Incorporation of slack and creep in the British Standard code of practice for calculating tension and deflection of geosynthetic reinforcement used in column-supported embankments

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ABSTRACT: Geosynthetic reinforcement with adequate stiffness, durability, and resistance to creep is important for good long-term load transfer performance within a geosynthetic-reinforced column-supported embankment (GRCSE). The British Standard BS8006 code of practice provides a practical approach for estimating tension developed in the geosynthetic reinforcement due to the vertical stress imposed by the embankment weight reduced by soil arching. This paper shows that the BS8006 code of practice can be expanded to account for slack introduced in the reinforcement during installation and for long-term creep. Both of these influences result in higher predicted maximum deflection of the reinforcement and lower in-service tension when compared to considering elastic strain only. Consideration of creep is addressed using the concept of residual strength adopted by British Standards for determining the long-term strength of geosynthetics. A design approach is presented that is conservative for estimating both vertical deflection and in-service tension in the reinforcement.

1 INTRODUCTION

Geosynthetic-reinforced, column-supported embankments (GRCSEs) have been used in soft ground conditions when there is a need to accelerate construction and/or protect adjacent facilities from the settlement that would otherwise be induced by the new embankment load. The columns in column-supported embankments can be driven piles or various types of formed-in-place columns. If driven piles are used, they are often fitted with pile caps to help transfer the embankment load to the piles. GRCSEs reduce settlement of the soft foundation soils by concentrating the embankment stress and live loads to the stiff columns through stress redistribution both above and below the foundation subgrade level. One such mechanism of load transfer is through the vertical component of tension developed in the geosynthetic reinforcement in response to the applied embankment stress reduced by soil arching. The reinforcement undergoes strain due to the tension developed, and it deflects vertically in compatibility with the reinforcement strain and the settlement of the soft foundation soils.

The British Standard provides codes of practice for determining the vertical stress acting on the reinforcement and for estimating the tension and deflection developed in the geosynthetic reinforcement. The approach for estimating the tension and deflection of the reinforcement can be applied separately from the procedure for determining the vertical stress acting on the reinforcement. The code of practice considers that the two-dimensional projection of the deflected shape of the reinforcement is parabolic across the clear span between adjacent columns and that the tension is uniform. The Swedish method summarized in Rogbeck et al. (1998) relies on the same parabolic assumption.

This paper presents an expansion of the British Standard code of practice to incorporate the influence of initial slack and creep on the calculated values of tension and deflection. A practical design approach that is conservative for both tension and deflection is also presented.

2 OVERVIEW OF BRITISH STANDARD CODE OF PRACTICE BS8006

Development of the British Standard code of practice for estimating the tension and maximum vertical deflection of the geosynthetic reinforcement is given in Jones et al. (1990). In this method, the reinforcement spanning adjacent columns is treated as a 2D cable segment and it is assumed to deform as a parabola in response to a uniformly applied vertical pressure, W_t. The arrangement for a 2D segment of geosynthetic reinforcement spanning adjacent columns is given in Figure 1.

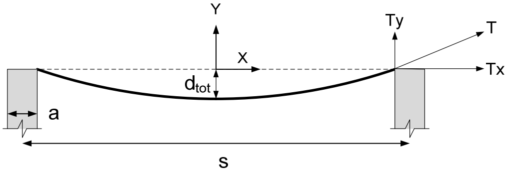

Figure 1: Parabolic approximation for reinforcement spanning adjacent columns

The center-to-center spacing of the columns is given by s, the width or diameter of the columns or caps is given by a, and the total maximum vertical deflection occurring at mid-span is represented by d_{tot}. The tension, T, in the reinforcement has vertical and horizontal components, T_y and T_x, which depend on the clear span (s-a) and the magnitudes of W_t and d_{tot}. The parabolic assumption has been shown to be reasonable for a cable with small vertical deflection relative to the clear span (Leonard 1988). For analysis of a 3D unit cell of a GRCSE, the magnitude of the uniform pressure acting across the clear span between adjacent columns can be approximated from the vertical embankment pressure reduced by arching, P, using the unit cell geometry. For a square array of columns, the ratio of W_t to P can be approximated by $(s+a)/2a$. McGuire and Filz (2008) discuss several methods for determining P, including some that consider the influence of subgrade support.

