JOURNAL OF GEOTECHNICAL GEOLOGY 18 (1) 655–658

Journal of Geotechnical Geology

Journal homepage: geotech.iauzah.ac.ir

Zahedan Branch,
Islamic Azad University

The effect of PVDs the length on lateral displacement of embankments

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ARTICLE INFORMATION

Received 27 March 2022
Revised 01 June 2022
Accepted 17 June 2022

KEYWORDS

PVD; Surcharge; Preloading; Lateral displacement; Consolidation.

ABSTRACT

One of the most challenging parts of every project including prefabricated vertical drains (PVDs) with surcharge preloading for ground improvement in construction period is lateral displacements that occur in toe of embankment. In this paper Finite element Geostudio 2018 was used for modeling and verification of the full-scale test embankment which were constructed to study the effectiveness of PVDs combined with surcharge preloading at Bangkok airport. The surcharge preloading was modeled by staged construction using a coupled analysis which gives best results for primary consolidation cases. Different depths were modeled and the results were compared and analyzed. It was shown that by increasing the installation depth of PVDs the lateral displacement increased underneath but lateral displacement at ground surface remain approximately constant. In the case of decreasing PVDs length the lateral displacement remains constant for ground surface and decrease slightly with respect to verified model. Although it should be mentioned that like any geotechnical big scale project because of distinct soil characteristic of clay soils and layers properties of any project, complete investigation and modeling is essential prior to finalizing the ultimate design by competence geotechnical consultants.

1. Introduction

Most of the world's essential infrastructure is built along congested coastal belts that are composed of highly compressible and weak soils up to significant depths. Soft alluvial and marine clay deposits have very low bearing capacity and excessive settlement characteristics, with obvious design and maintenance implications on tall structures and large commercial buildings, as well as port and transport infrastructure. Stabilizing these soft soils before commencing construction is essential for both long term and short term stability. Pre-construction consolidation of soft soils through the application of a surcharge load alone often takes too long, apart from which, the load required to achieve more than 90% consolidation of these mostly low lying, permeable, and very thick clay deposits can be excessively high over a prolonged period. If PVDs would be installed with a mandrel, the mandrel would change the characteristic of subsoil, especially in its very near vicinity. This disturbed annulus that is called the smear zone has a reduced lateral permeability and increased compressibility. In varied clays, the finer and more impervious layers are dragged down and smeared over the more pervious layers, which in turn decrease the permeability of the soil near the periphery of the drain (Indraratna, 2010). Barron (1948) suggested the concept of reduced permeability by arbitrarily lowering the apparent value of the coefficient of consolidation. Hansbo (1979) included a further explicit smear zone with a

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https://doi.org/10.30495/geotech.2022.692680

reduced permeability near the drain, surrounded by an outer undisturbed zone. Onoue and Foundations (1988) introduced a three zone hypothesis defined by (a) a plastic smear zone close to the drain where the soil is highly remolded during installation, (b) a plastic zone where the permeability is reduced moderately, and (c) an outer undisturbed zone where the soil is unaffected by installation. For practical purposes, a two-zone approach is generally sufficient. The effect of the smear zone should be taken into account in any model and design by proper parameters.

Finite element analysis (FEA) is a powerful method that can be used to model very demanding cases such as complex geometries, loadings and material properties, even for the simulation of a large-scale radial drainage consolidometer (Bamunawita et al., 2004), where analytical solutions are hard to obtain. Many literatures have attributed the difference between the numerical predictions and measured field data taken at site to various factors such as soil disturbance, smear zones, time-dependent load, well resistance, and partial penetration of drains and permeability. (Zaman et al., 2009) predicted the field behavior of a full-scale test embankment using the modified Cam-Clay model. (Murakami et al., 2014) introduced a numerical analysis model using an elasto-plastic FEM modeling incorporating the SYS Cam-clay for soil and water coupled problems. Based on the references, 2D plane strain condition would be used for finite element modeling of soil treatments including PVDs and surcharge preloading. The effect of the smear zone on soil conductivity and compressibility should be accounted for in the model.

