SETTLEMENT BEHAVIOR OF SOFT CLAY REINFORCED BY GRANULAR COLUMN

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1 INTRODUCTION

Granular column, consisting of granular materials compacted in a cylindrical hole in soils, has become a common practice for ground improvement to increase the bearing capacity and slope stability, reduce total and differential settlements, increase time rate of consolidation and resistance to liquefaction[1]. The purpose of this study is to investigate the behavior of granular column reinforced ground subjected to rigid loading through the small scale laboratory tests. The time rate of settlement of reinforced ground, the sharing of applied stress, the lateral deformation of column and the change of water content of clay and its compression are presented here.

2 EXPERIMENTAL SET-UP

The `unit cell` concept is considered to take the group effect of the granular column. The experiments are performed in a circular plastic mold of 442mm dia and 400mm high. The experimental set-up is shown in Fig.1. Ariake clay (Table 1) is used for preparing the testing soft ground. The clay is throughly remoulded at a water content about 125%.The clay slurry is poured taking care not to trap air bubbles in slurry. Pouring of slurry is carried out in three layers and the preliminary consolidation is conducted for each layer under the vertical pressure of 0.025kgf/cm^2 for 1 day. After the completion of pouring slurry and the preliminary consolidation, the final consolidation pressure of 0.10 kgf/cm^2 is applied for 7 days. The properties of remoulded Ariake clay is shown in Table 2. The granular column is installed at the center of the mold. A casing of diameter 148mm is driven in full depth of clay media and the clay is removed from inside. The granular material (Table 3) is placed in three layers and each layer is compacted by the steel hammer (5cm dia, 10.8cm high, 2.5kg and 30cm free fall). During the placing and compaction of granular material the casing is withdrawn gradually and gently. 12 (35mmx35mm) thin plates are placed along the periphery of column during construction to measure the radial deformation of column. After the installation of column the surface is levelled and the rigid plate (440mm dia) is placed over the surface. The pressure cells are attached with the top and bottom plates to measure the stress on column and soil. The pressure is appllied in two stages, σ_{01}=0.25 kgf/cm^2 (0 to 7 days) and σ_{02}=0.5 kgf/cm^2 (7 to 14days) through the pressurized rubber balloon.

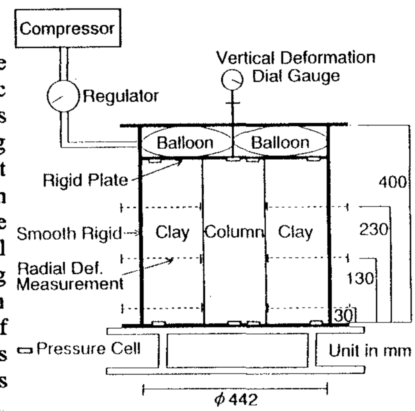

Fig.1 Experimental set-up

Table 1 Physical properties of Ariake clay

Natural Water content	W_n(%)	125~140
Specific gravity	G_s	2.623
Liquid limit	W_L(%)	99.2
Plastic limit	W_P(%)	39.6
Plasticity index	I_P(%)	59.6

Table 2 Reconstituted Ariake clay

Water content	W(%)	95~100
Initial void ratio	e_0	2.695
Degree of saturation	S_r(%)	100.0
Compression index	C_c	0.72

Table 3 Physical properties of granular material

Natural water content	W_n (%)	7.8
Specific gravity	G_s	2.700
Maximum dry density	γ_{dmax}(g/cm^3)	2.153
Optimum water content	W_{op}(%)	6.5
Effective diameter	D_{10}	0.40
Uniformity coefficient	U_c(D_{60}/D_{10})	13.0

3 RESULTS AND DISCUSSIONS

The tests are conducted for unreinforced (T_0) and column reinforced ground having different types of column namely not compacted (T_1), less compacted (T_2) and well compacted (T_3). The initial diameter(d_c) of all columns is 148mm while the compacted diameters are 148, 150.3 and 159mm for T_1, T_2 and T_3 respectively. The initial lengths (H) of columns are 320, 325 and 340mm and the initial dry desities of columns are 1.30, 1.765 and 2.051 g/cm^3 for T_1,T_2 and T_3 respectively.

Fig.2 shows that the settlement (S_t) of T_1 is considerably faster than that of T_0, which occurs due to radial drainage and the rapid decrease of column volume at the initial stage of loading but at the end of primary consolidation for σ_{02}, the settlement of T_1 is slightly less than that of T_0, indicates the reinforcing effect of column even for no compaction. This figure also shows that the settlement decreases with the increase of column density due to the higher stiffness of the column and the dilatancy effect of column material. The settlement ratio (ratio of the settlement of reinforced ground to that of unreinforced ground) varies from 1.07 to 0.69 and 0.93 to 0.68 with the increase of column density from 1.30 to 2.051 g/cm^3 for σ_{01} and σ_{02} respectively.

