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CALCULATION TECHNIQUES AND DIMENSIONING OF ENCASED COLUMNS
- DESIGN AND STATE OF THE ART

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ABSTRACT: Foundation systems with geotextile encased columns (GEC) are used for soil improvement and primarily for road embankment foundations in Germany, Sweden and the Netherlands since almost 10 years (Raithel et al. 2004), but latterly they are also used in dike construction In this paper, after the development of the foundation- and calculation systems and projects demonstrated, the essential main features of the calculation of the bearing and deformation behaviour are described.

INTRODUCTION

With the foundation system GEC gravel-sand-columns are installed into a bearing layer to relieve the load on the soft soils. Due to the geotextile casing in combination with the surrounding soft soils the column has a radial support, whereas the casing is strained by ring tensile forces. To withstand the high ring tension forces, the geotextile casings are manufactured seamlessly. Due to the supporting effects of the casing, a special range of application, in opposite to conventional column foundations (i.e. granualar piles), is in very soft soils (undrained shear strength $c_u < 15$ kN/m²) like peat or very soft silt/clay as well as sludge. By a non-encased column, the horizontal support of the soft soil must be equal to the horizontal pressure in the column. By a GEC, the horizontal support of the soft soil can be much lower, due to the radial supporting effect of the geotextile casing.

As a result a stress concentration on the column head and a lower vertical pressure over the soft soil and therefore a large settlement reduction is obtained. The columns act simultaneously as vertical drains, but the main effect is the load transfer to a deeper bearing layer. In total, just minor settlements are resulting after the construction period, what is on the one hand referred to the settlement reduction because of stress concentration above the columns and the following stress reduction above the soft layers, on the other hand to the increasing stress activated through the effect of the columns as vertical drain, so that the bulk of the settlements can be compensated during the construction period. Furthermore the creep and respectively secondary settlements are reduced.

INTERACTIVE STRUCTURAL SYSTEM

The GEC are arranged in a regular column grid. Based on the unit cell concept, a single column in a virtual infinite column grid can be considered.

The effectiveness of a grid column foundation concerning a reduction of sinking and an increase of stability, basically depends on stress concentration above the head of column linked with an unloading of the soft layers, which is possible because of an arch action in the ballast covering.

In encased columns the stiffness circumstances between the columns and the surrounding soft layer is normally aligned in that way, that it results in a flexible and self regulating structural system at nearly equal settlement between column and surrounding soft layer. In the case of a yielding of the columns, the loads first have the possibility to relocate on the soft layers, causing a rising of the resistance of soil and allowing an interactive re-relocation (Raithel 1999). Indeed, this first leads to some lower load relocation and respectively stress concentration above the heads of columns in contrast to rigid pile-like elements in encased columns. At normal case there is no need for additional measures like geosynthetic reinforced bearing layers assessed to membrane forces above the heads of columns.

Generally, an analytical, axial symmetric model according to (Raithel 1999) and (Raithel and Kempfert 2000) is used for calculating and designing a geotextile encased column foundation, see Fig.1. Based on the ring tension forces, it is possible to define the required stiffness of the geotextile casing by considering the product-specific factors of decrease (i. e. to considerate the influences by creep, installation damage, type of

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connection, chemical offences etc.) as well as the partial safety factor.

