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Numerical Investigation Impact of the Spacing between Vertical Drains on the Diameter of the Influence Zone

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ABSTRACT

Rapid developments of industrial and urban structures and infrastructures necessitate the utilization of remote or unsuitable lands that were not considered for construction in the past. The application of surcharge and prefabricated vertical drains (PVDs) is one the popular methods that is used all around the world as a result of simplicity and high efficiency. One of the issues that may occur in such reclamation projects, is the existence of sensitive infrastructures or structures in the vicinity of the treatment area. There are many variables that affect the diameter of the influence zone such as: the compressibility of weak layers, the height of clay stratums, length of the PVDs and the height of surcharge embankment and so on. In this literature the impact of spacing between PVDs was investigated using finite element modelling. Three test embankments as TS1, TS2 and TS3 were modeled and verified for the study. For TS1 (PVDs with 1.5 m spacing), TS2 (PVDs with 1.2 m spacing) and TS3 (PVDs with 1.0 m spacing) the diameters of the influence zone were 54.8, 46 and 42.3 m respectively. As the distance between the PVDs decreases, the influence zone decreases as well and becomes smaller. For the FEM simulation of only surcharge embankment in the absence of PVDs the influence zone after 400 days was 64 m in the case that only 0.65 settlement was reached. It can be seen that the inclusion of PVDs and the utilization of smaller quantities of spacing can be an effective way for the reduction of influence zones where there are concerns regarding adjacent structures or infrastructures.

Keywords:

PVDs, Influence zone, Surcharge, Consolidation, Weak clays.

1. Introduction

With respect to rapid developments of industrial and urban structures and infrastructures especially in remote or unsuitable lands, the ground improvement becomes a necessity in such projects. For the cases that include weak clays or peats, the method that includes embankment preloading and installation of prefabricated vertical drains (PVDs) is a suitable option for soil treatment. The vertical drains are installed to accelerate the consolidation process and reduce both time and overall cost of the project. According to a series of laboratory tests, Robinson [1] proposed that lateral stresses should be considered when estimating the vertical strains of the soil in the affected area. the magnitude of vertical and lateral strains also depends on the magnitude of horizontal stress. When the horizontal stress from the affected area is equivalent to the active pressure, a more vertical settlement is observed compared to when the horizontal stress is equivalent to the earth pressure at rest. Similarly, the lateral strain is greater when the horizontal stress from the affected area is at rest. For weak stratums, one of the main concerns is the stability of the embankment during the construction process, since there are many reports of such failures [2-5]. One of the issues that may occur in such projects, is the existence of sensitive pipe-lines or trenches in the vicinity of the treatment area. In all mentioned literatures considerable surficial and lateral displacements were reported but since they were all situated in areas where there were no specific main infrastructures, no damage was not reported for such cases. With regard to these considerable amounts of vertical and horizontal displacements, the damage to existing infrastructures were inevitable if they were situated in the influence zone of soil treatment area. Nguyen [6] investigated the influence zone for a project that includes surcharge and vacuum preloading and proposed a FEM procedure for determination of the influence zone. Liu [7] proposed an empirical formula for determination of the influence zone in the vicinity of the soil treatment areas and a measure as maximum value of the lateral displacement (ELD) where the safety distance between the boundary of the treated area and the surrounding building can be estimated when the soft soil foundation is consolidated by using a vacuum preloading method. In both of these articles the cases include both surcharge and vacuum preloading together and none of them considered the effect of surcharge alone. The determination of the influence zone depends on many factors such as: the compressibility specifications of weak layers, the groundwater level, the rate of loading in the construction of the surcharge embankment, the depth and spacing of the installed PVDs and so on. It can be seen that there are many influencing parameters that each one can greatly affect the diameter of the influence zone. Since there are many influencing factors a universal formula cannot be proposed for every project and for realistic situations the authors believe that for every project performing a FEM analysis is inevitable for determination of the influence zone. In this study the impact of the spacing between PVDs is investigated using FEM simulation.

