ANALYTICAL STUDY OF IMPROVEMENT EFFECTS ON PEATY GROUND BY VERTICAL DRAINS/VACUUM CONSOLIDATION

Nagoya University Student ○Nguyen Hong Son
Nagoya University Regular Mutsumi Tashiro, Regular Shotaro Yamada
Nagoya University Fellow Toshihiro Noda

1. INTRODUCTION

In constructing an embankment on a peaty ground, soil improvement is an essential request to prevent the risk of failure and the excessive settlement after the construction. Vertical drain method is one of the most effective method as reported in the field full-scale experiment and the finite element analysis (Tashiro et al., 2013). Recently, vertical drain combined with vacuum consolidation, hereafter noted as vacuum consolidation method, has been applied widely on which a tight contruction schedule is required. Based on results of numerical analyis, this paper discusses about the improvement effects of vertical drains/vacuum consolidation assuming a soft ground comprising peat and clay.

Sekiguchi et al. (1965) proposed a macro-element method to simulate 3-D ground water flow around drains under 2-D plane-strain condition without being influenced by the drain pitch and the finite element mesh division. However, a constant water pressure within the drains is always given based on the assumption that the permeability of the drain is sufficiently high. Yamada et al. (2013) suggested a new macro-element method which can deal with unknown water pressure within drains to simulate the well resistance depending on the permeability of soils/drain. In this study, a series of soil-water coupled finite element analysis mounted with this method were carried out by utilizing a geo-analysis code ***GEOASIA*** (Asaoka & Noda., 2007, Noda et al., 2008).

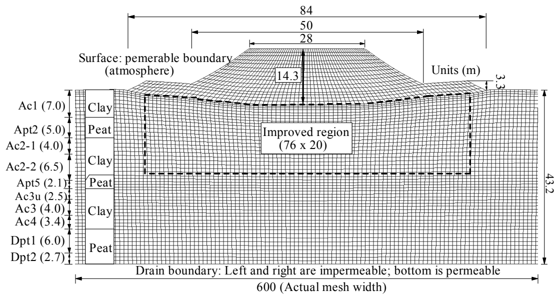


Fig. 1. Finite element mesh and boundary conditions

Table 1. Conditions of ground improvement

Case1	Non-improvement
Case2	PVD installed with 1.5 m drain pitches
Case3	PVD installed with 1.0 m drain pitches
Case4	PVD installed with 0.7 m drain pitches
Case5	PVD installed with 1.0 m drain pitches with applying vacuum consolidation

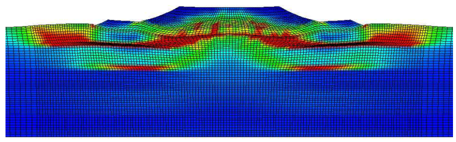
2. ANALYTICAL CONDITIONS

Fig. 1 shows the finite element mesh and boundary conditions (at the completion of the embankment) used in this study. Refering the peaty ground in the Mukasa area of Maizuru-Wakasa expressway (Tashiro et al. 2013, Nguyen et al. 2014), an approximate 40m soft ground underlying embankment containing peat and clay was modelled. The water pressure at the surface was constantly set to zero (atmosphere). The bottom was drained and two sides were undrained boundaries. In simulating the vacuum consolidation, the air-tight sheet was modelled by boundary conditions where the lower side was allocated to be drained condition to simulate applying/stopping vacuum pressure; meanwhile the upper side is undrained condition.

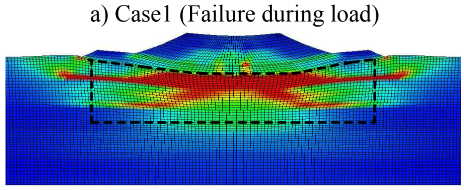
The embankment loading was represented by adding elasto-plastic elements of embankment on the ground surface. In all analyses, for simplicity, the total thickness of embankment was uniformly given as 14.3m under a simple loading rate (thickness/time) of 8cm/day, i.e. a relatively high loading rate was applied by assuming a tight schedule of construction.