Vertical equilibrium requires that T_y equals W_t applied over half the clear span, giving the relationship between tension and deflection provided in Equation 1.

$$T = \frac{W_t(s-a)}{2}\sqrt{1+\frac{(s-a)^2}{16{d_{tot}}^2}} \quad (1)$$

Equation 2 provides a binomial approximation for maximum deflection of the reinforcement based on the parabolic assumption. Equation 3, which is obtained by substituting Equation 2 into Equation 1 and applying the approximated ratio between W_t and P, provides the tension in the reinforcement as a function of geometry, stress, and total strain, ε_{tot}.

$$d_{tot} = (s-a)\sqrt{\frac{3}{8}\varepsilon_{tot}} \quad (2)$$

$$T = \frac{(s^2-a^2)P}{4a}\sqrt{1+\frac{1}{6\varepsilon_{tot}}} \quad (3)$$

The code of practice outlined in the British Standard uses an assumed strain approach whereby a value of working tensile strain, ε_t, usually 5 to 6 percent, and maximum creep strain, ε_c, of 2 percent, are chosen to estimate tension and deflection of the reinforcement (Jones et al. 1990). Filz and Smith (2007) provide an approach that considers stress-strain compatibility within the parabolic method by substituting $\varepsilon_{tot} = T/J$ into Equation 3, where J is the tensile stiffness of the reinforcement.

$$\begin{gathered} 96T^3 - 6\ddot{K}_g^2 T - \ddot{K}_g^2 J = 0 \\ \text{where } \ddot{K}_g = P\left(s^2-a^2\right)/a \end{gathered} \quad (4)$$

3 BASIS FOR INCORPORATING SLACK AND CREEP IN THE BRITISH STANDARD CODE OF PRACTICE

3.1 *Initial slack*

During construction of a GRCSE, the reinforcement is normally placed on top of a thin layer of granular material that acts as a cushion over the columns or pile caps. Tautness in the reinforcement is desired so that tension, resulting in load transfer to the columns, can develop at the onset of settlement of the foundation soils. Initial tautness in the reinforcement depends on the installation technique and quality of the workmanship at the project site. Factors such as poor grade control, construction traffic, and mismanagement of stormwater runoff can lead to an uneven cushion layer prior to reinforcement placement. Also, the flexural stiffness of some reinforcement may make it difficult for the reinforcement to lay flat. When perfect tautness is not maintained, the initial length of reinforcement spanning adjacent columns, L_o, exceeds (s-a). Slack, e_s, can be defined as a percentage of the clear span according to Equation 5.

$$e_s = \frac{L_0}{(s-a)} - 1 \quad (5)$$

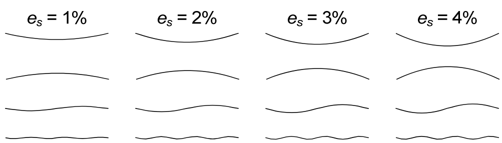

Figure 2: Graphic depiction of different magnitudes of initial slack

Figure 2 shows different magnitudes of slack without vertical exaggeration for reinforcement that initially takes on a shape approximated by a convex parabola, concave parabola, wrinkling that is one cycle of a sine function, or wrinkling that is three cycles of a sine function. Figure 2 shows that slacks of 1% to 2% could exist at some locations on a project site with average quality workmanship.

3.2 *Creep strain*

The accumulation of creep strain directly influences the magnitude of vertical deflection and total strain of the reinforcement. Less apparent are the effects of creep on the tensile strength and tensile stiffness of geosynthetic reinforcement. The International Organization of Standardization (ISO) Technical Report ISO/TR 20432:2007 has been adopted as the British Standard for determining the long-term strength of geosynthetics for soil reinforcement. In this report, the concept of residual strength (Naughton and Kempton 2004) suggests that there is essentially no degradation of tensile strength due to creep prior to creep rupture.

Naughton et al. (2005) showed that under light loading, the stress-strain relationship of aged polyester samples was almost identical to the virgin samples tested at the time of construction. Furthermore, it has been found that tensile stiffness of polyester materials can actually increase substantially under sustained load (Hirakawa et al. 2003). Therefore, in the absence of environmental degradation (e.g. hydrolysis) or installation damage, it may be acceptable to consider the tensile stiffness obtained from un-aged samples over the useful life of the embankment.

The creep rate is generally influenced by polymer type, stress level, temperature, stress relaxation through soil interaction, soil moisture, and geosynthetic structure (i.e. textile or rib structure) (Koerner 2005, Leshchinsky et al. 1997, ISO 2007). If the influences on creep rate are adequately captured for a particular application, the creep strain can be estimated as a function of time. Results of long-term creep tests showing creep strain versus time for a variety of geosynthetic reinforcement materials, load magnitude, and confinement conditions are available in published literature (Koerner et al. 1993, Greenwood et al. 2004, and Leshchinsky et al. 1997).