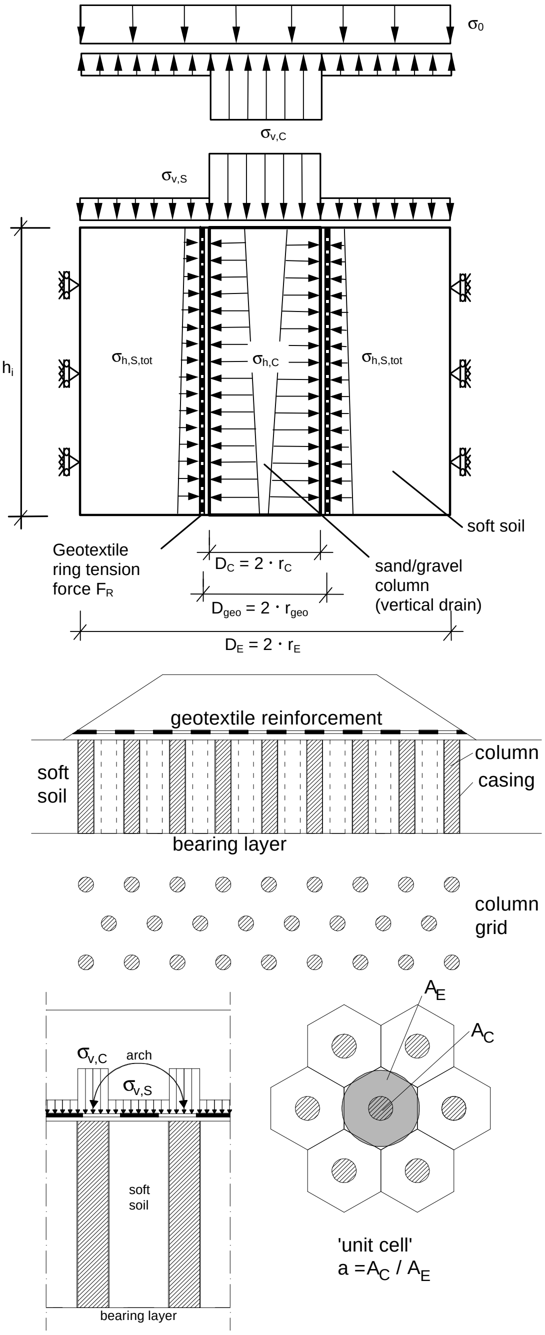

Fig. 1 Calculation model and schematic interpretations for the structural behaviour

PRODUCTION TECHNIQUES

Normally two installation methods are in practice. With the excavation method, an open steel pipe is driven into the bearing layer and the soil is removed by auger. By the vibro displacement method, a steel pipe with two base flaps is vibrated down to the bearing layer, displacing the soft soil. After that the geotextile casing is installed and filled with sand. After retrieval of the pipe under vibration a GEC filled with sand/gravel of medium density is produced. In Fig.2 the vibro displacement method (right) and the excavation method (left) are shown.

Fig. 2 Excavation and substitution technique with double flap pipe (pictures: Möbius AG)

The excavation technique should especially be preferred in soils with great penetration resistances and respectively, if vibration action to border buildings, traffic facilities etc. have to be minimised.

The advantage of the substitution techniques adverse the excavation technique is the faster and more economic production of the columns and the operational discharge of an initial tension in the soft layer. Moreover, no soils have to be extended and disposed.

PROJECT EXPERIENCES

In the mid-1990's, the first attempts were made to install encased sand columns. But the required techniques for installing a complete, self-regulating respectively interactive bearing system and the appropriate calculation models were developed since 1994. First bearing test on encased columns took place in Germany in 1994 and in 1996 the first foundation system 'geotextile encased columns (GEC)' for widening an about 5 m high railroad embankment on peat and clay soils in Hamburg was carried out.

Meanwhile the appropriate calculation model to calculate the ring tension forces and the settlements as realistic as possible by considering the different interactions between soft soil, casing and column was developed. Up to now there are more than 20 reference projects in Germany, Sweden and the Netherlands.

Especially in road and railroad construction extensive experiences with the system GEC exist. By means of measurements the effectiveness of the accomplished

GEC foundations could be proved. As an example the ground improvement at the railroad Karlsruhe-Basel is shown in the following. The 1 to 2 m high embankment was founded on a approx. 7 m thick alternating sequence of peat, sludge and clay layers with stiffness between $E_s = 0.7$ and 2.3 MN/m². To avoid vibrations at the existing rail track the columns (∅ 80 cm) were installed using the excavation method. The situation on site and typical measurements are shown in Fig.3.

