Parametric analysis of geosynthetic reinforced and pile supported embankment

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Abstract—To investigate the performance of pile supported embankment, five key influencing factors are chosen for parametric study. The influencing factors include the peak length of pile cap, pile diameter, pile spacing, elastic modulus of pile and tensile stiffness of geosynthetic. The settlement at the embankment crest and the lateral displacement are investigated. The results show that the elastic modulus of pile has a significant influence on the settlement and lateral displacement when the elastic modulus of pile increases from 100 to 5000 MPa. However, the influence is not obvious when the elastic modulus of pile increases beyond 5000 MPa. As the pile spacing increases, the settlement and lateral displacement decrease significantly at first, but the influence of pile spacing becomes less important again when the pile spacing exceeds 4.0 m. The tensile stiffness of geosynthetic has a significant influence on the differential settlement. However, the lateral displacement is reduced limitly with the increase of tensile stiffness of geosynthetic.

Keywords-pile supported embankment; geosynthetic; parametric analysis; ground improvement

I. INTRODUCTION

As the development of modern society progresses, transportation demand grows dramatically year by year. Numerous embankments have been built to support highways and railways. Inevitably, soft clays (for example, alluvial soil and peat) and other highly compressible soft soils, which used to be considered technically unsuitable for construction, are encountered. The adverse features, such as low shear strength, high compressibility and so on, challenge the geotechnical profession (Abusharar et al, 2009, Zheng et al., 2009, Zhang et al., 2013)[1~3]. Pile (or caped pile) supported embankments have been used to improve overall bearing capacity and mitigate post-construction settlements since early 1960s (Zhang, 2013)[4]. After the advent of reliable and durable geosynthetic, it was introduced in pile supported embankments as basal reinforcement to facilitate the load transfer (called geosynthetic-reinforced pile-supported (GRPS) embankments). Fig .1 shows an example of such a GRPS embankment[5~7].

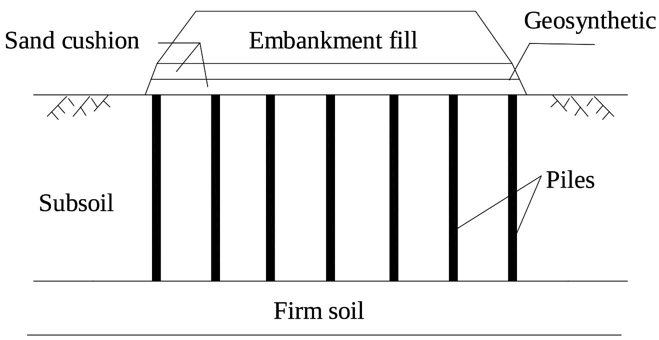


Figure 1. Illustration of GRPS embankment

In the present study, to investigate the performance of pile supported embankment, five key influencing factors are chosen for parametric study. The influencing factors include the peak length of pile cap, pile diameter, pile spacing, elastic modulus of pile and tensile stiffness of geosynthetic. The settlement at the embankment crest and the lateral displacement are investigated.

II. NUMERICAL ANALYSIS

The dimension and profile of the embankment model is shown in Fig .2. The embankment height is 6 m and the embankment crest is 24 m. A two-dimensional numerical model is established by the finite element program. The material properties of the numerical model are presented in Table 1.