4 DEVELOPMENT AND CONSEQUENCE OF INCORPORATING CREEP AND SLACK IN THE BRITISH STANDARD CODE OF PRACTICE

Accounting for the influences of initial slack, tensile strain, and creep, the final length of the reinforcement spanning adjacent columns, L_{final}, is equal to $L_o(1 + \varepsilon_t + \varepsilon_c)$, where the tensile and creep strains are defined in terms of the initial length and $L_o = (s - a)(1 + e_s)$ from Equation 5. For the purposes of establishing the correct parabolic geometry, total strain can be defined according to Equation 6. Using this definition, we can express total strain in terms of slack, tensile strain, and creep strain by Equation 7. Over a range of reasonable values for e_s, ε_t, and ε_c, we can neglect the influence of second order terms without significant consequence to the calculated value of ε_{tot} allowing for simplification of Equation 7 to the form given in Equation 8.

$$\varepsilon_{tot} = \frac{L_{final}}{(s-a)} - 1 \tag{6}$$

$$\varepsilon_{tot} = e_s + \varepsilon_t + \varepsilon_c + e_s\varepsilon_t + e_s\varepsilon_c \tag{7}$$

$$\varepsilon_{tot} = e_s + \varepsilon_t + \varepsilon_c \tag{8}$$

The value of total strain, incorporating the effects of initial slack, tensile strain, and creep strain can be substituted into Equation 3 with $\varepsilon_t = T/J$ to provide the compatible solution for tension.

$$\begin{aligned}&\left(96T^2 - 6\ddot{K}_g^2\right)\left(C_g + T\right) - \ddot{K}_g^2 J = 0\\ &\text{where } C_g = J\left(e_s + \varepsilon_c\right)\end{aligned} \tag{9}$$

Due to the geometry of the parabolic assumption, the tension in the reinforcement satisfying vertical equilibrium decreases for a given clear spacing and magnitude of W_t as the value of $(e_s+\varepsilon_c)$ increases. Figures 3a and 3b illustrate this trend and the corresponding trend for tensile strain across a range of reinforcement stiffnesses for typical values of column diameter and spacing. These trends highlight an interesting outcome of the inclusion of initial slack and creep. Creep strains occur over the service life of the GRCSE and the resulting deflection due to creep can impact settlement sensitive elements, such as pavements. The impact of initial slack however, depends on whether the slack is released during embankment construction. The release of slack results in an increase in the value of d_{tot}, which corresponds to a reduced tension, T, required to maintain a constant vertical component of tension, T_y. For the case of slack released prior to installation of settlement sensitive elements, the presence of initial slack would be beneficial by reducing the increment of deformation needed to produce the vertical component of tension necessary to resist the increment in W_t.

5 DESIGN APPROACH USING THE EXPANDED BRITISH STANDARD CODE OF PRACTICE

When compared to considering tensile strain alone, the inclusion of the influences of initial slack and creep in the British Standard code of practice result in higher estimated vertical deflection of the reinforcement. As can be seen in Figure 1, larger vertical deflection increases the vertical component of tension in the reinforcement thereby reducing the magnitude of tension required to satisfy vertical equilibrium with the applied pressure, W_t.

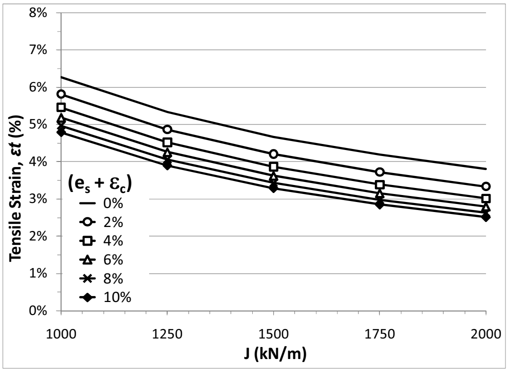

Figure 3a: Influence of initial slack and creep on in-service tension across a range of reinforcement stiffnesses

