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The Importance of Incorporating Hydraulic Modifier Function versus Step Loading in Ground Improvements Including Vacuum Preloading

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ABSTRACT

One of the new technology that is widely used in all the world is the vacuum preloading that accelerate the process of dewatering and consolidation process along with prefabricated vertical drains (PVD)s with or without surcharge preloading. In the finite element modelling (FEM) modelling process, the reduction in conductivity due to the consolidation and increase in stress of underneath layers, plays a dramatic role in prediction of the settlement. Appling a modifier function is a good means to account for reduction in the hydraulic conductivity in FEM modelling. To illustrate the importance, the importance of applying this function in the modelling, TV2 trial embankment in Bangkok airport was appointed as a case history. After the verification of the model, the model was run in the absence of hydraulic modifier. It was observed that the predicted final settlement after 160 days is increased from 0.94 m to 1.19. Also the curve pass is unreal base on the verified model, and the quantity of the calculated settlements are 10 to 25 percent overestimated. Since the clogging of PVDs pore, is one the obstacles in modeling procedure of the vacuum preloading, the clogging effect can be applied as a modification in the resultant hydraulic modifier function derived from lab tests. By applying the proper modifier function, more realistic results can be obtained in FEM modelling in such models including PVDs and vacuum and/or surcharge preloading.

Keywords:

Vacuum preloading, Consolidation, Hydraulic modifier, PVD, Clay.

1. Introduction

As the construction increased at onshore and distant places where the structure of the soil is composed of weak clays, the utilization of new system of land reclamation with high efficiency become inevitable. One of the new technology that is widely used in all the world is the vacuum preloading that accelerate the process of dewatering and consolidation process. The vacuum pressure is transferred to soil mas by means of PVDs, and mostly is used along with surcharge preloading if possible. One of the main challenges in the beginning of the design process and after preliminary soil investigation, is the determination of PVDs length and pattern, the height of the embankment, the required vacuum pressure and approximate of soil improvement time that is done mostly by FEM (finite element modelling) [1]. The design process of such complex systems as combination of PVDs and vacuum with/without surcharge preloading is very challenging due to the various uncertainties such as anisotropy [2], smear zone [3], embankment stability [4] , change in hydraulic conductivity [5] and so on. As the clay consolidate, the void ratio decrease and the both the horizontal and vertical conductivity decrease as well [5]. The determination of hydraulic conductivity parameters of soft soils is traditionally based on laboratory consolidation tests or falling head tests [6]. In the FEM modelling process, the change in conductivity due to the consolidation of underneath layers, plays a dramatic role in prediction of the settlement. Appling a modifier function is a good means to account for reduction in the hydraulic conductivity in FEM modelling. By neglecting this important function, acquisition of a realistic model that can predict the overall behavior of the soil treatment process is inevitable. To illustrate the importance of this function, first a case history including vacuum and surcharge preloading is presented and then the function is omitted to illustrate the settlement results with and without hydraulic modifier function versus step loading. The complexity of this modelling is two simultaneous preloading as vacuum and surcharge that change by time.

2. Materials and Methods

Bangkok airport is the case study that would be investigated here. The soil of the project has low strength and high compressibility issue, and a vast reclamation program was planned that includes the utilization of PVDs, vacuum preloading, stone columns, surcharge preloading and so on [7]. In order to investigate the efficiency of the proposed treatment designation, various pilot areas were instrumented and the proposed soil treatment system were constructed in small scale. TV2 was one of them that was built to investigate the efficiency of applying vacuum preloading along with embankment as surcharge. Figure 1 shows the soil parameters at the project. The PVD drains were installed to a depth of 12 m. The embankments were constructed to a height of 2.4 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 but this detail is not included in the illustrative analysis presented here. A one-meter thick sand blanket was placed on the site as a construction working pad [7]. The drains were installed from on top of the sand pad. The sand blanket was presumably also included to ensure that there would be no build-up of excess pore-pressures at the base of the embankment and to drain away water being squeezed out of the clay. The applied vacuum pressure and the construction sequence of the embankment is shown in Figure 2. Supplementary information on project site can be found in [7].

