

SOFT CLAY IMPROVEMENT TECHNIQUE BY DEWATERING AND MIXING SANDY SOIL

Flemmy Samuel Oye¹, *Kiyoshi Omine¹ and Zichen Zhang¹

¹ Graduate School of Engineering, Nagasaki University, Japan

*Corresponding Author, Received 30 March 2019, Revised 23 April 2019, Accepted: 10 May 2019

ABSTRACT: Treatment of soft clay is one of the problems in geotechnical engineering. A soil dredged from a pond is very soft because of high water content and possessing organic content. The soft soil is expected to be utilized as a geo-material. The purpose of this study is to investigate a cheaper, easier and environmentally friendly method in comparison with the conventional soil improvement methods for improving soft clay with low bearing capacity, low shear strength and excessive settlement. The proposed dewatering method was adopted to the soft clay collected from a pond in Kumamoto Prefecture, Japan. The functionality of this proposed method is thus, by inserting a geosynthetic material in the soft clay for dewatering and evaporation of excess water without energy. This is an effective, economical and low environmental impact method for dewatering because it does not require other resources such as chemicals using hardening agent or mechanical devices for dehydration with high pressure. In the experiment, it was found that Kumamoto clay with an initial water content of 1.5 times the liquid limit can be reduced to less than the liquid limit within a week by the proposed method. 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 the target cone index was also evaluated.

Keywords: Soil improvement, Soft clay, Dewatering, Geosynthetic material, Cone index

1. INTRODUCTION

The present urbanization trend all over the globe has resulted in year by year out the reduction of land resources suitable for civil engineering projects. Because of this problem, more and more infrastructure has been built recently on highly slurry clay soil, even on reclaimed land. Also, the limited space and restriction by governmental laws regarding the disposal of dredged soil have become environmentally and globally threat. Utilization of such soft soil is one of the environmental issues to be solved in the geotechnical engineering field.

Over the year several conventional approaches and techniques have been put in place for dewatering of high water content slurry soil and improving low strength. These are energy intensive and time serving, but not economical and environmentally friendly method. Some of which include ultrasound dewatering method, forced dewatering method, mechanical dewatering method, chemical dewatering method, etc. Asmatulu [1] proposed air pressure-assisted centrifugal dewatering technique for dewatering smaller particle size up to 200 μm , but its practice requires other energy sources to function. Ultrasound dewatering method has been effectively used for dewatering of sludge and dredged clay, however, it has a negative impact on the micro-properties of the sludge and soil properties. In an attempt to improve the ultrasound technique, Liyan Liu et al. [2] proposed a combined ultrasound with sulfate

radical oxidation for dewatering sludge, but this method has the potential to contribute to greenhouse gas. Basically, sludge and slurry dredged clay can be used as recycled geo-materials for landfill, and both materials share similar characteristics in terms of strength and water content [3]. Normally, the slurry clay must be adequately dried or dewatered to enhance efficient handling and trafficability by machine plant. Soft clay with high water content and low bearing capacity can be improved by dewatering using siphon [4, 5]. 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. In a remedial technique in place of the conventional approaches, the natural dehydration method has been used. An approach of drying the sludge or slurry material on an open space for excess evaporation of water with the aid of sunlight. Though this method is cost-effective and eases to maintain, it requires a large area of land to spread the slurry sludge or clay on and it is not suitable for the wet season.

In this study, the authors propose a proposed method by inserting a geosynthetic material in soft clay for dewatering and evaporation of excessive water without energy. This is a cheaper, easier and environmentally friendly method in comparison with the conventional soil improvement methods for improving soft clay with low bearing capacity and low shear strength. The proposed method was applied to the soft clay collected from a pond in Kumamoto in Japan for utilization as an

embankment material. The suction pressure of this method is derived from the absorbent and drying process of the polyester materials. The vacuum preloading method was firstly proposed by Kjellman [6] for cardboard wick drains. Though the mechanism of this proposed dewatering method may be partly similar to vertical drain and vacuum method, its uniqueness over the vacuum drain method is no need extra energy to function. In order to make clear conditions of dewatering, two different polyester materials are used and the effect of inserting the direction of the materials is also confirmed based on the experiment. Furthermore, the cone penetration test is carried out to ascertain the progressing strength by mixing sandy soil and effective mixing content for obtaining the target cone index is also discussed.

