A Model Incorporating Large Strain and Nonlinear Soil Properties for PVD-assisted Consolidation

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1 Introduction

In many coastal areas of the world, soft alluvial clays with very low bearing capacity and high compressibility may undergo excessive differential settlement and shear failure subjected to loads of infrastructure. Hence, the technique of pre-construction consolidation can be typically applied to enhance the soil strength as well as reduce the post-construction settlement. Prefabricated vertical drains (PVDs) combined with vacuum and surcharge preloading have been widely used to accelerate the consolidation of clays. Negative vacuum pressure is a proven effective technique which expedites the consolidation by directly increasing the effective stress, and reduces the excessive outward lateral displacement caused by the embankment load. Given that the traditional models on PVD consolidation were mainly based on a constant coefficient of consolidation (e.g. Hansbo 1981; Onoue 1988; Bergado et al. 1991; Indraratna et al. 1994, 2015; and Zhu and Yin 2004), the approach herewith tries to consider the soil nonlinearities and large strain occurred during PVD consolidation.

2 Radial consolidation model

A theoretical model for consolidation with PVDs subject to fill surcharge and vacuum preloading is developed based on a unit cell approach. The consolidation progress of a soil element outside the smear zone is governed by:

$$\frac{k_h}{m_v\gamma_w}\left(\frac{1}{r}\frac{\partial u}{\partial r}+\frac{\partial^2 u}{\partial r^2}\right)+\frac{k_v}{m_v\gamma_w}\frac{\partial^2 u}{\partial z^2}=\left(\frac{\partial u}{\partial t}-\frac{\mathrm{d}q}{\mathrm{d}t}\right) \tag{1}$$

where k_h and k_v are the horizontal and vertical permeability of undisturbed soils, respectively, m_v is the coefficient of volume compressibility, γ_w is the unit weight of water, u is the excess pore pressure and q is the surcharge loading. For the smear zone, Eq. (1) is modified by replacing k_h with k_s, the horizontal permeability of the remoulded soil. Vacuum p is captured as a boundary condition along the PVD, i.e. u=p at the interface of PVD and the soils. Large-strain effect is considered by the relationship between vertical material coordinate z and spatial coordinate a (Gibson et al. 1981, and Indraratna et al. 2016), i.e. $\frac{\partial z}{\partial a}=\frac{1+e}{1+e_0}$, where e is the void ratio and e_0 is the initial void ratio. The coefficients of permeability and compressibility of the soils may vary with the void ratio and can be considered with C_k and C_c, the slopes of e-log k and e-log σ_v' lines, respectively.

3 Case Study

To accommodate the expansion of Tianjin Port in China, a new pier was constructed on reclaimed land for a storage facility. Below the reclaimed soil layer (about 5 m) are soft soil layers of muddy clays (about 5 m) and soft silty clays (about 6 m), and a stiff silty clay layer. PVDs and vacuum preloading were adopted to accelerate the consolidation under surcharge loading. The preloading history and the settlements are plotted in Figure 1, which compares the results of the prediction against the field data and the results of three-dimensional finite element simulations (3DFEM) obtained by Rujikiatkamjorn et al. (2008). The comparison shows that the solution with large-

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strain effect and varying soil properties differs somewhat from that of small-strain theory and constant soil properties, but agrees much better with the field data. This case suggests that the consideration of large-strain effect and variation of permeability and compressibility can improve the accuracy of the calculation in consolidation for very soft normally consolidated marine clays.

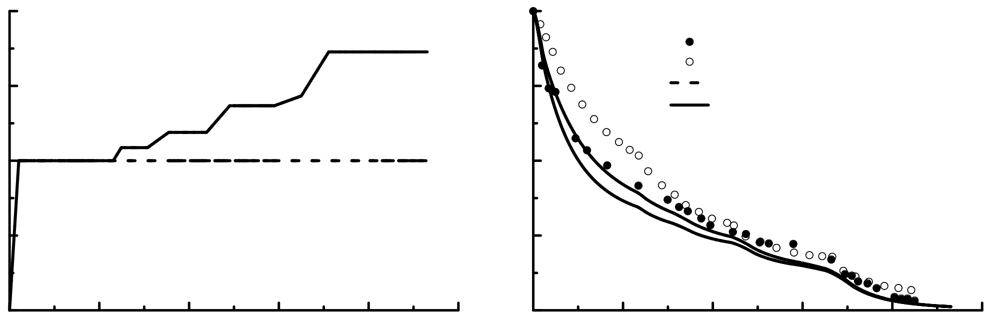

Figure 1: Preloading history and surface settlement for project at Tianjin Port

4 Summary

A theoretical approach was developed for the behaviour of PVDs under vacuum and fill surcharge preloading, which are used in stabilising the soft clay ground. The effect of large strain and soil nonlinearities with varying permeability and compressibility were incorporated. The application of this solution in predicting the settlement at the Tianjin Port revealed that the consideration of large-strain effect, and varying permeability and compressibility will increase the accuracy of the prediction for PVD-assisted consolidation. The traditional method based on small strain assumption may overestimate the consolidation speed.

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