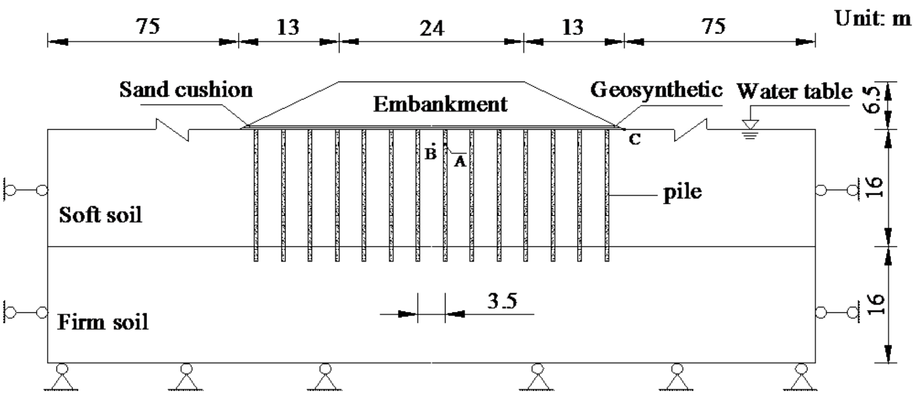
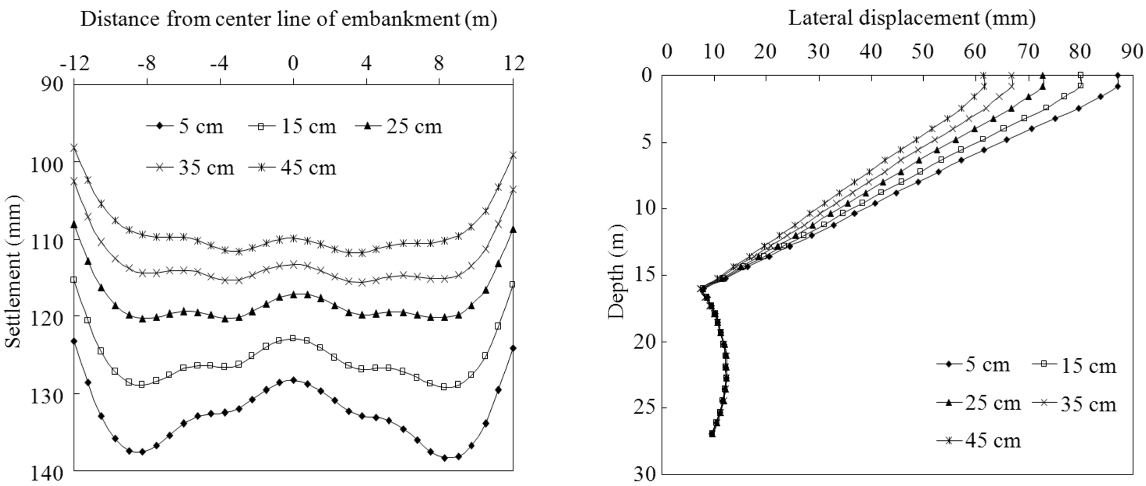


Figure 2. Cross-section of GRPS embankment

TABLE I MATERIAL PROPERTIES IN THE NUMERICAL MODEL

Parameter	Unit	Embankment	Sand cushion	Soft soil	Firm soil	pile
Material model	—	M-C	M-C	M-C	M-C	elastic
Sat. unit weight	kN/	20.4	21.3	19.5	20.2	—
Horizontal permeability	m/d	—	1.0	$8.630*10^{-4}$	$8.630*10^{-4}$	—
Vertical permeability	m/d	—	1.0	$1.06*10^{-4}$	$1.06*10^{-4}$	—
Effective Young's modulus	kPa	22000	20000	2200	25000	$1.0*10^{6}$
Effective Poisson's ratio	—	0.3	0.3	0.35	0.29	0.2
Effective cohesion	kPa	5	1.5	14	33	—
Effective friction angle	deg	25	30	10	15	—
Geosynthetic	Tensile elastic modulus: 86 KN/m					

The influence of peak length of pile cap is studied by analyzing five cases with 5, 15, 25, 35 and 45 cm. As shown in Fig .3, the settlement and lateral displacement change with the peak length of pile cap. As the peak length of pile cap increases, the settlement and differential settlement at the embankment crest decrease significantly. Similarly, the degree of decrease on the lateral displacement at the embankment toe is nearly the same with the peak length of pile cap increase from 5 to 45 cm.

