Soil improvement technique on clay by dewatering and mixing sandy soil

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ABSTRACT

Normally a soil dredged from a pond is very soft and has high water content. The purpose of this study is to investigate a cheaper, easier and environmental friendly method in comparison with the conventional soil improvement methods. The new idea of dewatering method was adopted to the soft clay collected from a pond. The functionality of this new method is thus by inserting a geosynthetic material (polyester) in the soft clay for dewatering and evaporation of excessive water without energy.

This is effective, economical and low environmental impact method for dewatering. In the experiment, it was found that the clay with initial water content of 1.5 times the liquid limit can be reduced to less than the liquid limit within a week by the new dewatering method. In addition to dewatering, sandy soil was mixed with the clay and cone penetration test was carried out. The effect of mixing content of sandy soil on cone index was also evaluated.

Keywords: soil improvement; soft clay; dewatering; geosynthetic material; cone index

1 INTRODUCTION

Over the year several conventional approaches and techniques have been put in place for the dewatering of high water content slurry soil and improving low strength; which are energy intensive, time saving, but not economical and environmental friendly. Some of which are vacuum method, grouting injection and cement stabilization methods. Soft clay with high water content and low bearing capacity can be improved by dewatering using siphon method (J. Tong, et al., 2012 and S. Soda, et al., 2015). This is a very simple and environmental-friendly method, however the dewatering by negative pressure does not continue a long time and the effect is limited. Suction pressure of this method is derived from absorbent and drying process of polyester material. A mechanism of the dewatering may be similar to vertical drain or vacuum method in partially.

The authors propose a new method by inserting a geosynthetic material in soft clay for dewatering and evaporation of excessive water without energy. This is a cheaper, easier and environmental friendly method in comparison with the conventional soil improvement methods. The new method is applied to the soft clay collected from a pond in Kumamoto Perfection in Japan for utilization as an embankment material. In order to make clear conditions of dewatering, two different polyester materials were used and the effect of inserting the direction of the materials is also confirmed. Furthermore, cone penetration test was carried out to ascertain the progressing strength by mixing sandy soil and effective mixing content for obtaining target cone index is also discussed.

2 MATERIALS USED

2.1 Kumamoto clay

The soil sample used for this experimental work was collected from a pond in Kumamoto Prefecture, Japan. The physical properties of the clay used in this study were investigated and clarified based on JGS soil test manual as thus natural water content=185%, liquid limit=121.98%, plastic limit=82.12%, plastic index =39.86, clay content=50%, silt content=15%, sand content=35%, organic content=23.4%, particle density=2.27g/cm^3.

2.2 Dewatering geosynthetic materials

In order to ascertain the level of depleting soil water content and to know the type of effective material, two different geosynthetic materials were used (A: woven material in thickness of 0.6 mm (Tere pack 020) and B: non-woven material in thickness of 2 mm (Twin guard TS-20) produced by DAIKA industries Co. LTD.). It is considered that these materials possess different dewatering characteristic abilities in terms of thickness, water tightness and texture.

3 LABORATORY TEST

3.1 Consolidation test

Kumamoto clay was prepared in a slurry at the water content of 185%. Consolidation test of the sample was performed based on the test method for one-dimensional consolidation properties of soils using incremental loading (JGS 0411). The slurry sample was poured into a container in inner diameter of 60 mm and height of 30 mm.

3.2 Dewatering and suction test

Three types of dewatering tests using geosynthetic materials were conducted. The test apparatus comprises of two polyester materials, a cylindrical container of 127.4 mm height and 100 mm diameter, plastic plate and plastic bag. The soil sample with a water content of 185% was poured into the container. The significant differences among the cases studied is the order of the arrangement of polyester dewatering material in the container. The test apparatus for dewatering is shown in Fig.1 (Case 1-A&B, Case 2-A&B and Case 3-A&B). Case 1 and 2 polyesters were vertically and horizontally placed, respectively, while Case 3 was a combination of both the order of arrangement, as illustrated in Fig.1. After which, the cylindrical container housing the plastic bag containing the sample was covered with a plastic plate, in order to prevent undue evaporation of moisture from the test. In order to access the depletion rate of water from the test sample as well as its degree of hardness on each dewatering day, a moisture transducer (tensionmeter with vacuum gauge) was installed in a sample combined condition as Case 3-A. This was done in the sample as Case 3-A order due to its high efficiency in the dewatering of the soil sample during the preliminary stage of this study. The dewatering process of this study lasted for 4 and 7 days and while the suction test lasted for 14 days. At the end of the dewatering period, the water content of the dewatered sample in each cases were determined using normal wet and dry method.

