EXPERIMENTAL STUDY ON THE CONSOLIDATION BEHAVIOR OF ULTRA-SOFT CLAY WITH HORIZONTAL GEOSYNTHETIC DRAINAGE LAYER BY SIPHON METHOD

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ABSTRACT

Siphon method is proposed to consolidate the ultra-soft clay with horizontal geosynthetic drainage layers. A series of small-scale and large-scale siphon consolidation tests were carried out in the laboratory. The consolidation behavior response of ultra-soft clay to the change of the initial water contents and the magnitudes of the siphon suction was investigated. Test results show the higher the initial water contents of the sample and the magnitude of the suction at viscous state, the greater the drainage and drainage rate are. The availability and effectiveness of the horizontal slurry-geosynthetic drainage system by siphon method is experimentally verified.

Keywords: Ultra-soft clay, consolidation, geosynthetic drainage layers, siphon method

INTRODUCTION

Dredging is essential for the maintenance and development of ports, harbors and waterways for navigation, remediation and flood management. Dredging creates large volumes of dredged material. Typically, the disposal of the slurry becomes a social concern gradually. The material can be a valuable resource although much of it is currently disposed because of economic, logistical or environmental constraints. Whereas, in many countries, there is lack of construction filling material for the embankment, etc. Therefore, developing techniques to utilize the slurry as a feasible filling material is of significant necessity. However, most of traditional improvement methods for the dredged material are featured by high energy-consumption or environmental harm (Shang et al. 2004). It is essential to provide an alternative to dispose and utilize the dredged slurry in a more environment-friendly, energy-saving manner. Until now, only some preliminary investigation on the availability and effectiveness of the siphon consolidation method has been conducted(Tong, et al. 2010 a,b,c;Umezaki et al. 2004).

In this paper, siphon method is proposed to consolidate the ultra-soft clay with horizontally geosynthetic drainage layer. A series of small-scale and large-scale siphon model tests were carried out. The consolidation behavior response to the change of the initial water contents and the magnitudes of the siphon suction are investigated, respectively. Based on the test results, the availability and effectiveness of the horizontal slurry-geosynthetic drainage system by siphon method is discussed.

TEST SCHEME

As shown in Table 1, the test scheme comprises the small-scale and large-scale siphon consolidation tests. The small-scale model tests include 4 tests with the sample at initial water contents of 0.8, 1.0 1.2, 1.5 times the liquid limit (LL) and 2 tests subjected to 3m and 5m initial siphon suction, respectively. Two large siphon tests involve the consolidation tests by the self-weight (siphon suction of 0) and 50 kPa siphon suction, respectively. The detailed test information is illustrated in Table 1.

Table 1 Test scheme for the siphon consolidation tests

Test no.	Magnitude of siphon suction(kPa)	Initial water content (%)
Si-0.8-3m	30 (3.0m)	62.3(0.8w_L)
Si-1.0-3m		77.9(1.0w_L)
Si-1.2-3m		93.5(1.2w_L)
Si-1.5-3m		116.8(1.5w_L)
Si-1.2-5m	50 (5.0m)	93.5(1.2w_L)
L-Si-1.2-5m		
L-Si-1.2-0m	0	

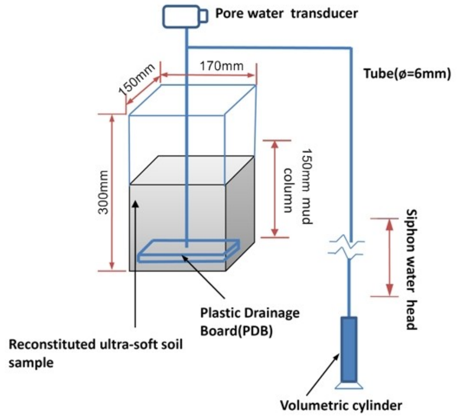
TEST SAMPLE AND APPARATUS

Test Sample

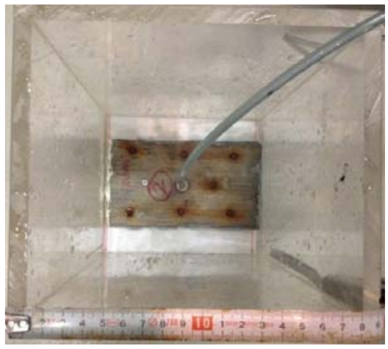
The test sample used in the study was dredged from Island city reclamation field of Fukuoka City, Japan. Its basic physical properties are presented in Table 2. The dredged slurry contains more than 25% clay (<0.005mm) and 60% silt (0.005~0.05mm).The liquid and plastic limits are 72% and 26%, respectively. The specific gravity is 2.673. According to the Unified Soil Classification System, the soil sample is categorized as MH.

