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Numerical Modeling of the Effect of Partial Penetration of Vertical Drains on the Consolidation Process, Case Study: Preloading of Sarbandar Decanter Units in Khuzestan, Iran

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ABSTRACT

The most important factor in soil preloading is the consolidation time. In any cases, if installation depth of the vertical drain is less than the design depth (which is equal to the thickness of the compressible layer), a delay of the consolidation process will occur. In this paper, effect of this parameter on consolidation time is evaluated by numerical modeling and then a case study (soil preloading project of Sarbandar decanter units in Khuzestan, Iran) is studied. In some areas in this project, the penetrating depth of vertical drains is less than the expected design depth. Comparisons are made between numerical modeling and the data from field instrumentation. It is concluded that if the penetration depth of vertical drains is more than 80% of the compressible layer thickness, the delay in the consolidation process seems to be negligible.

KEYWORDS:

Preloading, Penetration Length, Vertical Drain, Numerical Model, Soil Consolidation

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1- INTRODUCTION

Due to excessive consolidation settlement and low shear strength of saturated fine grained soil such as soft clays, ground improvement is vital for them. Preloading is one of the common practices for treatment of such soils. In this method, soil settles under surcharge loading while water drains out of it (i.e. dissipation of excess pore water pressure) and effective stress within the soil increases. Therefore, the post construction settlement of the soil reduces significantly. In order to accelerate soil preloading process (i.e. soil consolidation), prefabricated vertical drains (PVD) are installed in the soil to reduce the drainage path for water.

In the best case scenario, vertical drains would better to penetrate through the entire soft soil layer (design length). It may be possible, however, not to reach the entire soft soil layer under certain circumstances (such as low power installation equipment, facing a stiff sub-layer or lens, etc.). This means that there would be some delays in the consolidation process. Under this condition, a hydraulic gradient occurs between these two zones [1]. Indraratna and Rujikiatkamjorn (2008) [2] indicated that if the penetration length of PVD is more than 60% of the thickness of soft soil layer, the delay in vacuum assisted preloading process will be insignificant.

In this paper, a numerical modeling of the effect of partial penetration of PVD is investigated. The required time for 50% and 90% degree of consolidation for different PVD penetration depths are also illustrated. Finally, a case study (preloading of Sarbandar Decanter Units in Khuzestan, Iran) is considered to be compared with the results of the numerical model since PVDs were penetrated partially in some areas of the project.

2- THEORY OF RADIAL CONSOLIDATION

An analytical solution has been proposed by Barron [4] for a unit cell of soil with a vertical drain at the center as follows:

$$\frac{\partial u}{\partial t} = c_h \left[\left(\frac{\partial^2 u}{\partial r^2} \right) + \frac{1}{r} \left(\frac{\partial u}{\partial r} \right) \right] \quad (1)$$

In the above, u is excess pore water pressure due to surcharge, t is time, ch is the horizontal coefficient of consolidation, and r is the radial distance to vertical drain. Solving Eq. (1) yields to:

$$U_h = 1 - \exp\left[\frac{-8T_h}{\mu} \right], T_h = \frac{c_h t}{4r_e^2} \quad (2)$$

where, Uh is average degree of consolidation due to radial drainage, Th is time factor, re is equivalent radius of cylinder of soil around drain, and μ is a parameter considering drain spacing, equivalent diameter of drain, smear zone, etc.

3- NUMERICAL MODEL

For this investigation, an axisymmetric finite element scheme using ABAQUS was employed. The soil was modeled using modified Cam-Clay based on critical state and associated flow rule. 4-node elements with pore water pressure degree of freedom were considered to discretize the geometry. The size and number of elements were kept constant during the entire analyses. The soil was considered to be saturated throughout the modeling. In order to validate the numerical model considering radial drainage, the results of the theory of consolidation were compared with FEM. The comparisons indicated that there were good agreements between numerical model and theory.

To investigate the effect of Partial penetration of PVD, a 10 m soil cylinder was modeled. The length of PVD varied between 0 to10 m. The required times for 50% and 90% degree of consolidation (t_{50} and t_{90}) were compared for different models.

The results of the degree of consolidation for different models are illustrated in Figure 1. As expected, the consolidation process for the model with longer PVD length is significantly faster. Also, it is evident that difference between the PVD length of 8 m and 10 m is negligible.