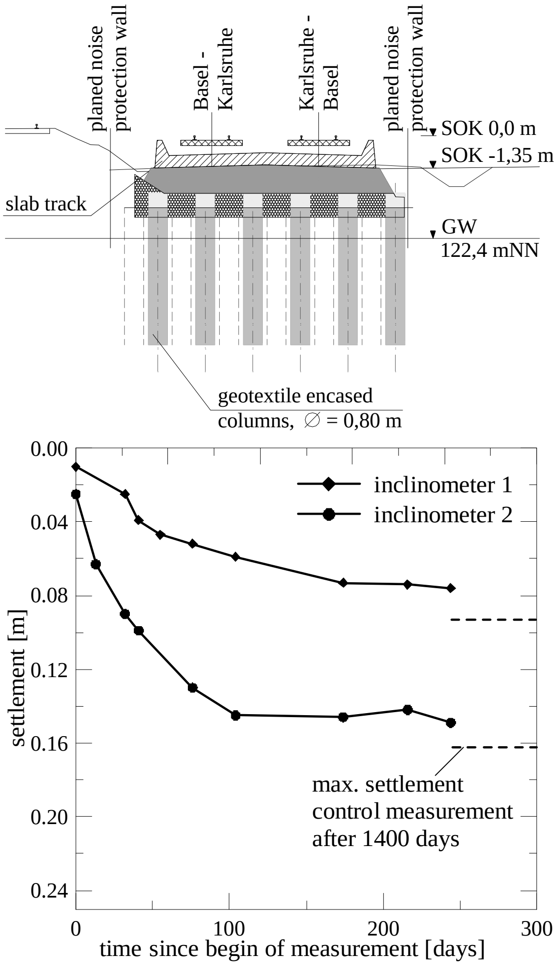

Fig. 3 Foundation and typical measurements at the project ABS/NBS Karlsruhe-Basel

In addition to using the foundation system in road construction there are meanwhile experiences in major hydraulic construction projects. Especially the area-extension of the airplane dockyard (EADS) in Hamburg-Finkenwerder by approx. 140 ha (346-acres) for the production of the new Airbus A 380 has to be mentioned. The 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 to fill up in the area under buoyancy, see Fig.4. The dike foundation was realized by about 60,000 geotextile encased columns 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. This dike is the new main water protection dike of the airplane dockyard. Furthermore another 10,000 columns were installed to relocate the existing ‘Finkenwerder Vordeich’ towards the river Elbe and to avoid sludge replacement, to increase the stability and to decrease the settlements of the dike. Typical soil conditions are shown also in Fig.4.

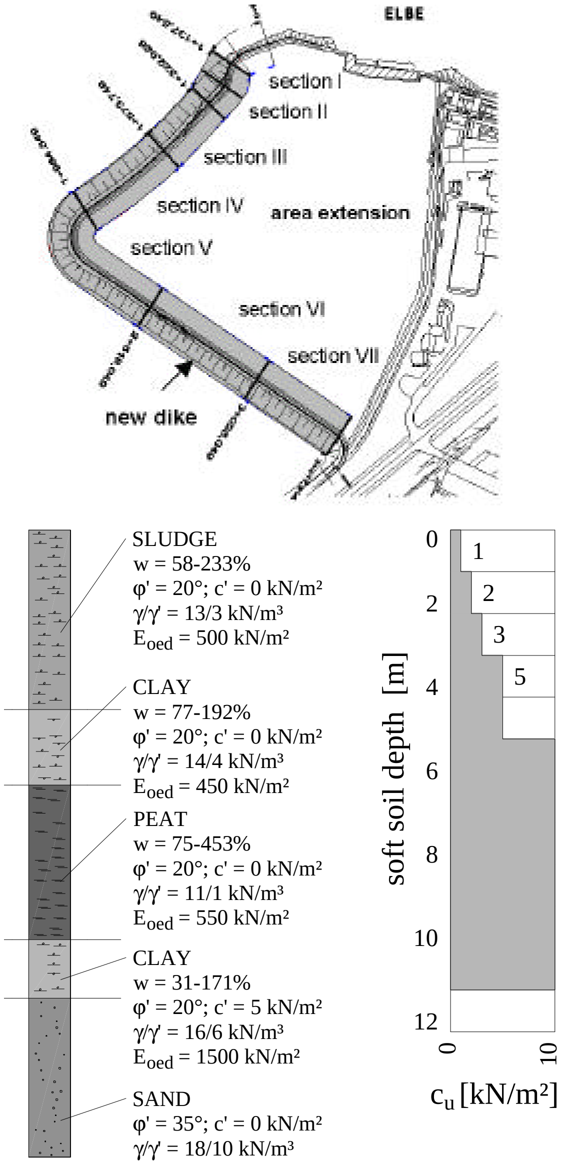

Fig. 4 Concept to reclaim land by the construction of a polder and typical soil boundary conditions

Due to the different soil conditions along the dike length 7 measurement cross sections were necessary. In a typical measurement cross section, 4 groups are placed, each containing one earth pressure gauge and one water pressure gauge above the soft soil layer, and two piezometers within the soft soil. In each cross section, one horizontal and two vertical inclinometers are used for the examination of the deformation behaviour. The measured settlement in dike section VI is shown in Fig.5.

