Deformation Analysis of Cohesive Soft Grounds with Solidified Surface under Fill Construction

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Summary

Surface layers are often solidified even in soft cohesive grounds. They would contribute to the stability of ground under fill constructions. In this paper, the solidified surface layer is modeled as an over-consolidated cohesive soil. The deformation behavior of the ground under the fill construction is calculated by the soil-water coupled finite element analysis adopting the subloading surface model falling within the framework of the unconventional plasticity and thus capable of describing the deformation behavior of over-consolidated soils.

Introduction

The stability, e.g. the settlement and the lateral displacement have to be predicted pertinently when the soil-fill is constructed on soft grounds. Solidified surface layers are often observed in cohesive soft grounds. However, a rigorous method for the evaluation on the contribution of solidified surface layer for the stability of soft grounds has not been established satisfactorily as yet.

The subloading surface model proposed by Hashiguchi [1] falls within the framework of the unconventional plasticity excluding the assumption that the interior of the yield surface is a purely elastic domain. The validity of this model has been verified for not only the normal-consolidated but also the over-consolidated soils under the monotonic and cyclic loading processes [1-3].

In this article the deformation behavior of the soft ground with a solidified surface layer on which a soil-fill is constructed is analyzed by the soil-water coupled finite element program incorporating the subloading surface model. Based on the results of calculation, the deformations including the settlements and the lateral displacements and the excess pore water pressures are discussed qualitatively from the viewpoint of the stability of fill construction.

Conditions for Calculation

The finite element mesh adopted for the analysis is shown in Fig. 1. The ground is

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divided into 637 elements (total 700 nodes) by the four-noded quadrilateral isoparametric elements. Both top and bottom boundaries are assumed to be drained while lateral boundaries are assumed to be undrained. The initial water level is set to be at the ground surface. The construction of the soil-fill is reproduced as the distributed load corresponding to the weight of fill (unit weight: 17 kN/m^3) as shown in Fig. 1, while the construction speed is selected to be 0.05 m/day which would be conventional at present. The material parameters for the ground and solidified surface layers are listed in Table 1. The initial stresses are given as follows:

$$\sigma_h = K_0 \sigma_v \,, \quad \sigma_v = \gamma_g h \,, \tag{1}$$

where, σ_h and σ_v are the horizontal and vertical stresses, respectively. γ_g is the unit weight of submerged soil mass and K_0 is the coefficient of earth pressure at rest. The solidified surface layer is modeled to be the over-consolidated soil, where the pre-consolidation stress P_c is set 10 kN/m^2 leading to OCR 8 at the top element. Calculation is performed for three cases listed in Table 1. Case-1 is without the solidified layer and Case-2 and 3 are with the various thickness of solidified layer. Besides, the high permeability is assumed for the solidified surface layer in Case-3.

