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An Analytical Study on the Performance of Basal Reinforcement in an Embankment Placed Over a Soft Clay Bed

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Abstract: The civil engineering infrastructure such as roads and railways require embankments to maintain the designed gradient all along its alignment and also for flood protection. These embankments pass over different types of natural ground and when they pass over soft clay beds, several challenges are to be addressed in terms of lower bearing capacity, excessive settlements and the lateral deformations. When the unconfined compressive strength of clay bed is less than or equal to 5 kPa, the traditional techniques such as stone columns, pre-loading with strip drains and other modification techniques are considered to be time-consuming and uneconomical for a project. In such cases, piles are being adopted to support the embankment to keep in pace with the project duration. However, the soft soil between the piles remains weak and the load transfer is to be facilitated by using a basal reinforcement at the top of piles. The basal reinforcement enables the system to develop the necessary arching action, so that the load transfer takes place to the piles. In order to understand the load transfer mechanisms, several investigators have been working using numerical techniques. The present work is an attempt to study the influence of pile spacing, basal reinforcement stiffness and its tensile strength in mobilizing the optimum soil - arching in order to facilitate the load spreading from the embankment to the piled clay bed using plaxis -3D. The input parameters were kept as the cohesion of soft clay bed and pile material properties such as the modulus of elasticity (E) and Poisson’s ratio (μ). The pile spacing, reinforcement stiffness and its tensile strength were kept as variables.

Keywords: *Soft clay***,** basal reinforcement; piled embankment; soil arching.

1 Introduction

Soft clays are found mostly all along the coast line of our country, including some other countries like Malaysia, Singapore, eastern Canada, Australia, Scandinavia, Alaska, Japan and Zealand [1]. These soft clays have a very low bearing capacity and settlement problems associated with the stability of structures [3]. Nowadays as the population is growing rapidly worldwide, there is a need for infrastructure development according to the requirements. As a part of infrastructure development, while constructing embankments for roads or railways, we may encounter the soft clay deposits which cannot be avoided due to inevitable project alignment. Deformations, excessive settlements, and stability issues are the common concerns when building roads, railways and other engineering projects on soft soils [2]. Suitable ground improvement techniques such as preloading, stone columns, electroosmosis and deep mixing were developed in order to overcome these problems to a greater extent [6]. However, these techniques cannot be used for all soft clay conditions and for different projects alike. The choice of the technique depends on the in-situ strength of the clay bed and the project duration [4]. Under constrained project duration, most of the ground improvement techniques are not viable, for which, currently, deep mixing and piled support systems have been evolved. The traditional ground improvement techniques cannot be used when the undrained shear strength of soft clay bed is in the range of 5-10 kPa (7).

One of the latest developments in the construction of high embankments over soft soil beds is the use of geosynthetic basal reinforcement along with piles in which the load transfer from the embankment to piles takes place by geosynthetic basal reinforcement through arching action. Different researchers have proposed different soil arching models like Hewlett and Randolph model, Zaeske model and concentric arches model [5, 6,7 & 8]. Several studies have been carried out based on these techniques using a traditional square group of pile arrangements with parametric variation such as pile modulus, embankment height and spacing of piles.

Previous research works have been concentrated on studying the effects of only square and triangular pile group arrangements [9, 10, 12 &13] with basal reinforcement to improve the load carrying capacity of soft soil beds. Moreover, many researchers have been working using uniaxial geogrid and its performance on piled embankments using 3D numerical techniques by continuum modelling. In the present work, an attempt is made to study the load transfer mechanisms in pile-supported embankments by optimizing the spacing of piles in rectangular pattern using bi-axial geogrid as basal reinforcement over the piles and the results are compared with the previous findings.

1.1 Material parameters

The analysis was carried out using the available PLAXIS 3D. The properties of soft clay are used as input parameters and these parameters are shown in Tables 1and 2.