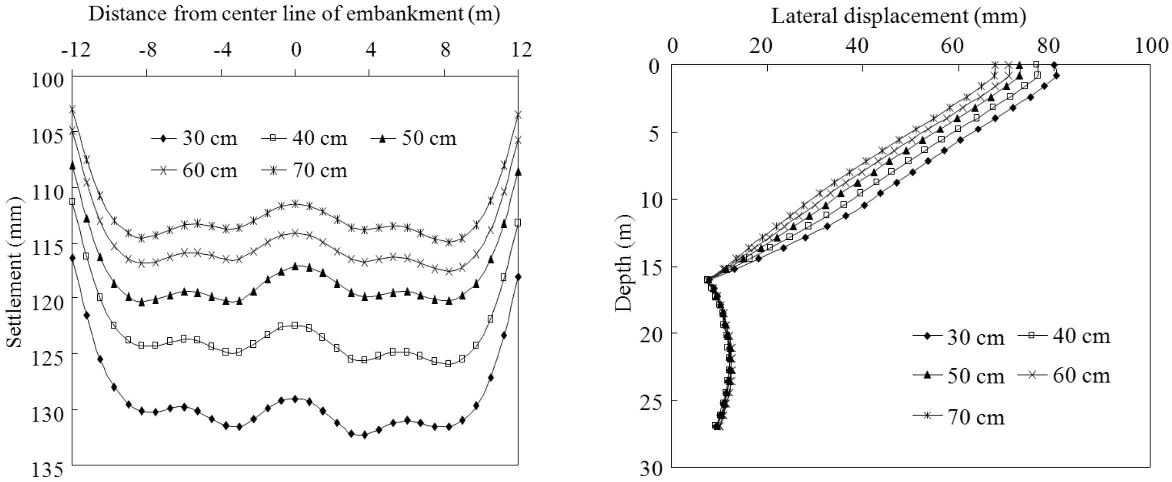


(a) Settlement at the embankment crest

(b) lateral displacement with depth

Figure 3. Influence of peak length of pile cap

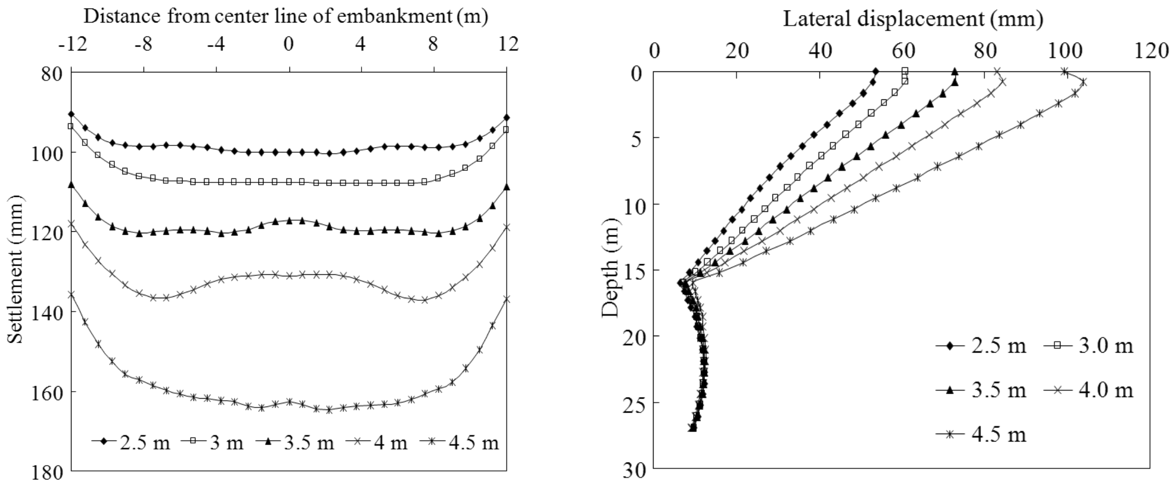
The influence of pile diameter is studied by analyzing five cases with 30, 40, 50, 60 and 70 cm. As shown in Fig .4(a), the settlement and differential settlement decrease with the increase of pile diameter. The differences on the settlement between the adjacent cases decrease gradually with an increase of the pile diameter. The effect of pile diameter on the lateral displacement is presented in Fig .4(b). The lateral displacement decreases with the increase of pile diameter. More importantly, the influence on the lateral displacement at the deep depth is significant.



(a) Settlement at the embankment crest (b) lateral displacement with depth

Figure 4. Influence of pile diameter

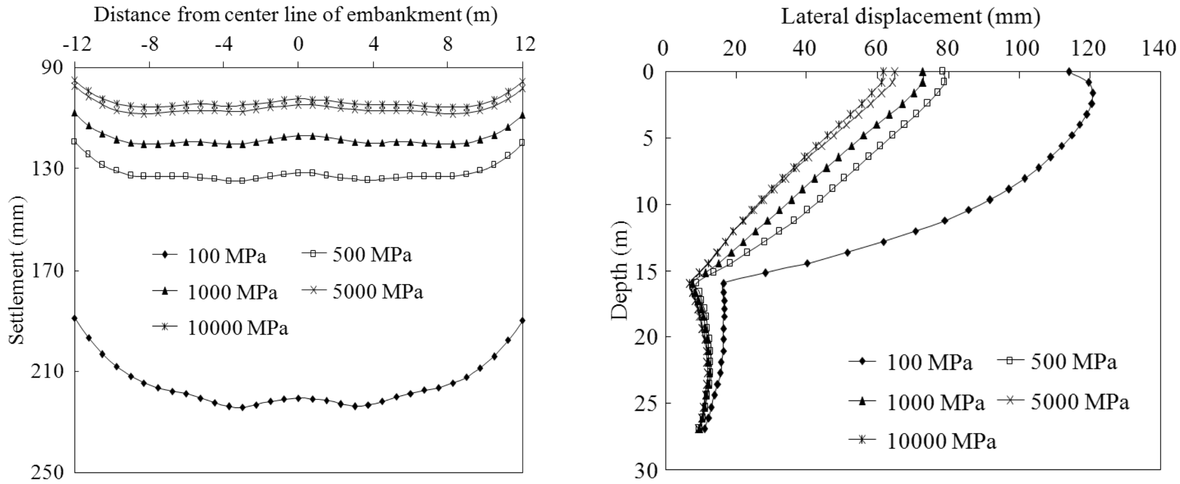
Pile spacing is an important design parameter in pile supported embankment. Closely spaced piles can transfer the surcharge load easily, but this makes the cost very uneconomical. However, the bearing capacity failure and slope stability failure will be encountered when a wide pile spacing are adopted (Han and Gabr 2002, Huang 2007)[8,9]. In this study, the influence of pile spacing is studied by analyzing five cases with 2.5, 3.0, 3.5, 4.0 and 4.5 m (Fig .5). As the pile spacing increases, the settlement and lateral displacement decrease significantly at first, but the influence of pile spacing becomes less important again when the pile spacing exceeds 4.0 m.



