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Acceleration self-weight consolidation method for dredged clay using plastic board drain

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ABSTRACT: The Plastic board drain (PD) method for self-weight consolidation has been proposed by the authors as one of soil improvement methods in reclamation works using high water content dredged soils. This method is the vertical drain method for accelerating self-weight consolidation using a PD and floating driving machine to consolidate such very soft grounds in a short period.Therefore, the effectiveness of the PD for self-weight and loading consolidation was confirmed by laboratory tests using a large size cylindrical container (H=210cm, D=30cm) filled with dredged clay slurry of high water content (w=1000%).

1 INTRODUCTION

In recent years, for maintenance of navigational channels or purification of the environment, it is often planned to dredge the clayey deposits on the surface of sea, and utilize the dredged spoils as landfill and manmade island materials. Typically, the dredged spoils are temporarily stored in a nearby sedimentation pond and then very soft ground is formed. Nevertheless, since an artificial ground filled with the spoils has a very high water content such as 200 to 300%, it is necessary to consolidate it properly for the utilization to landfill and manmade island. Kamon et al.(1991), Shinsha et. al. (1991) and Yoshikuni et.al. (1994,1995) have studied the vertical drain method using plastic board and horizontal drain method as one of the soil improvement methods in reclamation works for dredged clay. Therefore, the authors have developed the vertical drain method for accelerating self-weight consolidation using plastic board drains as a method of consolidate such very soft grounds in a short period. This method is not only possible to pour the large quantity dredged soils into the landfill pond but also is possible to utilize a landfill ground as soon as possible after the end of reclamation (Figure 1).

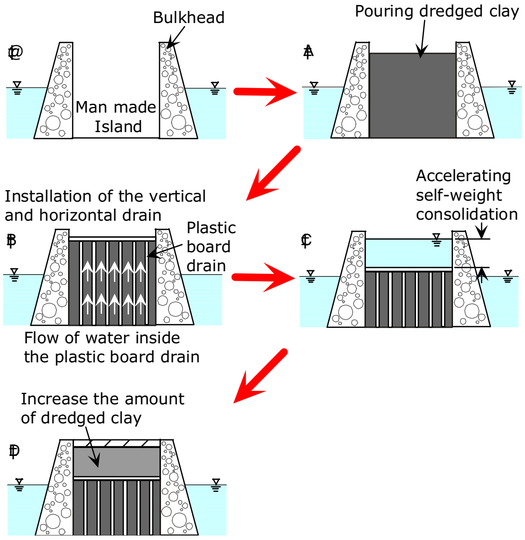

Figure 1 Plastic board Drain by Floating System

In this paper the effectiveness of the plastic board drain (PD) for self-weight consolidation was confirmed by the laboratory tests using a large scale cylindrical container (H=210cm, D=30cm). Moreover, the results from the loading consolidation tests after the self-weight consolidation tests is also reported.

2 TEST PROCEDURES

2.1 *Clay sample, PD and apparatus*

The clay sample used in this study was an alluvial marine clay called as Kanda clay, which was taken from the port of Kanda bay in Fukuoka prefecture, Japan. Pieces of shells were taken out from clay slurry by using a sieve of 2.0mm diameter. The physical properties of this clay are given as: ρ_s=2.691(g/cm^3), w_n=140%, w_L=84.2%, w_P=36.9% and Ip=47.3.

The clay slurry was completely remolded in a mixer with the 3% density salty water. At this stage, the three types of water

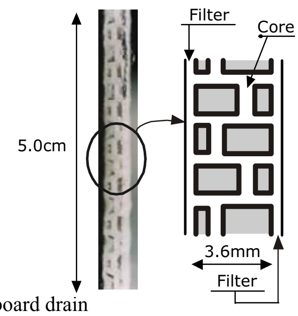

Figure 2 Plastic board drain

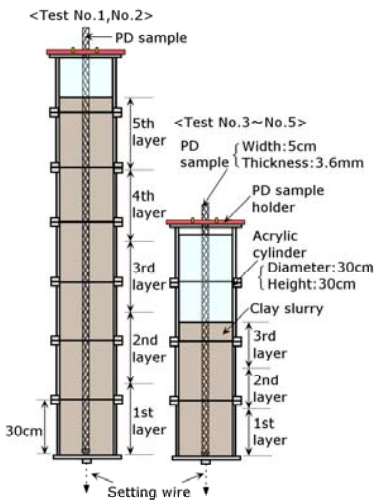

Figure 3 Self-weight consolidation test

content of prepared clay slurry are about 200, 500, 1000%.

