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Research Paper

Dewatering effect on dredged slurry clay by different types of drainage materials

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ABSTRACT

Kumamoto slurry clay has high water content and organic content. From the preliminary test, it was found that improvement effect of this clay by adding hardening agent such as cement is very small. It was also suggested that dewatering of the clay is important for improvement.

In this work, several types of drainage materials were installed in the slurry clay in the field and laboratory test conditions, respectively. A simple dewatering method of soft clay using geotextile as drainage materials was proposed based on the dewatering test results. The effect of the drainage materials on the slurry clay were evaluated by ratio of 7 day water content and initial water content of the slurry clay (w_7/w_0). The ratio of w_7/w_0 in the samples with string and cloth was 0.55 under the effective drainage condition in the laboratory test. The values of w_7/w_0 on the field dewatering tests with the drainage materials (string and cloth) are below 0.75.

In the laboratory and field dewatering tests, 25 and 35 kPa vacuum pressure can be obtained, respectively. It is indicated that the drainage materials are effective for reducing the water content of the slurry clay without applying external force of energy.

1 Introduction

Dredging of slurry sediment at sea or pond is increasing yearly and on daily bases. The handily and direct disposal of dredged sediment is problematic. This is because dredged sediment contains high water content and has low bearing capacity. These features of dredged sediment make it difficult to be used directly as land filling material without treatment. It is therefore important to dewater slurry sediment before use as landfilling material or dumping at the disposal site. According to Flemmy et al., (2019) and Zhang et al., (2019), dewatering of slurry clay before adding admixture will reduce the amount admixing agents (lime, cement or fly ash) needed for improving the strength of slurry clay.

There are numerous techniques for dewatering high water content sediment (slurry clay). However, a choice of dewatering method will be made by considering a treatment cost, period of construction, efficiency of the technique, and environmental impact. The dewatering of soft clay by preloading or surcharge method has been used widely in place of traditional sun drying method which takes 2 to 4 months to satisfactorily remove water from slurry clay/dredged sediment. However, dewatering by preloading without vertical drain is not spontaneous. During the dewatering process using preloading method,

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fine particles shift into the void pores of the soil. When this happens, the dewatering rate will be reduced. Generally, preloading method is not suitable for treating highly sensitive clay. According to Ali A. et al., (2019), vertical drains (sand, paper or PVD) are used to accelerate slurry clay dewatering rate.

The presence of vertical drain in the slurry clay reduces a drainage length of the slurry clay. When the drainage length of a soil is reduced, the water in the soil will move out at a shorter distance. However, vertical drain without preloading or vacuum method takes quiet time to complete dewatering process. The slow dewatering of slurry clay using vertical drain alone is due to clogging of the drainage material pore hole. According to Kaikia L.et al., (2005) and Bhatia S.K. et al., (1996), the openings or holes on a drainage material are clogged by fine soil particles as the water moves out through the vertical drain or dewatering material. Wang J. et al., (2019) encourage the use of vertical with vacuum or preloading method to accelerates the dewatering process. The inclusion of preloading or vacuum method to vertical drain dewatering method will eliminate the storage of water within the soil pores. However, energy (vacuum pressure) is lost when treating slurry clay with high water content. The treatment of slurry clay by vacuum pressure is not cost effective and environmentally friendly. According to Grzelak M.D. et al., (2011) and Kaixia L.et al., (2005), dewatering slurry clay using geotextile tube or bag is effective for relatively small volume of slurry clay. It can only be applied for small dewatering project and it takes longer time to dewater dredged sediment satisfactorily. This study is aimed to reduce slurry clay dewatering time by inserting drainage material into slurry clay for investigating the influence of drainage materials. Several types of drainage materials were installed in Kumamoto slurry clay both in the laboratory and in the field.
Suction sensor (pF) was installed in a slurry container with drainage materials both in the laboratory and field test condition for evaluating the dewatering effect.

2 Description of test materials

2.1 Mechanical properties of the slurry clay

In this experiment, soil sample was collected from a pond in Kumamoto Prefecture, Japan for the laboratory dewatering test. The physical properties of the clay were investigated and clarified based on JGS soil test standards. The laboratory soil sample has physical properties, such as natural water content =185% (it was adjusted to 200 % for the laboratory dewatering test condition), liquid limit =121.98%, the 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. 53 g/cm^3. Table 1 shows the ignition loss of the sample used for the laboratory dewatering test. Fig. 1 shows the particle size distribution curve of the Kumamoto clay (the soil sample for the laboratory dewatering test condition). While in the field dewatering test, soil samples (Kumamoto clay) were taken from different point of the pond for dewatering setup with and without drainage material. The field dewatering setup with drainage material has a natural water content of 145.0% and liquid limit of 93.64%. While the field dewatering setup without drainage material has a natural water of 220%. From the soil test results, improving the slurry clay by cement mixing will require a high volume of cement to bind the soil particles because of the large amount of organic mineral present in the clay and the high natural water content of the soil which ranges from 145 to 220%.

