Simplified Estimation and Graphs for Pre-Design of Geosynthetic-Encased Sand or Gravel Columns as Embankment Foundation

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Abstract

Embankments on soft subsoil supported by piles or stone columns have important advantages compared to „conventional" embankment foundation: no consolidation time is required, there is no import/export of additional embankment soil to accelerate consolidation or to compensate the settlement, practically no additional settlement occurs under traffic etc. The use of this solution is growing recently in Germany. Starting in 1994, a system for foundation of embankments in soft soil areas was developed by the German contractor Möbius and HUESKER Synthetic. The general idea was to create a less expensive alternative to the conventional piles of any kind and to eliminate in the same time the impossibility of constructing e.g. stone columns in very soft soils due to insufficient lateral support. The problem can be solved encasing a compacted sand or gravel column in a high-modular geosynthetic encasement. First projects started successfully in Germany in 1995. Meantime the solution proved to be very efficient for more than 15 huge projects. After intensive modifications over the years, solutions and corresponding high-modular low-creep geosynthetic encasements (Ringtrac®) are in the stage of maturity. Thus, the necessity of quick simplified pre-design procedures as a first guess of column pattern, Ringtrac®-parameters etc. is increasing. Based on series of analytical solutions (although under simplified assumptions) design graphs are developed and presented to meet the needs cited above. They are believed to be a simple pre-design tool for geotechnical engineers.

1 INTRODUCTION

Starting in 1994, a system for foundation of embankments in soft soil areas was developed by the German contractor Möbius and HUESKER Synthetic. The general idea was to create a less expensive alternative to the conventional piles of any kind and to eliminate at the same time the impossibility of constructing e.g. stone columns in very soft soils due to insufficient lateral support. The problem can be solved encasing a compacted sand or gravel column in a high-modular geosynthetic encasement (Fig. 1). Development of technology, design procedures and appropriate geosynthetics went hand in hand. First projects started successfully in Germany in 1995. Meantime the solution proved to be very efficient for more than 15 huge projects including the Airbus land reclamation on sludge in the city of Hamburg in 2001-2002 Kempfert et al (2002). At present, both analytical design procedures and numerical solutions are available.

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The general concept is shown in Figure 1.

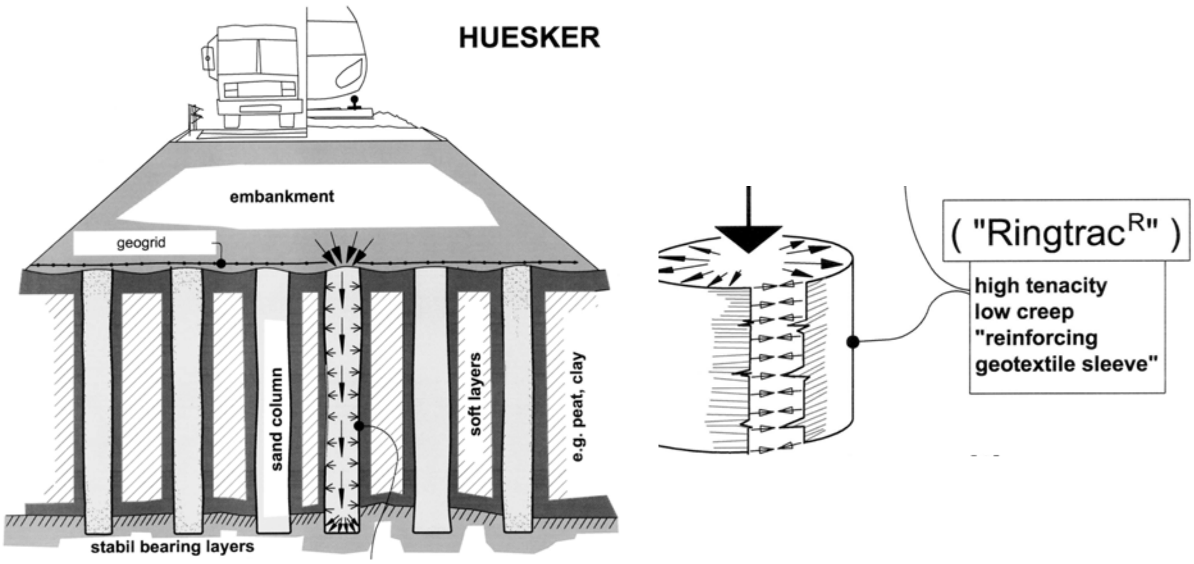

Figure 1. General principle of embankment on soft soil set on geosynthetic-encased columns (GEC)

