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Geosynthetic reinforced pile supported embankments: numerical simulation and design needs

C. P. AUBENY, Y. LI & J.L. BRIAUD, Texas A&M University, College Station, Texas, USA

ABSTRACT: There is a complex interaction between the embankment, the natural soil, the piles, and the geosynthetic mattress in geosynthetic reinforced pile supported (GRPS) embankment. This paper describes the use of a finite element simulation to study this complex interaction. This paper also describes the current design need s on the use of geosynthetic reinforced pile supported (GRPS) embankments in practice.

1 INTRODUCTION

A GRPS embankment embodies the following design concepts: (1) the embankment weight is transmitted to a geosynthetic mattress, and (2) forces in the geosynthetic mattress are transmitted through piles to an underlying bearing stratum. By transmitting loads past the soft soil stratum, settlement and stability problems are largely avoided. Further, since the design does not rely on consolidation of soft soils to control settlements or enhance stability, the long construction period associated with conventional staged construction or preloading designs is thereby avoided.

There are several design issues that should be considered when designing a geosynthetic reinforced pile supported (GRPS) embankment. They are lateral movement, mattress design, pile design, slope stability and settlement of GRPS embankments (Fig.1).

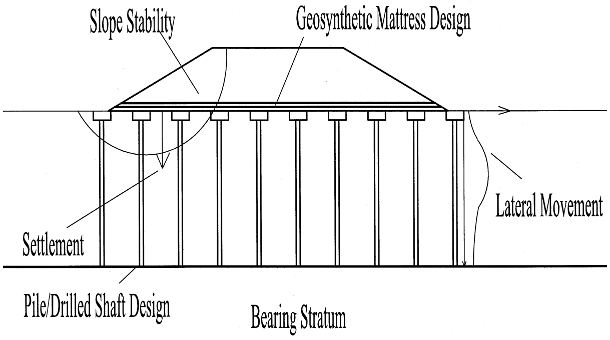

Fig. 1 Design issues in GRPS embankment

2 EXISITING DESIGN RULES

For some of the five design issues, there are some existing design rules. Yet for some of them, no design rules exist.

There is no well-accepted method for predicting the lateral movement of GRPS embankments. There are methods for predicting the lateral movement of unreinforced embankments**.** To calculate the tensile stress in the geosynthetic layer, existing methods include Terzaghi method (1943), Guido et al. method (1987), Hewlett & Randolph method (1988) and BS 8006 (1995). The shear force and bending moment of the piles in a GRPS embankment can be calculated after running special computer programs. There are also some empirical equations to obtain preliminary estimates of the maximum bending moment induced in the piles located at the embankment toe (Goh et al. 1997) For slope stability, there are several methods to calculate the factor of safety of slope reinforced by a row of piles: Lee et al (1995), Ausilio et al. (2001). For slope reinforced by several rows of piles and geosynthetics, only BS 8006 (1995) can be used. Due to the complexity of the settlement, no simple method exists for calculating the settlement of a GRPS embankment.

3 NUMERICAL SIMULATION

To simulate the behavior of a GRPS embankment, the authors used the general finite element program ABAQUS and the supercomputer at Texas A&M University to perform a series of 3-D analyse of a GRPS embankment. The dimensions and parameters of the simulated GRPS embankment are shown in Fig. 2. The mesh used is shown in Fig. 3.

Selected output of the ABAQUS runs are shown including the tensile stress in the geosynthetics, the bending moment and axial force in the piles, the settlement and lateral movement of the piles.

The bending moment and the axial force in the piles are shown in Fig. 4 and Fig.5. The locations of pile 8, pile 32 and pile 20 are shown in Fig. 2. Fig. 5 shows that the axial force in the piles increase with depth due to downdrag. The computer program PILENEG (Briaud & Tucker, 1997) can be used to calculate the downdrag load in the piles.

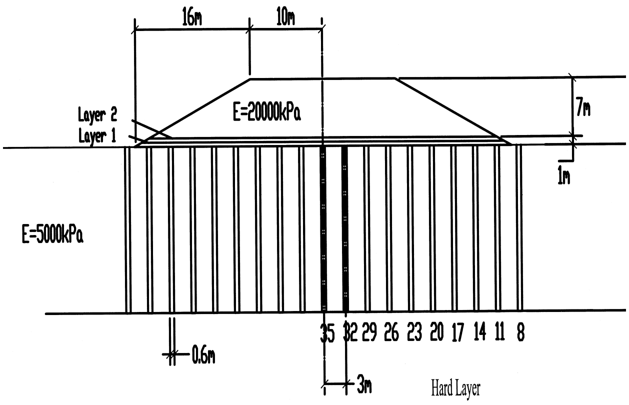

Fig.2 Dimensions and parameters of the simulated GRPS embankment

Fig. 6 and Fig.7 show the lateral movement and settlement at the top and bottom of the embankment. Fig.7 indicates that the waviness of the settlement profile which is obvious at the bottom of the embankment was disappeared at the top of the embankment.