Due to the foundation system GEC the dike could be constructed to a flood water save height of 7 m in a construction time of approx. 9 months. To complete the dike up to approx. 10 m, inclusive a cover of organic clay, a construction time of only approx. 15 month was necessary.

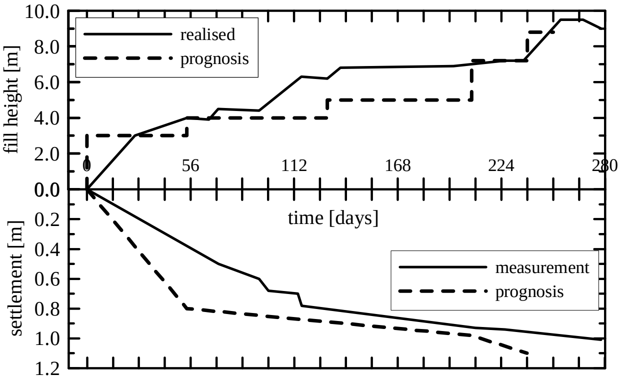

Fig. 5 Measured settlements, for example in section VI

SPECIAL ASPECTS IN CONCEPT AND DIMENSIONING OF A FOUNDATION WITH ENCASED COLUMNS

Through extensive measurements, especially at two test areas in the Netherlands and two test areas in Germany, there could be demonstrated, that the displacement columns were constricted until among the internal diameter of the pipe, because of the horizontal substitution stress by the application of the substitution technique with flap pipes.

To avoid a non-economic provision of the encasing and an underestimation of the appearing settlements, the diameter of the column, before loading by the construction proportional to the diameter of the substitution pipe, has to be considered in the dimensioning. Normally, this results from accretion of a consistent difference of diameter (if the case may be also lower and superior limit values) grounded on measurements of the constriction at comparable boundary conditions of production and soil types.

Additional numerical calculations can be made, whereas after the simulation of the displacement also the different constriction Δr_o in layered soils can be considered (see Fig.6 and 7). But it is necessary to calibrate the calculation results to the available measured values, because the exact modelling of the production technique (displacement under vibration) also can be acquired hardly with numerical methods. So an additional factor according to measurements is used for the validation of the calculation values by the design.

For the numerical calculation shown in Fig.7 the program PLAXIS was used. For the soft soil the Soft Soil Model (Cam-Clay type), for the sand and gravel of the column material the Hard Soil Model (modified Duncan/Chang model), was used. By the examination of a single column (according to the ‘unit cell concept’) and the use of an axial symmetric calculation model the ring tension forces, the settlement and the constriction for the design can be determined.

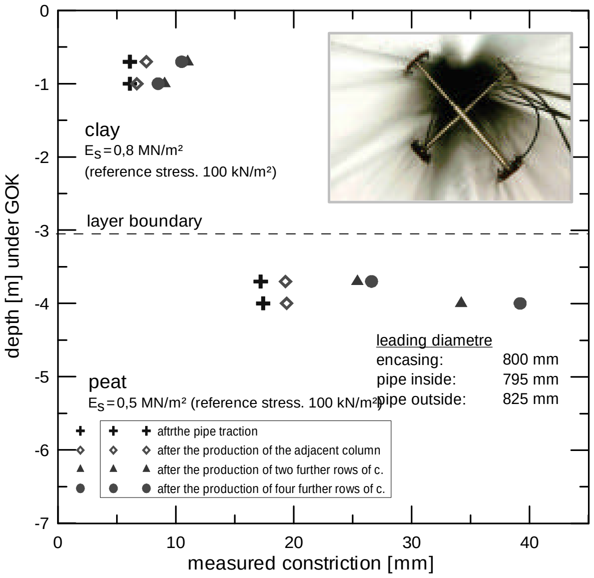

Fig. 6 Measured constriction of a column in layered soil

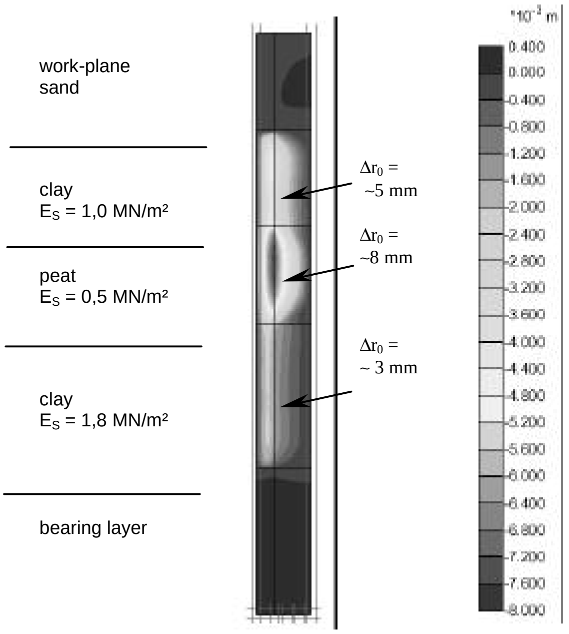

Fig. 7 Numeric (FEM) calculated constriction of a column (diameter 80 cm) in layered soil