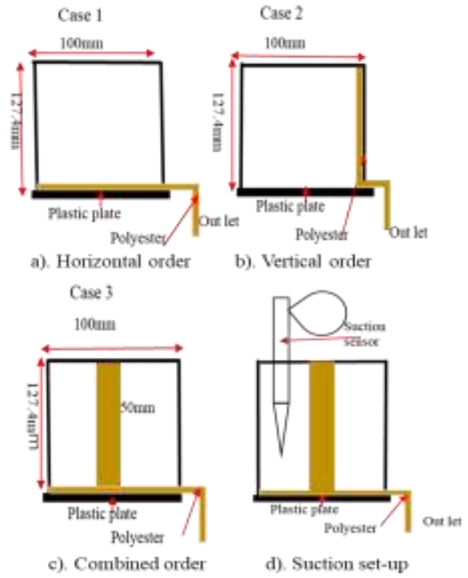

Fig. 1. Schematic diagram of dewatering apparatus and suction set-up.

3.3 Mixing sandy soil and cone penetration test

It was considered that only the dewatering method was not enough for improving the soft clay in a short period for utilizing as embankment material. Sandy soil, decomposed granite material, was used for the improvement of the dewatered sample. The sandy soil material was added to the sample at a sand mixing fraction ranging from 10 to 80% on the clay in different water contents of 101, 111, 125, 130 and 185%. Herein, the sand mixing fraction is defined as:

$$\text{Sand mixing fraction (\%)} = M_s/(M_s+M_{cw})\times 100 \quad (1)$$

where M_s=mass of dry sandy soil and M_{cw}=mass of clay in wet conditions.

Wide ranges of water content and sand mixing fraction were selected for determining the effective mixing condition in terms of strength. After addition of the sandy soil to the clay in different water content, the material was evenly mixed together and thereafter placed into compaction mold and compacted by 25 blow of free fall rammer. This process was repeated for all samples except for a sample with a water content of 185% at its slurry stage. Cone penetration resistant test was conducted for the compacted soil.

4 RESULTS AND DISCUSSION

4.1 Consolidation property

Consolidation test was started from a small vertical pressure of 4.9kN/m^2, because the clay with high water content in a slurry condition was used. Figure 2 shows relationship between void ratio and consolidation pressure on the clay. It was observed that a large volume change occurred in the first step of consolidation pressure in comparison to the later part of the test, as shown in Fig. 2. At this point, the soil is assumed to undergo sedimentation and coagulation processes, which led to the clogging of the initial void space of the sample with fine particles. It was also seen that the increased consolidation pressures at a specific time of the test further reduce the soil void pore.

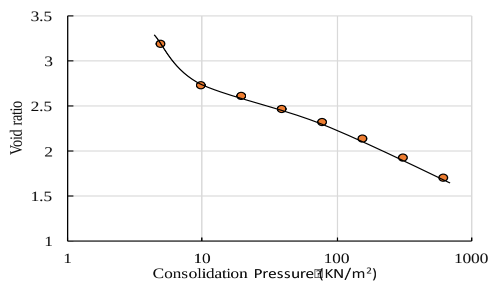

Fig.2. Relationship between void ratio and consolidation pressure on the clay.

4.2. Effect of dewatering by geosynthetic materials

Three types of dewatering tests using geosynthetic materials, namely, vertically and horizontally placed and a combination of both the order of arrangement were conducted as shown in Fig.1.

From the dewatering test result during 4 days, it was observed that a large volume of water was depleted from the test sample at the initial stage of the experiment. However, after 1 day period, there was a reduction in the dewatering volume. Irrespective of this short coming, the material A (thickness of 0.6 mm, woven) was more effective in the dewatering process compared to the material B (thickness of 2 mm, non-woven), precisely Case 3-A was found to be best order suitable in this experimental condition. The low dewatering effect recorded from the test cases with polyester material B was as a result of the non-woven nature and texture of the material B, irrespective of its large cross sectional area against the material A. From the dewatered sample surface, free water was found on the surface of the dewatered clay when the plastic plate cover was removed at the end of the dewatering test. This indicates that, material B acted as dampproof membrane hindering the depletion and the evaporation of excess water from the test soil sample.