Table 1. Parameters of subsoil and embankment material [11]

Property	Units	Subsoil (soft soil)	Pile material (Concrete)	Embankment (granular fill)
Unit weight, γ	kN/m^3	18	25	17
c of soil	kN/m^2	5	NA	1
ϕ of soil	Degrees	10	NA	45
Modulus of Elasticity, E	kN/m^2	500	25*E6	80000
Poisson's ratio, μ	NA	0.15	0.2	0.2

Table 2. Parameters of geogrid material used [11]

Properties	Units	XMD Values	MD Values
Aperture dimensions	mm	33	25
Tensile strength at 2% Strain	kN/m	4.1	4.1
Minimum rib thickness	mm	0.76	0.76
Tensile strength at 5% Strain	kN/m	8.5	8.5
Ultimate tensile strength	kN/m	12.4	12.4

Note: In machine direction (MD).
Direction perpendicular to the machine direction (XMD).

2 Methodology

As stated pervious, an embankment of 6 m height passing over soft clay bed was analysed for its stability using numerical method. Pile foundation coupled with geogrid-basal reinforcement is used below the embankment. The analysis was carried out in the following steps.

1. The sub-stratum is considered as 12 m thick soft clay bed followed by stiff soil.
2. Entry of input parameters for embankment material, geogrid and subsoil.
3. Numerical modelling of basal reinforced piled embankment in plaxis- 3D. The pile spacing in square, triangular and also in rectangular pattern with L/B ratio of 1.2 are studied. The pile diameter of 0.30 m is kept constant for all the patterns.
4. The L/B ratio of 1.2 is tried based on the suggestions made by Meena et al. (2020) to investigate the rectangular pattern also in addition to the traditional square/triangular patterns.

5. Boundary conditions for analysing the geosynthetic reinforcement mechanism in be tween embankment and pile foundation. The displacement in all the directions were restricted at the bottom boundary at the Z=0 plane.). Roller supports were used on the vertical boundaries, restricting horizontal movement. No boundary conditions are considered at the top of the embankment.
6. Load transfer patterns between embankment and foundation system by parametric variation under static condition.

In this analysis, a piled embankment reinforced with geosynthetic material is modeled in plaxis-3D and analyzed for different parametric variations. The model is shown in Fig. 1.

