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GEOTECHNICAL FABRICS REPORT

August 2002

volume 20.number 6

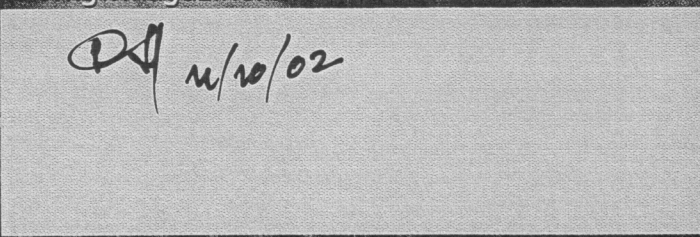
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Reclaiming land with geotextile-encased columns *Sand columns*

wrapped in geotextile provide ground improvement and support for soft soils reclaimed from the Elbe River in Germany.

New technologies emerge throughout the world today as engineers improve existing products and methodologies. This is also true within the geosynthetics field as land values and construction costs continue to rise, challenging today's geotechnical engineers to embark on new technologies and products with which they have very little experience. The following article presents a new foundation technology being used in Europe in water- and land-engineering projects in very soft soils; this technology will soon be used on a project in the United States. The new foundation system, geotextile-encased columns (GEC), was used to construct a dike on very soft sludge for land reclamation at the Elbe River in Hamburg, Germany.

The GEC foundation system is a further development of such well-known column foundations 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 such as peat or sludge (undrained

shear strength $c_u < 15 \text{ kN/m}^2$). 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 worldwide 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. Geotextile manufacturer Huesker-Synthetics produced the geotextile for the casing. The geotechnical engineering office of Kempfert + Partner Geotechnik worked on design and development. Today, these three companies have formed a partnership.

To implement the GEC system, a column-placement grid is employed. The diameter of both the column and the geotextile is 0.8 m (2.6 ft.). The distance between the columns is normally between

1.7 and 2.4 m (5.6 and 7.9 ft.). Based on the unit-cell concept, a single column in a virtually infinite column grid can be considered. A_S 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 1** shows the unit-cell concept described above.

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 and environmentally friendly, 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 Ringtrac® geotextile casing is installed and filled with sand. At this stage, the sand in the column is loose.

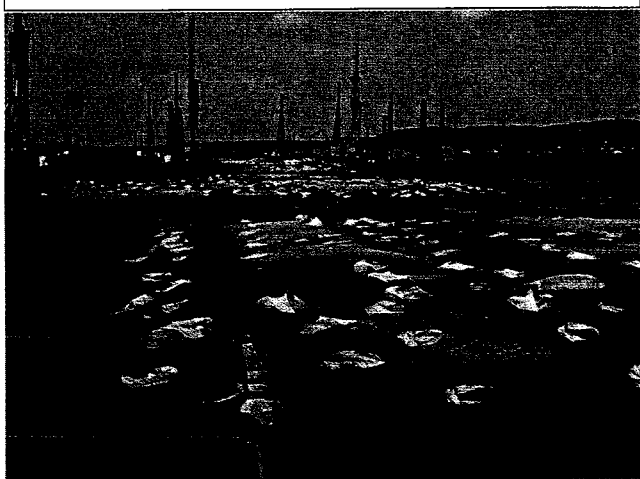
By removing the pipe under vibration (the two base flaps open automatically) a geotextile-encased column filled with sand of medium density remains. It is also possible to use other filling material for the columns, for example, fly ash or gravel.

Calculation model

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.

Figure 1 shows the calculation model with a horizontal stress in the column $\sigma_{h,c}$ due to the vertical stress $\sigma_{v,c}$ over the column head. There is also a horizontal earth pressure $\sigma_{h,s, \text{tot}}$ due to the vertical stress $\sigma_{v,s}$ over the soft soil as well as the horizontal support of the casing. This creates a difference in horizontal stress $\sigma_{h, \text{diff}}$. The stress difference results in an expansion of

Photo 1. Vibro displacement method from barges lying on soft soil.



the column, and the geotextile is under ring tensile forces F_R . The horizontal support depends also on the vertical pressure over the soft soil $\sigma_{v,s}$. As a result, a stress concentration above the column head is realized with a lower vertical pressure over the soft soil.