2. MATERIALS USED

2.1 Kumamoto Clay

Soil samples used for this experiment were collected from a pond in Kumamoto Prefecture, Japan. The physical properties of the clay were investigated and clarified based on JGS soil test standards 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%, soil particle density = 2.27 g/cm³. Figure 1 shows the particle size distribution curve of the Kumamoto clay.

In the preliminary test, it has been confirmed that the improvement effect by mixing cement is not obtained without a large amount of volume such as 400 kg/m³ in the natural water content as it is. Because Kumamoto clay is a ponded sediment with high water content and high organic content.

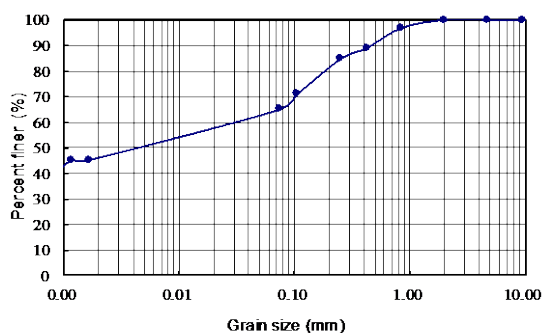
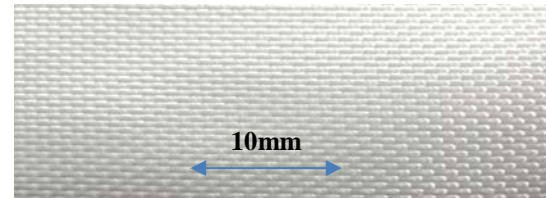


Fig.1 Particle size distribution curve of Kumamoto clay

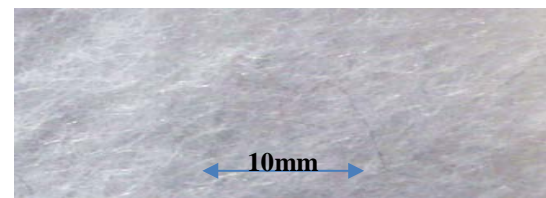
2.2 Dewatering Geosynthetic Material

In order to ascertain the level of depleting soil water content and to know the effective type of material, two different geosynthetic materials were

used, namely A: woven material thickness of 0.6 mm (Terepack 020) and B: non-woven material thickness of 2 mm (Twin guard TS-20) produced by DAIKA industries Co. LTD. As shown in Fig.2 a) and b), respectively. It is considered that these materials possess different dewatering characteristic abilities in terms of thickness, water tightness and texture.



(a) Woven polyester (material A)



(b) Non-woven polyester (material B)

Fig. 2 Dewatering materials used

3. LABORATORY TEST

3.1 Consolidation Test

Kumamoto clay was prepared in a slurry state at the water content of 185%. Consolidation test of the sample was performed based on the test method for one-dimensional consolidation properties of soil using incremental loading (JGS 0411). The slurry sample was poured into a container inner diameter of 60 mm and a height of 30 mm. The surface of the container was well trimmed using a knife and then plugged in into the consolidation apparatus. Surcharge loads were applied on the soil through the loading plate of the device and a displacement gauge was installed on the system from different applied loads at the same time interval.

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. Soil sample of 1200 g with a water content of 185% was poured into the container. The significant differences among the cases studied in this experimental work are the order of the arrangement of the polyester dewatering material in the container. The test apparatus for dewatering is shown in Fig.3 (Case 1-A & B, Case 2-A & B and Case 3-A & B.)

Polyesters in Case 1 and Case 2 were horizontally and vertically placed, respectively, while Case 3 was a combination of both the order of arrangement, as illustrated in Fig.3. Table 1 shows the types of dewatering materials in each case and their placement order. After which, the cylindrical container housing the plastic bag containing the sample was covered with a plastic plate to prevent undue evaporation of moisture from the test.