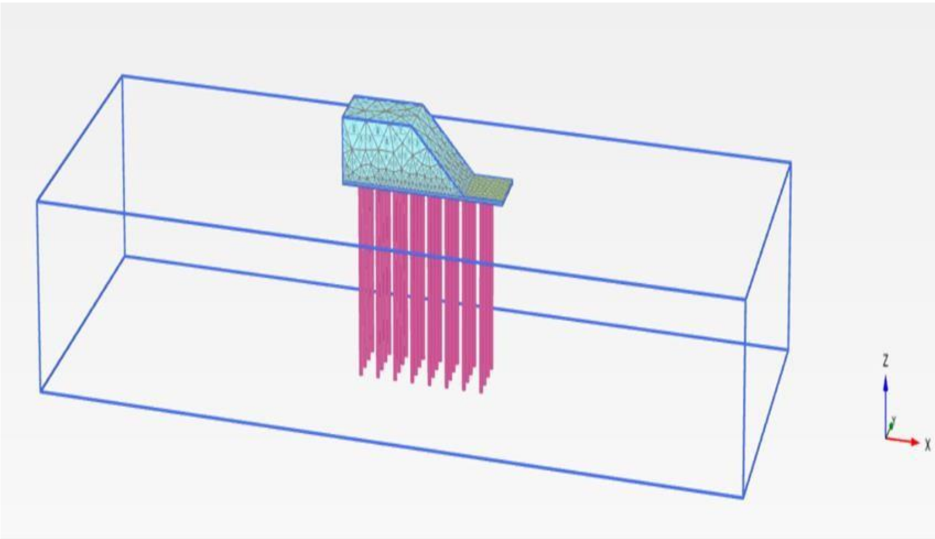

Fig. 1. Plaxis model showing the piled embankment

3 Results and discussion

3.1 Influence of Geogrid tensile strength and anchorage length on SAR

Fig. 2. presents the influence of geogrid tensile strength and its anchorage length on the Soil arching Ratio (SAR). It can be seen from this figure that the SAR decreases with increasing tensile strength and the corresponding increase in its anchorage length. The targeted SAR (The ratio of subsoil stress and the stress applied from embankment) of 0.2 (Meena et al) could be achieved for the tensile strength of 1200 kN/m with the corresponding anchorage length of 4.5 m. The SAR depends on the membrane effect of basal reinforcement which in turn depends on its tensile strength. Moreover, the length of basal reinforcement beyond the design length causes self - anchorage of the system, whereby, it will be subjected to stretching rather than slipping mechanism that causes reduction in soil - arching ratio.

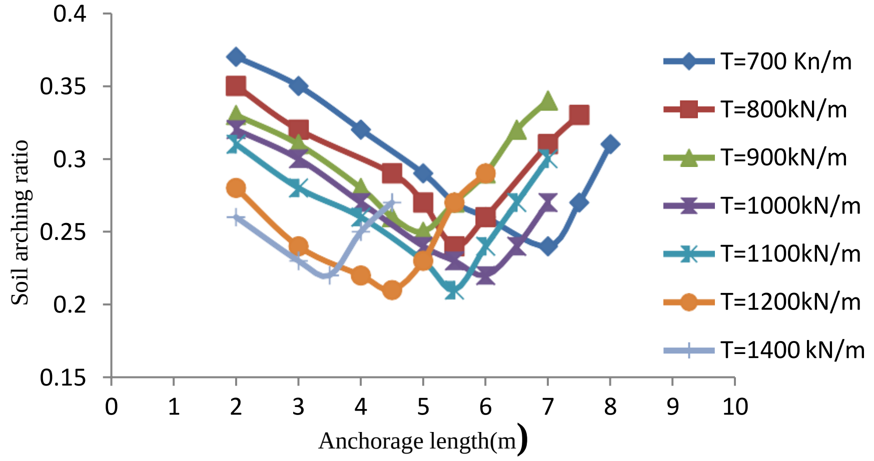

Fig. 2. Variation of SAR with geogrid anchorage length

3.2 Influence of Pile spacing and geogrid tensile strength on SAR

The influence of pile spacing and the tensile strength of basal reinforcement on the SAR is shown in fig 3. It can be observed from this figure that the SAR decreases with increasing pile spacing for a given tensile strength of basal reinforcement. The targeted value of SAR (0.20) could be obtained for the pile spacing of 5D for tensile strength of 1200 kN/m. From this, it can be understood that the basal reinforcement placed over the piles could mobilize its membrane effect between the piles optimally for 5D spacing of piles.