Table 1. Ignition loss of Kumamoto slurry clay

Sample for laboratory dewatering test	Ignition percentage
Ignition loss (%)	23.4

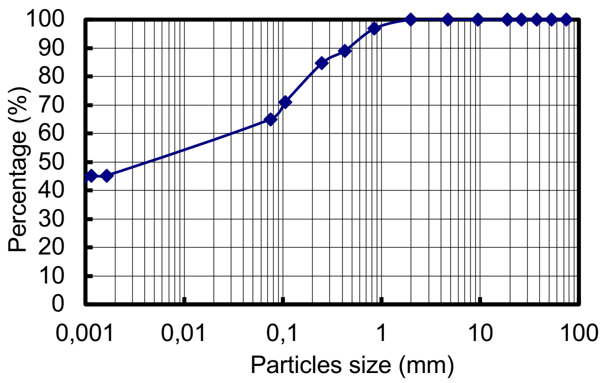


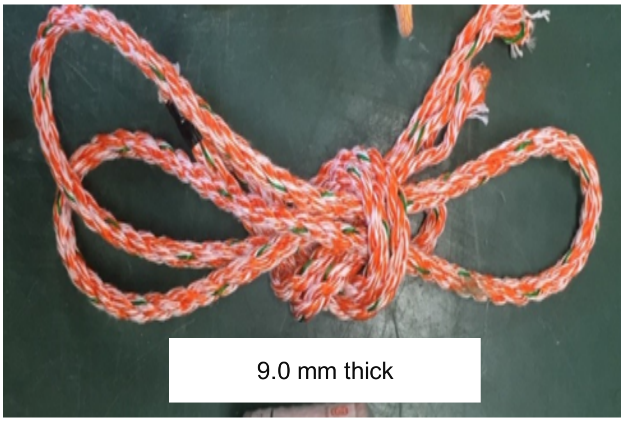
Fig. 1. Particles size distribution curve of Kumamoto slurry clay (Sample for laboratory dewatering test)

2.2 Consolidation test

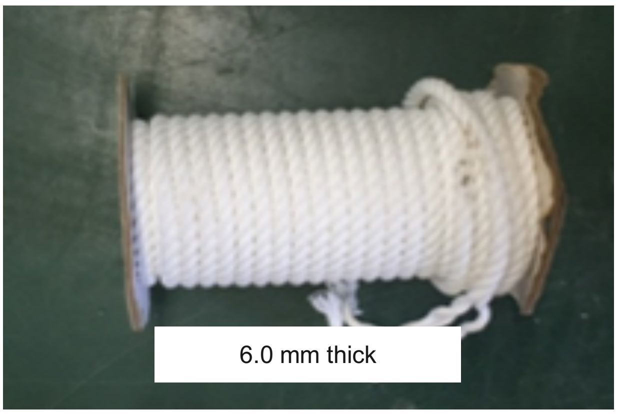
One-dimensional consolidation test was conducted using Kumamoto slurry clay (sample A) with an initial water content of 185 %. The test condition is based on the JGS 0411 load incremental procedure. The result from this test is used to scrutinize and illustrate the dewatering behaviors of the cases treated in this study. At the beginning of the consolidation test, 4.9 kN/m^2 vertical load was applied to the slurry clay. After the free water in the soil have been removed by the application of small weight vertical, greater loads were applied on the specimen after 24 hours interval of the time in which the previous load was added. The adding of loads to the specimen continues till 8 days based on JGS 0411 guidelines.

3 Methodology

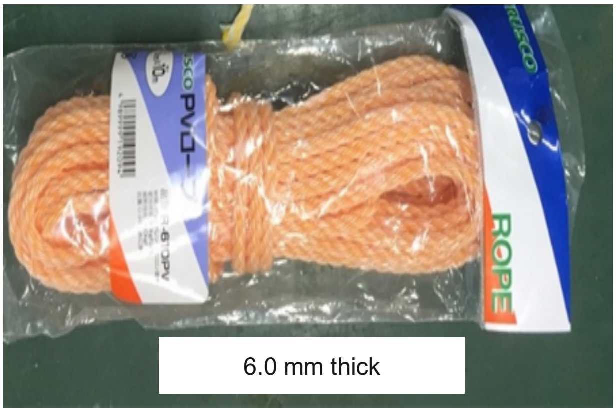
In this study, five drainage materials were used to accelerate the dewatering rate of the dredged sediment by inserting them in the slurry clay. The drainage materials are string (composite polyester), cotton, PV rope, woven and non-woven cloth (geotextile materials). The used drainage materials are grouped under two categories as polyester (strings) and geotextile materials (cloths). Figure 2 (a), (b) and (c) polyester material while Fig. 3 (a) and (b) geotextile materials. The drainage materials were installed in the slurry clay in each case of the test condition at specific distance in order to accelerate the dewatering rate of the slurry clay. The dewatering test comprises of two case studies, laboratory (by pouring slurry clay in a plastic bag and cylindrical PVD pipe) and field tests. The drainage materials in plastic bag filled with slurry clay were installed at 33mm pitch while the drainage materials in the slurry clay in a cylindrical PVD were installed at 50 mm pitch. For the field dewatering conditional, the drainage materials in Fig. 2 (a) and Fig. 3 (b) were installed in the slurry clay at 100 mm pitch.