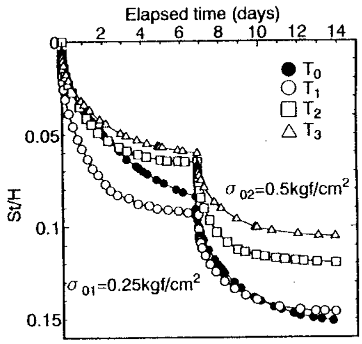

Fig.2 Time~settlement relationship

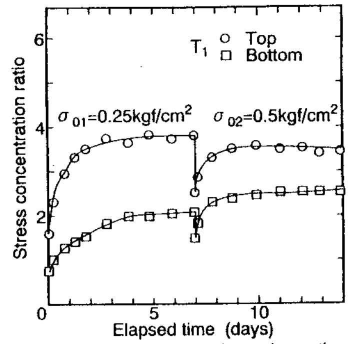

Fig.3 Stress concentration ratio vs. time

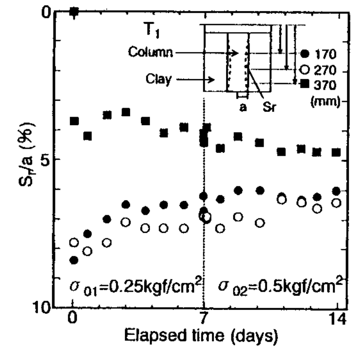

Fig.4 Deformation of column with time

The variation of stress concentration ratio (ration of stress on column to that of soil) n_c, with time for T_1 is shown in Fig.3. The value of n_c increases gradually with time and becomes constant. This observation is in agreement with the results presented by Leung & Tan [2]. This figure also shows that the value of n_c decreases from top to bottom of column, indicates the transfer of stress from column to soil along the depth.

The radial deformation (S_r/a) of granular column for the loosest state (T_1) with time is shown in Fig.4. It shows that the radius ($a=d_c/2$) of column decreases sharply at the initial stage of loading after that it rebound slighty and becomes almost constant. It also shows that the decrease of radius is more significant for the first stage of loading (σ_{01}) than that of for the second stage of loading (σ_{02}). In Fig.5, the radial deformation of column at the end of test are shown for T_1 and T_3 to demonstrate the effect of column density. The column radius is increased significantly for T_3 while it is decreased for T_1 and the column deformation is maximum at the depth of 170mm ($1.15d_c$), which in agreement with field measurement [3] that the maximum deformation generally occurs at a depth $1\text{–}1.5d_c$.

The variation of water content along the depth and radial distance at the end of T_1 is shown in Fig.6. It is observed that the value of water content decreases from top to bottom and from the side of mold towards the column. Due to the radial drainage of column and the vertical drainage at the bottom of mold, the clay gets stiffer from outside boundary towards the column and from top to bottom of the mold. The relationship between the initial density of column and compression of clay volume is shown in Fig.7. It is observed that the compression of clay volume is almost same for T_1 (11.50%) and T_3 (11.0%). This behavior reveals that the compacted column is effective as same as loose column to accelerate the consolidation of clay.

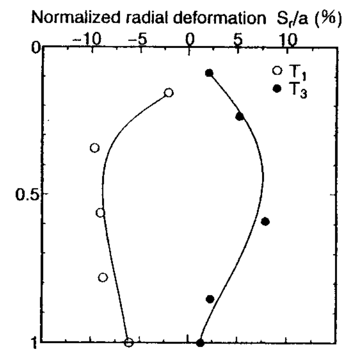

Fig.5 Radial deformation of column with depth

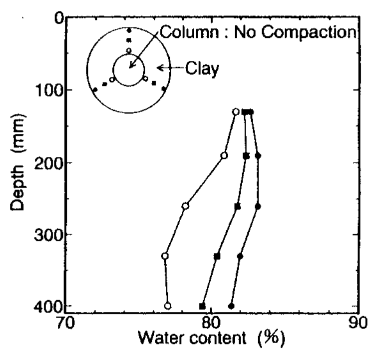

Fig.6 Change of water content of clay

4 CONCLUSIONS

The test results lead to the following conclusions: (i) Settlement of the composite ground reduces significantly with the increase of column density; (ii)Time rate of consolidation increases with the installation of column; (iii) Stress concentration ratio increases with time and becomes constant, it also decreases from top to bottom; (iv) Radial deformations of the loosest and the well compacted columns are noticeable and the maximum deformation occurs at a depth $1.15d_c$ and (v) Well compacted column is more effective than its loose counterpart due to its reinforcing and drainage function.

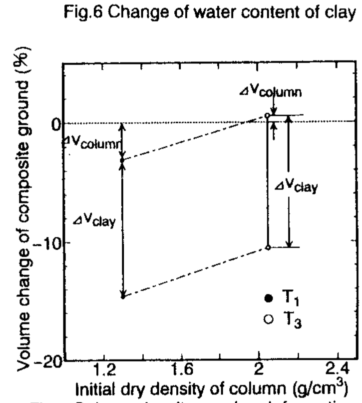

Fig.7 Column density vs. clay deformation

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