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. More details are shown in Raithel (1999) and also in Raithel and Kempfert (1999). The derived equations can be solved by iterative process, for which it is advisable to use a calculation program.

Project and soil conditions

The reclamation of 140 ha (346 acres) was needed to extend the airplane manufacturing facility of Daimler Chrysler Aerospace Airbus, a founding company of European Aeronautic Defence and Space Company (EADS), located in Hamburg, Germany. The new area will be used to manufacture the Airbus A380, a thousand-passenger aircraft, and other models.

The undrained shear strength c_u in the soft soil was between 0.4 and 10.0 kN/m² (27 and 685 lb./ft.²). For this reason, a conventional ground improvement with vibro-displacement piles or granular piles was not possible, because the c_u was much less than 15 kN/m² (1,028 lb./ft.²), and the horizontal support of an unencased column is not guaranteed.

Removal of the contaminated sludge would be expensive, and at this site, sludge removal was not permitted. Figure 2 (p.36) shows the undrained shear profile in the soft soil and one typical ground composition at this project site. The characteristic soil parameters for the project are shown in Table 1 (p.37).

Original concept

The original concept in the bid documents was to create a *polder* (a term used to de-

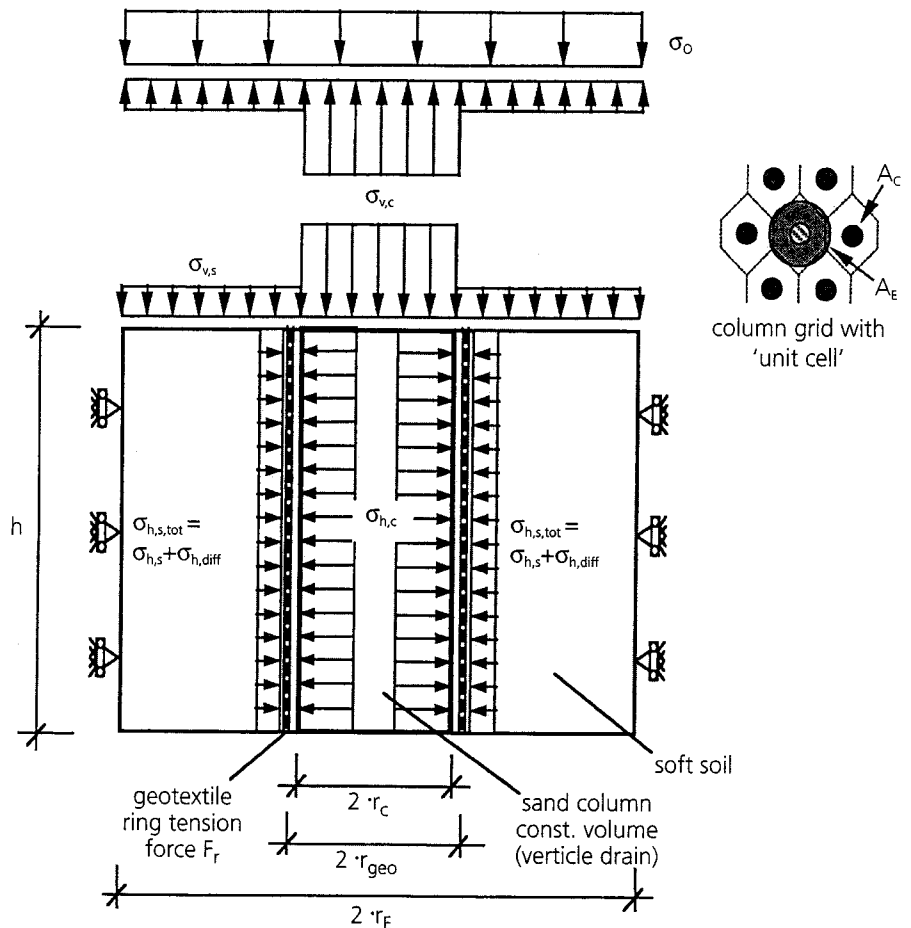


Figure 1. Calculation model for geotextile-encased column system

scribed any piece of land reclaimed from water) in the Elbe River, which is adjacent to the aircraft manufacturing facility. The design for enclosing the area (Figure 3) (p.39) required a 2,500-m (8,200-ft.)-long temporary sheet wall (red dotted line) to depth of 40 m (130 ft.) with rear-anchored raking piles to serve as a floodwall. In this area, the thickness of the soft soil layer (here contaminated sludge) is between 8 to 15 m (26 to 50 ft.). The reclamation site is also located in mud flats with low and high tides twice a day.