Material constants, initial conditions of the soils, and coefficient of permeability were deduced based on the laboratory test results (list of parameter is omitted). With respect to permeability properties, the relationship between void ratio e and coefficient of permeability k ($e=C_k \ln(k/k_0)+e_0$) was estimated from consolidation test. Prefabricated vertical drains (PVDs) were assumed to be installed from the ground surface with a length of approximately 20 m arranged in a square pattern. The permeability of drain was set as 4.0×10^{-2} cm/second.

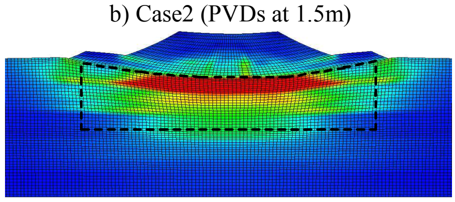
To assess the ground improvement effects on the peaty ground under embankment loading, five cases were investigated numerically as shown in Table 1. In the case 5, the vacuum pressure were reduced to -70kPa in 6 days, and after being kept in 27 days the embankment loading started. After finish embanking, the vacuum pressure had been maintained in 72 days.



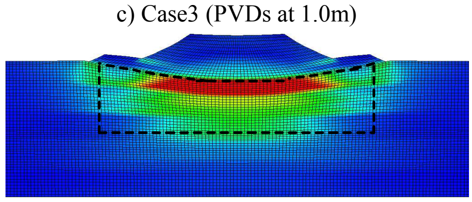
a) Case1 (Failure during load)



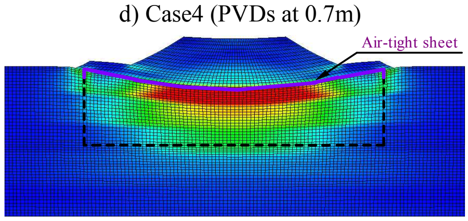
b) Case2 (PVDs at 1.5m)



c) Case3 (PVDs at 1.0m)



d) Case4 (PVDs at 0.7m)



e) Case5 (Vacuum+PVDs at 1.0m)

Fig. 2. Shear strain distributions

Keywords: Peat, Vacuum consolidation, Vertical drain, Macro-element
Contact address: Furo-cho, Chikusa-ku, Nagoya, 464-8603, Japan, Tel: +81-52-789-3834

3. CALCULATION RESULTS

Fig. 2 shows the shear strain distribution results from the all cases. In the case 1, a large-scale failure occurred in shallow peat layer during loading due to the poor permeability and the low strength of the peat inducing undrained shear deformation. Meanwhile, it is obvious that the ground improvement by PVDs is effective for preventing a slip failure during loading. However, in the case large drain pitch, the shear deformation in circular shapes could occur after the end of loading due to insufficient drainage effect. In addition, the smaller drain pitch (case 4) could be as effective as the combination with vacuum consolidation method (case 5) to increase the stability and reduce the ground deformation of the outside of improvement area.

The settlement curves and the residual settlement counted from the point of 72 days after the end of embankment loading (equivalent to the time of stop vacuum consolidation in the case 5) directly below the embankment center for the all cases except the case 1 are illustrated in Fig. 3. It can be seen obviously that the reduction of the drain pitch results in earlier settlement convergence and smaller residual settlement In addition, although the total settlement in the case 5 is slightly larger due to the additional load by the vacuum consolidation, the smaller drain pitch is, the more the total settlement could be reduced due to the suppression of the deformation caused by undrained shear. In the calculation results of this study, the combination with vacuum consolidation led to the reduction of residual settlement by around two-thirds. Moreover, the diminution of drain pitch from 1.0 m to 0.7 m could have roughly the same effect as the combination with vacuum consolidation.

Fig. 4 shows the lateral displacement directly under the toe of embankment slope (or improvement boundary) and the surrounding ground deformation at the end of embankment loading. Because symmetric ground was assumed, only the behaviors at left side were plotted. Focusing on the comparison between the cases 3 and 5 with an equal drain pitch, the combination with vacuum consolidation could reduce the maximum lateral displacement and ground uplift by approximately 70% and 50%, respectively. Respecting the cases of the PVDs only, the smaller the drain-pitch causes less the lateral displacement and the ground uplift. However, due to the lack of the inward deformation by vacuum pressure, only the PVDs could not sufficiently reduce the surrounding deformation as small as the combination with vacuum consolidation, especially in lateral displacement.

