Behavior Analysis of Pile Supported Embankments

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Abstract

Construction of embankments on soft or liquefiable ground is a common problem in road construction. An option gaining in popularity is to build the embankment on a grid of piles or columns that are constructed by ground improvement techniques like deep mixing and jet grouting overlaid by a bridging layer of granular soil and one or more layers of geosynthetic reinforcements. In this way the excessive settlements is prevented. In this study a tridimensional model of ground-pile-geosynthetic layers are considered. Model is developed using ABAQUS code. The Interfaces between the different elements of the system such as rigid piles, surrounding ground and geosynthetic layers are considered in model. The results show an arching effect which could be due to the large stiffness of the piles in comparison to the surrounding media. The settlement and the effectiveness of embankment on floating piles are studied. It could be concluded that generally an embankment on floating piles is an effective method for soft soil improvement.

Keywords: Pile supported embankment, Three-Dimensional FEM Analysis, Geosynthetics, Settlement

1. INTRODUCTION

Construction of highways and railways on soft ground causes the important settlements, which show the need to ground improvement techniques to reduce subsoil deformations after the embankment construction. One of the new methods to construct an embankment on soft soil is pile supported embankments. This method is practiced in two ways as shown in figure 1: Conventional pile-supported embankment (CPS) and Geosynthetic-reinforced pile-supported embankment (GPRS). In the later system, pile spacing increases and the ratio of pile cap area to overall area of embankment is reduced from 30 to 70% in CPS method to 10 to 20% in GRPS system [1]. In GRPS system the lateral inclined piles which are to control the lateral pressure in embankment are replaced by geosynthetic layers. Also in this system surface settlement (Δs) and settlement between the piles (Δs_0) are considerably reduced and settlement is no more a crucial problem in this method. Columns or piles are often constructed using the cast-in-place concrete piles or jet-grouted or deep-mixed columns and stone columns.

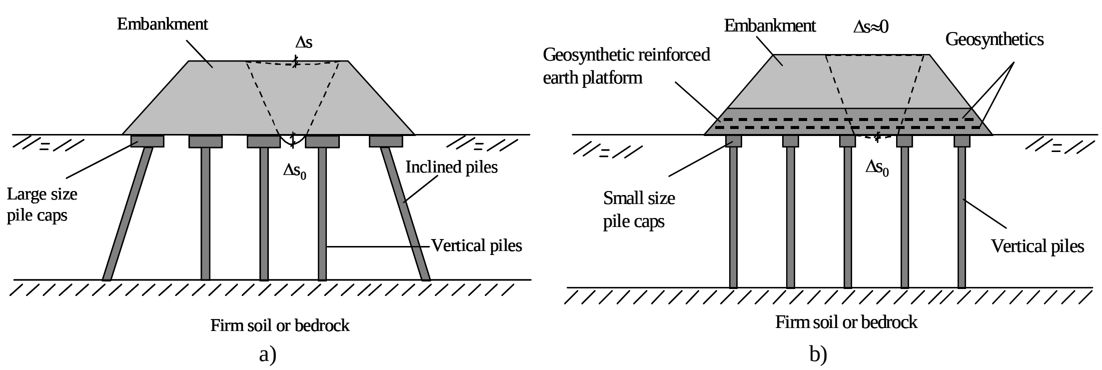

Figure 1. Pile supported embankments construction systems, a) Conventional pile-supported system (CPS), b) Geosynthetic-reinforced pile-supported embankment (GRPS)

2. LOAD TRANSMISSION MECHANISM AND ARCHING FORMATION IN EMBANKMENT

Nowadays, embankments of granular soils supported by piles are often used for road and railway constructions. Geotextile layers are usually applied on top of pile caps as reinforcement. This method is known as a piled embankment. As shown in figures 2 and 3 load transfer mechanism in GRPS system consists of two main components:

- Load transfer to pile caps by forming the arch in embankment.
- Membrane effect of the geosynthetic to transfer the load of the embankment beneath the arch.

Due to differential settlement between the stiff pile caps and the soft soil surface, the stresses in the granular embankment are redistributed and reoriented to form arches. This is known as soil arching. The soil arching mechanism transfers the embankment load above the arches and the external load directly to the piles as illustrated in Figure 2. When a geotextile is used, it holds the remaining load of the embankment and also transfers the load to the piles via its tension. The pile transfers the embankment load and the external load down to the deeper and firmer soil stratum. Hence, the soft soil bears less force and therefore produces less settlements. The piles that support the embankment can be end—bearing piles or floating piles. This thesis is mainly focused on the design of embankments on floating piles. Nevertheless, several aspects that relate the design of piled embankments in general are also considered. For floating piles, the settlement reduction is not as large as for end—bearing piles, but they create a homogenization that render settlements more uniform. I-Iere, it should be noted that settlements are mostly acceptable a long as they are uniform.