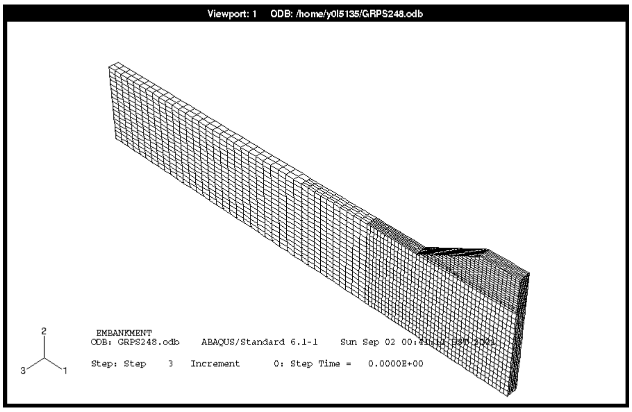

Fig. 3. 3-D mesh of the GRPS embankment

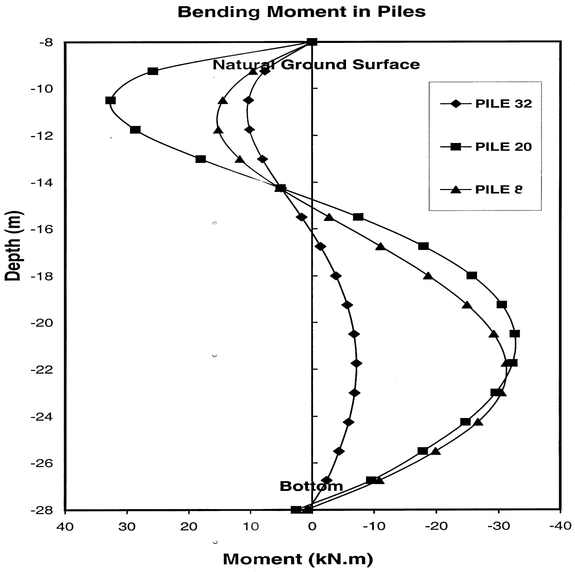

Fig. 4. Bending moment in the piles

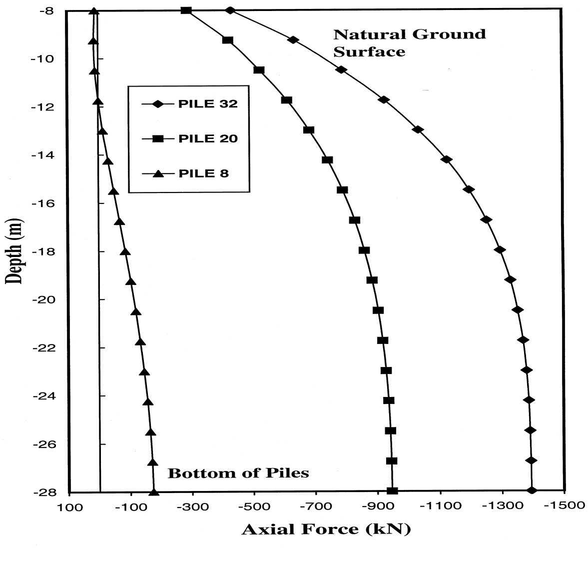

Fig. 5. Axial force in piles

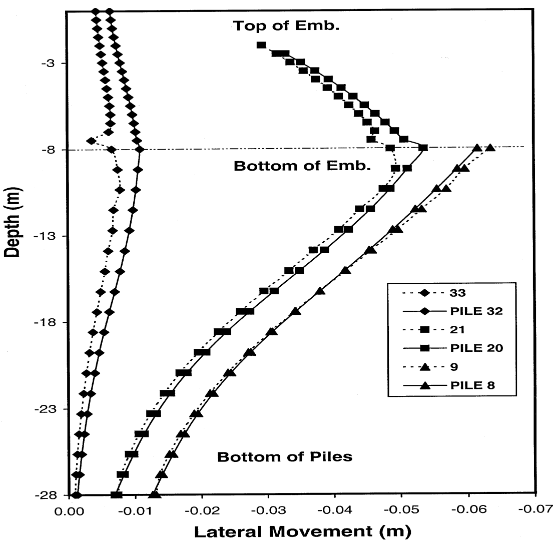

Fig. 6. Lateral movement of GRPS embankment and soil

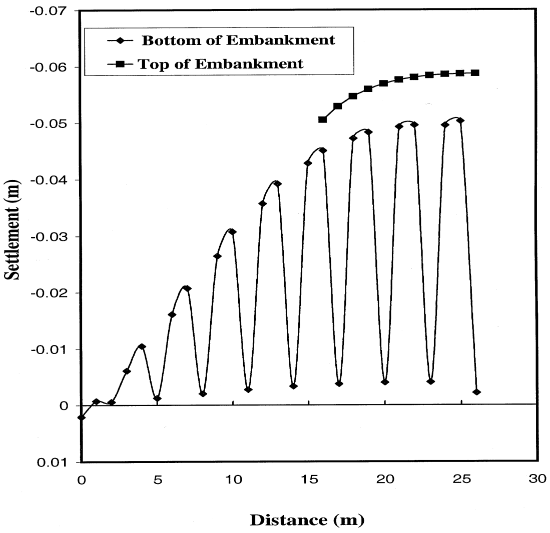

Fig. 7. Settlement at top and bottom of GRPS embankment

The current method to estimate lateral movement is for embankments without piles and geosynthetics. No method is available for calculating the lateral movement and settlement of GRPS embankment.

With the FEM and ABAQUS, one can get the line load in the geosynthetics in two directions. One is along the width of the embankment; the other is along the length of the embankment. The line load along the length is shown in Fig. 8 while the line load along the width of the embankment is shown in Fig. 9.

It can be seen that the line load in the geosynthetics is not constant between piles along the width and the length. Higher strains are generated on the piles. Kempfert et al. (1999) arrived at a similar conclusion.

4 CASE HISTORIES

