Geotextile Encased Columns (GEC): Load Capacity & Geotextile Selection

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Abstract

This paper summarises the analytical procedures used in the design of a new foundation system 'Geotextile Encased Columns' (GEC). Variations in the modulus and the tensile strength of the geotextile are presented to investigate their effect on the load capacity of the columns and overall settlement predictions. In addition, the selection of appropriate polymers and long-term design parameters for the geotextiles, compatible with the design life and performance of the columns, is discussed.

Introduction

The design and construction of vibro-displacement columns of compacted sand, or stone, have been well established (Priebe, 1976). However the use of such techniques in very soft ground is limited because the horizontal radial outward stress in the columns must not exceed the horizontal support offered by the adjacent soils, hence such techniques are generally applied to soils with an undrained cohesion (c_u) greater than 15 kN/m^2.

The use of a geotextile around the column provides radial support and enables the columns to carry higher loads and extends the use of these load bearing columns to very soft soils, peats and sludges which offer negligible radial support, cu < 2 kN/m^2.

Development of the technology, design procedures, and appropriate geosynthetics went hand in hand throughout the 1990's. GEC have been employed on a number of projects to date, including for the foundation of a dyke on very soft soils for a reclamation project on the River Elbe in Germany, (Kempfert et al, 2002) and more recently on construction of a rail embankment through a former municipal landfill cell in Holland, (Nods, 2002).

Geotextile Encased Columns

The general principal of GEC is similar to that of traditional piled embankments, in that they are designed to transfer the loading from the soil self weight, and imposed loadings on the embankment, and transfer them directly through the soft soil to a firm stratum beneath.

One important difference between conventional piled embankments, consisting of concrete, steel, wooden piles etc., is that these piles/bearing elements are more or less settlement-free, both during construction, and later under service loadings. If the design is appropriate, the compression stiffness of the piles is so high, that practically no settlement occurs at the top of the piles.

The vertical compressive behavior of the GEC 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 geotextile encasement (and to some extent by the surrounding soft soil), acting in a similar manner to the confining ring in an oedometer.

The mobilization of ring-forces requires some radial extension of the encasement (usually in the range of 2 to 5 % strain), leading to some radial "spreading" deformation in the sand (gravel) columns, and resulting, consequently, in vertical settlement at the top of column.

The GEC system cannot therefore be completely settlement free. Fortunately, most of the settlement occurs during the construction stage and can be compensated by some increase of embankment height. Finally a state of equilibrium is reached, ensured by the strength and stiffness of sand or gravel, soft soil radial counter-pressure and the confining ring-force in the encasement geotextile.

At present, both analytical design procedures and numerical solutions are available. Initial steps in the calculation process were first suggested by Van Impe, 1986, and numerical and analytical models developed by Raithel & Kempfert 1999, 2000. In order to enable comparison of results of the analytical procedures, an overview of the procedure is presented, see Figure 1; full details on the analytical procedures are available elsewhere (Raithel & Kempfert, 2000).

The GEC are arranged usually in a triangular grid pattern. Typical diameter of the columns is 800 mm and axial spacing of the columns is typically 1.7 to 2.4 m, hence the resulting area of treatment ranges from 10 to 25%.

The bearing behaviour of the GEC is complex. The bearing elements are significantly stiffer than the surrounding soil and therefore attract a higher load concentration from the overlying embankment. Conversely, the pressure acting on the adjacent soil is lowered with an overall reduction in the total settlement.

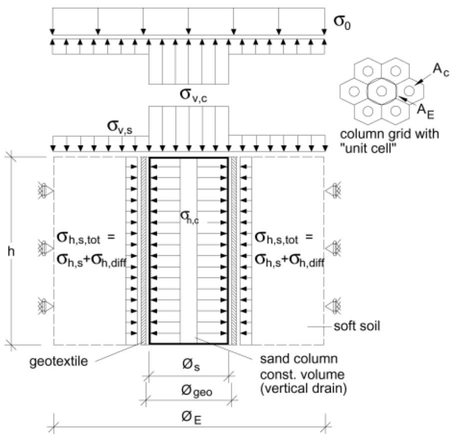


Figure 1. Analytical model for ‘geotextile coated sand columns’. (Raithel & Kempfert ,2000)