2. Material and Methods

The Second Bangkok International Airport or Suvarnabhumi Airport is situated about 30 km from the city of Bangkok. In the past, the site was occupied by rice fields for agricultural purposes. The area is often flooded during the rainy season and the soil generally has very high moisture content. Therefore, soft marine clays often present considerable construction problems, which require ground improvement techniques to prevent excessive settlement and lateral movement (Indraratna and Rujikiatkamjorn, 2006). TS2 was a test embankment constructed for investigation of the PVDs and surcharge preloading in Bangkok airport with PVD spacing of 1.2 meters. Details about surcharge preloading, soil specifications, vertical drain specifications and other related issues about FEM modeling can be found in (Indraratna and Redana, 2000). Geostudio Sigma/W 2018 coupled state was used for FEM modeling in plane-strain condition using a modified cam clay model. Fig. 1 illustrates the subsoil cross section of International Airport, Thailand (Indraratna and Redana, 2000). Most finite element analyses on embankments are carried out based on the 2D plane strain assumption. However, the consolidation around vertical drains is mainly axisymmetric. Therefore, to employ a realistic 2D finite element analysis for vertical drains, the equivalence between the plane strain analysis and axisymmetric analysis needs to be established especially for hydraulic conductivity (Indraratna and Rujikiatkamjorn, 2006). Because of the clay deposition process, the horizontal conductivity is higher than the vertical direction and the flow is horizontal to the drains. The procedure proposed by Pyrah et al. (1992) and Indraratna and Redana (2000) used to convert an axisymmetric to plane-strain conductivity. Since the top weathered clay was over consolidated, for obtaining a better convergence it was modeled as linear elastic. The mesh used in the model was quad and triangle which gives acceptable results for coupled analysis including consolidation. The upper air bound layer along with sand fill was modeled by a zero pressure boundary condition to account for water and air discharge true PVDs. Fig. 2 shows the geometry and the mesh of finite elements used for TS2 modeling. Fig. 3 shows the verification of the FEM model. As stated by Liu et al. (2021) in order to consider nonlinearity of the consolidation arising from evolving permeability and compressibility of the soil due to change in void ratio during consolidation and non-darcian flow regime for low permeability soil and large strain elasto-plastic behavior of the soil, a permeability modifier was applied in FEM analyses (Geostudio, 2018). Fig. 4 shows the verification of FEM model against measured field data for TS2 test embankment.

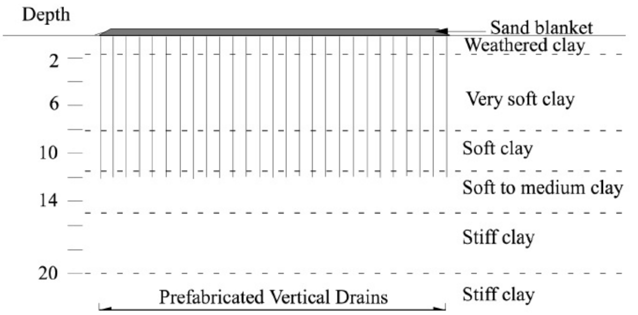

Figure 1. Cross-section of an embankment with the subsoil profile (Indraratna and Redana, 2000)