To access the depletion rate of water from the test sample as well as its degree of hardness at each dewatering day, a moisture transducer (Tensiometer with a vacuum gauge: DIK-8333, Daiki Rika Kogyo Co., Ltd.) was installed in a sample with a combined condition in Case 3-A as shown in Fig.4. This test was done in the sample of Case 3-A due to its high efficiency in dewatering the soil sample during the preliminary stage of this study. The dewatering process of this study lasted for 7 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 case was determined using the normal constant-temperature drying oven method. Cone penetration resistant test was also conducted for the dewatering samples.

Table 1 Types of dewatering materials in each case and their placement order

Case Study	Dewatering order	Geosynthetic material used
Case 1-A	Horizontal	Woven material A
Case 1-B	Horizontal	Non-woven material B
Case 2-A	Vertical	Woven material A
Case 2-B	Vertical	Non-woven material B
Case 3-A	Combined	Woven material A
Case 3-B	Combined	Non-woven material A

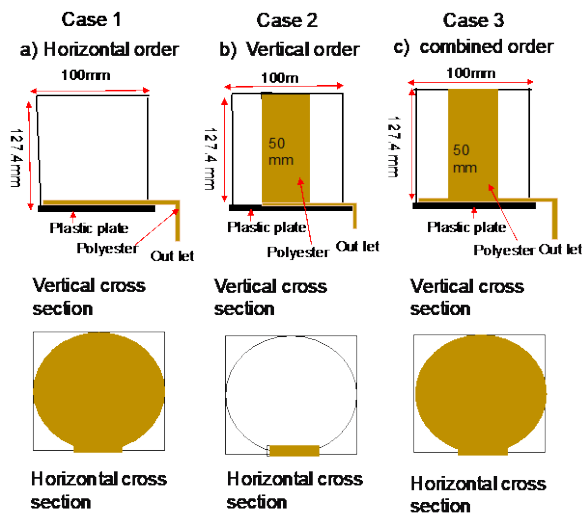


Fig.3 Schematic diagram of dewatering apparatus

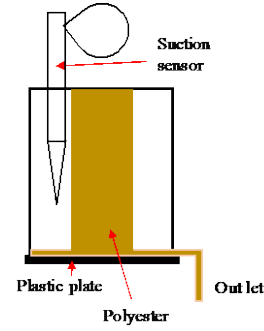


Fig. 4 Suction set-up in Case 3-A dewatering order

3.3 Mixing Sandy Soil and Cone Penetration Test

It was considered that only the dewatering method is not enough for improving the soft clay in a short period up to a targeted strength 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%. In this study, the sand mixing fraction is defined as:

$$S_{mf} (\%) = M_s / (M_s + M_{cw}) \times 100 \quad (1)$$

where S_{mf} = sand mixing fraction, M_s = mass of dry sandy soil and M_{cw} = mass of clay in wet condition. Wide ranges of water content and sand mixing fraction were selected for determining the effective mixing condition in terms of strength. After the addition of the sandy soil to the clay in different water content, the composite material was evenly mixed together and thereafter placed into compaction mold and compacted by 25 blows of free fall rammer. This process was repeated for all samples except the sample with 185% water content at its purely slurry stage. Cone penetration test was conducted for the compacted soil.

4. RESULTS AND DISCUSSION

4.1 Consolidation Property

Consolidation test was started from a small vertically pressure of 4.9 kN/m² because the clay with high water content in a slurry condition was used. Figure 5 shows the relationship between void ratio and consolidation pressure of 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.5. 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 increase of the consolidation pressures at a specific time of the test further reduces the soil void pore in line [7]. This change in the applied load exerts a stronger influence on the permeability coefficient, which in turn influences the dewatering properties of the clay material.