(a) Composite string polyester

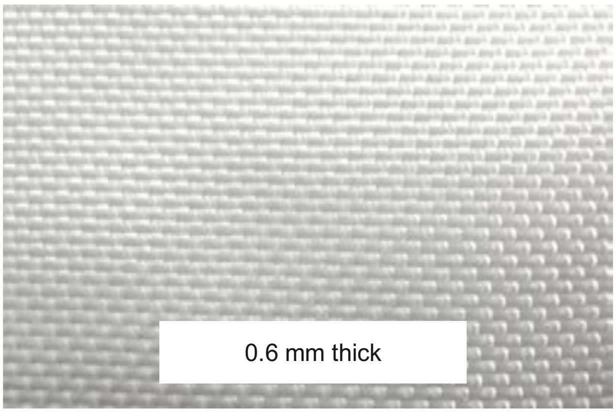


(b) Cotton rope

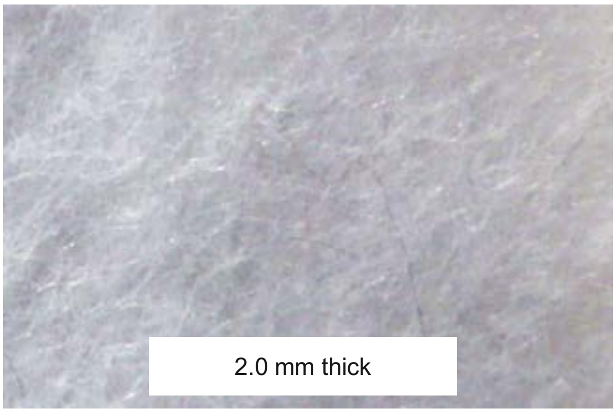


(c) PV rope

Fig. 2. Polyester drainage materials (strings)



(a) Woven geotextile



(b) Nonwoven geotextile

Fig. 3. Geotextile drainage materials (cloths)

3.1 Laboratory dewatering test

3.1.1 Dewatering behavior of clay using drainage material (strings)

In this study, the ability of the series of drainage materials to remove water from slurry clay were investigated. This was done to know the drainage material with good feature to dewater water from the tested soil sample at a short time. In this study, 7 day was chosen as the maximum dewatering time. Because every drainage material has a specific water discharging rate. Slurry clay of 200 % water content was poured into a plastic bag of 200 mm length and 76 mm diameter. Then, each drainage material was installed in the plastic bag filled with slurry clay at a radius of 38 mm. After this was done, the surface of the plastic bag was sealed with plastic tape. The plastic seal prevents evaporation of water from the plastic bag and allows water to drain out only through the installed drainage material with 200 mm outlet. The dewatering rate of each drainage material inserted in the slurry clay was measured using weighing balance. It was difficult to measure the suction increment of the slurry clay using suction pF sensor in this tube dewatering test condition due to its instability to stay upright. Therefore, plastic bag was kept in a horizontal position, as shown in Fig. 4.

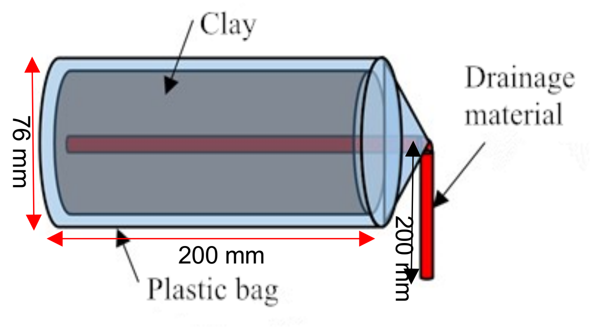


Fig. 4. Setup with plastic bag and string

3.1.2 Dewatering behavior of clay using drainage material (cloths)

In this case study, the abilities of the drainage materials (cloths) in removing water from the slurry clay were determined under three installation conditions, namely, vertical, horizontal and combined order. The cloth materials used in this test are woven and non-woven geotextile material. For easy identification, they are named as cloth A and B, respectively. Three dewatering cases were treated in this section. Slurry clay with water content of 185% was poured into a 127 mm height and 100 mm wide cylindrical PVD pipe with a plastic bag. The cloth drainage materials were installed in the PVD pipe filled with slurry clay. Figure 5 shows the setups where drainage materials were vertically and horizontally installed. Figure 6 shows the setup in which the drainage materials are installed in combine order alongside with a pF sensor setup. In case 3 as shown in Fig. 6, the drainage materials were installed in the slurry clay in vertical and horizontal direction. The idea behind installing the drainage materials in combined manner was to increase the suction pressure in the slurry in order to facilitates fast removal of water from the slurry clay. The dewatering rate of the sample in each case was measured daily and the test lasted for 7 days. For better understanding of the dewatering trend, suction pF sensor was installed in a sample with the same dewatering condition as that of combined case with woven geotextile material (case 3-A). The pF sensor was installed in the slurry clay in case 3 at a depth of 100 mm in a spot closed to the drainage material installed in case 3. The pF sensor was installed in case 3-A sample, because it has the highest dewatering rate during the preliminary test. The pF suction test lasted for 14 days.