2 GENERAL PRINCIPLES AND MECHANISMS OF FUNCTIONING

The general idea remains the same as for piled embankments: to “take over” the load from the embankment and to transfer it directly through the soft soil to a firm stratum. One important difference should be pointed out: embankments on concrete, steel, wooden etc. piles are more or less settlement-free both during the construction and during service under traffic. If the design is appropriate, the compression stiffness of the piles is so high, that practically no settlement occurs at the level of pile tops or caps (say at the base of embankment). Strong horizontal geosynthetic reinforcement is usually installed at that level to bridge the soft soil between piles and equalize embankment’s deformations.

It is important to know, that generally the vertical compressive behavior of the GEC’s is softer. The vertical sand or gravel column starts to settle under load mainly due to radial outward deformation. A confining radial inward resistance is then provided by the Ringtrac®-encasement (and to some extent by the surrounding soft soil), acting similar to the confining ring in an oedometer, but being more extensible. Shortly speaking, finally a state of equilibrium is reached, ensured by the strength of sand or gravel, confining ring-force in the encasement and soft soil radial counter-pressure (which could be even zero: then the bearing capacity is ensured only by the Ringtrac®). The mobilization of ring-forces requires some radial extension of the encasement (usually in the range of 2 to 5 % strain in the ring direction), leading to some radial “spreading” deformation in the sand (gravel) columns and resulting consequently in vertical settlement of the top of column. The final result is that the system on GEC’s cannot be completely settlement-free. Fortunately, most of the settlement occurs during the construction stage and can be compensated by some increase of embankment height.

From the point of view of design, there are two possible ways to reduce and control the settlement:

First, increasing the column density per unit area of embankment foundation, say the “percentage” of columns in the base (in the plan view: area of columns / total base area). Usual values range from 10 to 20 %. This can be achieved increasing the diameter of columns (usual range is 0.6 to 0.8 m) and/or decreasing the axial spacing between them (usual range is 1.5 to 2.5 m).

Second, increasing the tensile module J (tensile stiffness) and strength of the Ringtrac® in the ring direction, which is the bearing one confining the non-cohesive column. The higher the tensile module, the less the ring-strain, the less the radial outward deformation of the encased sand (or gravel) and finally the lower the resulting vertical settlement of column’s top (see above). The ring tensile stiffness and strength can influence the behavior of the system (e. g. the settlements) in a significant way. In Figure 2 two typical strain vs. tensile force graphs of different types of Ringtrac® are depicted (short-term).

Note, that for an appropriate design not only the short-term modules, but the long-term ones (after creep) have to be taken into account as well. The long-term modules can be read out from the Ringtrac®'s isochrones (Ringtrac® Data 1997-2003), which are not shown herein. For the Ringtrac® only low-creep polymers are used.