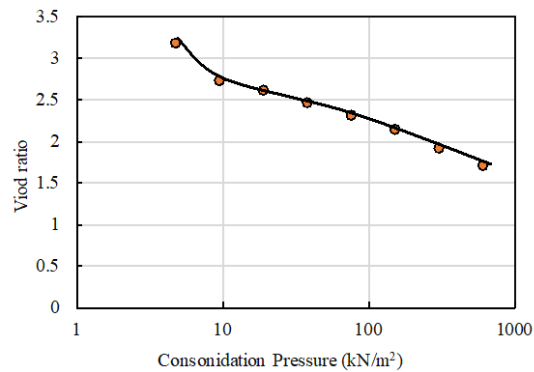


Fig. 5 Relationship between void ratio and consolidation pressure

4.2 Effect of Dewatering by Geosynthetic Materials

Three types of dewatering tests using two geosynthetic materials, vertically and horizontally placed and the combination of both order of the arrangement, was conducted as shown in Fig.3.

Figure 6 shows the dewatering test result for 7 days. It was observed that a large volume of water 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. This reduction in the dewatering volume is due to the effect of sedimentation, coagulation and flocculation of fine soil particles. At this point of the experiment, the finer soil particle moved into the void pore, resulting in the sample hardly as the particles cling to each other. Irrespective of this short coming, 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 the 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 the 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 cover was removed at the end of the dewatering test. This

indicates that material B acted as a damp proof membrane hindering the depletion and the evaporation of excess water from the test soil sample.

After 7 days of the dewatering, the water content of the samples was measured at the top, middle and bottom parts of the samples. Table 2 shows the water content and cone index of the samples after 7 days dewatering. Figure 7 shows a situation of Kumamoto clay after 7 days dewatering. It is found that the clay is progressing to drying condition for 7 days.

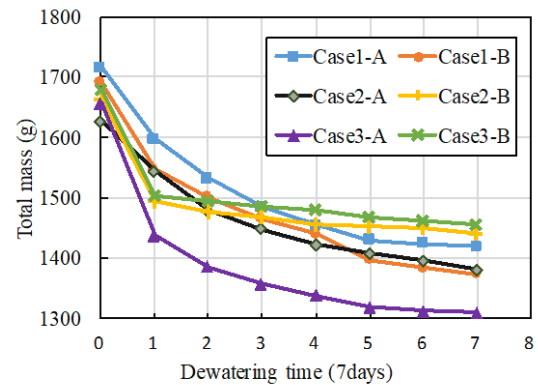


Fig.6 A change of total mass of the samples during dewatering period for 7 days

Table 2 Measured water content and cone index of the samples after 7 days dewatering

	Measured water content (%)				Cone index (kN/m²)
	Top	Mid.	Bottom	Ave.	
Case 1-A	129.6	103.2	104.1	112.3	111.6
Case 1-B	110.2	105.7	107.6	107.8	99.2
Case 2-A	117.2	115.2	123.9	118.8	48.1
Case 2-B	118.6	123.7	132.4	124.9	26.4
Case 3-A	100.8	104.4	107.8	104.0	215.5
Case 3-B	114.3	114.3	121.9	119.6	26.4



Fig.7 Kumamoto clay after 7 days dewatering

Figure 8 (a)~(c) shows the relationship between the dewatering ratio and dewatering period in each test condition, where the effect of water depletion is evaluated by a ratio $R=w/w_i$ of average water content (w) and the initial water content ($w_i=185\%$) in this study. The average water content was calculated from the initial water content and dewatering volume of the samples.