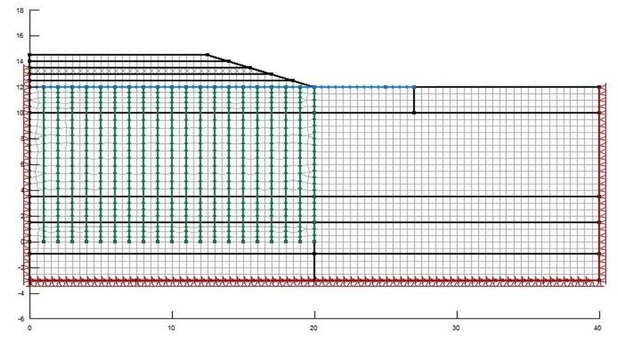

Figure 2. geometry and the mesh of finite element of TV2

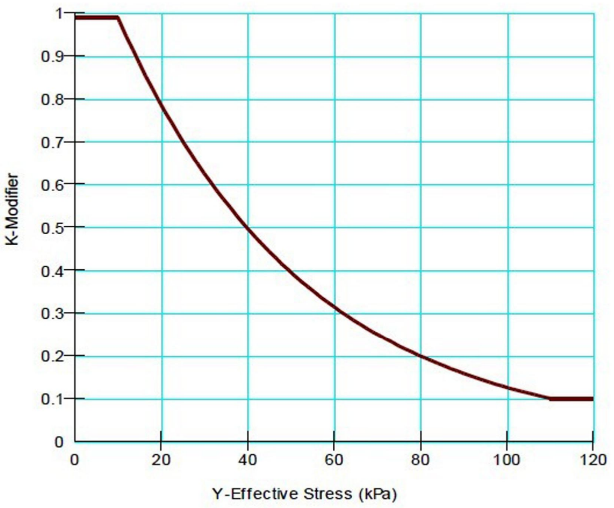

Figure 3. Hydraulic permeability modifier

3. Results and Discussions

Based on the verified FEM model, different depths for PVDs were modeled and the resultant lateral displacement curves are shown in figure 5. . The range of depths is from 3.5 meter to 19 meters with the 1.5 meter intervals. For the upper bound it is 13.5,15, 17.5 and 19.5 meters and for the lower bound it is 3.5, 5, 7.5, 9 and 10.5. Figs. 5 and 6 illustrate the schematic views of PVD installation in 19 and 9 m.

Fig. 7 shows the Lateral displacements of PVDs at 13.5, 15, 17.5, 19 m length against verified FEM models with 12 meters PVDs length after 365 days. As it can be seen by increasing the PVDs length, the quantity of lateral displacement decrease at ground surface and remain constant till depth -4 m, and increase with depth with respect to verified FEM model. For PVDs with 17.5 and 19 meters' installation, unlike other cases which the lateral displacement starts to decrease after -5 m, the lateral displacement starts to increase in -9.5 m and a concave shape is formed. Fig. 8 shows the lateral displacements of PVDs at 3.5, 5, 7.5, 9, 10.5 meters' length against verified FEM models with 12 meters PVDs length after 365 days. By decreasing the PVDs length, the lateral displacement at ground surface remains constant, and decrease slightly by decreasing the PVDs length installation with respect to verified FEM model.

As it is shown in Fig. 9, an increment of 62% in PVDs length (19 m PVDs) lead to 33% increase in final settlement and decreased the treatment time by 40%. Since lateral displacement at ground surface is of great interest for engineers, it can be seen that by increasing the PVDs length, no significant change arises. The outward forces as a result of soil treatment including PVDs and surcharge loading, is responsible for surface cracks that can seriously damage pavements and building nearby. In the case for decreasing PVDs length, as a result of constant embankment surcharge load the surface ground lateral displacement remain constant. Since the consolidation rate and vertical settlement increase by increasing the PVDs length, and increase in lateral displacement was expected but the concave shape is not what really expected in the first sight. In the case of PVDs with 12 m, the maximum lateral displacement occurs in approximately middle of the weakest layer (very soft clay). As the length of PVDs increases, the soft clay layer and also soft to medium clay layer undergoes a greater settlement. Since the bottom layer is stiff clay and the confinement force is greater in these layers because of depth effect and especially as result of added surcharge embankment, a sandwich phenomenon happens that can be seen in the shape of a concave in 17.5 and 19 m PVDs installation.

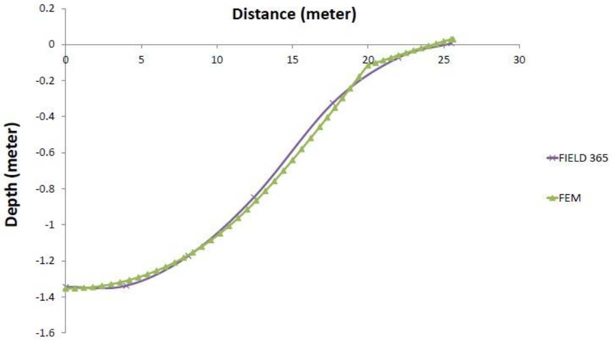

Figure 4. FEM settlement curve vs. TS2 (Indraratna and Redana, 2000)