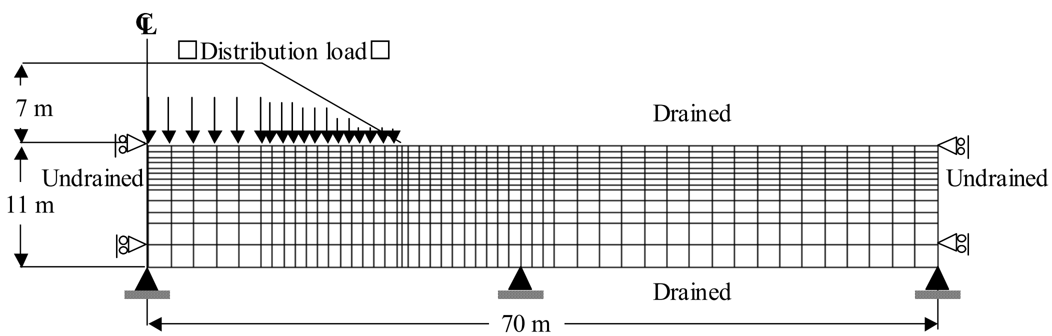


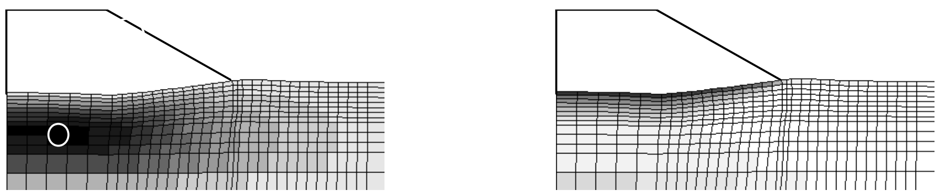
Fig. 1 Finite element mesh adopted for the analysis

Table 1. Material parameters

Case	γ_g (kN/m^3)	v	ρ	γ	φ (°)	u	K_0	k (m/day)	P_c (kN/m^2)	Thickness of solidified layer (m)
1	16	0.33	0.08	0.016	36.4	10	0.5	8.64×10^{-4}	-	-
2			0.02	0.002					10	0.5, 1.0, 1.5, 2.0
3								8.64×10^{-2}		

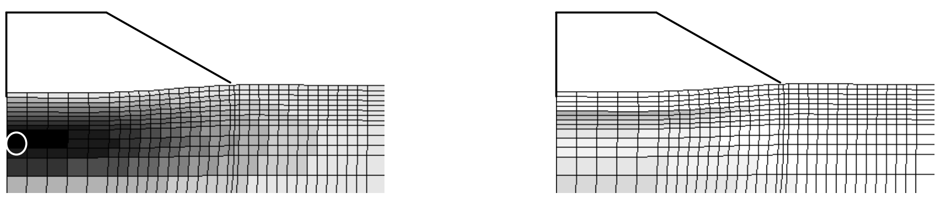
Calculated Results and Discussions

Fig. 2 shows the comparisons of the distributions of excess pore water pressure and volumetric strain in the deformed mesh just after the completion of fill construction (140 days after the beginning of construction) for three cases of grounds. The ground surface settlements are 100, 71 and 84 cm at the center of fill but are 123, 68 and 76 cm at the shoulder of fill for case-1, 2 and 3, respectively. The permeability in case-2 is smaller than that in case-3. Then, the progress of settlement in case-2 is smaller than that in case-3, but the final settlements are almost identical. On the other hand, the maximum excess pore water pressures are 91, 94 and 77 kPa in case-1, 2, 3, respectively at the area marked white circles. The maximum excess pore water pressure in case-2 is larger than that in case-1. It would be caused the generation of well-compressed area beneath the solidified



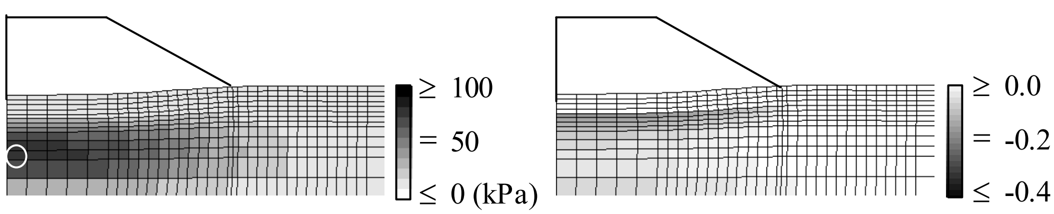
Excess pore water pressure Volumetric strain