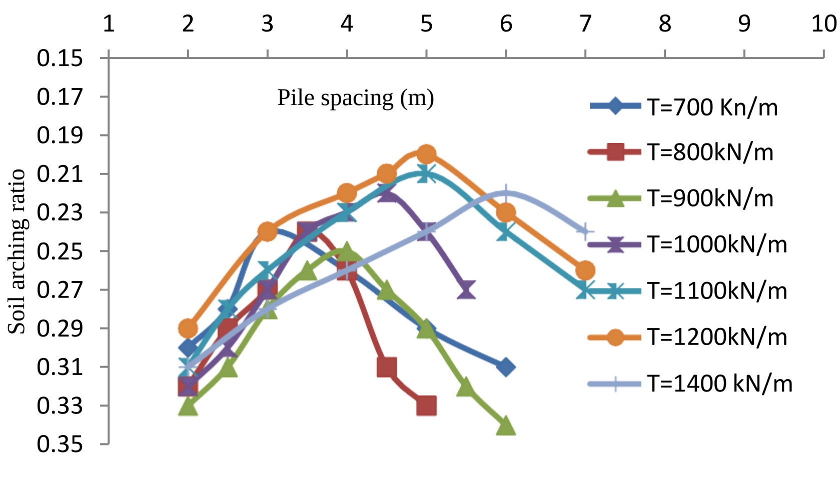

Fig. 3. Variation of SAR with Pile spacing

3.3 Influence of Pattern of piles on SAR

As stated previously, the rectangular pattern of piles was investigated instead of square or triangular patterns in the present work. The relative influence of these patterns on SAR is shown in fig. 4. It can be seen from this figure that the rectangular pattern (L/D= 1.2) of piles is found to be effective compared to the conventional square or triangular pattern of piles. This could be due to the change of loading pattern towards 2 - dimensional condition.

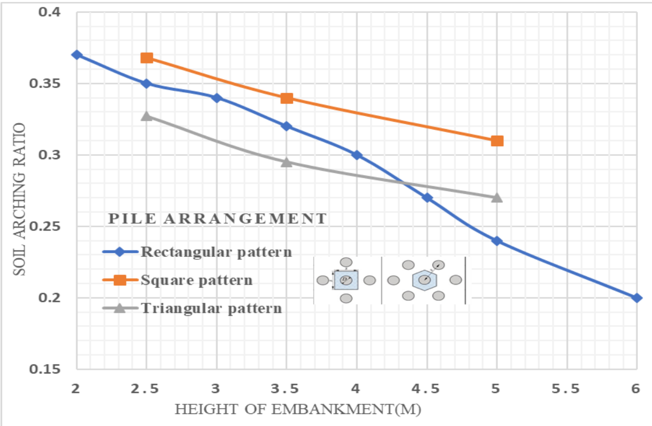

Fig. 4. Variation of Height of Embankment height vs Soil Arching Ratio

3.4 Influence of no of cyclic loading on settlement.

The influence of simulated cyclic loading on settlement of embankment and pile head is shown in Fig. 5. The piled embankment with basal reinforcement under cyclic loading has shown a settlement of 10 mm over 2000 cycles and stabilized. The pile head has shown a settlement of 2 mm under cyclic loading up to about 500 cycles and stabilized. These settlements indicate the promising performance of the piled embankment with basal reinforcement over soft clays.

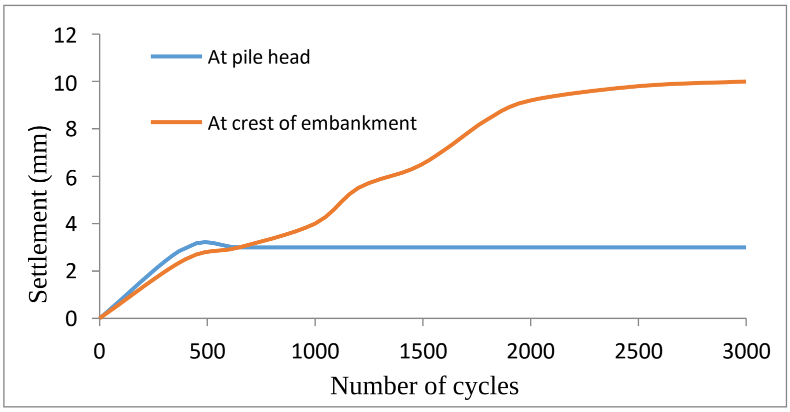

Fig. 5. Variation of settlement with number of cycles

4 Conclusions

The following conclusions are drawn based on the analytical investigation carried out in the present work.

7. For a given soft ground condition, there exists an optimum value of tensile strength for the basal reinforcement in order to obtain the optimum pile spacing to support the embankments. For the soil condition simulated in the present work, the optimum tensile strength of geogrid for basal reinforcement is found to be 1200 kN/m that resulted in optimum pile spacing of 5D for targeted soil arching ratio of 0.20. Further increase in tensile strength does not increase the soil arching ratio.
8. For soil properties simulated in this analysis, the anchorage length required to mobilize the tensile strength of geogrid is found to be about 4.5 m.
9. The pile basal reinforcement system has resulted in a settlement of 2 mm at the pile head which indicates the promising performance of the proposed system to construct embankments over soft clay beds. As the pile tips are resting on stiff/hard stratum, the total settlement is also negligible.
10. The pile spacing in rectangular pattern with L/B ratio of 1.2 is found to be more beneficial compared to the traditional triangular or square pattern of piles.