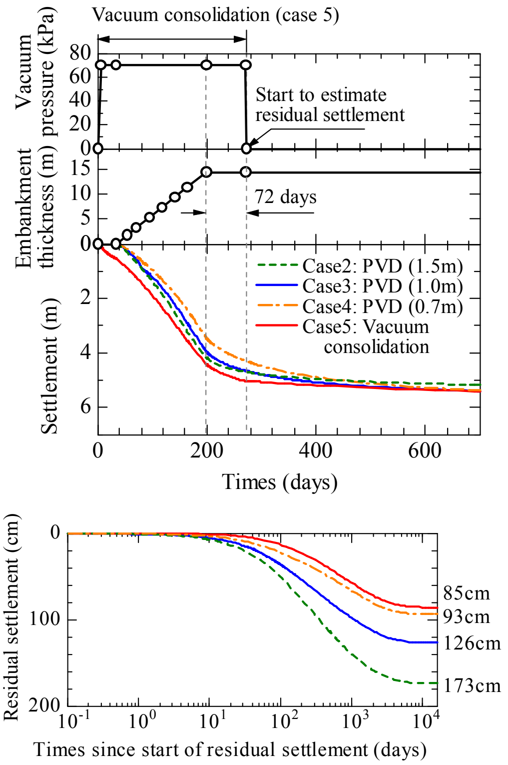


Fig. 3. Settlements at ground surface

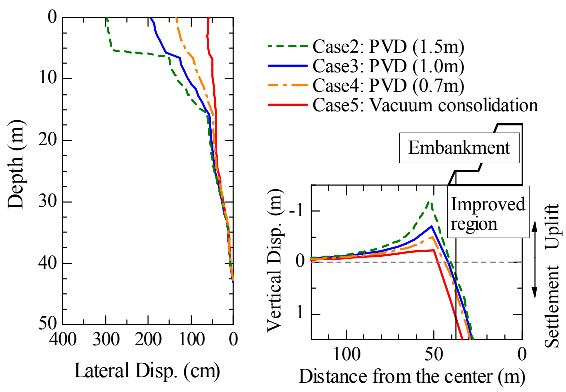


Fig. 4. Lateral displacements and surrounding deformations at the end of loading

4. CONCLUSIONS

In this study, the improvement effects on peaty ground by vertical drains/vacuum consolidation method were examined by using a new-proposed macro element method. The simulation results indicated that the ground improvement by PVDs is effective for avoiding a slip failure during loading. However, when the drain pitch is too large, the circular shear deformation could occur after the end of loading. The PVDs installation with a sufficiently small drain pitch could have almost the same effect as the combination with vacuum consolidation to promote the dissipation of excess pore water pressure in soil, i.e., to reduce the residual settlement. However, only the PVDs could not sufficiently reduce the surrounding deformation as small as vacuum consolidation, particularly in lateral displacement. Therefore, it is important to select a suitable specification for the improvement method such as the drain pitch or the necessity of combination with vacuum consolidation depending on the ground conditions and the peripheral foundations.

REFERENCES

Asaoka and Noda: All soils all states all round …, Int. Work. on Constitutive Modeling, Hong Kong, China, 2007, pp.11-27.
Nguyen, H.S., Tashiro, M., Yamada, S., Noda, M., Yamada, K., Takahira, K., Inagaki, M.: Evaluation for improvement effect by vertical drains/vacuum …, 49th Conf. on JGS, 2014.
Noda, T., Asaoka, A. and Nakano, M.: Soil-water coupled finite deformation analysis based on a rate-type equation of motion incorporating SYS Cam-clay model, S&F, 48(6), 2008, pp.771-790.
Sekiguchi, H., Shibata, T., Fujimoto, A., Yamaguchi, H.: A macro- element approach to analyzing the plane-strain behavior of soft foundation with vertical drains, 31st Symposium of JSSMFE, 1965.
Tashiro, M., Inagaki, M., Asaoka, A.: Prediction of and countermeasures …, ground containing peat, 18th ISSMGE, 2013.
Yamada, S., Noda, T., Tashiro, M. and Nguyen H. S.: Simulation of well resistance phenomena using macro elements with water pressure within drains as unknowns, 48th Conf. on JGS, 2013.