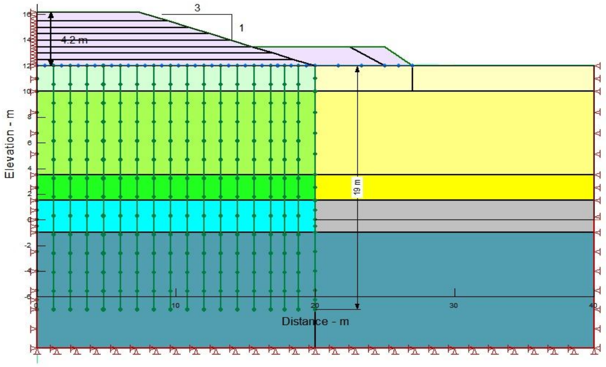

Figure 5. Example of PVDs installation at 19 m depth

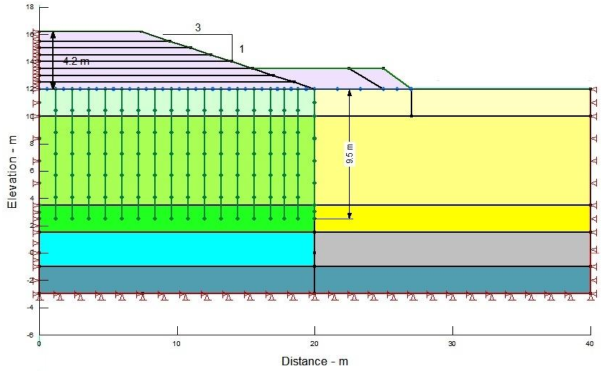

Figure 6. Example of PVDs installation at 9.5 m depth

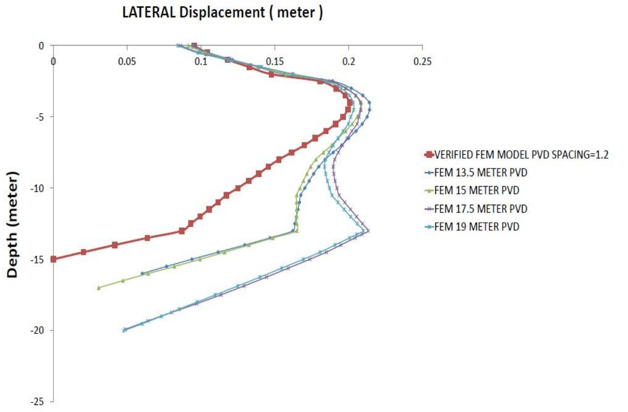

Figure 7. Lateral displacements of PVDs up to 19 meters' against verified FEM models with 12 m PVDs length after 215 days

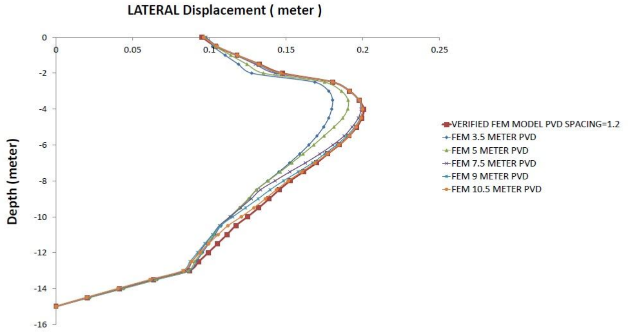

Figure 8. Lateral displacements of PVDs up to 19 meters' against verified FEM models with 12 m PVDs length after 365 days

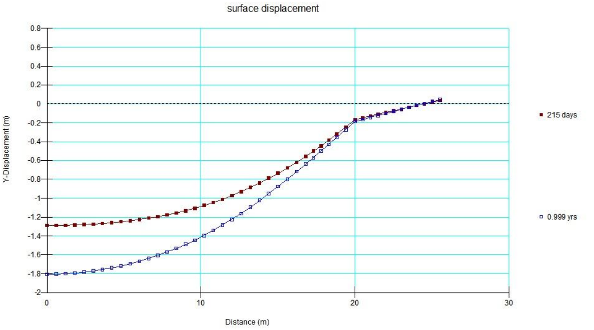

Figure 9. Settlement after 215 and 365 days

4. Conclusion

Finite element Geostudio 2018 was used for modeling and verification of the full-scale test embankment. Different depths were modeled and the results were compared and analyzed. It was shown that by increasing the installation depth of PVDs the lateral displacement increased underneath but lateral displacement at ground surface remain approximately constant. In the case of decreasing PVDs length the lateral displacement remains constant for ground surface and decrease slightly with respect to verified model. As a result of greater confinement forces at greater depths and also fill placement above and also the presence of a stiff clay as the bottom layer, a concave shape appeared in soft clay and medium to soft clay layers that can be seen in lateral displacement curves for 17.5 and 19 m PVDS.

For instance, an increment of 62% in PVDs length lead to 33% increase in final settlement and decreased the treatment time by 40% in the case of PVDs length with 19 meters' length. It can be seen that by increasing PVDs length the required time for achieving final settlement decreased and also the final settlement increased that should be considered for different scenarios with respect to project final cost to obtain the optimum design.

Acknowledgements

The authors wish to thank the Estahban Branch, Islamic Azad University for giving the permission of the study.

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