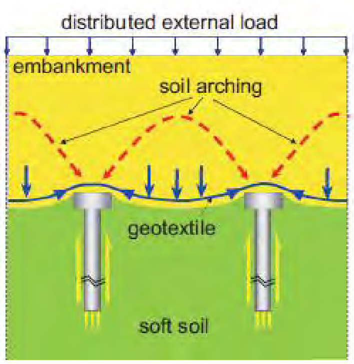

Figure 2. Load Transfer Mechanism in GPRS system

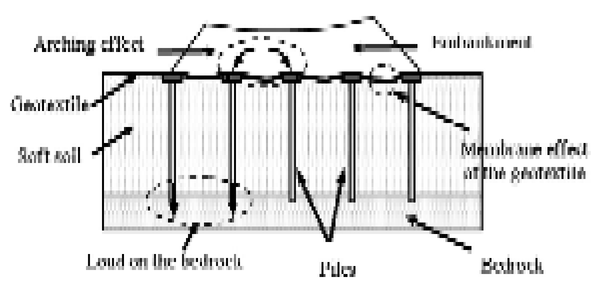

Figure 3. Roles of different components in Load Transmission Mechanism in GRPS system

3. NUMERICAL MODEL OF GPRS SYSTEM

Most of the piled embankments incorporate geotextiles as reinforcements. Since the 1980s, increasing interest in piled embankments has led to an increase in research on rational approaches for soil arching in granular embankments. The aim of previous research was mainly to determine the amount of load transferred from the embankment to the piles, as well as the requirement of the geotextile tensile strength [2-4]. Today, some of the research findings have been adopted as guidelines for piled embankments design such as Nordic guidelines, British standard B58006, and the German method EBGEO 2004 [5-6]. In recent decades, numerical methods such as finite element analysis with the support of computer technology have been increasingly used in the field of geotechnical engineering. Since around 1990, the importance of numerical analysis in investigating piled embankments has constantly grown [7-10].

Nowadays, numerical analysis of piled embankments is strongly recommended, especially for detailed designs. Nevertheless, guidelines for a proper numerical analysis of piled embankments are not yet available. Geosynthetic layers which serves as the reinforcing layers, not only serve to increase the load share of the piles but also with the arching mechanism reduce the settlements. To investigate the effect of geosynthetic layers and in general the behavior of GRPS systems a numerical model as shown in figure 4 is considered. The model characteristics are shown on table 1.

Table 1- Characteristics of Model

Pile Spacing, s (m)	Pile cap Dimension, a (m)	Angle of internal friction of embankment fill, ϕ(deg)	γ (kN/m^3)	Embankment Height (m)	E (MPa)	Poisson Ration, ν	Geosynthetic Strength , J (kN/m)
1.5	0.6	30	19	1	87	0.2	500

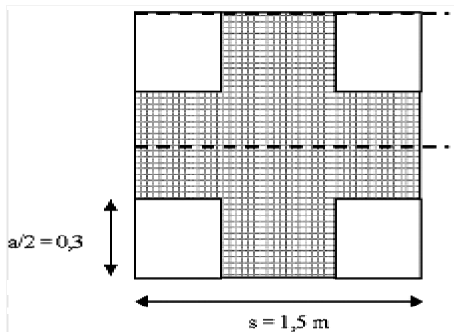

Figure 4. Plan of the model consisting the Geosynthetic and pile caps

3.1 GEOSYNTHETIC STIFFNESS MODULUS

To investigate the effect of geosynthetic stiffness modulus, J, on embankment settlement 5 different models as shown in table 2 are considered. The geosynthetic stiffness modulus is varied between 500 to 5000 kN/m. The results of numerical model show that Settlement is greatly reduced with the inclusion of a geosynthetic layer. The greater the stiffness of the geosynthetic reinforcement, the smaller the geosynthetic settlement.

Table 2- Characteristics of Numerical Model and Results

	Modeling case Number				
	1	2	3	4	5
Geosynthetic Stiffness Modulus, J, (kN/m)	500	1000	1500	2500	5000
Result of mofeling on Geosynthetic Settlement (m)	0.18	0.14	0.13	0.11	0.08