A PD sample used in this study was 50mm width, 3.6mm thickness, which has the composite boards with filter sleeve attached to the profiled core as shown in Figure 2. The water con tained in clay slurry is drained through the inside of a core, when the PD sample is inserted into very soft clay ground.

The testing apparatus used for investigation of self-weight consolidation characteristics of slurry dredged clay consisted of 7 parts of large scaled cylindrical container (H=210cm) as shown in Figure 3. This each container has D=30cm inner radius and H=30cm height. The inner surface of the cylindrical container is made of acrylic with 1cm in thickness.

2.2 *Test procedure*

2.2.1 *Self-weight consolidation test*

In this study, the acceleration self-weight consolidation tests using PD were carried out to investigate the influence of initial water contents of dredged clay as shown in Table 1. In Test No.1 and 2 the samples were prepared by pouring the clay into the cylindrical container up to a height of 100mm for a period of five days. Similarly for Test No. 3, 4 and 5, clay was poured into the containers up to 70mm for three days. The pouring of dredged clay used the water pump. In the case of Test No.1 and 2, the PD sample was inserted at the center of the sample after 24 hours. On the other hand, in the case of Test No.3, 4 and 5 it was done immediately after the pouring of the clay. After pouring of each layer, the surface settlement and excess pore water pressure were measured. The surface of water level was kept constant throughout the experiment. In the case of Test No.2, PD was allowed to deform with the self-weight consolidation of clay. However, in the case of Test No. 3, 4 and 5, both ends of the PD were fixed so that the length of the drainage path remain the same. Settlement of dredged clay was observed visually.

Teble 1 Test condition

Test No.	Initial water content (%)	No. of layer	Pouring amount (cm/day)	Average water content (%)	PD	Installation condition	Water content at installation of PD(%)
1	1000	5	100	1040	×		
2				1068	○	Free	416
3	1000	3	70	938	○	Fix	524
4	500			495	○		420
5	200			206	○		206

2.2.2 *Loading consolidation test.*

A series of tests(Sato et al.,2000) are carried out as follows:

1. After self-weight consolidation, a stage loading consolidation tests for Test No.1 and Test No.2 was performed with the vertical loads of σ_v=19.6kPa and 49.0kPa. The tests were performed in step by step way under the consolidation pressure.
2. After the each loading consolidation test, the constant head permeability test carried out to investigate the permeability performance of PD samples in the clay specimen under constant loading.
3. After the 2nd stage loading test, in order to investigate the strength properties of clay specimen for each tests, the cone penetration tests were carried out at the top of clay sample.
4. In the case of Test No.2, after the final consolidation step in the model test is finished, the mold was disassembled carefully so as to see the deformations of the prefabricated drains inside the clay.
5. After the consolidation test, the local water contents of the clay was measured. The points were chosen with the radiation from the center at the middle of PD. It was measured to a depth direction 5 cm each.

3 TEST RESULTS AND DISCUSSIONS

3.1 *Self-weight consolidation test*

Figure 4 shows the time-settlement relations of the slurry clay surface for Test No.1 and No.2 after the full height of clay slurry is reached.

These results indicate that the settlement of Test No.2 terminated in 61days after start of measurement. On the other hand, the settlement of Test No.1 terminated in 310 days. The relation of time-settlement indicates markedly that the consolidation is accelerated by PD. In this Figure, the final settlement, S_f, is estimated by using a hyperbolic fitting method for Test No.2 data. Based on the above-mentioned procedure, the final settlements (S_f) is about 90.1cm, which is calculated by the each consolidation curve. The degree of consolidation for Test No.1s and Test No.2s was calculated from the final settlements (S_f).

The effect for accelerating consolidation by means of PD is estimated by comparing the consolidation time at U=90%. The results are shown in Table 2. The self-weight consolidation in which the PD is set up at the center of sample has accelerated the time as much as 11.5 times of the case without PD. This result indicates that it is very effective for accelerating the consolidation by the use of PD during self-weight consolidation.

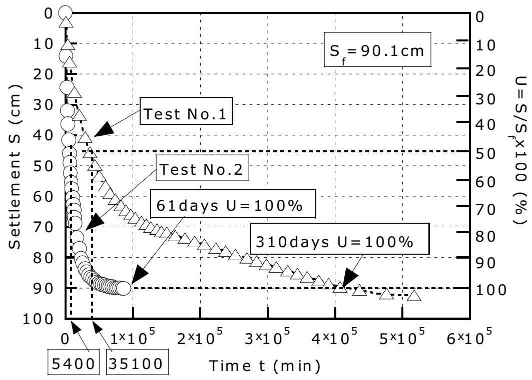

Figure 4 Relationships between elapsed time and height of clay surface for each layer