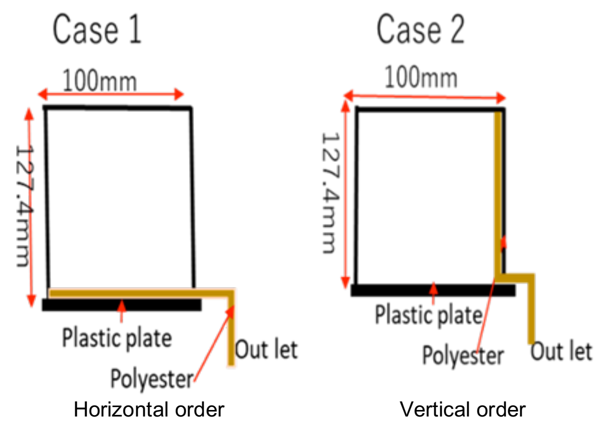


Fig. 5. Setups with drainage materials (cloths) installed in horizontal and vertical order

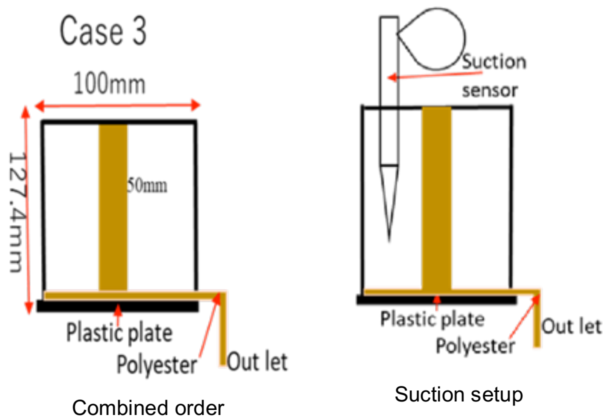


Fig. 6. Setup with drainage materials (cloths) installed in combined order with a suction sensor

3.2 Field dewatering test

Two different dewatering tests were conducted in the field. In one of the tests, drainage material was not installed in the slurry clay. This test was done in this manner for evaluating and comparing the dewatering efficiency of the setups with drainage materials over a setup without drainage material.

3.2.1 Field dewatering test without installation of drainage material

The water content of the soil sample for this test is 220%. The dredged slurry clay was poured into a designed drainage bag. After that, the drainage was covered and the soil water could move out from the drainage bag The water content of the soil sample for this test is 200%. The dredged slurry clay was poured into a designed drainage bag. After that, the drainage bag was covered and the soil water could move out from the drainage bag without placing surcharge load on it. Soil sample was taken from the drainage bag after seven day for measuring Water content. The setup without the installation of drainage material is shown in Fig. 7.

Fig.7. Setup of drainage bag (T K bag, Daiga co. Ltd)

3.2.2 Field dewatering test setups with drainage material

In this test, the slurry clay used has 185% water content. The dredge slurry clay was poured into 1200 mm high and 1000 mm wide drainage bag made from woven geotextile material. After that, drainage materials such as string (composite polyester) and cloth (non-woven geotextile) were respectively installed in the drainage bag at 100 mm apart. The drainage setup filled with slurry clay was opened to the atmosphere. Exposing the slurry clay to atmosphere enhance evaporation of moisture from the slurry clay surface. After seven days, the soil samples were taken from the middle point between the drainage materials for measuring water content.
The setup is shown in Figs. 8 and 9, respectively.

Fig. 8. Field setup composite polyester material (string)

Fig. 9. Field setup with non-woven geotextile (cloth)

4 Laboratory dewatering test results and discussions

4.1 Influence of consolidation pressure on void ratio.

Figure 10 shows the relationship between void ratio and the applied consolidation pressure. At the beginning of the consolidation test, the application of 4.9 kN/m^2 vertical load reduces the soil water faster compared to the later days of the test. From Fig. 10, the compression index (Cc) of 0.5 was obtained. Although void ratio of the clay is large, the value of Cc is relatively small comparing that of a typical sediment clay in Japan. It indicates that dewatering of the clay needs force or energy equivalent to large consolidation pressure.

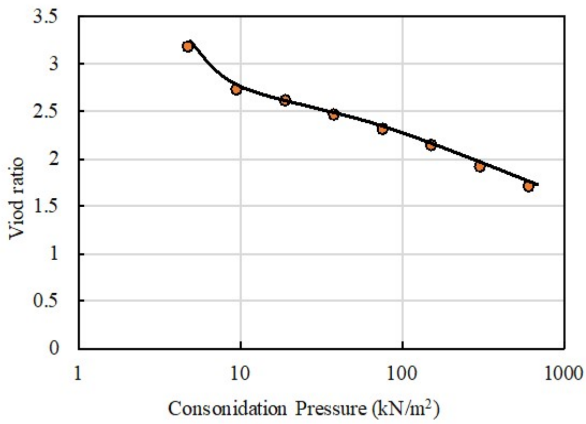


Fig. 10. Relationship between test results and discussion

4.2 Dewatering of drainage material (string) on slurry clay

Dewatering rate of a slurry clay is influenced by both soil properties and type or arrangement of drainage material. Therefore, to dewater slurry clay satisfactorily, it is important to investigate performance of drainage material. The average water content in the dewatering test was derived from the following formula.

$$w = \frac{m - m_s}{m_s} \times 100 \qquad [1]$$

Where w is the average water content of the dewatering day, m is the total mass of the clay per day, same as m= m_w + m_s, ms is the mass of the solid clay and it is constant. While m_w is the wet mass water in the clay and it changes per dewatering day.