Protected by the temporary sheet wall, a constant water level (Figure 3) (p.39)

was to be maintained within the area, and the first sand layers were to be filled under buoyancy. The 140 ha (346 acres) area was to be raised to the height of 5.5 m (18 ft.) above sea level by a combination of sand-trickling, sand-slucing and hydraulic filling. Following a three-year consolidation of the soft soil within the enclosure, a dike, functioning as the real flood control measure, was to be filled up to the height of 9 m (29.5 ft.) above sea level. In the final step, the temporary sheet wall and the old existing dike line were to be removed.

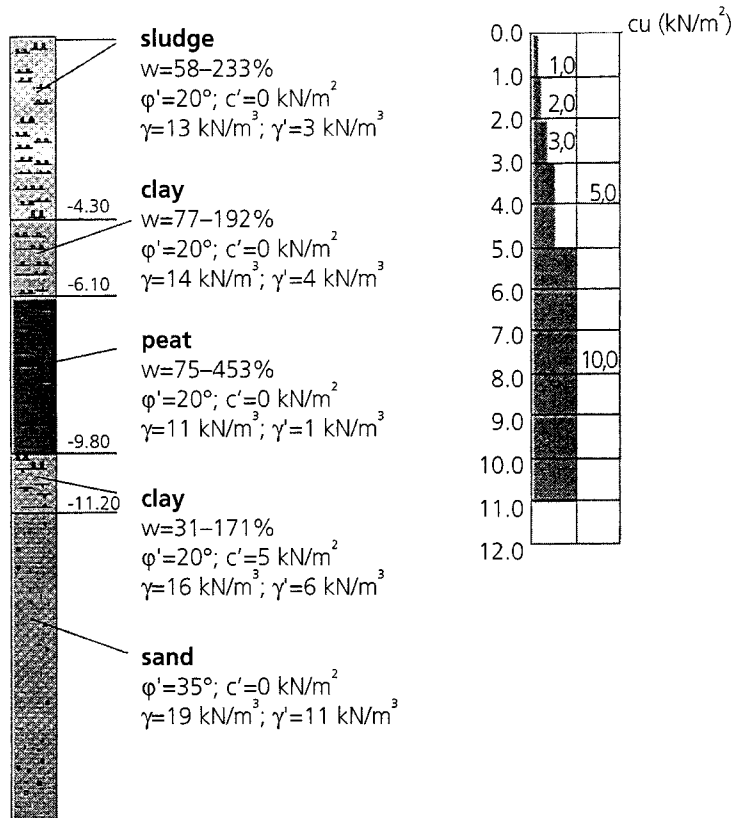


Figure 2: Example of soil conditions (undrained shear profile).

A temporary enclosure was necessary because the first sand layers (3.0 m [9.8 ft.] above sea level) could be built up only in the area under buoyancy. Without this preparation, the soft soils and attendant stability problems would be moved into the river and into the tide flat areas where soil displacement is not allowed.

Value-engineering concept

The value-engineering concept uses the GEC system 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 dike itself functions to maintain the polder.

The sand-filled columns are encased by the seamless, circular-woven geotextile, which is made of polyester threads. The sand columns under the base of the dike were installed by the vibro-displacement method. In comparison with the original concept, this solution saved a considerable amount of sand, due to both the steeper slope (1:6 vs. 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 flood-proof height of 7 m (23 ft.) above sea level within only eight months.