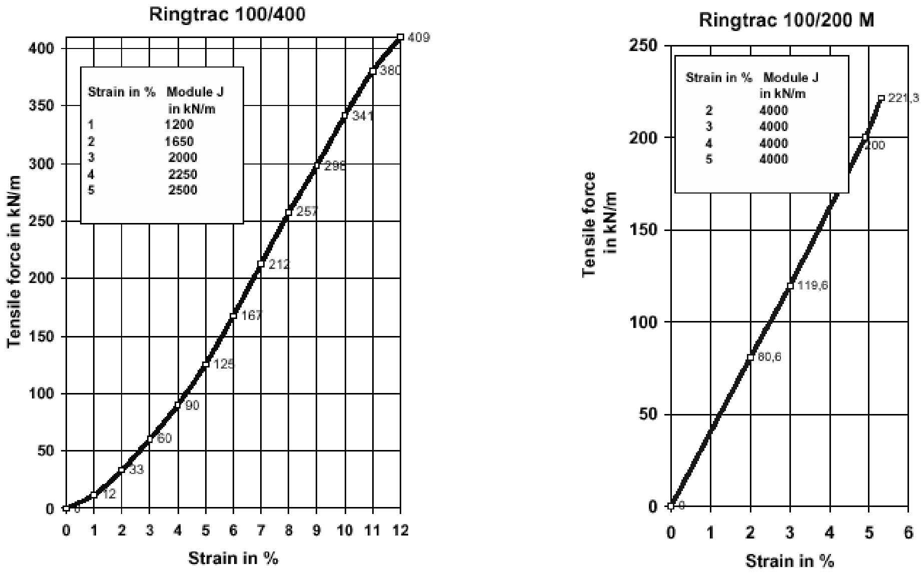

Figure 2. Typical short-term strain-tensile force graphs for different Ringtrac®'s

3 OPTIONS AND CONSTRUCTION TECHNOLOGY

Regarding the construction technology, generally two different options are available.

First option (the so called displacement method): a closed-tip steel pipe is being driven down into the soft soil, then the Ringtrac® is being installed inside and filled with e.g. sand. The tip opens, and the pipe is being pulled upwards under optimized vibration, thus compacting the column.

The second option (with excavation of the soft soil inside the pipe) uses an open pipe. After the pipe has been driven down, special tools are excavating the soil. Thereafter the procedure is the same as above.

From the point of view of the Ringtrac® used, two common options are available.

First option: the diameter of Ringtrac® $D_{Ringtrac}$ is a bit larger than the diameter of the steel pipe D_{Pipe}, allowing for a better mobilization of soft soil radial counter-pressure after pulling up the pipe, because the sand column can widen radially and provoke a counter-pressure easier from the same beginning. The disadvantage is a larger settlement due to the larger radial deformation (see above).

Second option: the $D_{Ringtrac}$ is equal to D_{Pipe}, resulting in less soft soil mobilization, higher ring-tensile forces and reduced settlement. The second concept is the preferred one at present. Figures 3 and 4 show an overview of the displacement method and a GEC after construction "in air" for a demonstration test field.

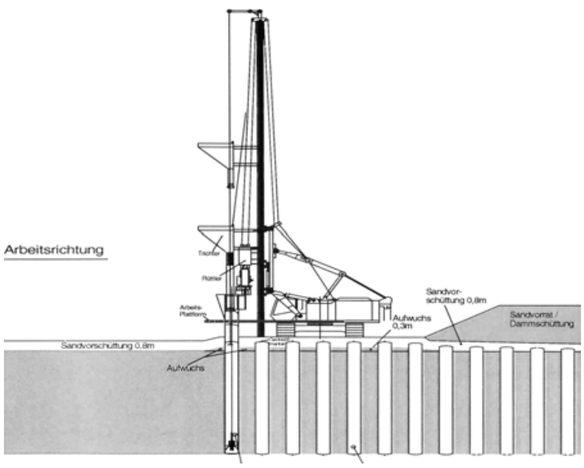

Figure 3. Displacement method of construction

Figure 4. A test column constructed "in air" for a demonstration in a testfield

4 DESIGN AND CALCULATION METHODS

For design and calculation purposes different methods have been developed over the years. First suggestions can be find in Van Impe (1989). Thereafter for a relatively short period (about 1994-1996) methods focused on FEM-analyses. At that time this was very time-consuming, and the results seemed to be not really reliable. Consequently, additional research had to be performed to develop more appropriate design tools. Two analytical procedures were the result of these efforts Raithel (1999), Raithel & Kempfert (2000), designated later herein as "simple" and "sophisticated" (but not in the original references cited above). During the last two years a revival of FEM occurs to some extent due to faster PC's and more user-friendly codes, but it is still believed that the analytical procedures mentioned above are good enough for common situations, especially due to the still non-perfect constitutive models with FEM regarding e. g. geosynthetics, the input-data sensitivity etc. Due to the lack of place our FEM experience regarding the Ringtrac®-GEC's will be not discussed herein.