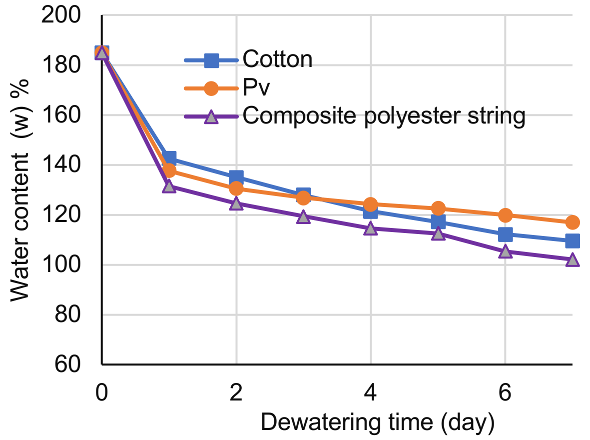


Fig. 11. Relationship between water content and dewatering cases materials (strings) of Fig. 2. (a), (b) and (c)

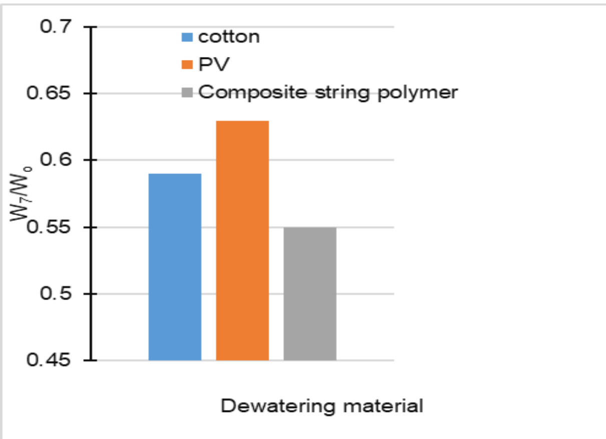


Fig. 12. Relationship between w_7/w_0 drainage material (strings) of Fig. 2. (a), (b) and (c)

As shown in Fig. 11, the higher the drainage material could discharge water from the slurry clay, the faster the dewatering rate. From the test result as displayed by Figs. 11 and 13, the water content of the tested soil dropped sharply from 0 to 1 day of the test compared to the other time. This is due to the free movement of water through the soil particle at the earlier stage of the test. After the 1 day of the test the out flow of water drops, as a result of clogging of the drainage path by fine particles of the soil. From the test result as shown Fig.11, composite polyester material has the highest dewatering rate compared to cotton rope and PV rope. It reduces the slurry clay of 185.0% initial water content to 102.09 % after 7 days. Composite string material is effective because it is made of polymer and cotton material. Both drainage materials have great ability to drag out water. According to Siamak, S. et al., (2015), the addition of polymer (admixture) to slurry clay increases the slurry clay permeability rate. In addition, chemical polymer is 9 mm thick while its counterparts are 6 mm thick. Drainage material with large surface area accelerates dewatering of slurry clay. This is because the large surface area of the drainage material further reduces the distance in which the soil water would have flow to. It was found that high suction pressure exists in the soil closer to the string polymer (drainage material) interface. This suction pressure facilitates quick dewatering of water from the soil closer to drainage material compared to soil particles far from the drainage material (Henbo et al., 2004 and Radkakrishran et al., 2010). In other words, if the drainage length is short, water will move out from the sediment faster.

In the dewatering test using strings, composite string polymer was more effective than other dewatering materials (cotton rope and PV rope). Composite string polymer is effective because it is made up of polymer and cotton material. According to Kevin., (2014), Flemmy et al., (2019) and Bhatia. S. K. et al., (1996) work, every drainage material has different ability to absorb and drag out water from slurry clay. In this view, the choice of drainage material to be used for dewatering slurry sediment depends on the soil properties of the dredged sediment.

The effect of the drainage materials on the slurry clay were obtained from the ratio of the 7 days water content and the initial water content of the slurry clay (w_7/w_0). As shown in Fig. 12, the ratio of w_7/w_0 in these drainage materials is between 0.55 to 0.65 and it indicates that the effective dewatering from the slurry clay is obtained by using drainage materials of string without energy.

4.3 Dewatering effect of drainage material (cloth) on slurry clay

Three types of dewatering tests using two geosynthetic materials, vertically and horizontally placed and the combination of both order of the arrangement, were conducted as shown in Fig.6.

Figure 13 shows the dewatering test result for 7 days. It was observed that average water content of the samples decreases quickly at the initial stage of the experiment. However, after 1 day period, there was a small 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.

Figure 14 shows the ratio of w_7/w_0 for each sample after 7 days dewatering. Irrespective of this short coming, cloth A (thickness of 0.6 mm, woven) was more effective in the dewatering process compared to the cloth 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 cloth B was because of the non-woven nature and texture of the cloth B, irrespective of the large cross-sectional area against the cloth 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.

The initial water content of the soil is 1.52 times its liquid limit. According to Chai J.C et al., (2019) and Hong Z.S, (2010), slurry clay with initial water content (Wo) 1.0 to 2.0 times its liquid limit will consolidate but sedimentation of the soil particles will not occur. Figure 15 shows the pF results from the laboratory test. The installation of drainage material in vertical and horizontal direction (combined condition) of the dewatering test facilitates quick dissipation and settling of the slurry clay. The strength of the slurry clay increased from zero kPa to 25kPa due to the installation of drainage material in the setup in vertical and horizontal condition (combined order) as shown in Fig. 15. From the pF suction incremental curve in Fig. 16, the pF meter reads zero on the first day of the test but it increases progressively due to the depletion of water from the clay. This means the efficiency of a setup with drainage material does not depend on the drainage material used only but also on the allowable dewatering days for the dewatering process.