Therefore, the foundation and ground improvement GEC system:

- eliminated 35,000 tons of steel, since a sheet wall was not necessary;
- saved 150,000 m³ (17,939 yd.³) of tidal mud-flat reclamation;
- used 1,100,000 m³ (1,438,746 yd.³) 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 1,000 m);
- shortened construction time for the dike from 3 years to 8 months; and
- produced a dramatic settlement reduction and a high settlement acceleration similar to that of vertical drains.

Design results

On the basis of the above-described analytical calculation model and additional FEM calculations, the grids were designed with more than 60,000 columns using dif-

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Reclaiming land with geotextile-encased columns

Soil type	weight γ/γ [kN/m ³]	water content [%]	friction angle ϕ' [°]	cohesion c' [kN/m ²]	oedometric modulus E_{oed} [kN/m ²]*
Sludge	6/16	60–230	20	0	600
Clay	4/14	70–200	20	0	450
Peat	1/11	75–450	20	0	550
Fill sand material	10/18	10–30	32.5	0	30,000

(*) for a stress level $p_{ref}=100\text{kN/m}^2$

Table 1. Soil mechanical parameters.

ferent types of geotextile. The stiffness of the geotextile casing was between $J = 1,800$ and $2,800 \text{ kN/m}$. 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 8 and 15 m (26 and 50 ft.). For this project, the ratio of the influence area A_E to the column area A_S to A_S/A_E was between 0.10 and $0.20 = 10$ to 20% . As a result of the stability calculations, a geotextile with a high tensile strength (maximum high tensile force 500 – $1,000 \text{ kN/m}$) was required 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. 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 (16 to 26 ft.) above sea level. The factor β ($\beta =$ settlement without GEC / settlement with GEC) of ground improvement in soft soil amounted to about $\beta = 2.5$ to 4 .

Installation

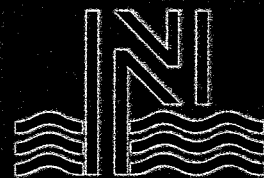
With both economy and ecology in mind, the vibro-displacement method was used for the entire Hamburg project. However,

the soft soil surface along the planned dike line varied between 0.8 m (2.6 ft.) above sea level to 2.5 m (8.2 ft.) 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 barges with dimensions of $11 \times 110 \text{ m}$ ($36 \times 360 \text{ ft.}$) to better contend with tidal fluctuations of 3.5 m (11.5 ft.). At low tide, work continued with the barges resting directly on the soft soil, as shown in Photo 1. After installation, the column heads were stabilized by filling sand between the columns. Notably, no tidal erosion was observed.

Installation of the GEC system on land was also performed at this site. This land installation method has also been used for numerous road and railway projects in Germany, the Netherlands and Sweden.

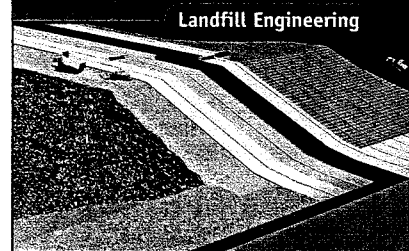
Displacement of soft soil leads to an uplifting of the soft soil within and around the column grid. The heaving of this soil produced wavelike deformations at the surface of the grid. The lifting was measured at up to 3 – 8% of the column depth. This effect duplicated those produced in scale model tests (Geduhn, Raithel and Kempfert 2001) conducted



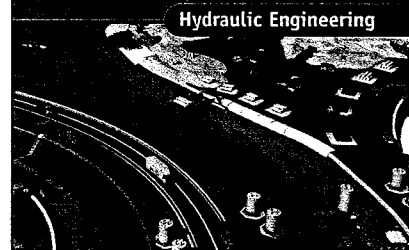
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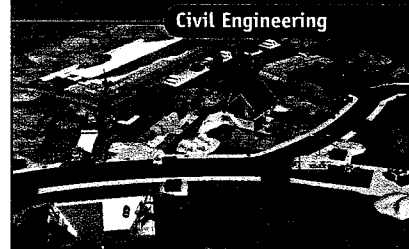
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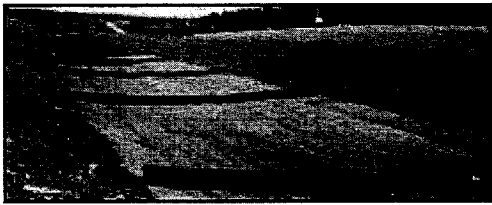