Because of the increasing number of projects a tool for quick pre-design orientation becomes necessary to allow an overview e. g. of the lower and upper limits of the system for a given situation. It should focus on the main design factors controlling e.g. the settlement of embankment: the tensile module J in ring direction and the "percentage" of columns. Graphs are believed to be such a simple pre-design tool. Such series of graphs are presented below for some typical situations only due to the lack of place. They are based on series of analytical calculations using both the "simple" and "sophisticated" procedures, but not on FEM-analyses.

5 TYPICAL SITUATIONS PRESENTED

The thickness of soft soil below embankment is 10 m (usual range for the projects until now is 8 to 16 m). The soft soil is homogeneous. Three embankment heights are analyzed: 4, 8 and 12 m. The key deformation parameter of the soft subsoil, the oedometric module E, is assumed to be 0.5 MPa and 1.5 MPa (for a reference stress of 100 kPa) to give a feeling for the system settlements in really soft soils. Three different "percentages" of column foundation (see above) are analyzed: 10, 15 and 20 %. Values < 10 % are risky, values > 20 % sometimes not really economically efficient, although possible. The system is displayed in Figure 5.

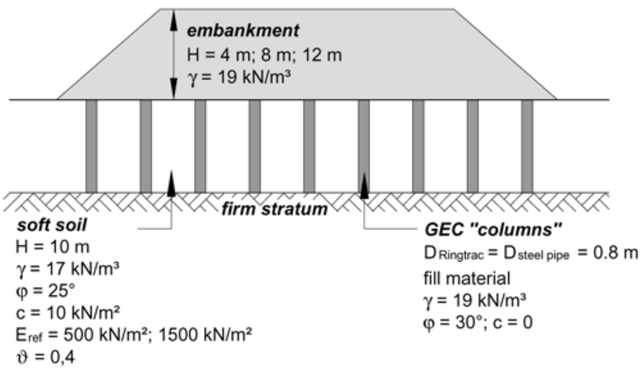

Figure 5. Overview of system analyzed in the examples (graphs)

6 TYPICAL GRAPHS FOR THE SETTLEMENT

The graphs are shown in Figure 6. As parameter on the X-axis the tensile module J is chosen, and on the Y-axis the settlement s on top of the GEC. The curves are bundled depending on the "percentage" of columns (on the right: 10, 15 and 20 %) and on the procedure applied ("simplified" and "sophisticated"). Thus, there is a set of three parameters on every graph: two of them can be assumed as input, the third one will be the output. Height of embankment and oedometric module of soft soil are shown above every graph together with the settlement for an equivalent case without columns. Note, that the range of J from 1000 to 4000 kN/m for both short- and long-term modules corresponds to "real" Ringtrac®'s.

Only as a rough estimation for other cases than the depicted ones interpolations could be performed.