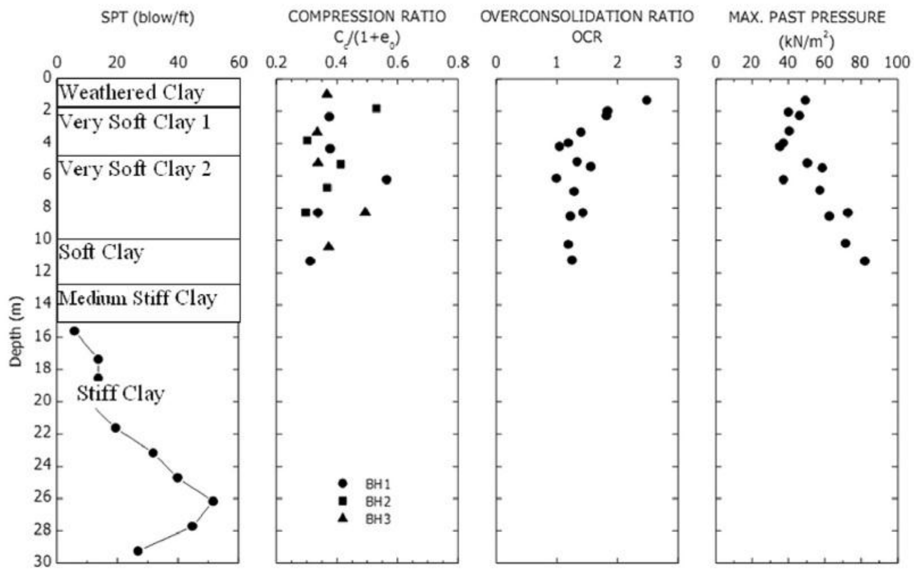
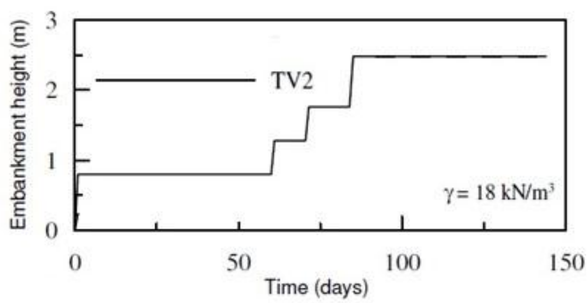
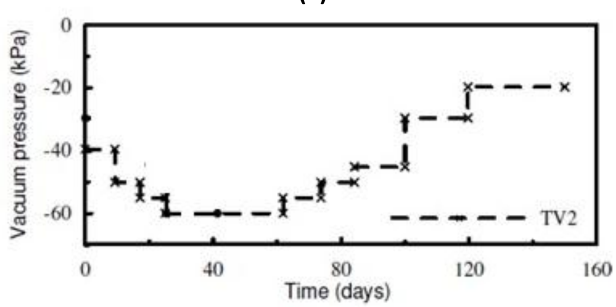


Figure 1. soil parameters in Bangkok airport [8].



(a)



(b)

Figure 2. The construction process of preloading in Bangkok TV2 (a)Sequential placement of surcharge embankment vs. time (b) vacuum pressure application vs. time [9].

The modified cam clay model for FEM as its efficiency is proven in such complex model by different researchers [10-12]. Geostudio 2018 coupled analysis with sequential embankment loading was used for modelling. The modelling of the TV2 is done before by the authors , for detailed specification of the modelling procedure, data's can be found in [13, 14]. The verification of the model is shown in Figure 3.

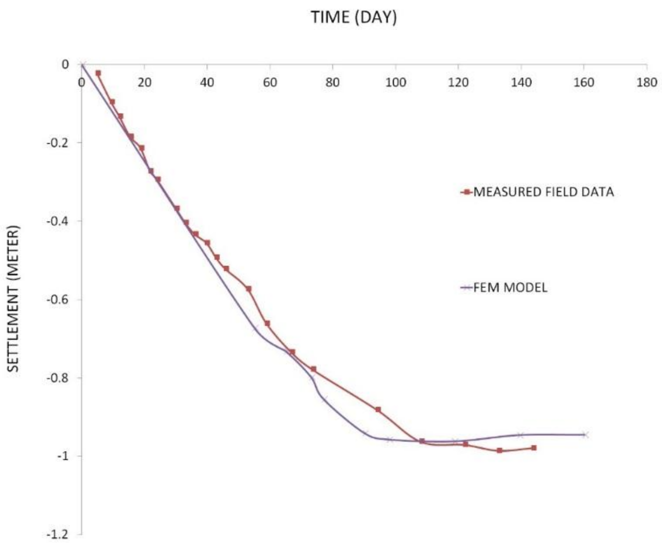


Figure 3. the verification of the embankment TV2 vs. measured data at site (measured data from [15]).

2.1. Hydraulic Conductivity Function

In order to investigate the importance of consideration of the hydraulic conductivity function vs. sequential loading the hydraulic modifier function that was used in verification model (Figure 4) was omitted. The results are presented in next section.