Figure 2. A test column constructed in air from Ringtrac®

The design is based on the unit cell concept shown in Figure 1. The vertical stress from the overlying embankment σ_o acts over the hexagonal area of influence of a single column (unit area), A_E, and is equivalent to the loading on the sand column, $\sigma_{v,c,}$ acting over the area of the column, A_C, plus the vertical load, $\sigma_{v,s}$ acting over the area of the adjacent soil, (A_E-A_C). The variation in vertical stress concentration acting over the sand column, $\sigma_{v,c,}$ and the adjacent soil, $\sigma_{v,s}$ creates a variance in the horizontal radial stresses in the column and adjacent soil and results in a ring tensile force, F_R in the geotextile.

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

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

Secondly, to increase the load capacity in each of the columns. The key parameters that affect the load bearing capacity of the GEC are the horizontal earth pressures mobilized by the sand or gravel fill placed within the columns, $\sigma_{h,c,}$, the horizontal earth pressure mobilized by the adjacent soil, $\sigma_{h,s,}$ and by the tensile stiffness of the confining geotextile. The higher the tensile module J (tensile stiffness), the less the ring-strain, the less the radial outward deformation and finally the lower the resulting vertical settlement of columns. The ring tensile stiffness and strength can therefore influence the behaviour of the system (e.g. the settlement) in a significant way. The geotextile is therefore required to support the horizontal stress variance for the design life of the structure.

Geotextile Selection

In order to maintain this equilibrium state, designers need to have confidence in the long-term behaviour of the geotextile, which provides radial support to the columns, over the service life of the columns. In this regard, not only the design strength of the encasing geosynthetic is important, but also the short and long-term stress/strain behaviour. Partial loss of radial support would result in bulging of the columns, redistribution of the vertical stresses, resulting in a proportional increase in the vertical stresses acting on the adjacent soil, and hence lead to further settlement. Sudden or total loss of radial support would exacerbate this settlement, which could possibly lead to settlements exceeding serviceability limits, or even ultimate limit state conditions being reached.

One key step in the production of the support geotextile was the development of seamless weave technology enabling a seamless, supporting, circular geotextile to be created, Ringtrac®. Figure 2 shows a field trial of a test column

Prior to this development seams had to be incorporated, the efficiency of the sewn seam in transferring the tensile strength across the seam varied considerably, depending on the type of seam employed, yarn type and method of sewing. Typical values for strength transfer across the seam, range from 30-70% of the initial characteristic strength (BS 8006, 1995), and reliance on consistent seam strength requires good quality assurance procedures and rigorous testing.

The long-term behaviour of geotextiles has long been an issue with designers, however extensive research on their degradation effects, including creep strain, mechanical and environmental damage etc., have helped to allay most of these concerns, and indeed geosynthetics have become a part of mainstream Civil Engineering, offering practical solutions for geotechnical soil reinforcement applications.

The polymer employed largely determines the properties of Ringtrac®. The design engineer’s ideal geosynthetic reinforcement would possess the following characteristics:

- high modulus (low, soil-compatible strain values, rapid mobilisation of tensile force)
- low propensity to creep (high long-term tensile strength, minimum creep extension, lasting guarantee of tensile force)
- high permeability (lowest possible hydraulic resistance and as a result, no increasing pressure problems)
- little damage during installation and compaction

- high chemical and biological resistance in all conceivable environments

The assumptions of a linear load/elongation relationship of the geosynthetic material warrants further clarification since all polymers are essentially non-linear visco-elastic materials and as such are load rate dependant. All engineering materials, including steel when subjected to constant stress, will exhibit the effects of creep. For most engineering metals, or glasses, creep is usually only significant at temperatures above about 300°C, however creep at ambient temperatures is normal for polymers.
Creep strain, is a well-documented characteristic of polymeric materials (Greenwood, 1990), therefore when quoting ultimate tensile strengths of geosynthetic, these need to be considered with respect to the rate of strain and ambient temperature.