Small-Scale Siphon Test Apparatus

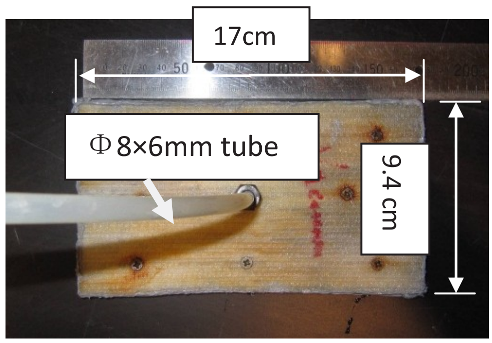
The small-scale model test apparatus is shown in Fig. 1. The test apparatus is mainly composed of acrylic tanks, a prefabricated drainage board (PDB), and plastic siphon tube. The prefabricated drainage board (PDB) was installed in the right center of the bottom of the tank along the length direction horizontally to serve as a drainage layer. As shown in Fig. 1c, d, the length, width and thickness of the prefabricated drainage board are 170mm, 96mm and 3.9mm, respectively. A 3m and 5m long plastic tubes fully filled with de-aired water were utilized to yield the corresponding siphon suction head, respectively. The pore water transducer was installed at the upper end of the tube to measure the variation of the siphon suction head. The pore water transducers were made by Tokyo Sokki Research Institute, the full range was 200kPa, and the linear accuracy was 0.1 kPa. During the tests, a piece of wrap membrane covered on the surface of the mud to alleviate the evaporation, which could be a major cause for causing the cracks.



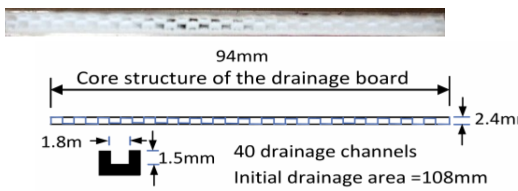
(a) Schematic diagram



(b) Bird view of the cell with installed drainage layer



(c) Bird view for PDB



(d) Lateral view for PDB

Fig. 1 Small–scale siphon drainage test apparatus

Table 2 Basic physical properties of soil sample

Specific gravity G_S	Natural water content (%)	Liquid limit (%) w_L	Plastic limit (%) w_P	Plastic Index I_p
2.673	89.4-93.1	77.9	36.7	41.2

Large-Scale Siphon Test Apparatus

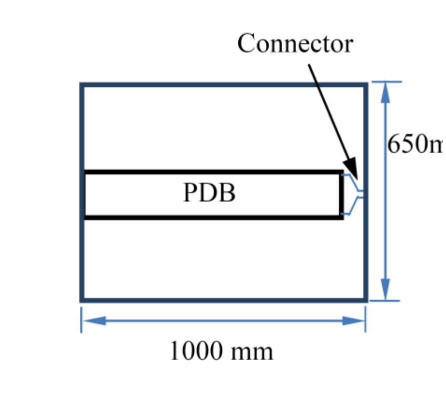
Figure 2 shows the large-scale siphon model test apparatus. The length and width of the rectangular model tanks for accommodating the sample are 1000 mm and 650 mm, respectively. A long saturated plastic tube (Φ=6mm) connected to the drainage layer installed at the bottom of the tank was employed to yield the initial siphon suction. The water drainage volume during the consolidation process was measured by the volumetric cylinder placed at the 5 m lower than the altitude of the tank.The detailed information for the test apparatus is indicated in Fig. 2.