The rate of water depletion is evaluated by a ratio of the water content of the dewatering periods (w_7: 7 days) and the initial water content (w_i=185%) in this study. And the effect is also evaluated by a ratio of the water content of the dewatering periods (w_7: 7 days) and the liquid limit (w_L=122%) in this study. These values are indicated in Table 1.

From the table, it was found that the dewatering rate of the clays depends on the dewatering materials (A & B) and the order of arrangement (Case 2 and 3).

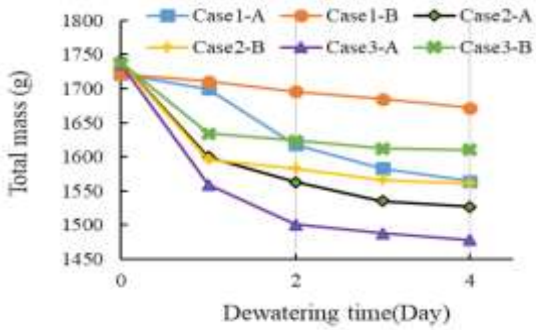

Fig.3. The dewatering rate of the dewatering materials and order of arrangement after 4days.

Table 1. Dewatering rate of the clays after 7 days.

	Case 2-A	Case 2-B	Case 3-A	Case 3-B
w_7 (%)	109	117	101	125
w_7 / w_i	0.59	0.63	0.55	0.68
w_7 / w_L	0.89	0.96	0.83	1.03

It indicates that the thin geosynthetic material (material A) is effective and the combined arrangement of vertical and horizontal dewatering (Case 3). In the experiment, it was found that Kumamoto clay with the initial water content 1.5 times the liquid limit can be reduced to less than the liquid limit within a week by the new dewatering method.

The water content of the samples in all the dewatering cases decreased non-linearly as expected. It is considered that suction increases in the case with higher level of depletion by dewatering of the polyester material. Khosravi et al. (2016) indicated that a hardening response in the test sample as the suction increases occurs and shear modulus G_{max}, which, in turn, increases as the soil sample dries.

A change in the suction pressure (pF) value on the clay during 14 days in the dewatering test is shown in Fig.4. Suction pressure (pF), matric suction, and osmotic suction are used sometime interchangeably. They are defined below for clarity purpose.

Suction pressure (pF) is the logarithm of the height of the water column (cm) to give the necessary suction. Matric suction (kPa) is the attraction of the soil solid for water absorption which markedly reduced the free energy movement of absorbed water molecule. On the other hand, osmotic suction is the attraction of the soil solid for water to reduce the free energy of the soil solution. Soil water pressure head is calculated by the following equation:

$$h = p + L \qquad (2)$$

where, L=the vertical distance from the water surface to the center of the porous cup of the tensiometer, p = relative pressure of the converted head from digital negative pressure gauge and h is the pressure head.

Figure 4 shows the change of soil suction pressure pF during 14days in the dewatering test. It was found that the amount of water content in the sample was the determining factor of the increase in the suction value. At the initial water content of 185%, the pF value was almost zero. But it increases dramatically after 1 day of the elapsing dewatering time and goes onward to pF=2.4 after 14 days. This indicates that the increase in water content will lead a reduction in the suction, which will further decrease the average volumetric stress acting on the soil skeleton with consequent elastic volumetric expansion. (Enrique et al., 2008).

The increased suction pressure (pF) value shows the sedimentation and the hardening of the slurry sample as the free water depletes from the soil material. The phenomenon behind the dewatering behavior of the soil sample (Pham Van et al., 2012) can be attributed to the process at which the slurry soil began increasing the bonding force (angle of friction) among its particles and the increment of the pF value is an indication of the reduction of the sample void pore.

