THE POSSIBILITY OF DELAYED SETTLEMENT OF ULTRA-SOFT GROUND CONTAINING PEAT DUE TO EMBANKMENT LOADING COMBINED WITH VACUUM CONSOLIDATION

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1. INTRODUCTION

A large delayed settlement of 11m has occurred (Hirata et al. (2010)), and amount of 1.5m addition has been predicted for over the next 70 years, given from the test embankment applying for approximately 50m of the ultra-soft ground containing peat in Mukasa area of Maizuru-Wakasa expressway (Inagaki et al. (2010b), Tashiro et al. (2010)). The other embankment located at the distance of 300m from the test embankment has been applied the embankment loading combined with vacuum consolidation method to avoid instability of embankment and shorten construction time. The estimations of initial in-situ ground conditions and the 2D plane strain numerical analysis utilizing ***GEOASIA*** (Asaoka and Noda, 2007, Noda et al., 2008) mounted with SYS Cam-clay model (Asaoka et al., 2002) indicated that the possibility of the delayed settlement of the ultra-soft ground containing peat at the new embankment is lower than that of the test location.

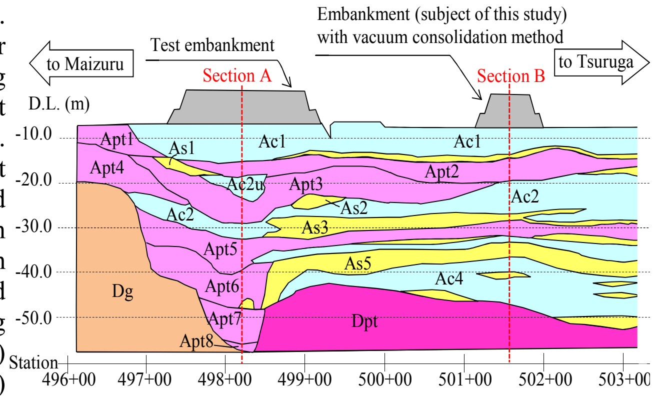
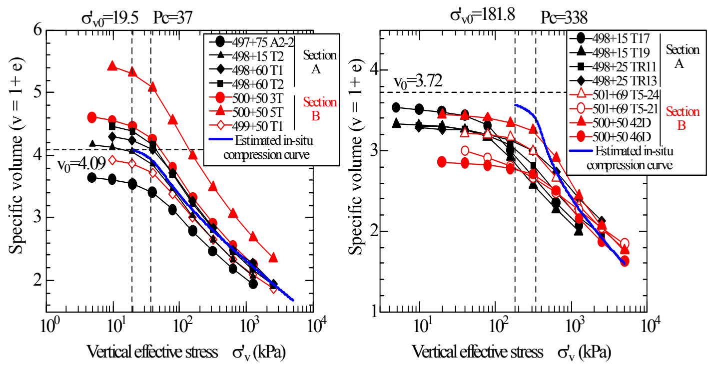


Fig. 1.The schematic outline of soil strata in Mukasa area (longitudinal section)

2. INITIAL GROUND CONDITIONS

The schematic outline of soil strata in Mukasa area is shown in Fig. 1, in which the section A and B match up with the test embankment and the new embankment applying vacuum consolidation method, respectively. The layer structures of the both sections are slightly different. The compression curves shown in Fig. 2(a) support that soils in the shallow layers (Ac1) in both sections are considered as the same "type" and "condition"; meanwhile, Fig. 2(b) shows the same "type" of soils in both sections for deep peat layers but higher consolidation yield stress and more rigid state in the section B. Fig. 3 illustrates the initial pore water pressure, in-situ vertical effective stress and consolidation yield stress. The measured pore water pressure indicates that the section A has been influenced by artesian condition while the section B has been not affected. As results, the peat layers in section B were in the state of over consolidated and more rigid.

In Fig. 2 the blue lines are the estimated in-situ compression curves for layers Ac1 and Dpt2 of the section B deduced with a consideration of disturbance effects using the proposed method by authors (Inagaki et al., 2010a). Here, the deep peat layer Dpt2 displays a dramatically decrease of specific volume in the region under the consolidation yield stress due to the failure of soil skeleton. However, this layer also possesses the high consolidation yield stress, and therefore the possibility of delayed settlement is low.



(a) Shallow layer (Ac1) (b) Deep layer (Apt7 and Dpt2)

Fig. 2. Example of undisturbed compression curves and estimated in-situ curves at section B

3. DELAYED SETTLEMENT ANALYSIS

The FEM mesh and its boundary conditions are shown in Fig. 4, in which, the subsoil layers were expanded horizontally from the layer structures at the center of embankment. The airtight sheet is presented by green line; the under part of this line is in the drainage condition; meanwhile, the upper is given undrained boundary representing the role of airtight sheet.

