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 first 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.

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 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 embolding 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.
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 and 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 similar 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 $\sigma_{ref} = 100$ kN/m²).
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.

\[
\sigma_{h,c} = \sigma_{v,c} \quad \text{(horizontal stress in the column due to the vertical stress \( \sigma_{v,c} \) over the column head.)}
\]

\[
\sigma_{h,tot} = \sigma_{h,s} + \sigma_{h,diff} \quad \text{(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

<table>
<thead>
<tr>
<th>Dike-section</th>
<th>Part</th>
<th>High m above sea level</th>
<th>Grid ( A_C/A_E ) [%]</th>
<th>ca. number of columns</th>
<th>Settlement cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>II</td>
<td>middle side</td>
<td>+9.25 +5.50</td>
<td>17</td>
<td>4.400</td>
<td>50</td>
</tr>
<tr>
<td>III</td>
<td>middle side</td>
<td>+8.90 +5.50</td>
<td>15</td>
<td>5.700</td>
<td>41</td>
</tr>
<tr>
<td>IV</td>
<td>middle side</td>
<td>+8.90 +5.50</td>
<td>15</td>
<td>8.000</td>
<td>70</td>
</tr>
<tr>
<td>V</td>
<td>middle side</td>
<td>+8.90 +5.50</td>
<td>15</td>
<td>17.000</td>
<td>109</td>
</tr>
<tr>
<td>VI</td>
<td>middle side</td>
<td>+8.90 +5.50</td>
<td>15</td>
<td>12.000</td>
<td>95</td>
</tr>
<tr>
<td>VII</td>
<td>middle side</td>
<td>+8.90 +5.50</td>
<td>20</td>
<td>9.800</td>
<td>169</td>
</tr>
</tbody>
</table>
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 $\beta$ ($\beta$ = settlement without GEC / settlement with GEC) of ground improvement in soft soil amounts to about $\beta = 2.5$ to $3.5$. This values for the ground improvement factors $\beta$ could also been 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, see 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.

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 8: Increase of the undrained shear strength in the soft soil between the columns in comparison before and after installation the columns](image)

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](image)
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 built.

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.

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.

### REFERENCES