2. Material and Methods

The Bangkok Airport is situated in a wet area where there is about 10 m of soft clay under a 2 m surficial over-consolidated crust [8]. Stiff clay extending to a depth of 20 to 24 m underlies the soft clay. Figure 1 shows the common geotechnical properties of the reclamation land. Figure 2 shows the Three pilot embankments were constructed to investigate the various PVDs characteristic and installation pattern at site in Bangkok [9, 10]. The PVD drains were installed to a depth of 12 m. The embankments were constructed to a height of 4.2 m with 3H: 1V side slopes. The base areas were approximately 40 x 40 m. There were actually 1 m high berms around the base extending out 5 m that included in the FEM analysis presented here. Three trial embankments were built as TS1 with 1.5 m PVD spacing, TS2 with 1.2 m PVD spacing and TS3 with 1 m PVD spacing to examine

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the performance of the system in various situations. A one-meter thick sand blanket was placed on the site as a construction working pad. The drains were installed from on top of the sand pad. The sand blanket was included to ensure that there would be no build-up of excess pore-pressures at the bottom of the embankments and to drain away water being discharged out of the clay as a result of PVDs. The sand blanket is included in the model as a boundary condition. The effect of the sand can be modeled by specifying a zero-pressure boundary condition along the ground surface. The physical implication is that there will be no build-up of positive pore-pressures at the ground surface. Any water discharge at the ground surface would disappear through the sand in the FEM model. The Modified Cam-Clay constitutive relationship is used here for the soft clay as in most of the literatures it was used since it gives the best results for such complex coupled analyses[11, 12]. The clay is essentially normall to slightly over-consolidated. It appears that the degree of over-consolidation varies somewhat with depth. In this analysis, the Lambda and Kappa values were taken to be the same for the very soft and the lower soft clay. This gives results closer to what was measured and avoids unnecessary sophistication. The weathered surficial clay is over consolidated and consequently it is acceptable to treat this layer as behaving in a linear-elastic manner. Using a linear-elastic constitutive relationship also helps with maintaining numerical convergence near the ground surface where the stresses approach zero. The sand fill is also modelled as a soft linear-elastic material and the soil parameters are set as being total-stress parameters. This avoids having to deal with pore-pressures built up in the embankment. These simplifying assumptions are acceptable because we are primarily interested in using the fill as a means to apply the surcharge preloading here and don't want to investigate the stability or other issues related to unsaturated consolidation in the embankment body. The actual stress-strain response of the sand is not of significant importance [8].

The FEM modelling is lengthy and was done by the authors in previous literatures that can be accessed for eager readers for more detailed information from [13-15]. The finite element model and boundary conditions used in the analysis is shown in figure 2. The verification of the settlement curves for the test embankment TS1, TS2 and TS3 are shown in the figure 3. Although the FEM simulation predictions agree well for final settlements, as it can be seen as the spacing between PVDs decreases, the amount of overestimation in settlement curves increases as well. This phenomenon might be attributed to delay in stress transference that has been reported by various articles too [16, 17].

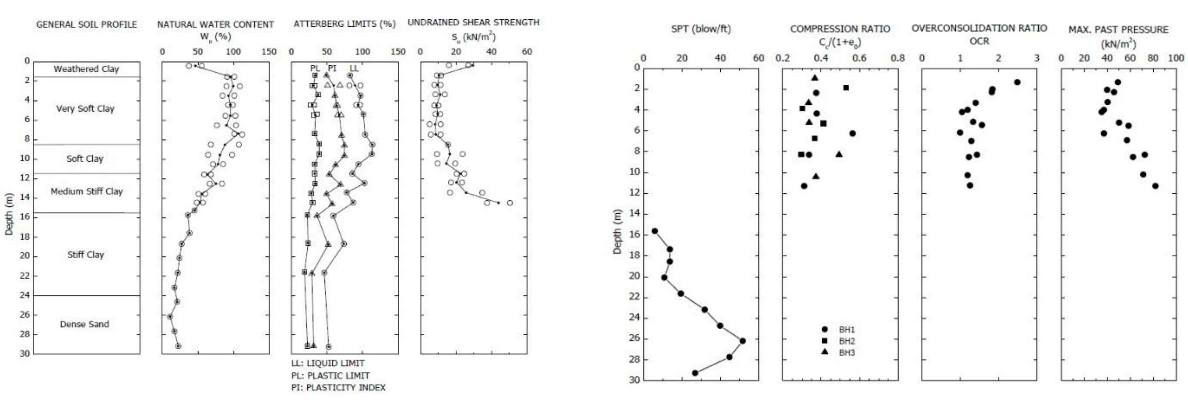


Figure 1. the geotechnical properties of the reclamation area in the Bangkok airport [10].