Chai J.C. et al., (2019) reported that an Ariake clay with initial water content of 1.5 times its liquid limit has a remoulded yield stress of 2.0 kPa without the application of surcharge load. However, as shown in Fig. 15, the soil generates 25 kPa pressure through the installation of drainage material in the slurry clay.

4.4 Relationship between void ratio and suction/consolidation pressure.

A relationship between void ratio and suction was established from the calculated daily water content of the dewatering test and conversion of pF to suction pressure as shown in Fig. 16. Suction (pF) is the logarithm of the height of the water column (cm) to give the necessary suction and it is related to matric suction which is the pressure that dry soil exerts on the surrounding soils to equalize the moisture content in the overall block of soil. In this study the pF of the tested soil was evaluated using formula number 2 (Flemmy et al., 2019).

$$h = p + L \qquad [2]$$

where L = the vertical distance between the surface of water and the center of the porous cup of the tensiometer, p = the pressure of the converted head from the digital negative pressure gauge and h is the total pressure head. The total pressure head is a component of the matrix suction and the osmotic suction.

It was observed that both parameters are similar and more than 20 kPa vacuum pressure can be applied to the test soil sample without the aid of external energy.

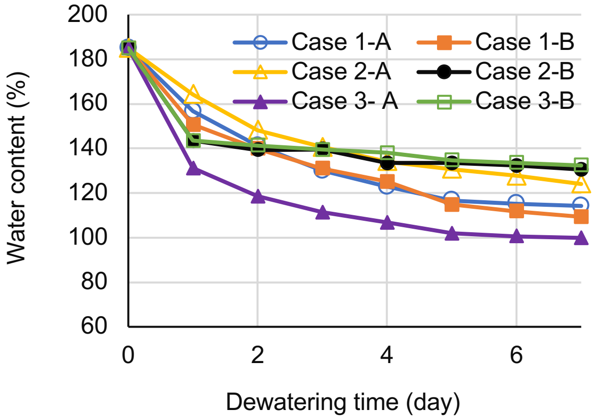


Fig. 13. Relationship between water content and drainage materials (cloths)

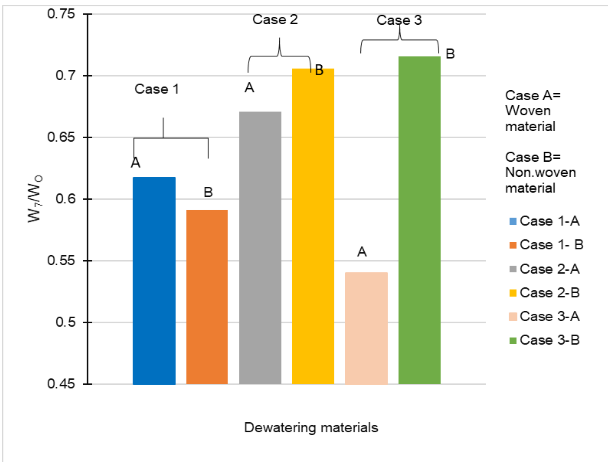


Fig. 14. Relationship between w_7/w_0 and drainage material of dewatering setup with cloths

5 Field dewatering test results and discussions

5.1 Dewatering rate of a geotextile bag without drainage material

Geotextile bags or tubes are used for small volume of slurry clay and these take longer time to remove water from slurry sediment (Ali A. et al., 2019 and Mooi Young et al., 2002).

From the dewatering setup containing Kumamoto slurry clay of 220% water content in a drainage bag, the water content of the soil after 7 days under dewatering condition was 215%. The performance of the drainage material was compared from the ratio of 7 day water content (w_7) and the initial water content (w_0) of the slurry clay.

In this dewatering test, it was found that the value of w_7/w_0 is 0.98 for 7 day and it is very small. Therefore, the relevance of drainage material in slurry clay is needed for reducing the drainage length of the soil, which fosters quick removal of water from slurry clay (Takashi et al., 2020 and Siamak S. et al., 2015).

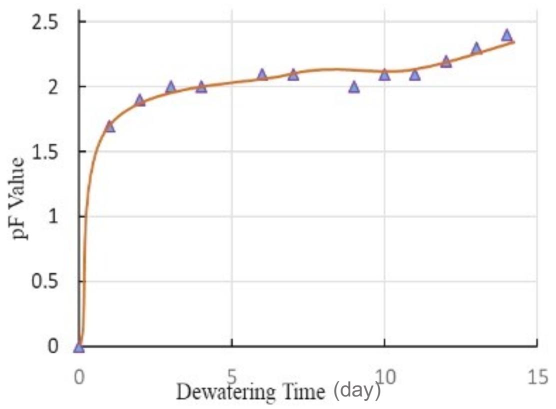


Fig. 15. Relationship between void ratio and suction/consolidation pressure

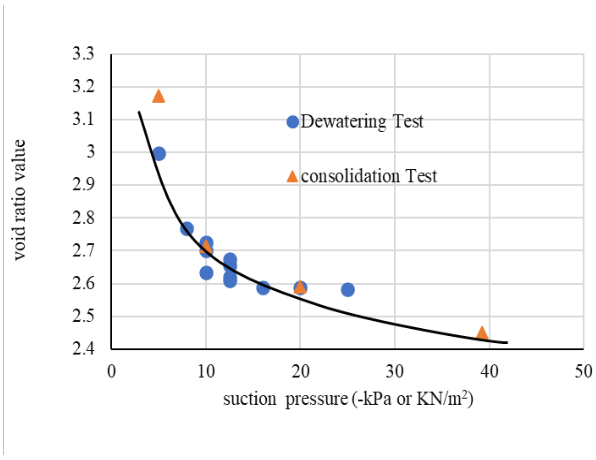


Fig. 16. Relationship between void ratio, consolidation and suction pressure

5.2 Influence of dewatering materials (cloth and composite string).

Dewatering rate of slurry clay is related to soil properties of the slurry clay and performance of the drainage materials. Inserting drainage material in the slurry clay helps in reducing the drainage length of the soil.