During the sinking of the displacement pipe it gets down to a rising of the pore excess pressure and after its decrease an increase of undrained shear strength in the soft layers. To quantify his influence to the stability in the soft layers, there were made extensive researches.

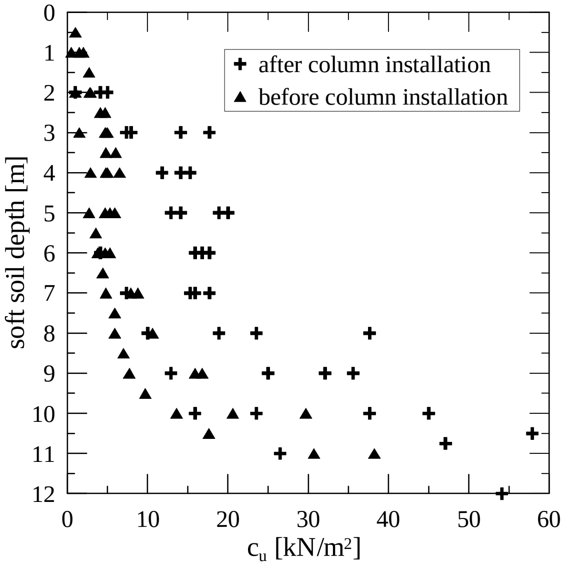

Fig. 8 Measured increase of undrained shear strength by displacement column installation (field tests)

In (Raithel 1999) there are results of in situ measurements described, which show, that at the beginning of the vibrating a rising of the pore excess pressure occurs, but the peak values were broke down rapidly. (Maybaum and Mühlmann 2002) are presenting results of big scale model tests and numeric calculations, which also show, that a continuous rising of the pore excess pressure occurs during the insertion. The peak values thereby occur directly in the region of the column, large-scale hydrodynamic conditional structure breakdown, like e.g. a condensation in the soft layers, is not recognized. Comparative vane soundings show the not drained shear strength were meliorated through the inserting of the displacement pipe. In large-scale tests in consideration of a single column, there could be measured a melioration by the factor 1.5 to 2.0. In small-scale tests (Scale 1:10) considering a 15% column grid ($A_C/A_E = 15\%$) there even could be measured an increasement with factors of 3 to 3.5 in consideration of the model laws.

In situ measurements for the development of the shear strength in practice shows also a minimal increasement of approx. 1.5 to 2.0 (see Fig.8).

In the displacement technique it gets down to a lifting of the soft soil in the range of the columns, because of the substitution of the soft soil at the column installation. This effect has especially to be considered in the case of adjacent buildings, and can lead to, e.g. by the calculation of a dam filling, a decrease of the load, that has to be considered, because of the lesser filling amount until the reaching of the gradient.

Fig. 9 Small-scale model test (scale 1:10)

The ground heightening can apparently be observed in situ. For their quantification there were made extensive in situ measurements within a test area, but also small- and large-scale tests. In Fig.9 the acquired heightening, which is established with small-scale tests (scale 1:10), is demonstrated exemplary for the production of the third range of columns. Because of the presented experiences the expected heightening can be appreciated with approx. 5 to 10% of the soft layer.