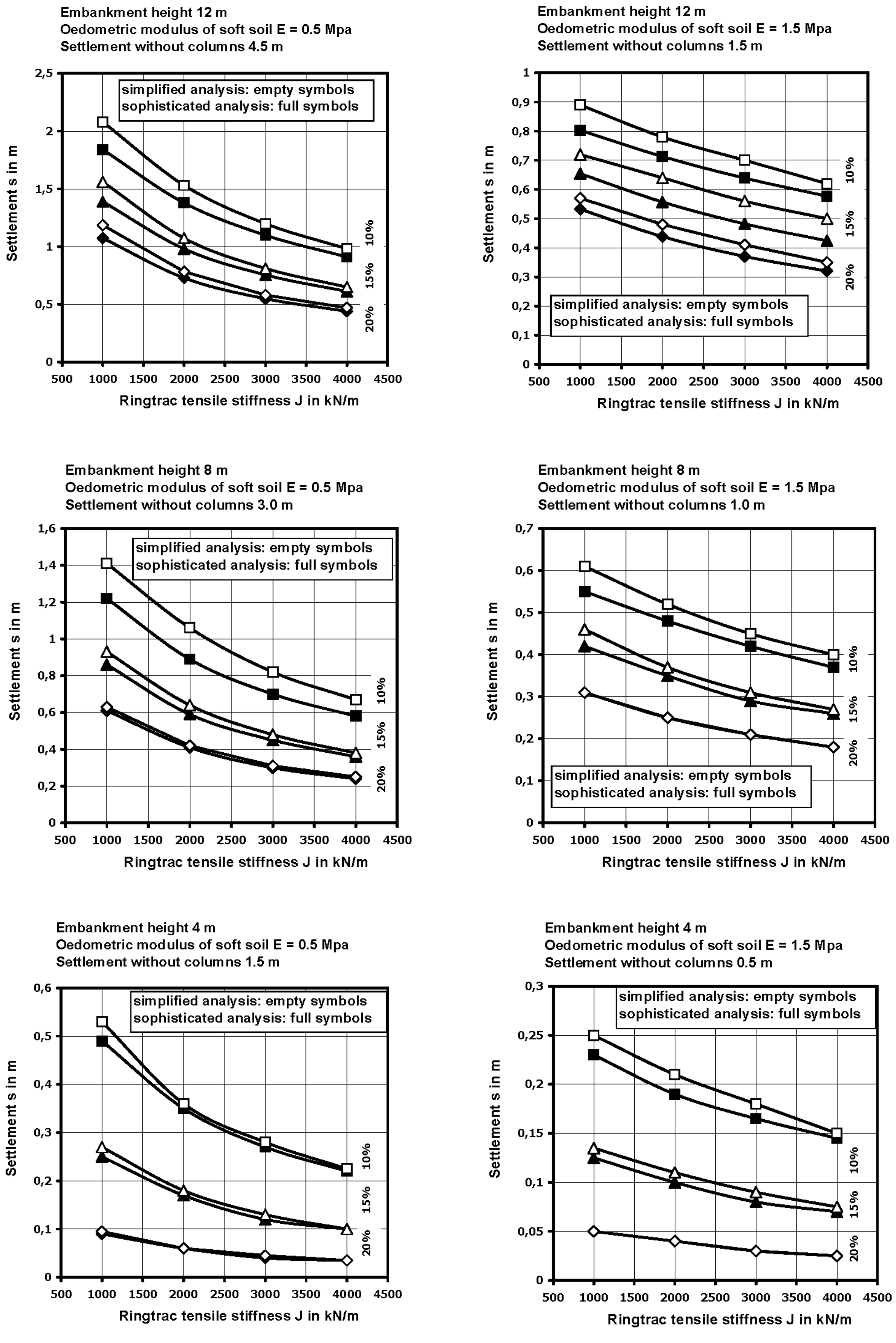

Figure 6. Typical graphs for the settlement depending on the surcharge, the oedometric module of the soft soil, the applied design procedure, the tensile stiffness of Ringtrac® and the „percentage

7 FINAL REMARKS

A series of design calculations were performed for dimensioning of Geotextile Encased Columns (GEC) beneath an embankment on soft soil. Two recent analytical procedures were used, which are believed to be precise enough. A “standard” case was analyzed, varying some important parameters in a typical practice-related range. The results are presented as graphs which can be used in a simple way for rough pre-design calculation of settlements and/or required “percentage” of columns and/or for determining the required tensile module in ring direction of the geotextile encasements (Ringtrac®).

The aims of the work are:

To show the influence mainly of the typical factors ring-tensile module, “percentage” of columns in the embankment base and soft soil oedometric module. (Note, that the first two of them can be varied in a wide range by the geotechnical engineer to find out the optimal solution).

To show in a quick way the “lower” and “upper” limits of the system for a given case. To perform “best” and “worst” case quick pre-design calculations for cases with only insufficient information available. To find out which data and parameters are critical for the design in a given case for finding out e.g. is a more precise geotechnical survey necessary for the final design etc.

Some issues should be pointed out:

In the range of parameters on the graphs presented single and double interpolations are allowed with an acceptable loss of precision. The soft soil is assumed to be homogeneous with depth and the diameter of encasement to be equal to the diameter of the installation steel pipe for the purpose of simplicity and due to the lack of place. (More wide-range analyses including also FEM will be published separately).

The range of ring tensile modules used corresponds to the short- and long-term values of real geosynthetics (Ringtrac®’s of different types) and is not only a model abstraction. The work presented does not pretend to be complete. The idea is to show a possible way for rough estimation and orientation.

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