(a) String

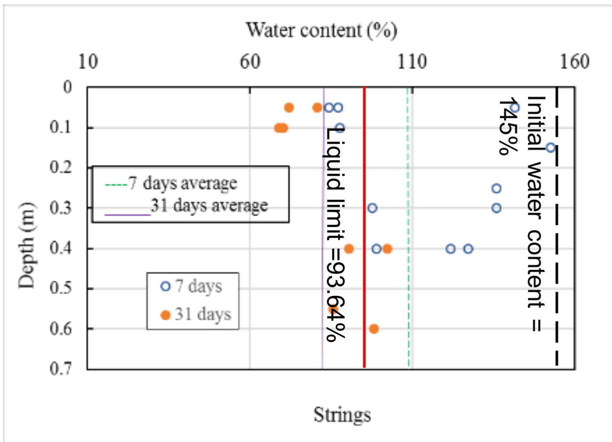
(b) Cloth

Fig. 17. Effects of drainage materials and dewatering days in removing water from slurry clay

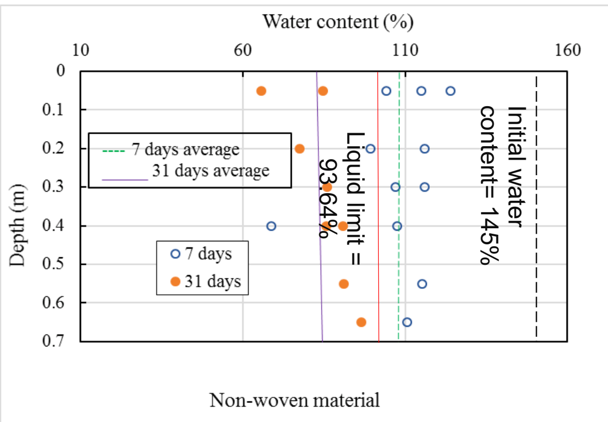
Figure 17 (a) and (b) show the situation of the field samples with the drainage materials of string and cloth for 7 days dewatering period, respectively. Secondly, the slurry clay in the dewatering setup with composite string polymer as shown in Fig. 17 (a) settled after 7 days as water dissipated from the sample. The settlement rate is enhanced by the suction pressure induced in the soil by the dissipation of water and the gap created by the installed string to another. While settlement does not occur in dewatering setup with non-woven (cloth) drainage material as shown in Fig. 7 (b). This is because as cloth is installed in the soil, it creates a block of wall which confined the soil particle to itself. The confinement of the soil particle by cloth (drainage material) generates suction pressure that prevents the volume of the soil sample to change at the surface of the setup rather settled inside as observed at the end of the field test. Figure 18 (a) and (b) show a change of the water content in the depth for 7 and 31 days dewatering period. The field dewatering test result as shown in Fig. 18 (a) and (b), composite string polymer and non-woven geotextile (cloth) have an average water content of 109.0 % and 108.0, respectively within 7 days. In both the field tests, the water content of the slurry clay with the installed drainage materials did not reduce below its liquid limit within 7 day but within 31 day. However, the installation of drainage material in dredged slurry clay reduces the dewatering day compared to the case of geotextile bag without drainage material which takes two or four months to consolidate slurry clay.

Comparison of a ratio of W_7/W_0 in each dewatering test with or without the drainage material after 7 days is shown in Fig. 19. The water contents at 7days were obtained as an average value in the depth. Although W_7/W_0 on the dewatering test without the drainage material is almost no change, the values on both the dewatering tests with the drainage materials (string and cloth) are below 0.75. It is indicated that those drainage materials are effective for reducing the water content of the slurry clay without energy. From Fig. 19, it is seen that both drainage drainage material in terms of water discharging ability and their surface area. The drainage materials (composite materials, (cloth and string materials) have same dewatering trend. This is due to the characteristics of the string) is made up of cotton and polymer material. The both drainage materials (cotton and polymer) are effective for removing water while cloth (non-woven geotextile) has larger surface area which further reduces the average drainage length of the soil which accelerates the dewatering rate.

The dewatering trends of the clay with the cloth and the string in the field test are similar and like that of standard consolidation settlement trend as shown Fig. 20. The field pF value simultaneously increases as void ratio of the clay decreases. The increase of the suction pF and the reduction of the void ratio is aided by the daily dissipation of water from the soil through the drainage material installed in the slurry clay.