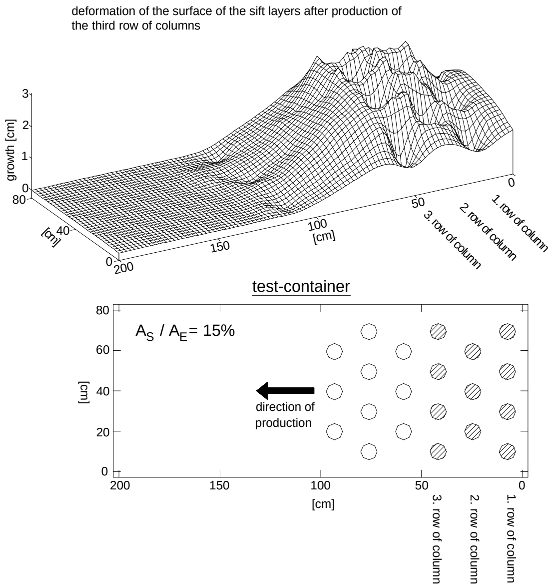

Fig. 10 Deformation of the surface of the soft layer after the production of the third row of column

LONG TIME SETTLEMENT BEHAVIOUR (CREEP)

The effectiveness of a grid-shaped column foundation in consideration of a settlement reduction, is essentially based on a stress concentration above the heads of columns, linked with an unloading of the soft layers, which is made possible because of an arch action in the ballast covering. The primary settlements thereby occur towards the laws of the consolidation theory, whereas an enormous acceleration of settlement is given, because of the effect of the encased columns as big vertical drains.

As a rule a big part of the primary settlements subsides during the construction period and can be compensated.

For the detection of the residual settlements there are to consider the primary settlements and also the secondary- and creep settlements.

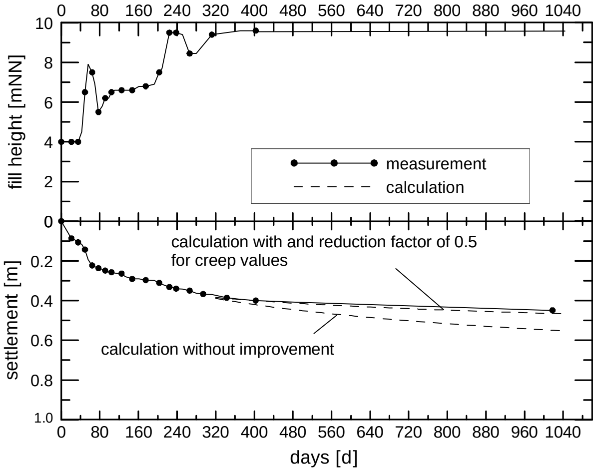

Fig. 11 Results from long-time measurements and calculations

In the literature (see e.g. Edil et al. 1994) is described, that creep deformations result against these load change, which create the deformation. As the soft layer is less loaded, because of the stress concentration above the columns, so there is generally to count on a reduction of the creep settlement compared to the unimproved basement soil, because of the application of encased columns. Furthermore, the soft layer in consideration of the creep settlements underlies a stronger settlement than the column does. Hence, as a rule it gets down to a change in load relocation, because of the interactive load-bearing system and finally to a new equilibrium condition. Therefore, with a column foundation a further reduction of the creep settlements is reached, compared to the unimproved situation.

This effect could also be approved with measurement techniques in available long-time measurements. In Fig.11 measurement results of the dike foundation for the enlargement of the factory premises of the aircraft dockyard in Hamburg-Finkenwerder are demonstrated compared to calculational prognoses of the creep settlements. The outcome of this is, that by the approach of creep coefficients, which were declared and respectively differentiated for the unimproved basement soil (i.e. without column foundation), considerable bigger creep settlements were prognosticated in comparison to the measurement results. With a calculational prognosis using a correction factor of 0.5 for the creep settlements of the unimproved basement soil (see equation 1), the measurement results, in contrast, can well be reproduced.

$$s_k = R_{GEC} \cdot c_\alpha \cdot h_1 \cdot \log (t_{sk} / t_1) \qquad (1)$$

with:

s_k	creep settlement using GEC
R_{GEC}	Reduction factor by GEC = 0.25 to 0.5
c_α	creep factor
h_1	thickness of soil after consolidation
t_{sk}	time
t_1	end of consolidation

GERMAN RECOMMENTATIONS AND STANDARDS

At present, there is worked on the preparation of chapter 6.10 of EBGEO “Gründungsssystem mit geokunststoffummantelten Säulen” within the working group of the DGGT. A first concept of this recommendation is already available. Basically, here should be compiled recommendations for construction, calculation and realisation of geosynthetic encased column foundations. Comply with this regulations, the effectiveness of the foundation is ensured. The structure of the current concept comprises the scopes:

1) Terms and definitions
2) Effectiveness and application scopes
3) Production technique
4) Concept recommendations and construction notes
5) Materials
6) Details for calculation and dimensioning
7) Test criteria, tolerances and quality control

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