From this study, it is understood that optimizing the tensile strength of basal reinforcement is more beneficial compared to the costly piling process at closer spacing, especially for supporting the area loads such as embankments.

5 References

1. Ariyarathne, P.; Liyanapathirana, D.S.; Leo, C.J. Comparison of Different Two-Dimensional Idealizations for a GeosyntheticReinforced Pile-Supported Embankment. Int. J. Géoméch. 2013, 13, 754–768.
2. Bhasi, A.; Rajagopal, K. Numerical investigation of time dependent behavior of geosynthetic reinforced piled embankments. Int. J. Geotech. Eng. 2013, 7, 232–240.
3. Henrique Magnani Oliveira, Mauricio Ehrlich, Marcio Almeida, Embankments over Soft Clay Deposits: Contribution of Basal Reinforcement and Surface Sand Layer to Stability, Journal of Geotechnical and Geoenvironmental Engineering Vol. 136, Issue 1 (January 2010), DOI: 10.1061/ASCÊ GT.1943-5606.0000200
4. Hewlett, W.J.; Randolph, M.F. Analysis of Piled Embankments. Ground Eng. 1988, 21, 12–18.
5. Marián Drusa, Ladislav Kais, Roman Bulko, 3D Approach of Arching Effect in Basal Reinforcement Layer, Procedia Engineering, Volume 91, 2014, Pages 352-357, ISSN 1877-7058, https://doi.org/10.1016/j.proeng.2014.12.073.
6. Meena, N.K.; Nimbalkar, S.; Fatahi, B.; Yang, G. Effects of soil arching on behavior of pile-supported railway embankment: 2D FEM approach. Comput. Geotech. 2020, 123, 103601.
7. Nunez, M.; Briançon, L.; Dias, D.C.F.S. Analyses of a pile-supported embankment over soft clay: Full-scale experiment, analytical and numerical approaches. Eng. Geol. 2013, 153, 53–67.
8. Peet, T.C. & Eekelen, S.J.M.. (2014). 3D numerical analysis of basal reinforced piled embankments. 10th International Conference on Geosynthetics, ICG 2014.

9. Pham, H.; Dias, D.; Dudchenko, A. 3D modeling of geosynthetic-reinforced pile-supported embankment under cyclic loading. Geosynth. Int. 2020, 27, 157–169.
10. S.J.M. van Eekelen, A. Bezuijen, A.F. van Tol, Validation of analytical models for the design of basal reinforced piled embankments,Geotextiles and Geomembranes, Volume 43, Issue 1, 2015, Pages 56-81, ISSN 0266-1144, https://doi.org/10.1016/j.geotexmem.2014.10.002.
11. Van Eekelen, S.J.M.; Bezuijen, A. Dutch Research on Basal Reinforced Piled Embankments. In Proceedings of the 2013 GeoCongress Conference, San Diego, CA, USA, 3–7 March 2013; Meehan, C., Pradel, D., Pando, M.A., Labuz, J.F., Eds.; ASCE: Reston, VA, USA, 2013; pp. 1838–1847.
12. Zhang, L.; Zhou, S.; Zhao, H.; Deng, Y. Performance of Geosynthetic-Reinforced and Pile-Supported Embankment with Consideration of Soil Arching. J. Eng. Mech. 2018, 144, 06018005.
13. Zhuang, Y.; Cui, X.; Zhang, S.; Dai, G.; Zhao, X. The load transfer mechanism in reinforced piled embankment under cyclic loading and unloading.