Table 2 The effect for accelerating consolidation

U(%)	Consolidation		The effect of acceleration	
	Test No.2 t_1	Test No.1 t_2	t_2/t_1	t_1/t_2
50	5400	35100	6.50	0.15

Figure 5, 6 and 7 show the settlement curves of each layer at the end of 24 hours for the Test Nos. 3, 4 and 5 respectively. In the case of Test No. 3, each layer shows no differences of the amount of settlement. 50 cm of settlement per day was observed leading to a clay layer of 20 cm. These results demonstrate that there is no accelerating effect of the PD in this case. Also, it can be seen that the settlement curve has reached the phase transformation point at about 2 hours after the start beyond which the rate of settlement decreases. This may be due to the observation made by Takada et al according to which, at first the particles settle due to flocculation and then the self-weight consolidation starts. On the other hand, in Tests 4 & 5, the effect of the PD was clearly observed as seen in the Figures 8 and 9. Comparing these two figures it can be observed that the effect of PD is more pronounced in the case of Test No. 5 in which the settlement starts rapidly after the installation of the PD than in the case of Test No. 4. These also show that the accelerating effect of PD also depends to a great extent on the initial water content of the clay. Figures 8 and 9 show the change of water content of the sample with time for the Tests No. 3, 4 and 5.

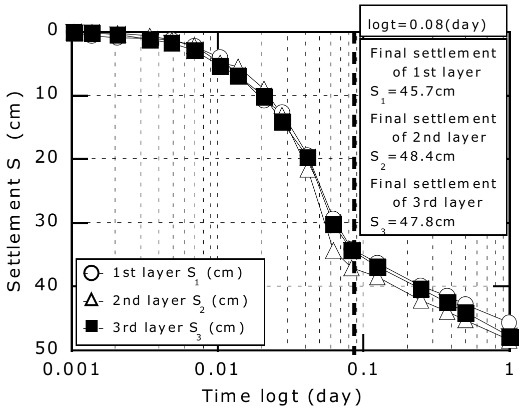

Figure 5 Relationships between elapsed time and settlement (No.3)

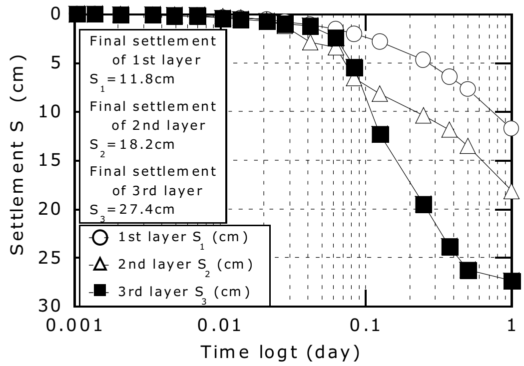

Figure 6 Relationships between elapsed time and settlement (No.4)

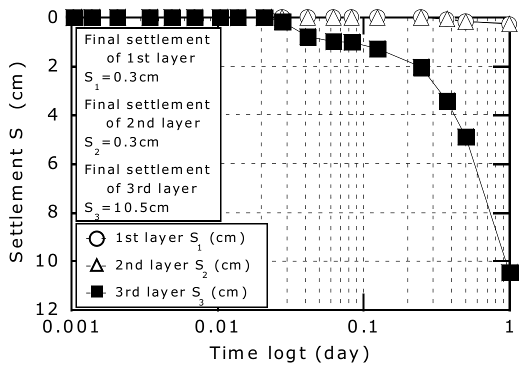

Figure 7 Relationships between elapsed time and settlement (No.5)

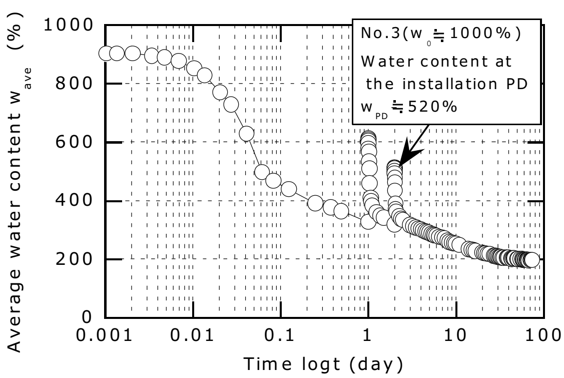

Figure 8 Relationships between elapsed time and average water content (No.3)