(a) Settlement at the embankment crest (b) lateral displacement with depth

Figure 5. Influence of pile spacing

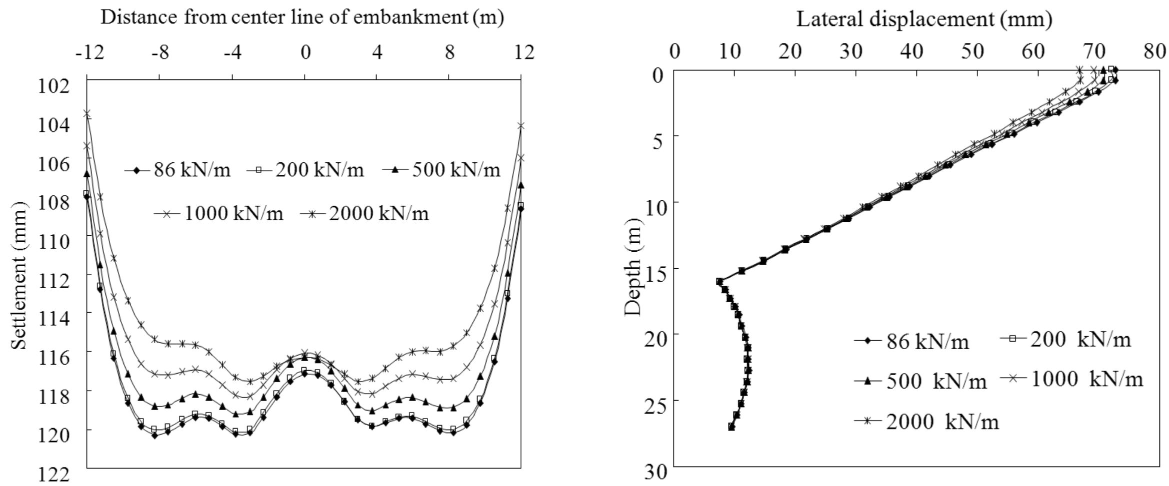
The influence of elastic modulus of pile is studied by analyzing five cases with 100, 500, 1000, 5000 and 10000 MPa. As shown in Fig .6(a), the elastic modulus of pile has a significant influence on the settlement when the elastic modulus of pile increases from 100 to 5000 MPa. However, the influence is not obvious when the elastic modulus of pile increases beyond 5000 MPa. Similarly, Fig .6(b) shows that the lateral displacement decreases with the increase of elastic modulus of pile.



(a) Settlement at the embankment crest (b) lateral displacement with depth

Figure 6. Influence of elastic modulus of pile

Geosynthetic used in the GRPS embankment is expected to enhance the pile efficiency and embankment stability by transferring load from the subgrade to the piles and reducing lateral displacement, respectively (Chen et al. 2008)[10]. The influence of tensile stiffness of geosynthetic is studied by analyzing five cases with 86, 200, 500, 1000 kN/m and 2000 kN/m of tensile stiffness of geosynthetic. Fig .7 shows that the tensile stiffness of geosynthetic has a significant influence on the differential settlement. However, the lateral displacement is reduced limitly with the increase of tensile stiffness of geosynthetic.



(a) Settlement at the embankment crest (b) lateral displacement with depth

Figure 7. Influence of tensile stiffness of geosynthetic

III. CONCLUSIONS

In this paper, to investigate the performance of pile supported embankment, five key influencing factors are chosen for parametric study. The influencing factors include the peak length of pile cap, pile diameter, pile spacing, elastic modulus of pile and tensile stiffness of geosynthetic. The following conclusions can be drawn:

(1) As the peak length of pile cap increases, the settlement and differential settlement at the embankment crest decrease significantly. Similarly, the degree of decrease on the lateral displacement at the embankment toe is nearly the same with the peak length of pile cap increase from 5 to 45 cm.

(2) As the pile spacing increases, the settlement and lateral displacement decrease significantly at first, but the influence of pile spacing becomes less important again when the pile spacing exceeds 4.0 m.

(3) The elastic modulus of pile has a significant influence on the settlement and lateral displacement when the elastic modulus of pile increases from 100 to 5000 MPa. However, the influence is not obvious when the elastic modulus of pile increases beyond 5000 MPa.

(4) The tensile stiffness of geosynthetic has a significant influence on the differential settlement. However, the lateral displacement is reduced limitly with the increase of tensile stiffness of geosynthetic.

Acknowledgments

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