TEST METHOD

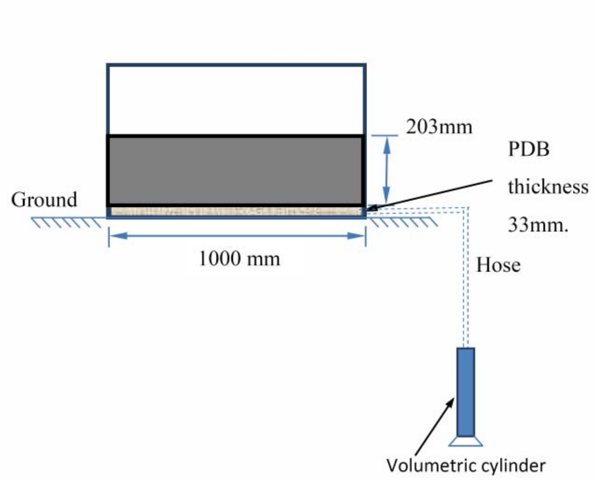
Small-Scale Siphon Test

Initially, the silicon oil was uniformly lubricated around the inner wall of the cell to reduce the peripheral friction between the specimen and the inner wall of the tank during the settlement. The PDB were saturated with distilled water and placed on the center of the bottom along the length direction (shown in Fig.1b) to serve as drainage layer.The sample was carefully placed in small patches in tank and gently agitated with a thin rod to remove any noticeable air voids. Then the plastic siphon pipe was saturated with de-aired water to yield siphon suction head. The pore water transducer was installed at the highest end of the siphon tube to monitor the variation of the siphon suction during the drainage process. A piece of wrap membrane covered the top of the sample to minimize the evaporation, which could be a major cause for yielding fissure and cracks on the surface of the sample. The variation of the drainage water volume during the consolidation process was measured by the volumetric cylinder. The test was terminated until the drainage was completed, as identified by the flattening of the drainage water volume versus time curve. After the tests, the micro-vane shear apparatus was utilized to measure the initial and final shear strength of the sample along the vertical profile.

(a) Large-scale model tank with dimension of 1000 mm×650mm



(b) Schematic vertical view



(c) Schematic front view

Fig. 2 Large-scale siphon model test apparatus

Large-Scale Siphon Test

Firstly, the soil was mixed with electric agitator to obtain the desirable water content in the small tanks. Special attention was paid to the elimination of the entrapped air and bubbles in the slurry. The next step was the installation of the drainage layer. The PDB, K6 sand layer, filter paper were placed in the tank from bottom to top consecutively. Then the drainage layer was soaked with water by applying the vacuum through the opening end of the siphon tube to eliminate the possible entrapped bubble in the drainage layer. The whole drainage layer line was considered as saturated when no noticeable bubble was observed in the siphon tube and no extra water remained on the drainage layer surface. Then, the freshly mixed clays with high workability were immediately poured into the model container to ensure full saturation by 4~5 layers. The sample surface was covered by the membrane to prevent the development of the fissures and cracks induced by the evaporation, which would possibly result in the significant decrease of the siphon suction head.

TEST RESULTS AND ANALYSES

Effect of Initial Water Content

The change of water drainage volume versus time for ultra-soft clay with different water contents ($0.8w_L$, $1.0w_L$, $1.2w_L$, $1.5w_L$) under 30 kPa siphon suction is shown in Fig. 3. The total water drainage volume increases with the initial water contents with similar tendency.

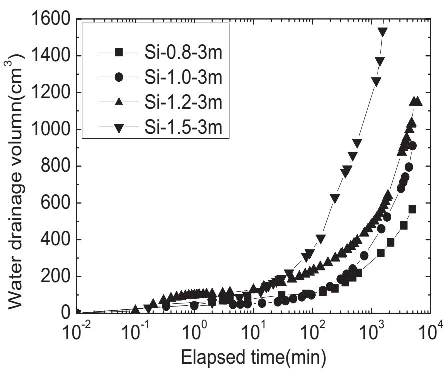


Fig. 3 Change of drainage water volume versus time for ultra-soft clay with different water contents by 30 kPa siphon suctions

Figure 4 shows the change of drainage rate versus time for ultra-soft clay with different water contents ($0.8w_L$, $1.0w_L$, $1.2w_L$, $1.5w_L$) under 30 kPa siphon suctions. At the initial stage, the drainage rate increases with the initial water contents. Then the four curves converge into one at around 6000 min after loading. Their drainage rates at the point of convergence was 0.1cm^3/min, the corresponding average water content of the sample was around 60%.

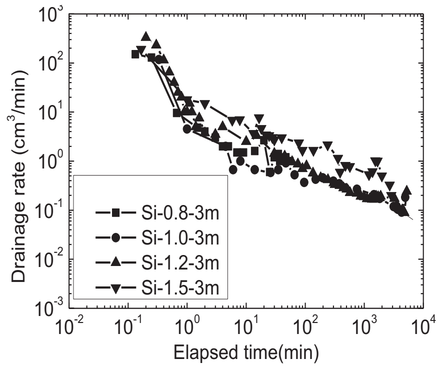


Fig. 4 Change of drainage rate versus time for ultra-soft clay with different water contents by 30 kPa siphon suctions

Figure 5 show the change of average water content for ultra-soft clay with various initial water contents subjected to 30 kPa siphon suction. All the curves converge at around 5844 min after loading and the corresponding average water content of the sample was 60%. It is consistent with the converge point of the drainage rate curves. Finally, about 30% of the water involved in the slurry has been drained out by the suction, suggesting the effectiveness of the siphon method.