(i) Case-1 without solidified layer



Excess pore water pressure Volumetric strain

(ii) Case-2 with 2.0m thick solidified layer

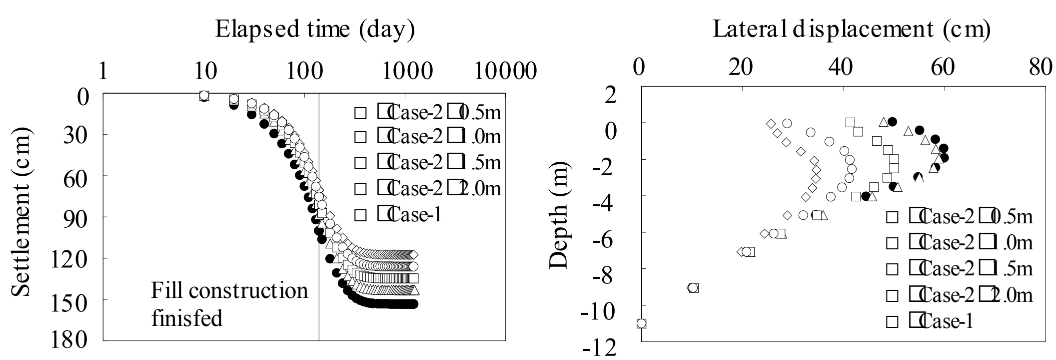


Excess pore water pressure Volumetric strain

(iii) Case-3 with 2.0m thick solidified layer

Fig. 2 Distributions of excess pore water pressure and volumetric strain surface layer. The volumetric strains at the marked area in case-1, 2 and 3 are -0.024, -0.032 and -0.052, respectively. The excess pore water pressure in case-3 is smaller than that in case-2 due to the higher permeability of solidified surface layer. From these considerations, it could be concluded that the solidified surface layer is advantageous to prevent the deformation of cohesive soft ground under the fill construction.

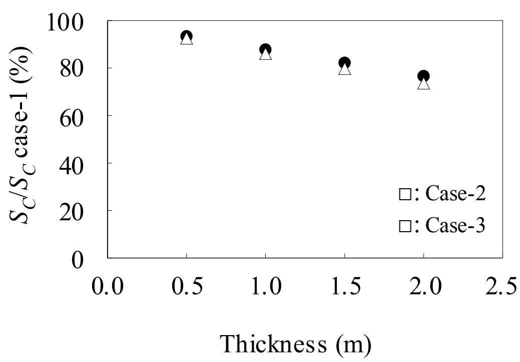
The transition of surface settlements at the center of fill in case-2 for the various thickness of solidified surface layer with the elapsed time after the beginning of fill construction is shown in Fig. 3. The distribution of lateral displacements in the direction of depth is also depicted in this figure. The calculated results in case-1 are also shown in this figure for reference. As shown in the left figure, the settlement in all cases increase with the progress of the consolidation of the soft ground up to one year after the fill construction. The settlement in case-1 is largest finally reaching 153 cm. The settlement decreases about 10 cm as the thickness of solidified layer increases 50 cm. On the other hand, the lateral displacement is about 50 cm at ground surface and the maximum lateral displacement is about 60 cm at the depth 2 m from the ground surface. The lateral displacement in case-2 with 50 cm thick solidified layer is almost equivalent to that of case-1. The maximum lateral displacement decreases 8 cm as the thickness of solidified layer increases 50 cm. In addition, the depth at which the maximum lateral displacement is induced becomes deeper with the increase in the thickness of solidified layer. Therefore, thickness of solidified layer is required to be effective in preventing the lateral displacement.



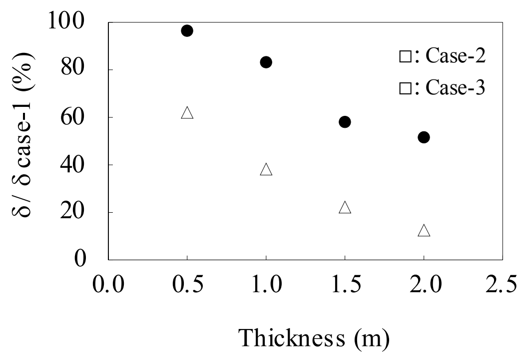
(i) Settlement (ii) Lateral displacement