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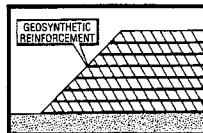
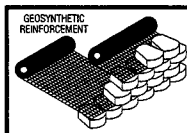
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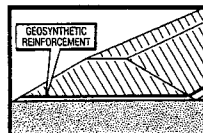
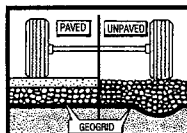
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before the start of this project. The measurement results of the scale model tests were directly transferable to those made at the actual site.

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. Furthermore, an increase by a factor of two in the shear strength of the surrounding soft soil was measured, which shows the additional stabilizing effect of the installation method.

Summary

The GEC foundation system was used successfully to construct a dike in very soft soil for the purpose of land reclamation. The foundation system shows a flexible and self-regulating bearing behavior. The installation methods have been thoroughly tested, both in this offshore project and in many other railway and road projects with GEC since 1996. The advantages of this system are:

- It is usable in very soft soils like peat, clay and sludge with $c_u < 15 \text{ kN/m}^2$.
- A short construction time is possible.
- Settlements can be greatly reduced.
- Settlement acceleration is as rapid as that of vertical drains.
- The calculation system has been perfected.
- No stability problems have been observed or measured during the filling process in combination with a geotextile or geogrid.
- The bearing system is flexible and can withstand considerable horizontal deformations.
- Vibro-displacement installation compresses the soft soil, increasing its shear strength.

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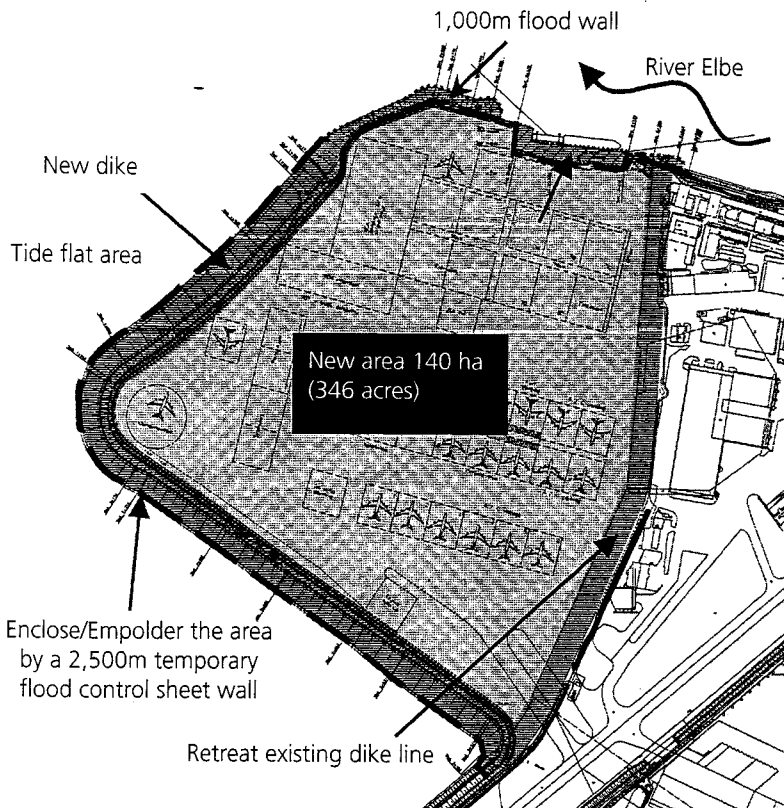


Figure 3. Concept to reclaim land by the creation of a polder (original concept).

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