During the literature review, 14 case histories on GRPS embankment were collected. The information about these case histories such as soil conditions, pile type, design parameters are listed in Table.1.

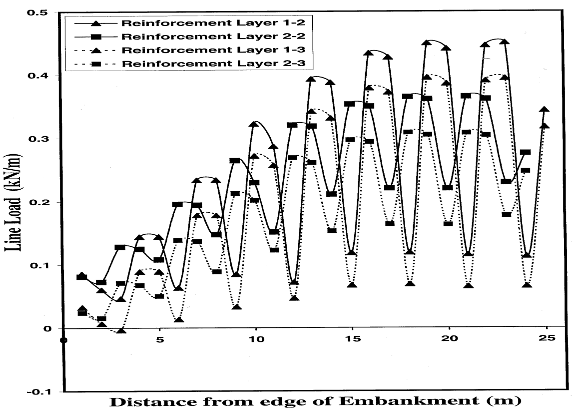

Fig. 8. Line load in geosynthetics along the length of the embankment

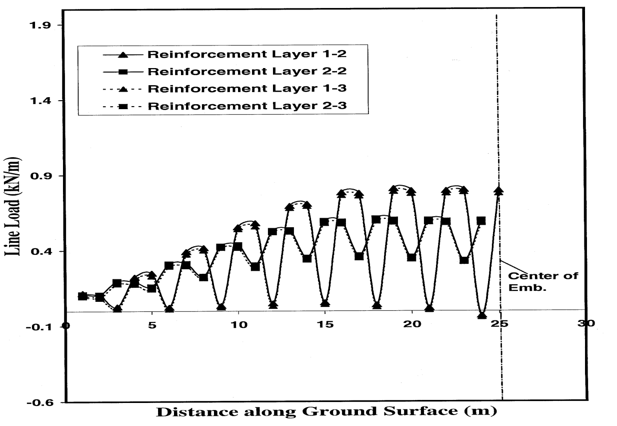

Fig. 9. Line load in geosynthetics along the width of the embankment

5 DESIGN NEEDS

A simple design method to predict the lateral movement of GRPS embankments needs to be developed because current methods to calculate the lateral movement are for an unreinforced embankment and soil without piles.

There is also a need to develop a simple design method to calculate the tensile line load in the geosynthetics used in GRPS embankment. Although there are several methods available to calculate the tensile line load, the prediction results of these methods exhibit a large scatter and do not agree with the measurements (Li et. al. 2001). Currently, the only reliable method for calculating the tensile line load in geosynthetics is by carrying out proper three-dimensional numerical analyses (Kempton et al. 1998).