Fig. 3 Settlement and lateral displacement

Fig. 4 shows the reduction of the surface settlements and lateral displacements for various thicknesses of solidified surface layer in case-2 and 3. The settlement at the center of fill, S_c, and the lateral displacement at the tail of fill, δ, are normalized by those values $S_{c\,\text{case-1}}$ and $\delta_{\text{case-1}}$ in case-1, respectively. As the solidified layer becomes thicker, the settlement and lateral displacement would be reduced. The reduction rate of the lateral displacement is much more remarkable than that of the settlement for all cases as the thickness increases. For example, in case-2, the reduction ratios become 20 % for the settlement and 40% for the lateral displacement at the 1.5 m thick solidified layer, respectively. Moreover, the lateral displacement of case-3 is reduced drastically as compared with that in case-2. This comes from the fact that the excess pore water pressure in case-3 is smaller than that in case-2 as mentioned above. Therefore, it can be concluded that case-3 is more effective than case-2 to prevent the deformation of soft ground under fill construction.



(i) Surface settlement



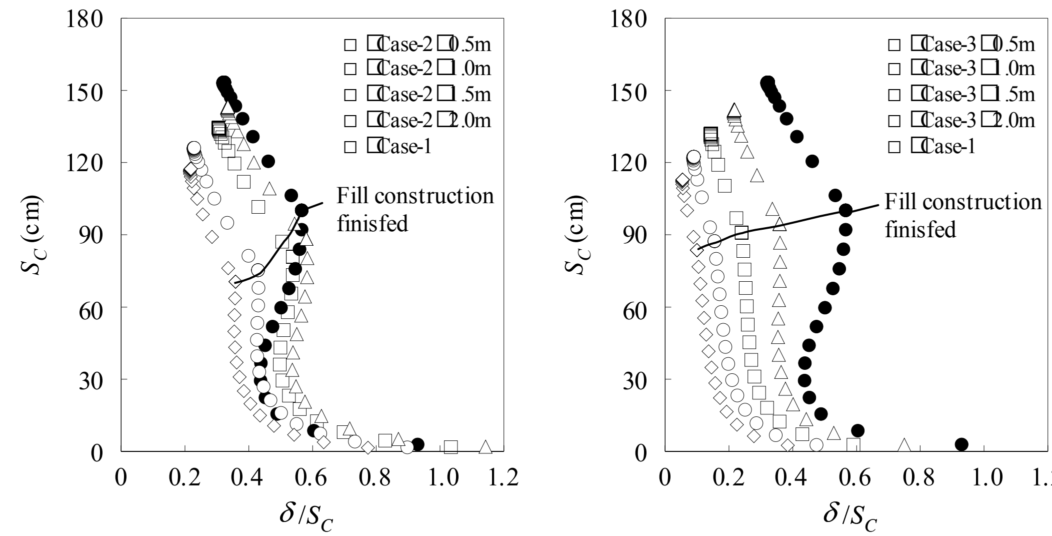
(ii) Lateral displacement

Fig. 4 Reduction of deformation for various thicknesses of solidified layer

Fig. 5 shows the stability charts of case-2 and 3, which are originated by Matsuo and Kawamura [4]. The chart is made on the relations between *Sc* and δ/S_C, which is used widely for monitoring the foundation stability under fill construction in Japan. If the plotted dots go up towards the left side, the foundation under fill construction is judged to be stable. The foundation in the case-1 becomes unstable after the *Sc* reaches 30 cm but it becomes stable again after S_C reaches 90 cm. From all the final dots in all cases, only two cases of case-2 with 0.5 and 1.0 m thick solidified layers became partially unstable for *Sc* of 30 to 90 cm. These two cases are more unstable than case-1 for these settlements, because the δ/S_C in two cases to be bigger than that in case-1. From the engineering points of view, it might be concluded that the thickness of the solidified layer should be more than 1.5 m for the safe design in the present case study.

Conclusions

A series of numerical analyses was conducted to investigate the effect of thickness of solidified layer on the cohesive soft ground surface. It could be concluded that the solidified layer should be thicker than 1.5 m if it does not have a high permeability in the



(i) Case-2 (ii) Case-3

Fig. 5 The foundation stability under fill construction

present case study. The present finite element program would be widely applicable to the prediction of deformation behavior of soil structures, while the problem of the fill construction on the soft cohesive ground was analyzed in the present study.

Reference

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