Relationship between void ratio and suction was obtained from the dewatering test, where void ratio is calculated from the average water content and the suction is converted from pF value. Figure 5 shows the relationship between the void ratio and the suction together with the void ratio and the consolidation pressure obtained from the consolidation test. It is interesting that both relations are fitted as a unique curve. This indicates that the dewatering process is similar to consolidation behavior and suction pressure more than 20 kPa can be applied without energy.

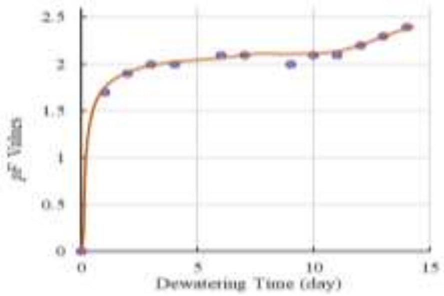

Fig. 4. The change of soil suction pressure pF during 14days in the dewatering test.

4.3 Improvement effect by mixing sandy soil

In addition to dewatering, sandy soil was mixed with the clay and cone penetration test was carried out. Effect of mixing sandy soil with the clay at different water contents is shown in Fig.6. In the condition of 185% water content, there is no improvement in the cone index until 70 or 80% of the sand mixing fraction. However, when the sandy soil of 50% is mixed with the clay with less than 120% water content, there is a notable increase in the cone index. In addition, the cone index of the clays in the cases of 111 and 101% water content decreases when a small amount of sandy soil was added in comparison to the initial cone index without mixing of sandy soil. This may be due to the disturbance on the clay, while mixing with sandy soil, which led to the released of the absorbed free water by the organic material in the soil sample test, since the physical property test of the soil used in this study shows that the soil material has a large amount of organic content. Figure 7 shows relationship between the cone index and initial water content of clay in different sand mixing fractions. The effective mixing content of sandy soil, together with decreasing of water content by dewatering for obtaining target cone index can be evaluated from this chart.

3 CONCLUSION

In this study, a new idea of dewatering method was adopted to the soft clay collected from a pond in Kumamoto perfection in Japan. Geosynthetic material was inserted into the soft clay for dewatering of excessive water without energy.

In the experiment, it was found that Kumamoto clay with initial water content at 1.5 times of the liquid limit can be reduced less than liquid limit within a week by the new dewatering method. From the measurement of the suction of the clay during the dewatering test, it was found that the dewatering process is similar to the consolidation behavior and also vacuum pressure more than 20kPa can be applied without energy.

This is effective, economical and low environmental impact method, because it does not require other resources such as chemicals using hardening agent or mechanical devices for dehydration with high pressure. In addition to dewatering, sandy soil was mixed with the clay and cone penetration test was carried out. The effective mixing content of sandy soil for obtaining target cone index was also evaluated.

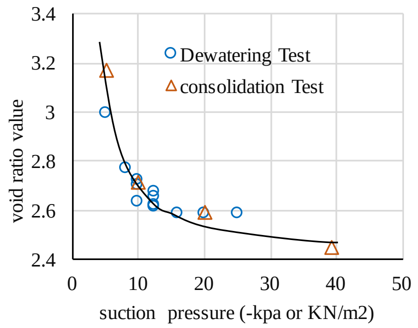

Fig.5. Relationship between void ratio and suction or consolidation pressure.

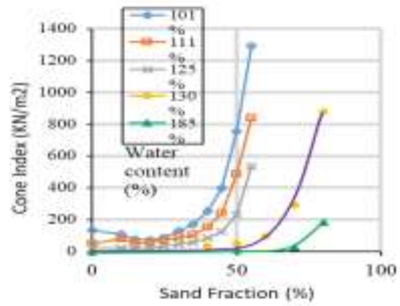

Fig.6. Relationship between cone index and sand mixing fraction in different water contents.

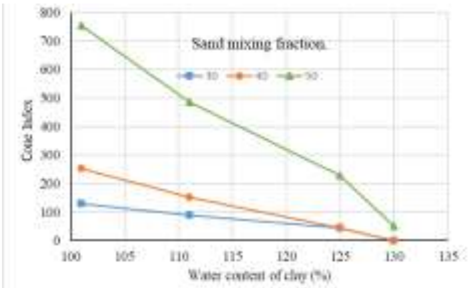

Fig.7. Relationship between cone index and initial water content of clay in different sand mixing fractions.

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