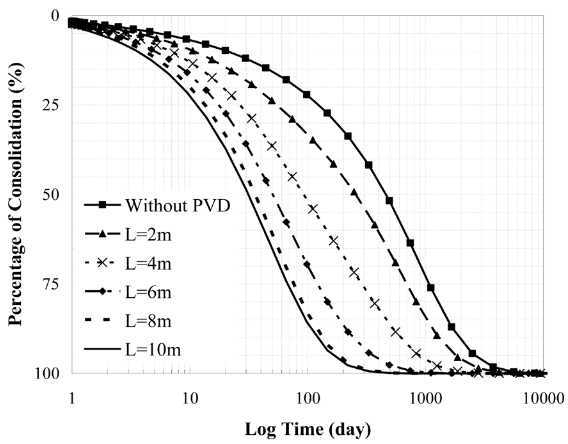

Figure 1. Effect of length of PVD on consolidation time

4- CASE STUDY: SARBANDAR PRELOADING PROJECT

The project is located North-West of Sarbandar City in Khuzestan Province, Iran. Before construction of the two concrete water reservoirs and a decanter unit, soil preloading with vertical drains was nominated for ground improvement method. The triangle pattern with 1.5 m spacing was designed for PVDs. In order to control the progress of soil consolidation, various instruments including vibrating wire piezometer, Casagrande piezometer, surface settlement, magnetic extensometer, and inclinometer were used. The geotechnical investigation indicated that subsurface layers comprised of a 16 m soft clay layer (the layer that was treated) overlaying an 8 m silty sand over a 6 m thick stiff clay. The average penetration of the PVDs was approximately 14 m but in some areas it was partially penetrated to about 10 m.

The results of numerical model of case study with the field measurements are presented in Figures 2 and 3, showing the variations of soil settlement at different depths with time. It can be seen that there is a good agreement between FEM results and field instrumentation. Also, due to the partial penetration of PVDs in some areas, the soil settlement at specific time was lower than other areas. For example, Figure 3 shows that after 220 days of preloading, the surface settlement for areas of low penetration of PVDs was 307 mm whereas for other areas was 391 mm.

5- CONCLUSIONS

In this paper, the effect of partial penetration of vertical drains on the soil consolidation process was investigated using a numerical simulation. Following the validation of numerical model, it was shown that the effect of partial penetration of PVD on t50 was negligible in case the length of PVD is higher than 60% of the soil layer, whereas this value for t_{90} was 80%.

A case study in which PVDs were penetrated down to 63% of the soft clay layer was also considered as part of this study. It was seen noticed both in the field and numerical model that there was a delay in consolidation time for those areas. Moreover, at nearly 220 days after preloading, the soil settlement in low penetration of PVDs was 84 mm less than areas with PVD length around 90% of the thickness of soft clay. Therefore, is should be noted that at the time of PVD installation, at least 80% of the soft soil layer must be covered by vertical drains in order to minimize the delay in consolidation process.

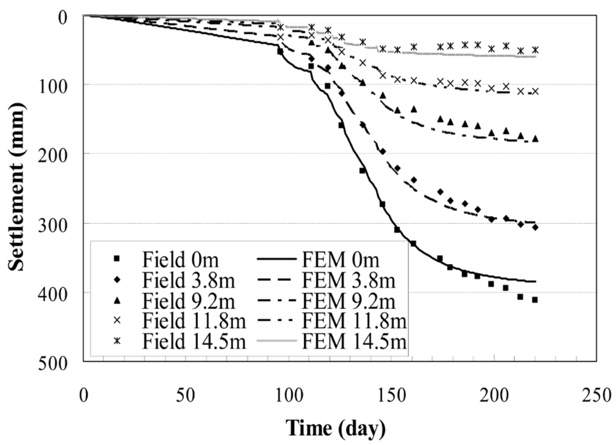

Figure 2. Comparisons of field data and FEM for Soil settlement against time at various depths

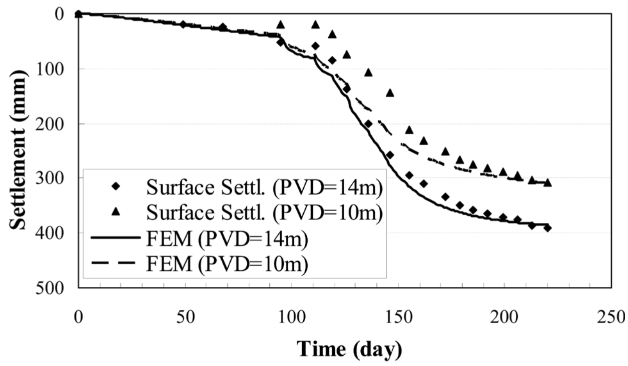

Figure 3. Effect of length of PVD on surface settlement

6- ACKNOWLEDGMENTS

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