The initial in-situ ground conditions and material parameters

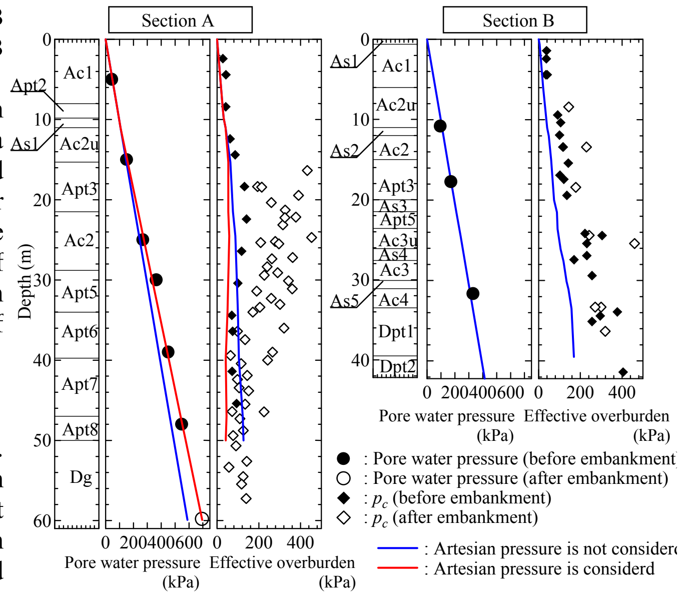


Fig. 3. Estimated distributions of initial pore water pressure and effective overburden pressure

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estimated by the laboratory test results (list of parameters is omitted) were input to finite element analysis to simulate measured settlement data in section B. The permeability of each layer was determined by trial and error method (mass permeability). The simulation procedure followed the actual construction sequence such as: firstly, the 3m of embankment had been built on Nov. 2005; secondly, vacuum pressure about -70kPa was applied from Apr. 2012; thirdly, the main embankment of 8m high was constructed from May. 2012; fourthly, the vacuum pressure was stopped in Dec. 2012; and recently, the ground has been subjected under the embankment load.

As the results, the total settlement amount (the first step is omitted) at the center of embankment is shown in Fig. 5, the excellent matching between analysis results and measured data has been observed for during whole construction time up to date in almost depths. The excess pore water pressure results generally fit with measured data (figure is omitted). In order to predict the delayed settlement, the simulation continued after vacuum pressure stop using the same soil parameters. The result shown in Fig. 5 indicates that this settlement for over one year is not more than about 13 cm that may have to be caused by the deformation of the deep peat layer. The compression behavior of elements in layer Dpt1 under embankment center (black solid line) is illustrated Fig. 6, the consolidation procedure had completed just crossing to the in-situ consolidation yield stress. Even if in the case of 1.5 times as high as the actual embankment, stress state is not far beyond the consolidation yield stress. The results also confirm a low possibility of long-term settlement may have to be occurred.

4. CONCLUSIONS

In this study, the possibility of delayed settlement of the ultra-soft ground has been improved by embankment loading combined with vacuum consolidation method evaluated though the estimation of initial in-situ ground conditions and numerical analysis by ***GEOASIA***. The deep peat layer possessing the high initial degrees of structure, by contrast, has higher consolidation yield stress. Therefore, the occurrence of delayed settlement is possibly low defined by measurement results, only less than 13cm of residual settlement for over more than 1 year after stopping vacuum consolidation. However, this simulation applied mass permeability method is unlikely express the impact of the permeability of each soil layer in the ground. In order to solve these problems, macro element method by Yamada et al. (2013) could be considered as an appropriate solution.

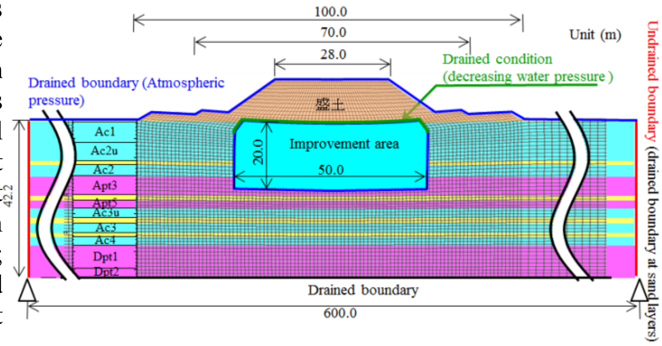

Fig. 4. FEM mesh and boundary conditions

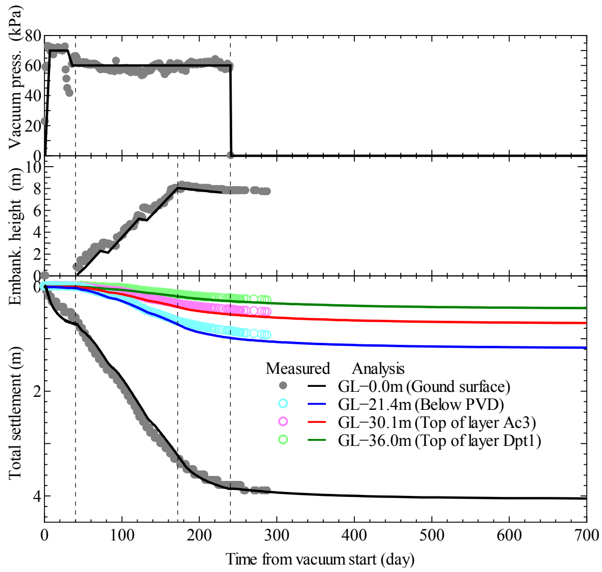

Fig. 5. Settlement under the embankment center

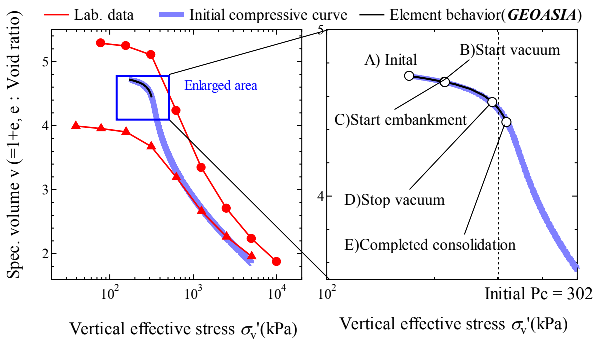

Fig. 6. Behavior of elements in layer Dpt1 under embankment center

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