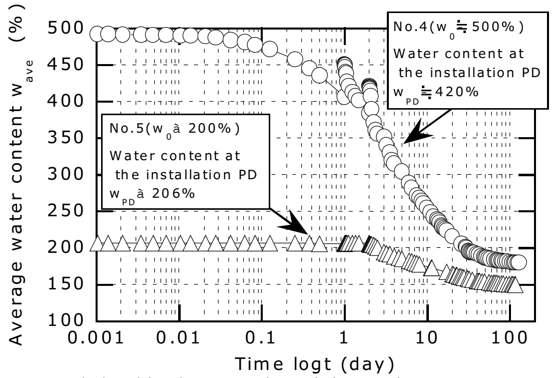

Figure 9 Relationships between elapsed time and average water content (No.4,No.5)

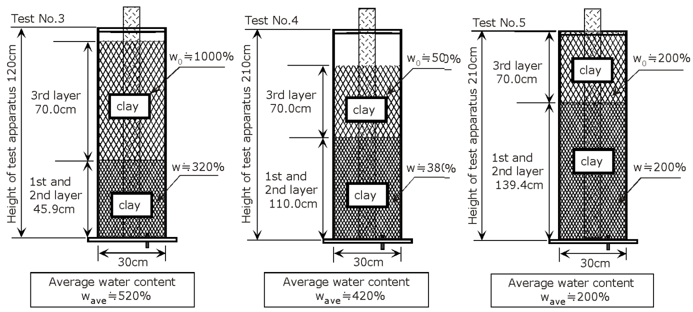

Figure 10 Water content of PD installed

The distributions of the water contents immediately after the installations of the PDs are shown in Figure 10. In the case of Test No. 3, the water content after installation of the PD is very high. This is due to flocculation effect of the particles as explained earlier, and hence in this case shows no effect of PD due to the high water content. As seen in Figure 10(a) water content of 1000% covers 60 % of the container. Due to this the water flows within the particles rather than making its way trough the PD. Therefore, PD can not contribute to the self weight consolidation process. On the other hand as seen in Figure 9 the average water contents are 420 and 206% respectively for the Test No. 4 & 5. If we observe Figures 10(b) and 10(c), we can see that in the case of Test No. 4, 60% of the whole layer has the water content of 380% while in the case of No. 5 the whole layer has the water content of 200%. In these two cases, due to self-weight consolidation of the particles, the water flows through the PD and hence shows the effect of using PD. From the above observations it can be said that in order to achieve accelerating effect of PD for very soft clay with high water content, the clay has to have the self-consolidating effect. Also in this case low water content and uniformity of the water content can be more effective while using PD. Therefore while using PD in the construction site, the water contents of the site need to be determined accurately before the execution.

3.2 *Loading consolidation test*

The settlement versus elapsed time curves for self-weight consolidation and consolidation with surcharge of Test No.1 and Test No.2 are shown in Figure 11. In this Figure, the relation of time-settlement indicates that the consolidation is markedly accelerated by PD for each loading step. The rate of initial settlement of Test No.2 is greater than the case without PD for each loading steps. Comparing the elapsed time for the end of consolidation, the Test No.1 requires about three times longer period than that of Test No.2. This result indicates that the PD after high deformation by self-weight consolidation still maintains a high permeability performance.

Therefore, the effect of acceleration using PD is estimated by comparing the consolidation time at U=50% for each loading step. The results are shown in Table 3. The consolidation with surcharge in which the PD is set up at the center of sample has accelerated the time as much as 11.5 and 25.9 times for each loading steps than that without PD. This result indicates that the use of PD during loading consolidation is very effective for accelerating consolidation. After the final consolidation step in the model test, the mold was disassembled carefully so as to see the deformations of the prefabricated drains inside the clay.

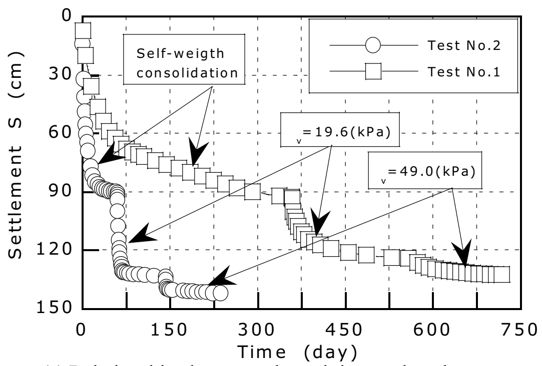

Figure 11 Relationships between elapsed time and settlement

Table 3 The effect for accelerating consolidation

U (%)	v (kPa)	Consolidation Time(min)		The effect of acceleration	
		Test No.2 t_1	Test No.1 t_2	t_2 /t_1	t_1 /t_2
50	19.6	2500	17190	6.9	0.15
50	49.0	1330	34430	25.9	0.04

Figure 12 shows the deformations of PD inside the clay. A PD sample was deformed and bent with large curvature by consolidation and received the strain up to 70% to the axial direction. The photograph shows that the PD sample undergoes large deformation following the settlement of a model ground. A sharp local kinking was not observed.