There is also a need to develop guidelines to calculate the shear force and bending moment of piles in GRPS embankment.

There is a need to develop a method to calculate the settlement of GRPS embankments because no specific analytical method has been developed for calculating the settlement of a piled embankment.

The pile efficiency is defined as the proportion of embankment weight carried by the piles. The prediction results using one of the current formulas for pile efficiency of GRPS embankment agree reasonably well with the measurements (Li et. al. 2001).

Most methods available to calculate slope stability are for slopes reinforced by a single row of piles and they do not take the effect of the geosynthetics into account. (Lee, C.Y. et al. 1995. Hassiotis, S. et al. 1997) Only the BS 8006 (1995) method considers both piles and geosynthetics. The correctness of BS 8006 (1995) needs to be verified.

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TABLE 1. CASE HISTORIES OF GRPS EMBANKMENT

Case No.	Reference	Application	Soil condition	Pile type	Geosynthetic type	Design parameters
1	Reid et al. (1983)	Near bridge abutment	Soft clay	Concrete displacement pile	Membrane (paraweb)	H=10m, s=3.5-4.5m, a=1.1-1.5m, P_c=5-14%, N=1
2	Barksdale et al. (1983)	Railway	Very soft peat	Rigid stone columns	Fabric	H=7.6m,s=1.6-2.2m,d=0.51-0.56m,T=0, P_c =6-8%, N=1
3	Jones et al. (1990)	Railway	Very soft alluvium and peat.	Semi-precast concrete pile.	Geotextile “Paralink”	H=3-5m, s=2.75m,a=1.4m, T=0.5m, P_c=20%, N=1
4	Tsukada et al. (1993)	Street pavement	Peat	Concrete pile	Geogrid “Tensar SS2”	H=1.5m, s=2.1m, d=0.8m, P_c =11%, N=1,T=0
5	Holtz et al. (1993)	Pavement	Uniform grey clay	Timber pile	Geotextile “multifilament	H=5-6m,s=1.5m,a=1m, P_c=44%, N=3
6	Bell et al. (1994)	Toll Plaza	Highly compressible peat and estuarine clay	VCC The columns.	Tensar SS2 geogrid	H=2.5-6.0m,s=2.2-2.7m, d=0.4m, N=2
7	Card et al. (1995)	Docklands Light Railway (DLR)	Silty organic clay, Peat and Clay/sand	Driven or continuous flight augured piles	Biaxial Tensar SS2 geogrid	H=2.5-3m,s=3m, a=1m, N=3, d=0.45m.
8	Topolnicki (1996)	Highway and tramway	Loose fill, peat Organic clay	VCC	Geogrid “Tensar SS1” and ‘Tensar SS2”	H<1.5m,s=1.8-2.5m, d=0.55m, P_c =9-17%, N=2-3, T=0
9	Brandl et al. (1997)	Railway	Peat and organic silt	Driven pile	Geogrid	H>2m, s=1.90m,d=0.118m, a=1.0m, P_c =35%, N=3.
10	Geo-Institute (1997)	Highway embankment bridge abutment	A mixture of soft clays, silts and sands with bands of peat	VCC/Stone columns	Geotextile	H<7m, s=1.6m for VCC and s=2.2m for stone column. N=1.
11	Jenner et al (1998)	Bypass	Peat and soft silty alluvial strata	VCC	Tensar SS1 and Tensar SS2 geogrid	H=4-7m,s=2.05-2.35, d=0.45m,a=0.75m,N=2-3.
12	Rogbeck et al. (1998)	Full scale testing.	Loose silt and fine sand	Precast concrete pile	Geogrid	H=1.7m, s=2.4m, a=1.2m, P_c=25%,N=1
13	Kuo, et al. (1998)	MSE Walls	Very soft waste clay	Timber pile.	Geotextile	H=6m,s=1.5m,d=0.3m, P_c=3%, N=2.
14	Alzamora et al. (2000)	Segmental retaining walls	0 to 1 blow count organic silt and clay	Jet grout column	Uniaxial Geogrid	H=2-8.2m, s=3m, d=1.2m, P_c =13%, N=3

Note: H- embankment fill height; s-pile spacing at centers; d-pile diameter; a- cap width; T- cap thickness; c-cushion thickness; e-efficacy (%); P_c- percent coverage of pile caps; N- number of geosynthetic layers; VCC- vibro concrete column; Efficacy- defined percentage of the embankment load carried by pile cap.