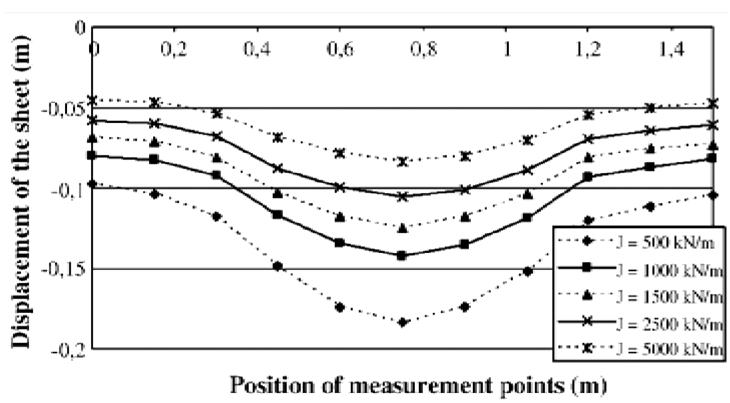

Figure 5. Effect of geosynthetic tensile strength on maximum settlement in geosynthetic sheet

3.2. EFFECT OF SUBSOIL MODULUS ON GEOSYNTHETIC SETTLEMENT

All the design methods such as EBGEO (2004) consider a void below the geosynthetic layer. The resistance from the soil below the GRPS platform is ignored. This leads to a conservative design. In practice, there will be some support provided by the soil below.

This will considerably reduce the tension in the reinforcement. It is found that the resistance from the soil below the GRPS platform is $0.18\gamma H$ to $0.15\gamma H$ where γ is the unit weight of the embankment fill and H is the height of the embankment. Later, a finite element model by Kempton et al. (1998) proved that partial support from the reinforcement reduced the tensile force in the reinforcement significantly. However, it seems to be reasonable to consider a cavity under the GRPS platform if the settlement below the platform is caused by factors other than the embankment loads.

Results of numerical results are shown on figure 6. It shows clearly that high modulus of subsoil has an adverse effect on geosynthetic settlement. It can be justified by the fact that on stiff subsoil the arching does not occur and the membrane effect of geosynthetic is almost vanished.

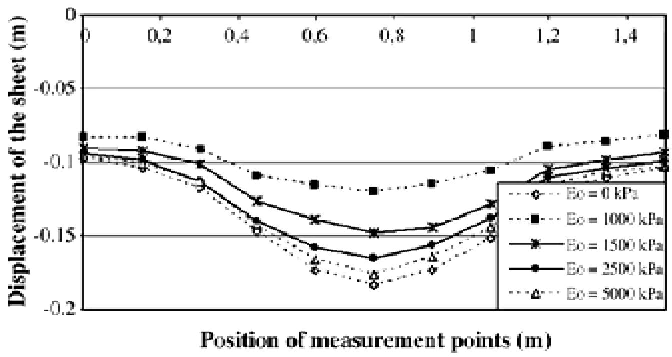

Figure 6. Effect of subsoil modulus on settlement in geosynthetic sheet

3.3 TENSION IN REINFORCEMENT AND GEOSYNTHETIC STRAIN

The British Standard BS8006 (1995) suggests the following formula for an extensible reinforcement. The tensile load T_{rp} per metre "run" generated in the reinforcement resulting from the distributed load W_T is given by:

$$T_{rp} = \frac{W_T(s-a)}{2a}\sqrt{1+\frac{1}{6\varepsilon}} \tag{1}$$

Where T_{rp} is the tension in the reinforcement and ε the strain in the reinforcement, a and s are shown on figure 4 and are pile cap dimension and pile spacing, respectively.

The tension in the reinforcement is calculated taking into consideration the maximum allowable strain in the reinforcement. Six percent strain is considered the upper limit for transferring the load to the piles. The load/strain curve should be studied at different load levels. The upper limit should be reduced for shallow embankments to prevent differential movements on the surface of the embankment. To avoid long term localized deformations at the surface of the embankment, the long term strain should be kept to a minimum. A maximum creep strain of 2% is permitted for permanent construction.

This tensile load is developed as the reinforcement deforms during embankment construction. If it does not deform during construction, the tensile force is not developed; i.e., the load is not carried by the reinforcement till the foundation settles. Alternative equations should be used to determine the tensile strength of inextensible reinforcement.

4. EFFECT OF EMBANKMENT HEIGHT ON SETTLEMENT

To investigate the effect of embankment height on the load transmission mechanism and geosynthetic settlement, different embankments with the heights of 0.25 to 3 meters and with the characteristics shown on Table 1are considered. The results are shown in figure 7. The results show that geosynthetic settlements increases when embankment height increases and there is a certain embankment height corresponding to maximum settlement of geosynthetic, after this point geosynthetic settlement decreases when embankment height increases. It could be justified by the arching mechanism in embankment and membrane behavior of geosynthetic layers which prevent from more settlement of geosynthetic.