In order to investigate the permeability characteristics of the PD in the clay after the test, vertiacl permeability tests were performed under the constant head. This coefficient of permeability is estimated to be k= 4.3 cm/sec from the amount of drained water using the Darcy's law. It turns out that it fully has the drainage function as compared with the permeability of model clay foundations.

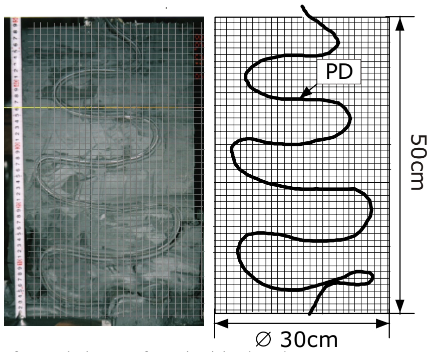

Figure 12 Deformed shape of PD inside the clay

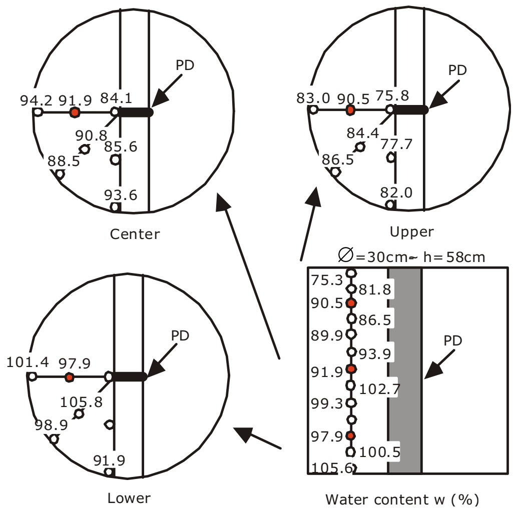

Figure 13 The distribution of water content of clay specimen

Figure 13 shows the distribution of water content of the depth and radial direction in the clay sample. The water content of clay specimen increase with increasing with depth because of the skin friction of acrylic container. On other hand, the water content of each radial direction plane indicate that it tends to be small with going near the PD sample. These results indicate that the drainage of clay specimen occur toward PD sample.

4 CONCLUSIONS

The conclusions obtained in this study are summarized as follows:

(1) The PD material has high permeability under large deformation due to self-weight consolidation.

(2) The use of PD during self-weight consolidation is very effective for accelerating. The consolidation by means of PD has been accelerated at 6.5 times as the case without PD at U=50%.

(3) The accelerating effect of PD also depends to a great extent on the initial water content of the clay. Therefore while using PD in the construction site, the water contents of the site need to be determined accurately before the execution.

(4) The PD after large deformation by self-weight consolidation maintains a high permeability performance. Comparing the elapsed times at the end of consolidation, the Test No.1 requires about three times as longer time as of Test No.2.

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6 REFERENCES

Kamon, M., Pradhan, T.B.S. and Suwa. 1991 : Evaluation of design factors of prefabricated band- shaped drains, *Proc . of International Conference of the Geotechnical Engineering for Coastal Development (Geo-Coast'91)*, Vol.1, pp.329-334.

Sato, K., Yoshidai, N. and Nomura, T. 2000 : Self-weight and loading consolidation behaviour of dredged clay with plastic board drain, *Proc. of International Seminar on Geotechnics in Kochi (IS-GK2000),* pp.147-152.

Shinsha, H., Watari, Y. and Kurumada, Y. 1991 : Improvement of very soft ground by vacuum consolidation using horizontal drains, *Proc, of International Conference of the Geotechnical Engineering for Coastal Development (Geo-Coast'91),* Vol.1, pp.387-392.

Imai, G. 1980 : Settling behavior of clay suspension, *Soils and Foundations*, Vol.20, No.2, pp.61-77.

Yoshikuni, H., Kim, H., Hirokane, S., Moriwaki, T. and Kusakabe, O. 1991 , Consolidation behaviour of dredged clay ground improved by horizontal drain method, *Proc, of International Conference of the Geotechnical Engineering for Coastal Development (G eo-Coast'91)* , Vol.1, pp.99-103.

Yoshikuni, H., Hirokane, S., Moriwaki, T. and Kusakabe, O. 1994, A study on the effectiveness of horizontal drain method (in Japanese), *Journal of Geotechnical Engineering (JSCE)*, No.499, pp.87-96.