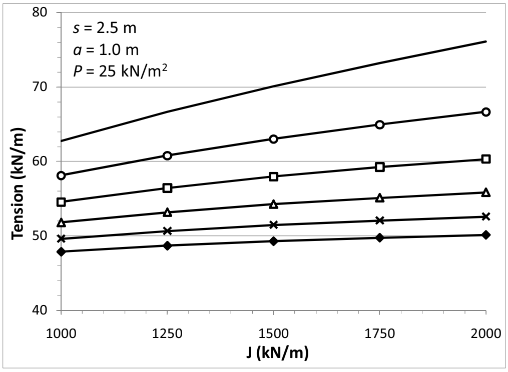

Figure 3b: Influence of initial slack and creep on in-service tensile strain across a range of reinforcement stiffnesses

Therefore, a reasonable design approach is to perform the analysis twice, once with the inclusion of creep and initial slack and once without. The tension estimated from the analysis ignoring creep and slack will be conservative for selecting a geosynthetic with adequate strength. The deflection estimated from the analysis including creep and initial slack will be conservative for the maximum deflection of the reinforcement at the time of interest and selecting a geosynthetic with acceptable creep behavior. The stiffness of the reinforcement considered for the analysis including creep should be the initial design value, including installation damage, reduced for environmental degradation expected at the time of interest.

Further development of this approach could include studies undertaken to determine appropriate values of e_s to use for design.

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REFERENCES

Filz, G.M., and Smith, M.E. 2007. Net vertical loads on geosynthetic reinforcement in column-supported embankments. *Proceedings*, *Geo- Denver*, *Geotechnical Special Publication 172*, ASCE, Reston, VA

Greenwood, J.H., Kempton, G.T., Brady, K.C., and Watts, G.R.A. 2004. Comparison between stepped isothermal method and long-term creep tests on geosynthetics. Proceedings of the 3rd European Conference on Geosynthetics, Munich, Gernany, pp. 527-532.

Hirakawa, D., Kongkitkul, W., Tatsuoka, F., Uchimura, T. 2003. Time-dependent stress-strain behavior due to viscous properties of geogrid reinforcement. *Geosynthetics International*, Vol. 10, No. 6, pp. 176-199.

IS0 2007. Guidelines for the determination of the long-term strength of geosynthetics for soil reinforcement. *Technical Report 20432*, Geneva, Switzerland.

Jones, C. J. F. P., Lawson, C.R., and Ayres, D.J. 1990. Geotextile reinforced piled embankments. *Proceedings, 4th International Conference on Geotextiles, Geomembranes, and Related Products,* Vol. 1, G. Den Hoedt (ed), The Hague, pp. 155-160.

Koerner, R.M. 2005. *Designing with Geosynthetics, 5th Edition,* Pearson Prentice Hall, New Jersey, USA.

Koerner, R.M., Hsuan, Y., and Lord, A.R. 1993. Remaining technical barriers to obtaining general acceptance of geosynthetics. *Geotextiles and Geomembranes*, Vol. 12, No. 1, pp. 1-52.

Leshchinsky, D., Dechasakulsom, M., Kaliakin, V.N. and Ling, H.I. 1997. Creep and stress relaxation of geogrids. Geosynthetics International, Vol. 4, No. 5, pp. 463-479.

Leonard, J.W. 1988. *Tension Structures,* McGraw Hill, New York, USA.

McGuire, M.P., Filz, G.M., and Almeida, M.S.S. 2009. Load-Displacement Compatibility Analysis of a Low-Height Column-Supported Embankment. *Proceedings, International Foundations Congress and Equipment Expo*, *Geotechnical Special Publication 187*, ASCE, Reston, VA

McGuire, M.P., and Filz, G.M., 2008, Quantitative comparison of theories for geosynthetic reinforcement of column-supported embankments, *Proceedings*, *GeoAmericas 2008*, Cancun, Mexico, 1303-1312.

Naughton, P.J., Balderson, T. & Laronzo, R., 2005. The properties of polyethylene encased high tenacity linear elements. *Geosynthetics and Geosynthetic-Engineered Soil Structures, Contributions from the Symposium Honoring Prof. Robert M. Koerner*, Ed Ling, H., Kaliakin, V.N. & Leshchinsky, D., pp 19-38.

Naughton, P.J. and Kempton, G.T. 2004. Creep strain in a residual strength procedure. *Proceedings, International Conference on Geosynthetics and Geo-Environmental Engineering*, Mumbai, India.

Rogbeck, Y., Gustavsson, S., Sodergren, I., and Lindquist, D. 1998. Reinforced piled embankments in Sweden - design aspects. *Proceedings, Sixth International Conference on Geosynthetics*, Vol. 2, Rowe, R.K. (ed.), Atlanta, Georgia, pp. 755-762.