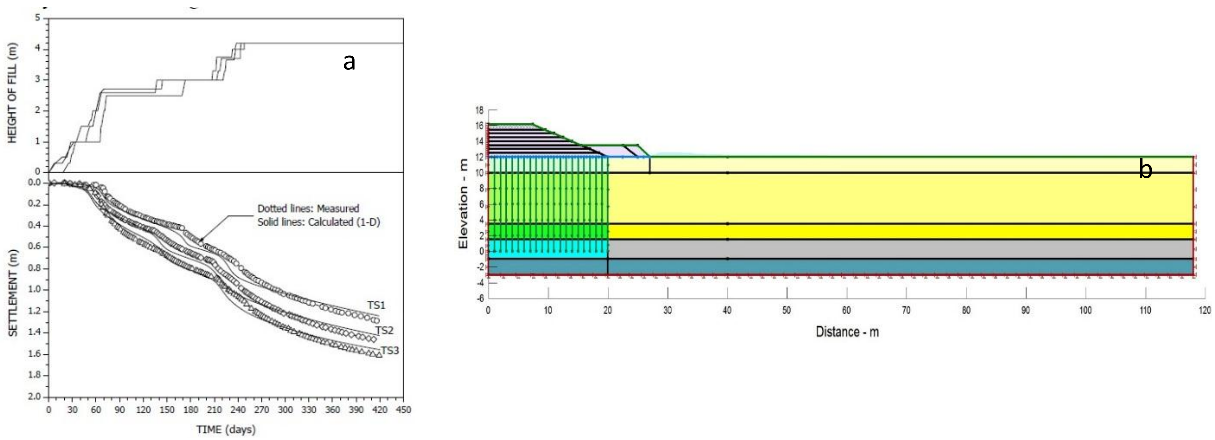


Figure 2. (a) Measured settlements reported by Bergado [10] (b) The schematic view of FEM used in the analyses.

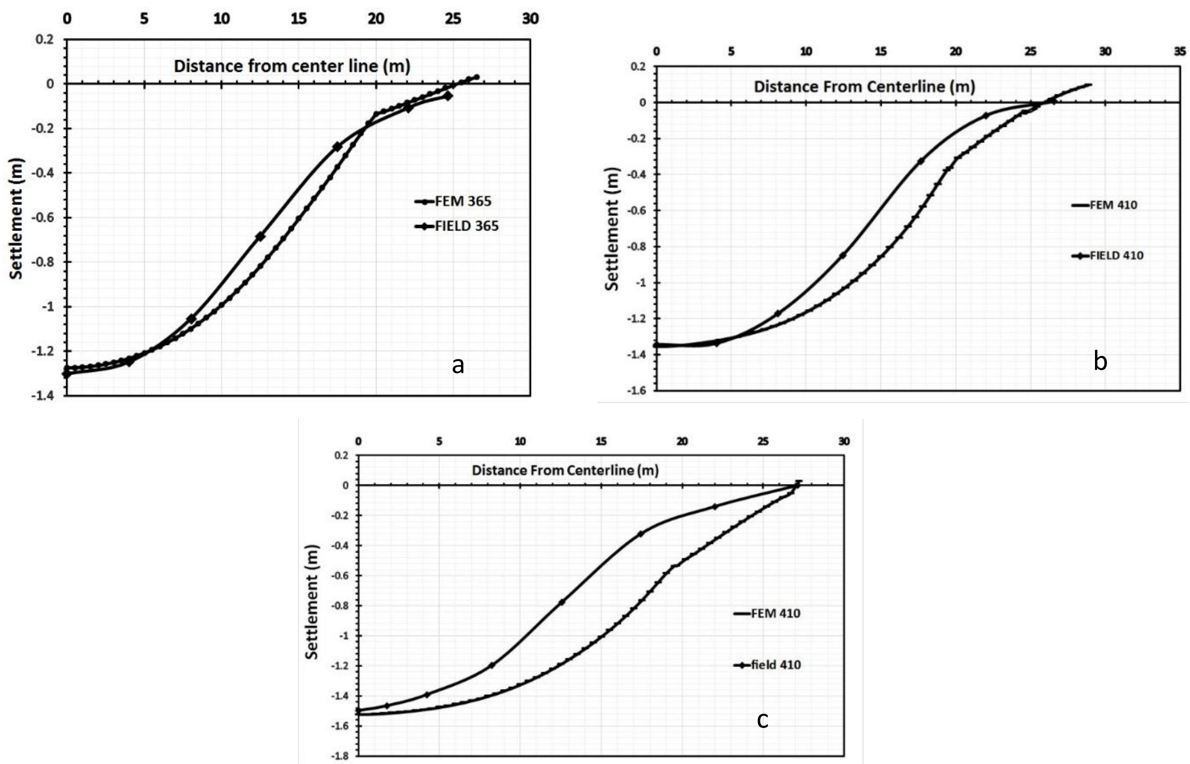
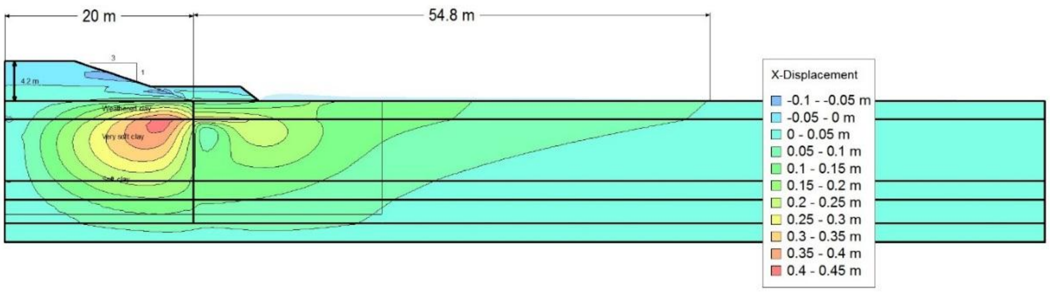