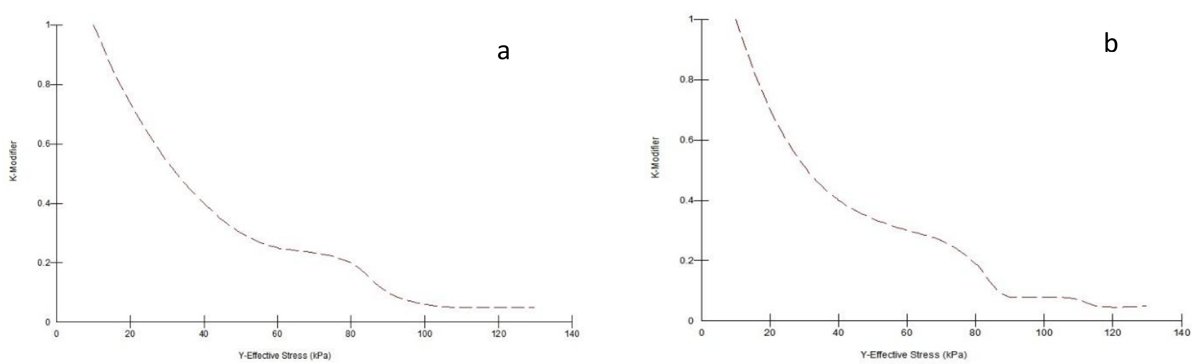


Figure 4. The hydraulic modifier vs. effective stress used in the FEM model (a) the soft clay layer (b) the very soft clay layer.

3. Results and Discussions

As it can be seen in Figure 5, after the omission of the hydraulic function modifier the results become overestimated, and the predicted final settlement after 160 days is increased from 0.94 m to 1.19. also the curve pass is unreal base on the verified model, and the quantity of the calculated settlements are 10 to 25 percent overestimated. During the soil treatment process, large strains and deformations can occur with significant changes in stiffness and drainage path, but the prediction magnitude of these deformations is very important in determination of design parameters. Apart from change of the conductivity resulted from reduction in clay void ratio, as a result of the high seepage velocities resulting from elevated hydraulic gradients from applied vacuum pressure, the particles can start to move with discharge water through PVDs. These particles can then either clog the pores of the PVDs structure and clog the seepage passage. The clogging in PVDs pore would also decrease the rate of the consolidation. This phenomenon was reported by [2, 16 and 17]. This is another issue that illustrate the importance of consideration of proper hydraulic modifier function as an intermediary parameter in the modelling process. The hydraulic modifier function can be estimated base on odometer or triaxial tests for step loadings base on the surcharge and vacuum schedule of the project in lab preferably from undisturbed specimens. The clogging effect can be applied as a modification in the resultant hydraulic modifier function. By applying the proper modifier function, reasonable results can be obtained in FEM modelling.

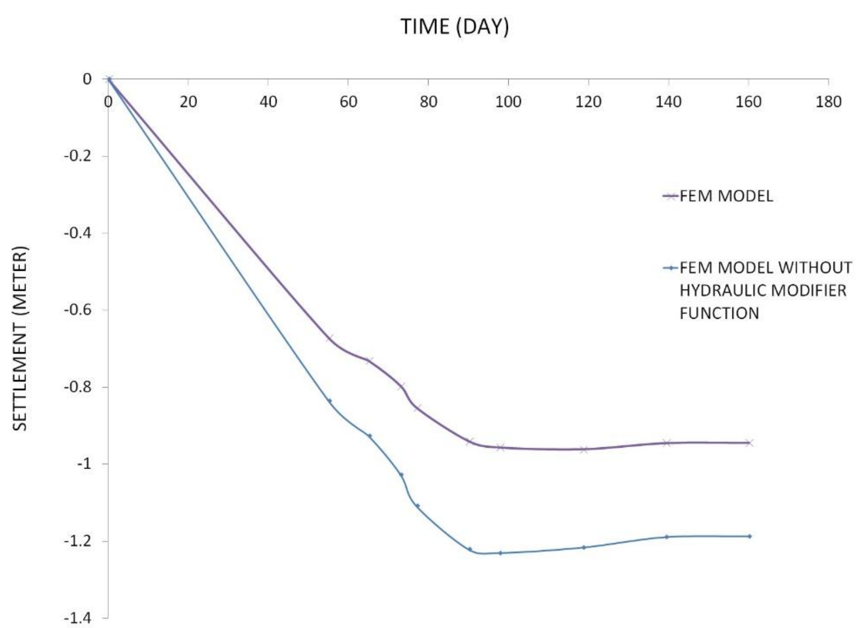


Figure 5. The verified FEM model vs. the FEM model without hydraulic modifier function

4. Conclusions

A case study of TV2 trial embankment and its verification was presented. To illustrate the importance of the consideration of the hydraulic modifier in FEM analysis, the functions used in the model was omitted and the result of the FEM was compared with the verified model. It was observed that the predicted final settlement after 160 days is increased from 0.94 m to 1.19. Also the curve pass is unreal base on the verified model, and the quantity of the calculated settlements are 10 to 25 percent overestimated. as a result of the high seepage velocities resulting from elevated hydraulic gradients from applied vacuum pressure, the particles can start to move with discharge water through PVDs and clog the pores of the PVDs structure and as a result slow down the consolidation process. The clogging effect can be applied as a modification in the resultant hydraulic modifier function derived from lab tests. By applying the proper modifier function, more realistic results can be obtained in FEM modelling in such models including PVDs and vacuum and/or surcharge preloading.

5. References

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