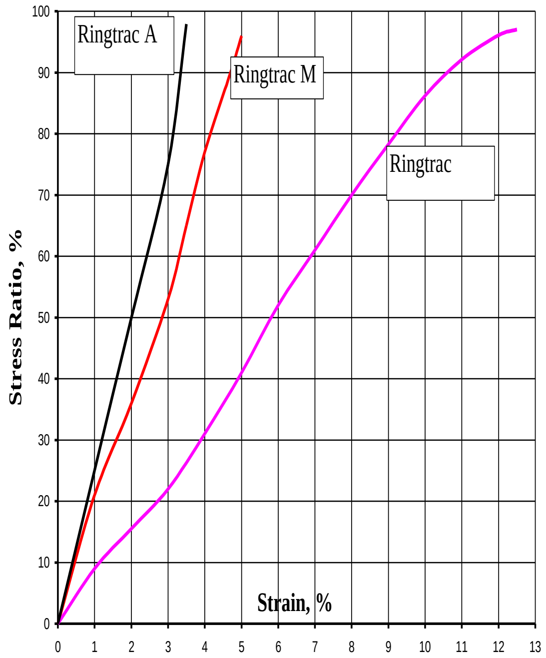


Figure 3. Initial Stress /Strain curves for different types of Ringtrac®

Fortunately, index property tests exist, EN ISO 10319 provides recommendations for the determination of index tensile properties for geosynthetic reinforcement, whereby the rate of elongation is in the range 20% ± 5%/min, and undertaken in controlled conditions with the relative humidity 65 ± 5% and standard temperature 20 ± 2°C. The yield point is normally used to define the limit of the materials performance. A minimum of five tests is performed and the mean yield stress and mean strain determined along with the standard deviation for each. Most manufacturers then quote the ultimate characteristic tensile strength as a 95% confidence limit equivalent to 1.64 standard deviations below the mean value.

The polymer used to produce Ringtrac® determines its properties. Standard Ringtrac is produced using high tenacity polyester (PET), Ringtrac® M is produced using Polyvinyl Alcohol yarns (PVA) and Ringtrac® A is produced using Aramid yarns (Figure 3). In controlling deformations in the column the designer needs to consider not only the initial tensile stiffness of the Ringtrac®, but also the stiffness relevant to the column's design life, and additional settlements due to creep strain of the column confinement. Real time creep data and accelerated creep testing can be used to generate a family of either isometric curves, presented as creep strain against log time, for a series of constant loads; alternatively this data can be used to generate the more familiar isochronous curves of stress against strain for a given/constant time. A family of isochronous curves is included for Ringtrac® M in Figure 4.

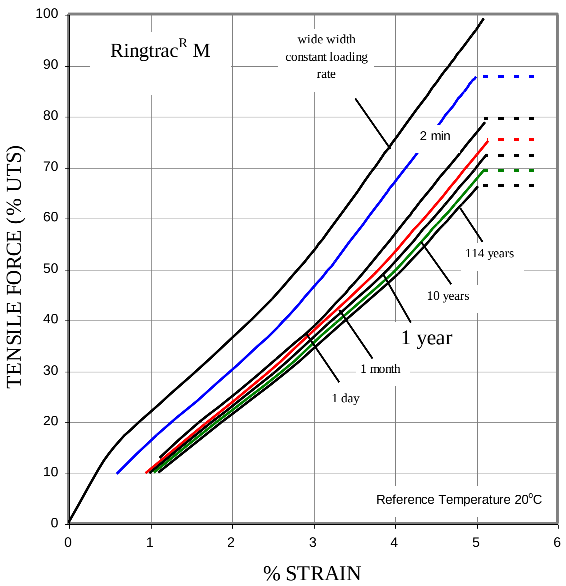


Figure 4. Isochronous curves for Ringtrac® M

By comparing the relevant stiffness of the Ringtrac® at the end of construction, (t1) and at the end of the service life (t2), the designer is able to predict post construction settlements related to creep strain of the Ringtrac®, see Figure 5. It should be pointed out that each of the three polymers used for the production of Ringtrac® (high tenacity Polyester, Polyvinyl Alcohol and Aramid) have a low propensity to creep.