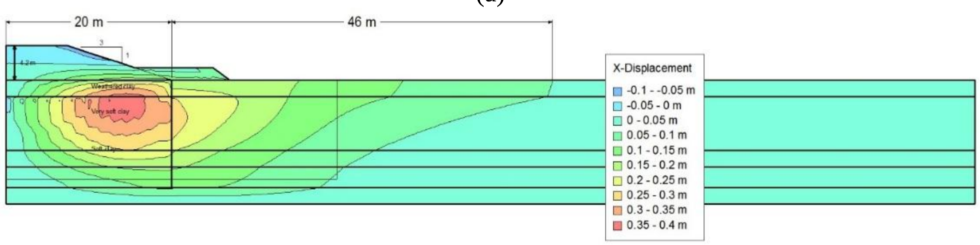
Figure 3. The settlement curves of the test embankments vs time (a) TS1 after 365 days (b) TS2 after 400 days (c) TS3 after 400 days.

3. Results and Discussions

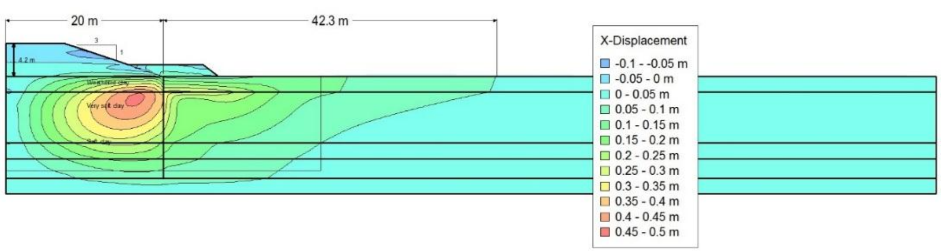
Figure 4 shows the contour diagram of x-displacement of TS1, TS2 and TS3 with 1.5, 1.2 and 1 m PVDs spacing respectively based on the verified models. It is clear that as the distance between the PVDs decreases, the influence zone decreases as well and becomes smaller. For the TS1 case, the influence zone is 54.8 m that has the greatest influence zone. For TS2 and TS3, the diameter is 46 and 42.3 m respectively. Figure 5 illustrates the influence zone of the TS2 embankment in the case where the PVDs were omitted from the verified FEM model. In the absence of PVDs the influence zone has increased to 64 m while the settlement has only reached the quantity of 0.65 m that is approximately only half of the settlement of TS2 embankment. From these FEM simulations it can be seen that the PVDs somehow cause an inward movement in the models that is similar to vacuum preloading that was also reported by [6, 7]. Although by the decrease in the PVDs spacing the quantity of the influence zone has decreased, but even in the case of TS3, the amount of 42.3 m is still a very large amount. In the absence of PVDs, regardless of the system with low efficiency, the diameter of the influence zone is so high that this method can only be applied on remote areas where there are no significant structures or infrastructures in the vicinity of the treatment area. Even for the cases that include PVDs, the method is still not suitable for urban areas where there are many pipelines and underground infrastructures and foundations and application of other methods like cement or vacuum preloading might be considered for such areas. In areas that have a reasonable distance from sensitive infrastructures, the application of the