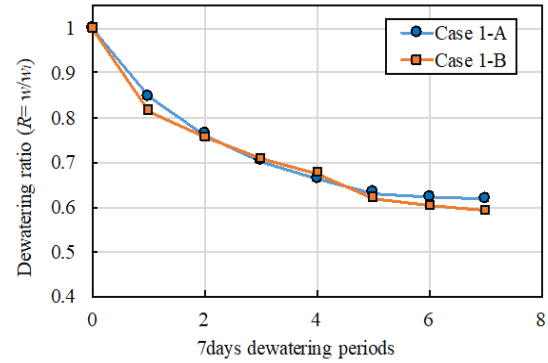
As shown in Fig.8 a), the dewatering materials used in Case 1- A & B have similar dewatering effect on the test samples for 7 days. The dewatering ratio R after 7 days was approximately 0.6 in the horizontal placement order. From Fig.8 b), Case 2- A & B were found to have similar dewatering effect as we have in Case 1-A & B. Material A with a dewatering ratio of 0.67 was slightly better off than material B in this case. However, the dewatering effect of Case 2-A & B in the vertical placement order is less than that of Case 1-A & B. This slight less of the dewatering effect was influenced by the surface area of the dewatering material, 6,370 and 7,850 mm² for Case 2 and Case 1, respectively. In Case 3-A and B (combined order), as shown is Fig.8 c), it was found that the test sample with a dewatering ratio of 0.54 in Case 3-A was dramatically effective for 7 days dewatering period. It is considered that the material B in Case 3-B acted as a damp proof membrane preventing the excess removal of water from the test sample. This positive dewatering mark in Case 3-A was enhanced by the combined system and the polyester type of dewatering material A.

As shown in Table 2, it was observed that the sample using the material A has a high cone index in comparison with that of material B in each test case. Especially, the sample in Case 3-A with the combined arrangement of vertical and horizontal dewatering indicated a high cone index value of 215.5 kN/m².

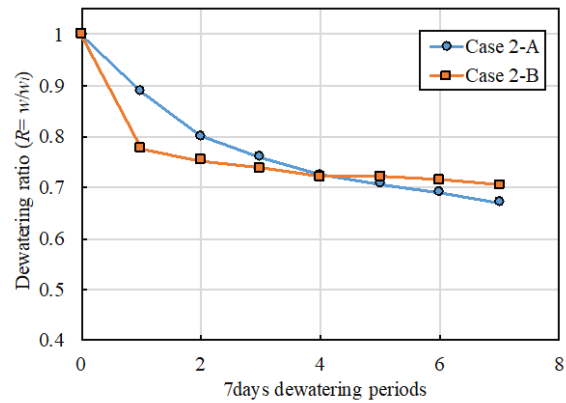
Table 3 shows the dewatering effects of the clays after 7 days, where the value of w_7 is the measured water content after 7 days in Table 2. It was found that the dewatering rate of the clays depends on the dewatering materials (A & B) and the order of arrangement (Case 1 to Case 3). In addition to the dewatering ratio of w_7/w_L and w_7/w_i of Case 3-A, it can be said that more than two-third of the water content can be dewatered and up to 20% drop of the liquid limit can be reclaimed respectively after 7 days.

Kumamoto Clay with the initial water content at 1.5 times the liquid limit can be reduced to less than the liquid limit within a week by the proposed dewatering method. The water content of the samples in all the dewatering cases decreased non-linearly as expected. It was considered that suction

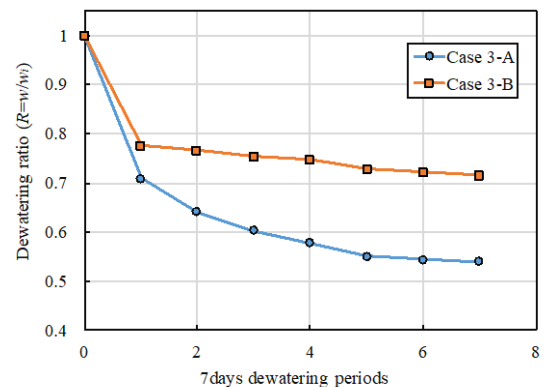
increases in the cases studied with a higher level of depletion by the dewatering effect of the polyester material type. Khosravi et al. [8] indicated that a hardening response in the test sample as the suction increase will, in turn, increase the shear modulus G_{max} as the sample dries.



a) Horizontal placement order



b) Vertical placement order



c) Combined placement order

Fig.8 Relationship between dewatering ratio and dewatering period in each test condition

Table 3 Dewatering effects of the clays after 7 days

	Case 1-A	Case 1-B	Case 2-A	Case 2-B	Case 3-A	Case 3-B
w_7 (%)	112.3	107.8	118.8	124.9	104.0	119.6
w_7/w_i	0.61	0.58	0.64	0.67	0.56	0.65
w_7/w_L	0.92	0.88	0.99	1.02	0.85	0.98

A change in suction pressure (pF) value on the clay during 14 days in the dewatering test is shown in Fig.9. Suction pressure (pF), matric suction and osmotic suction are used sometimes interchangeably. They are defined below for clarity purposes.