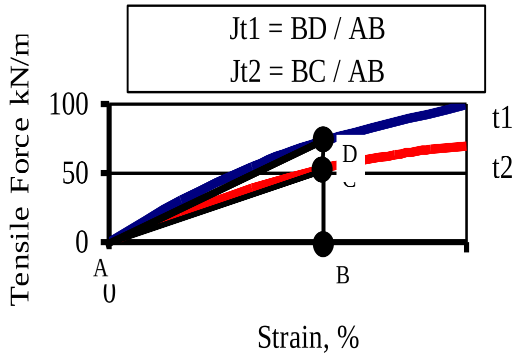


Figure 5. Example of assessment of time dependant tensile modulus

Comparative Calculation

Based on the analytical procedures outlined earlier a study was undertaken to compare the settlement prediction, strain and Ringtrac® stress for differing circumferential stiffness, and area of columns in the foundation soil. The assumed loading consisted of 4, 8 &12 m high embankments with a bulk unit weight, γ, equivalent to 19 kN/m^3, constructed on homogenous foundation soil, 10 m deep. 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) and Poisson's ratio, ν to be 0.4. Three different "percentages" of column foundation are analyzed: 10, 15 and 20 %. GEC 800 mm in diameter are installed in the foundation soil, filled with a sand with an effective $\varphi = 30^o$ and bulk unit weight, γ = 19 kN/m^3. A range of tensile stiffness moduli J, kN/m varying from 1000 to 4000 kN/m was checked. 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. (More wide-range analyses including also FEM will be published separately).

Results And Discussion

The results are shown as graphs in Figures 6 to 11. They are presented with the settlement s, in metres on top of GEC versus the tensile moduli J, kN/m with differing percentage of column area, group on the same graph. The results of the analytical comparison show that utilizing Ringtrac® with a greater tensile stiffness increases the load capacity of the GEC with an associated reduction in the overall settlement, and increase in circumferential stress.

The aims of the work was to provide a quick preliminary pre-design calculations for cases with only limited soils information available, to find out which data and parameters are critical for the design in a given case, and to show the influence of the typical variables affecting the system i.e. ring-tensile moduli, percentage of columns in the embankment base and soft soil oedometric moduli of the in-situ soil.

In the range of parameters on the graphs presented single and double interpolations are allowed with an acceptable loss of precision.

Conclusions

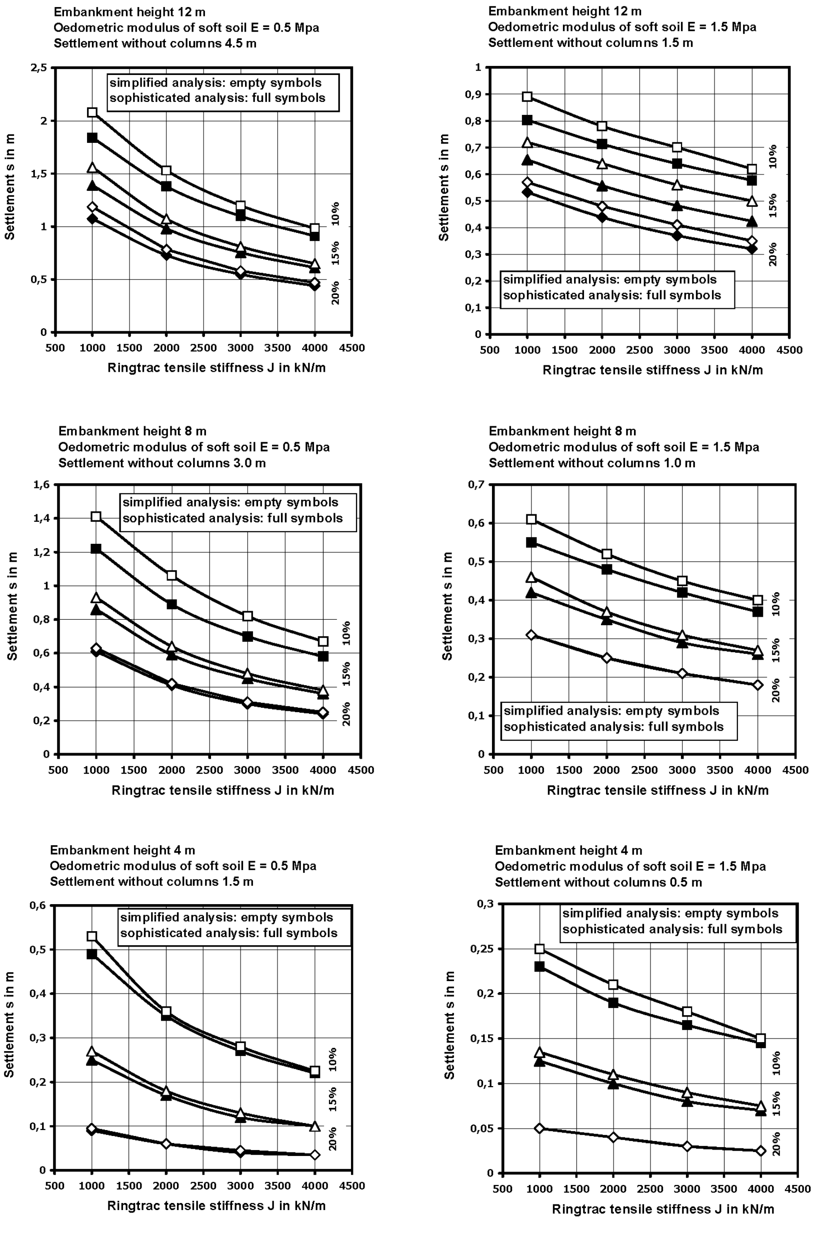
GEC have already proved a practical foundation system for embankments constructed on very poor soils ($c_u < 2$ kN/m^2).