possible minimum spacing would be an option in the designation of such treatment systems by qualified consultants. As it was shown in this literature FEM simulation is the best way for such situations that should be considered with respect to precise mapping of underground and adjacent infrastructures and structures. Since every project has its own unique geotechnical condition, the application of empirical formulas might not be wise at all.



(a)



(b)



(c)

Figure 4. The contour diagram of x-displacement of (a) TS1 (PVDs with 1.5 m spacing) (b) TS2 (PVDs with 1.2 m spacing) (c) TS3(PVDs with 1.0 m spacing) test embankments based on the verified models.

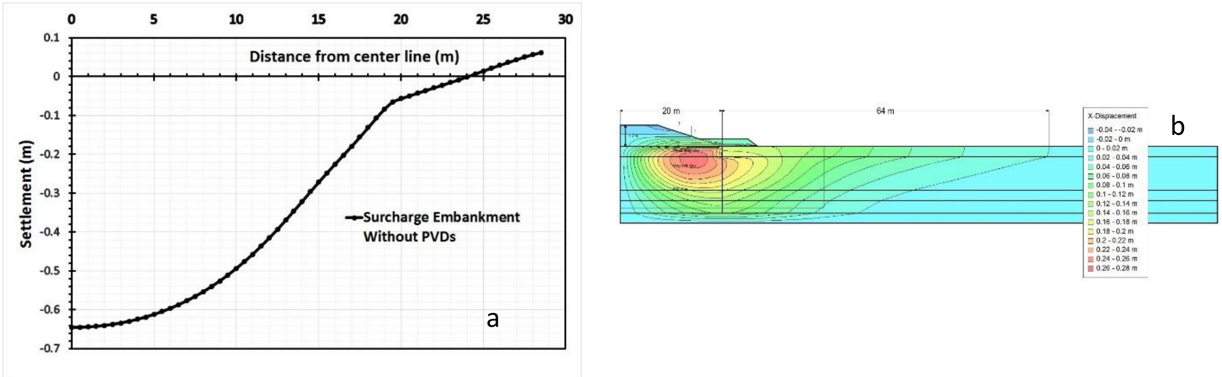


Figure 4. (a) The settlement curve of the TS2 embankment (b) The contour diagram of x-displacement of the TS2 case without PVD after 400 days

4. Conclusions

Three test embankments as TS1, TS2 and TS3 were introduced and verified that were built for investigation of the effectiveness of the combination of surcharge embankment and PVDs in Bangkok international airport. Based on the FEM verified simulations, the horizontal displacement contours were drawn for comparison of the influence zone in the vicinity of the treatment area. For TS1 (PVDs with 1.5 m spacing), TS2 (PVDs with 1.2 m spacing) and TS3 (PVDs with 1.0 m spacing) the diameters of the influence zone were 54.8, 46 and 42.3 m respectively. As the distance between the PVDs decreases, the influence zone decreases as well and becomes smaller. For the FEM simulation of only surcharge embankment in the absence of PVDs the influence zone after 400 days was 64 m in the case that only 0.65 settlement was reached. It can be seen that the inclusion of PVDs and the utilization of smaller quantities of spacing can be an effective way for the reduction of influence zones where there are concerns regarding adjacent structures or infrastructures.

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