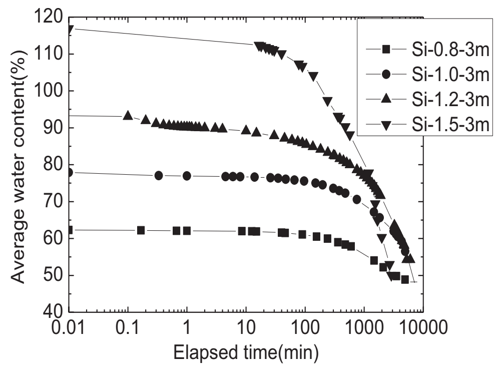


Fig. 5 Comparison of change of average water contents for ultra-soft clay with various initial water contents

Effect of Suction Magnitude

The change of drainage water volume versus time for ultra-soft clay with initial water contents of $1.2w_L$under 30kPa and 50kPa siphon suctions are shown in Fig. 6. The two curves is very close to each other. The averagewater content under 50 kPa siphon suctions is slightly less than that under 30 kPa suctions. The final average water contents of the whole sample subjected to 30 kPa and 50 kPa suctions are around 52.4%, 50.2%, respectively.

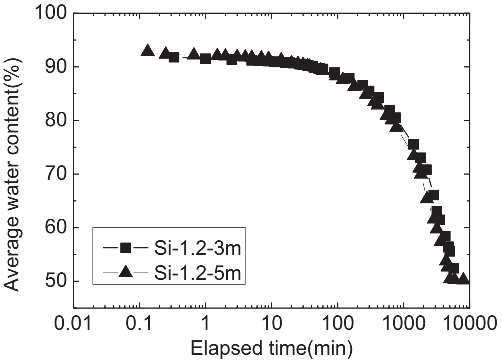


Fig. 6 Change of average water content versus time under 30 kPa and 50 kPa siphon suctions

Figure 7 shows the comparison of average void ratio subjected to 4.9 m siphon waterhead and self-weight large-scale consolidation tests, respectively. For the self-weight consolidation test, the corresponding siphon suction can be deemed as 0 kPa. At the initial 10 min, the drainage water volume shows little difference. However, the water drainage volume with self-weight (0 kPa suction) gradually becomes less with 4.9 m siphon suction and stops in few minutes. For tests L-Si-1.2-0m and L-Si-1.2-5m the corresponding average void ratio decrease from thesame initial value 2.49 to final values of 2.32 and1.9, respectively. It indicates that the siphon consolidation method is much more effective than the self-weightconsolidation.

Comparison of the Consolidation Behavior in the Small–Scale and Large-Scale Tests

Table 3 shows the coefficients of consolidation C_v at soil state for the small-scale test (Si-1.2-5m) and large-scale test (L-Si-5m), respectively. Both of the values of C_v are obtained through the fitting curve according to the conventional consolidation theory. The two values are very close to each other, indicating the influence of the thickness of the drainage layer on the consolidation behavior is insignificant. It further verifies the availability and effectiveness of the horizontal siphon drainage method in a larger scale dimension.

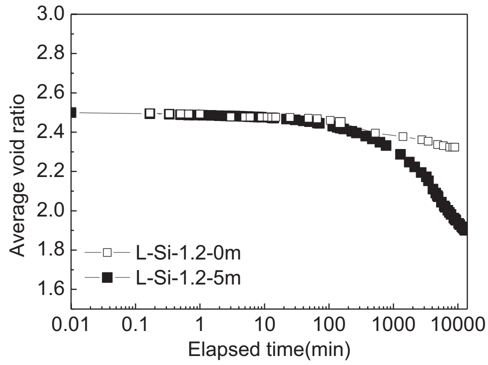


Fig. 7 Average void ratioversus time when subjected to 4.9m and 0 m siphon suction head

Table 3 Comparison of the coefficient of consolidation for small and large scale siphon consolidation tests

Test No.	Soil stage C_v (cm^2/min)
L-Si-1.2-5m	0.043
Si-1.2-5m	0.036

CONCLUSIONS

A series of small-scale and large-scale siphon consolidation tests for the ultra-soft clay with the geosynthetic drainage layer were carried out in the laboratory. The following conclusions are drawn from the test results:
1) Test results show that the horizontal geosynthetic drainage system by siphon method is effective to consolidate the ultra-soft clay.

2) The higher the initial water contents of the sample and the magnitude of the suction at viscous state, the greater the drainage and drainage rate are.The siphon consolidation method is much more effective than the comparative self-weight consolidation.

3) The coefficient of consolidation obtained from large-scale model siphon tests show insignificant discrimination to that from the small-scale siphon tests, further verifying the availability and effectiveness of the horizontal siphon drainage method in a larger scale dimension.

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