Suction (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 adsorbed water molecules. On the other hand, osmotic suction is the attraction of the solid for water to reduce the free energy of the soil solution. Soil water pressure head is calculated by the following equation.

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

where L = the vertical distance from that water surface to the center porous cup of the tensiometer, p = relation pressure of the converted head from the digital negative pressure gauge and h is the pressure head. The total suction h is made up of two components, namely the addition of the matrix suction and the osmotic suction.

From the suction test result, it was observed that the amount of water content in the sample is the determining factor of pF value. At the initial water content of 185%, the value of pF was almost zero. But it increases dramatically after the elapsing of the dewatering period of day 1 and goes to 2.4 pF equivalent to 25 kPa after 14 days. This indicates that the increase in water content will further decrease the average volumetric stress acting on the soil skeleton with consequent elastic volumetric expansion [9]. The phenomenon behind the dewatering behavior soil sample [10] can be attributed to the process when the slurry soil began to increase in 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. In addition, the shape of the pF curve changes significantly in relation to the adjustment of the soil pore size influenced by the overburden weight of the soil and dewatering periods in accordance to Vanapalli et al. [11]. The regained stiffness and hardness rate of the sample was

enumerated from the relationship between pF value and dewatering time, as shown in Fig.9. From the graph, it was observed that the pF value was influenced by the decrease of the moisture content brought about by the dewatering days, dewatering polyester material and the considered case order (Case 3-A).

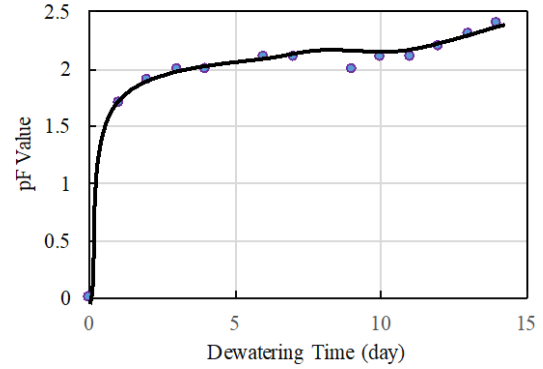


Fig.9 Relationship between pF and dewatering time

Relationship between void ratio and suction was obtained from the dewatering test, where the void ratio was calculated from the average water content and the suction was converted from pF value. Figure 10 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 in this test is similar to consolidation behavior and vacuum pressure more than 20 kPa can be applied without energy.

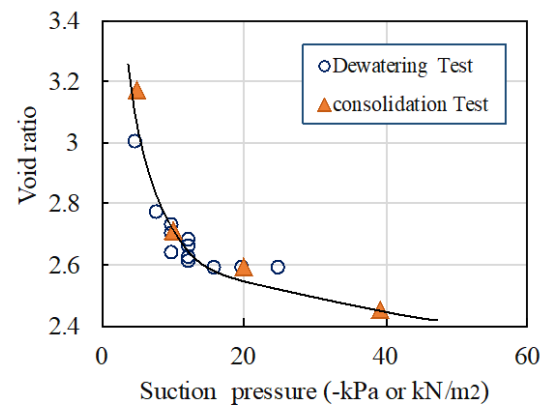


Fig.10 Relationship between void ratio and suction or consolidation pressure

4.3 Improvement Effect by Mixing Sandy Soil

In addition to the dewatering, the sandy soil was mixed with the clay and the cone penetration test