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 for determining the required tensile module in ring direction of the geotextile encasements (Ringtrac®).

The load bearing capacity of the columns can be optimized by the geotechnical engineer by varying the ring-tensile module and percentage area of columns in the embankment base. Additionally by selection of appropriate polymers with low creep propensity the post construction creep strain related settlements can be reduced to negligible levels.

The range of tensile moduli (from 1000 to 4000 kN/m) corresponds to the range of short and long-term moduli offered by the current Ringtrac® family of products.



Figures 6 to11. Preliminary design charts for GEC system

References

British Standard Institution (1995). BS 8006. *Code of Practice for Strengthened/reinforced soils and other fills*. British Standards Institute. London.

EN ISO 10319: (1993); Geotextiles: Wide Width Tensile Test

Greenwood, J.H. (1990). *The creep of geotextiles.* Proceedings of the 4th International conference on geotextiles, geomembranes and related products, The Hague, ed. Den Hoedt G. Balkema, Rotterdam, Netherlands, pp.645-650.

Kempfert, H.-G., Möbius, W., Wallis, P., Raithel, M., Geduhn, M., McClinton, R.G., (2002) *Reclaiming land with geotextile-encased columns.* Geotechnical Fabrics Report, Vol. 20. No.6. pp34-39.

Nods, M. (2002) *Put a sock in it " geotextile encased sand columns are preventing settlement of a high speed railway embankment in the Netherlands.* Ground Engineering. December pp. 25.

Priebe, H. (1976). *Abschätzung des Setzungsverhaltens eines durch Stopfverdichtung verbesserten Baugrundes*, Die Bautechnik 53, H. 5.

Raithel, M., Kempfert, H.-G. (1999). *Bemessung von geokunststoffummantelten Sandsäulen.* Die Bautechnik 76, Nr. 12.

Raithel, M., Kempfert, H.-G. (2000). *Calculation models for dam foundation with geotextile coated sand columns.* Proc. International conference on Geotechnical & Geological Engineering GeoEng. Melbourne

Raithel, M., Kempfert, H.-G., Kirchner, A.; (2002). *Geotextile-encased columns (GEC) for foundation of a dike on very soft soils.* Proceedings 7th ICG International Conference on Geosynthetics, Nice, France, September, pp.1025-1028

Van Impe, W.F. (1986) *Improving of the bearing capacity of weak hydraulic fills by means of geotextiles.* Proc., 3rd International Conference on Geotextiles. Vienna, Austria, pp. 1411-1416