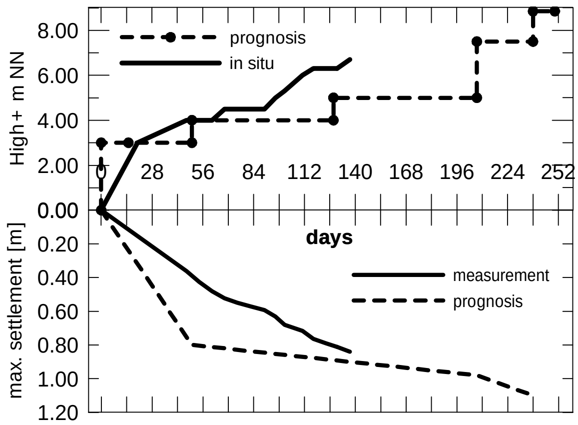

Figure 9: Measured settlements in section VI

8 FILLING

Protected by the dike, a constant water level was to be maintained within the area, and the first sand layers were to be filled under buoyancy.

Generally the total area was divided in different filling sections according to the different soil conditions. In Figure 10 the approximate division of the area is show.

Figure 10. Division of the area for filling of the first sand layers

A special section in the total area is the so called 'Teilfläche Sektionsbau', shown at the right corner of the total area in figure 10.

The filling of this section must be started before the dike was finished. For enclosure of this section, a small temporary dam up to 3 m above sea level, founded on about 4000 geotextile encased columns, was builded.

After the filling up to a high of about 3.1 m to 3.6 m above sea level, the working level for the installation of vertical drains was reached.

The vertical drains are inserted in a triangular grid with grid distances of 0.5 m to 1.0 m. Figure 11 shows the installation.

Figure 11. Installation of vertical drains in detail

After the installation of the vertical drains the area was to be raised to the minimum height of 5.5 m above sea level by a hydraulic filling.

To minimize the settlements after the construction time, due to the strict settlement requirements of 10 to 30 cm, a temporary surcharge by a higher filling (up to 10 m above sea level) was used.

In figure 12 a typical measured time-settlement curve after filling is shown.

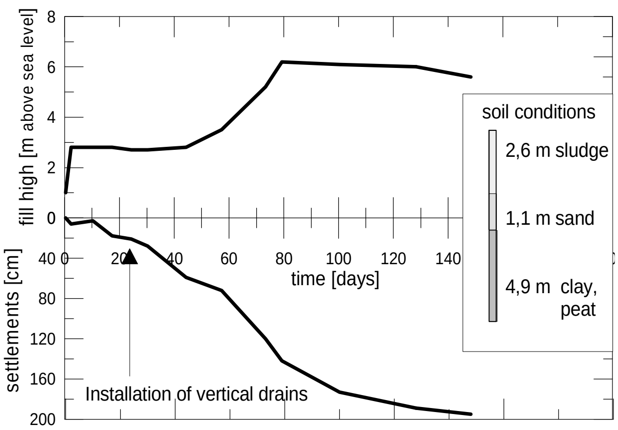

Figure 12. Measured time-settlement curve after filling

9 SUMMARY AND CONCLUSIONS

The factory site of the airplane dockyard (EADS) in Hamburg-Finkenwerder will be enlarged by approx. 140 ha (346-acre). The necessary area-extension is located in the ‘Mühlenberger Loch’ adjacent to the west of the existing factory 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 (System Möbius GEC) with a diameter of 80 cm, which were sunk to the bearing layers with 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 distinct deformability in a building time of approx. 9 months to a safe high water height.

The 346-acre area was to be raised to the height of 5.5 m above sea level by a combination of sand-trickling, sand-sluicing and hydraulic filling. Figure 13 shows the area with filling in February 2002.

Figure 13. Overall view of the area in February 2002

REFERENCES

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

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

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

Kempfert, H.-G. et al. 1999. Model Tests for Analysis of the Bearing and Deformation Behaviour of Column Foundations. *Geotechnical Engineering for Transportation Infrastructure.* Balkema, Rotterdam.