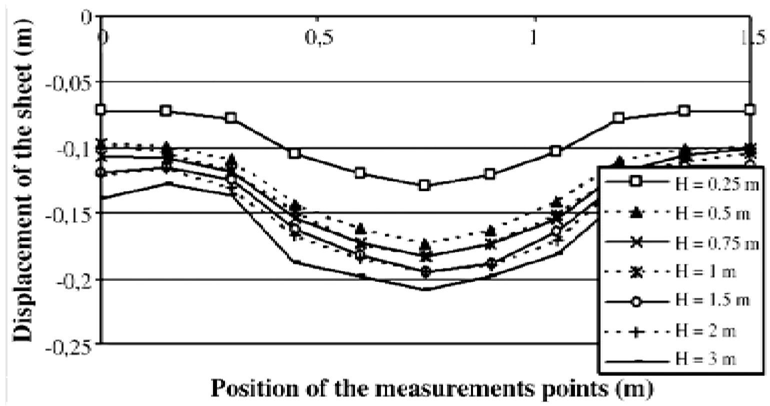

Figure 7. Effect of Embankment Height on Geosynthetic reinforcing sheet Settlements

5. STRESS CONCENTRATION RATIO

The stress concentration ratio is a parameter that is used to quantify load transfer. It is defined as the ratio of the stress on the pile caps to the soil between the pile caps. It is defined as the following relation (see fig. 8):

$$n = \frac{\sigma_c}{\sigma_s} \tag{2}$$

where σ_c and σ_s are the stresses on pile cap and on the soil, respectively.

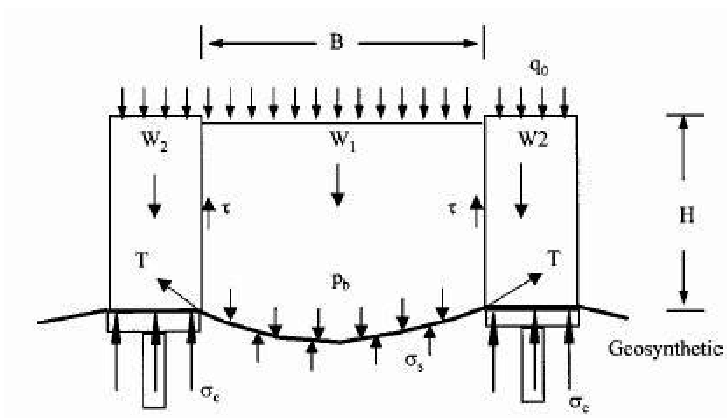

Figure 8: Load Transfer Mechanism [12]

The stress concentration is a global index which incorporates the mechanism of soil arching, tension membrane or apparent cohesion effect and pile-soil stiffness difference. It is found indicated that the value of n for conventional pile embankments ranged between 1 to 8 [11]. This ratio increased with the increase in the ratio of the embankment height to the net spacing between the two near edges of the caps on the piles. The n values for the GRPS systems on concrete piles ranged from 8 to 25, which is much higher than the conventional piled embankments [12]. This increase in n is due to the inclusion of the geosynthetic layer.

The *n* value depends on the stiffness or rigidity of the foundation. The stress concentration for a fully flexible foundation resting on a pile-soil composite foundation without soil arching is said to have a *n* value equal to one. The concentration ratio for a rigid foundation is very high. The GRPS system can be considered as an intermediate state between flexible and rigid foundations.

6. EFFECT OF SOFT SOIL THICKNESS

Thickness of the soft soil layer affects the pile bearing function and its dimensions. In the case that the soft soil is not thick, the piles act as the end bearing piles. Contrary in the case that the soft soil layer is sufficiently thick the piles have a frictional and in case of reaching a stiff layer end bearing function could be occurred. In Dutch design guidelines for pile-supported embankments (road construction on peat and organic soils) (CUR 226, 2010) [13], piles are considered as the end bearing piles.

7. CONCLUSIONS

Soft clay and other compressible soils have a tendency to settle under heavy loading. There are various soil improvement techniques used to prevent these settlements. The technique used in any particular case depends on soil conditions, the availability of equipment and the cost required for improvement. Piles, stone columns, vibro-concrete columns, deep mixed columns are some of the commonly used techniques. The GRPS system is gaining popularity in embankment construction over such soils. Geosynthetic-reinforced pile-supported embankment is an economical and rapid solution for construction of embankments on soft soil. Using geosynthetic in embankment construction reduces the embankment settlement. Comparison of 3D FEM analysis and current design methods such as EBGEO (2004) show that such methods are conservative and needs to reviewed. The effects of different parameters such as tensile strength of geosynthetic, embankment height and geosynthetic location in embankment are studied. The results show that these parameters have important effects on system behavior. Settlement is greatly reduced with the inclusion of a geosynthetic layer. The greater the stiffness of the geosynthetic reinforcement, the smaller the settlement. The settlement also decreases with an increase in the stiffness of the piles.

8. REFERENCES

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