was carried out. The effect of mixing sandy soil with the clay at different water contents is shown in Fig.11. In the condition of 185% water content, there is no improvement in the cone index until 70 or 80 % of the sand mixing fraction was added. However, when the sandy soil of 50% was 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 their initial cone index without mixing of sandy soil. This may be due to the disturbance on the clay while mixing with sandy soil. Secondly, this problem is traceable to the low strength of the soil material from the particle curve distribution as shown in Fig.1 and its high organic content, which enables to store in water within the soil pore region. In support to this insinuation, according to Zaid H.M. and Mohd Raihan T. [12], the increase in the moisture content of a soil is because of the water held within the flocculent soil structure zone with a trace of the water containing organic materials. This implies that the loss of the cone index after the addition of 10 and 20% admixture (sandy soil) was due to the released of the water held within the soil pore while mixing with sandy soil. It is considered to act as a lubricant against the frictional force between the clay particle and the added sandy soil.

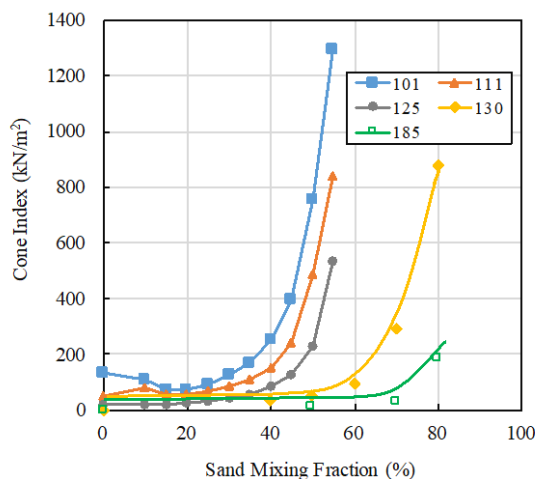


Fig.11 Relationship between cone index and sand mixing fraction in different water content

Figure 12 shows the relationship between the cone index and initial water content of the clay in different sand mixing fractions. In the classification of construction surplus soil, cone index values of 200, 400 and 800 kN/m² are used in Japan. The effective mixing content of sandy soil, together with decreasing water content by dewatering for obtaining the target cone index can be evaluated from this chart. From the chart, it can be understood

that the higher the amount of water in the soil, the higher the sand admixture needed to improve its strength vice versa. This behavior indicates that the percentage of water volume in a soil mass is the predominant parameter that determines its strength irrespective of the admixture ratio.

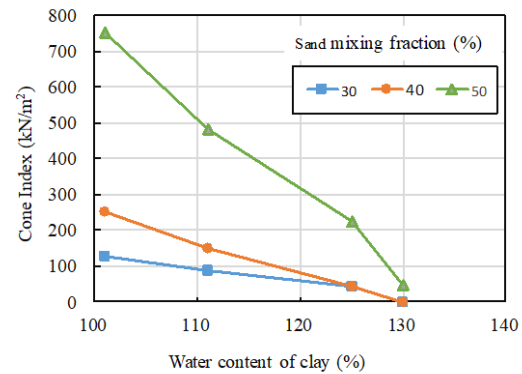


Fig.12 Relationship between cone index and initial water content of clay in different sand mixing fractions

5. CONCLUSION

In this study, a cheaper, easier and environmentally friendly method was adopted to the soft clay collected from a pond in Kumamoto Prefecture, Japan. Geosynthetic material made with polyester was inserted in the soft clay for dewatering and evaporation of excessive water without energy.

In the experiment, it was found that Kumamoto clay with an initial water content of 1.5 times the liquid limit within a week could be reduced to a volume lesser than the liquid limit by the proposed 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 vacuum pressure more than 20 kPa can be applied without energy.

This is an effective, economical and low environmental impact method for dewatering slurry clay because it does not require other resources such as chemical using hardening agent or mechanical devices for dehydration with high pressure.

In addition to the dewatering, the sandy soil was mixed with the clay and the cone penetration test was carried out. The effective mixing content of sandy soil for obtaining the target cone index was also evaluated based on the relationship between the cone index and water content of clay after dewatering.

6. ACKNOWLEDGMENTS

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