(a) String



(b) Cloth

Fig. 18. Effects of drainage materials and dewatering days in removing water from slurry clay

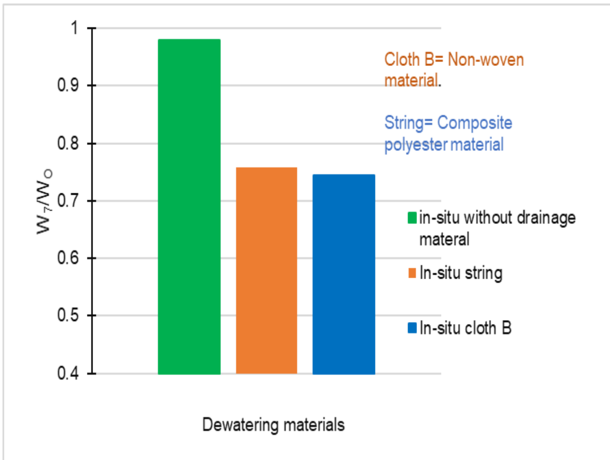


Fig. 19. Comparison between setups with and without drainage material w_7/w_0 after 7 days

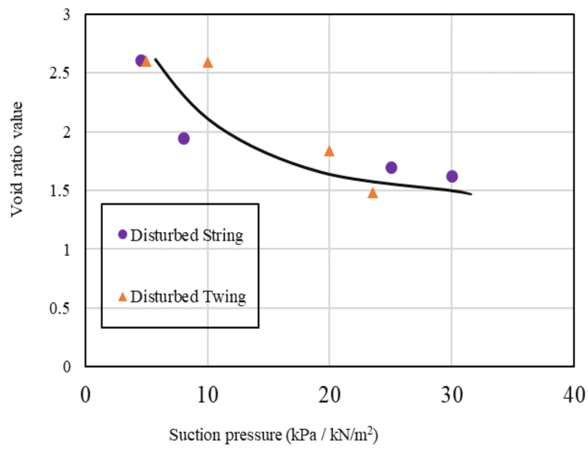


Fig. 20. Relationship between void ratio of field test and consolidation pressure

6 Conclusion

In this study, the effect of different types of drainage materials (several strings and cloths of woven/non-woven geotextile) for dewatering of the slurry clay was investigated. A simple dewatering method of soft clay using geotextile as drainage material was proposed. This method was also applied to field scale condition. From the laboratory and field results, the following conclusion are obtained.

1. The effect of the drainage materials on the slurry clay were evaluated from the ratio (w_7/w_0 of the 7 day water content and initial water content of the slurry clay. The ratio of w_7/w_0 in the samples with different strings is between 0.55 to 0.65. It is also found that the dewatering effect of cloths (woven or non-woven geotextile) depends on not only type of cloth but also the direction of drainage material or combination.
2. The dewatering effect of the field tests with or without the drainage material after 7 days was compared. Although w_7/w_0 on the dewatering test without the drainage material is almost no change, the value on both the dewatering tests with the drainage materials (string and cloth) are below 0.75.
3. The relationship between the pF and void ratio describes the dewatering efficiency of the clay. In the laboratory and field dewatering tests, 25 and 35 kPa vacuum pressure can be obtained, respectively. It is indicated that the drainage materials are effective for reducing the water content of the slurry clay without applying external force or energy.

7 References

Ali, A., Mohammed, S. and Ameer A., 2019. Evaluation of vertical drain with different materials. International Conference on Civil Engineering, 584 (1012011.Doi.10.1088/1757).

Bhatia, S.K., Smith, J.L., and Christopher B.R., 1996. (Geotextile Characterization and Pore-size Distribution: Part 3. Comparison of methods and Application to design. Geosynthetics International, **3** (3): 301-328.

Chai, J.C., Fu H.T., Wang J., Shen S.L., 2019. Behavior of PVD unit cell under vacuum pressure and a new method for consolidation analysis. Computer and Geotechnics ,120.103415.

Chai J.C., Shen, S.L. and Geng, X.Y., 2019. Effect of initial water content and pore water chemistry on intrinsic compression behavior. Mar Geores. Getech., **37** (4):417-23. https://doi.org/10.1080/1064119X.2018

Flemmy, S.O., Omine, K. and Zicheng, Z., 2019. Soft clay improvement technique by dewatering and mixing sand soil. International Journal of Geomate, **17** (63): 9-16.

Grzelaki, M.D., Maurer, B.W., Pullens, T.S., Bhatia. and Ramarao, B.V., 2011. A comparison of test methods adopted for assessing geotextiles tube performance. Geo-Frontial, Doi:10.101061/41165 (397) 219.

Henbo, S O., 2004. Consolidation of clay with reference to influence of vertical drainage. Swedish Geotechnical Institute Proceedings, 18: pp 160.

Hong, S.Z., Yin, J., Cui, Y.J., 2010. Compression behavour of a constructed soil at high initial water contents. Geotechniquè, **60** (9): 691-700. Htts://doi.org/10.1680/geot.09.p.059.

Jun, W., Guo, H., Hangtao, F., Yuangiang, C., Xiuqing, H., Xiaoming, L., Yawei, J., Jun, J. and Jian, Z., 2019. Vacuum preloading combined with multiple flocculant treatment for dredged fill improvement. Engineering Geology,**259**, 105194.

Ka ixia, L. and Bhatia, S.K., 2005. Geotextile tube: Filtration performance of woven geotextiles under pressure. Proceedings of NAGS 2005/GRI- 19, Cooperative Conference, Las Vegas, NV, USA.

Kevin, 2014. Geotextile tubes and their application. Georgia Southern University. https:// digitalcommons.georgiasouthern.edu/etd.

Mooi Young, H.K., Gaffney, D.A. and Mo, X., 2002. Testing procedures to assess the viability of dewatering with geotextile tubes. Geotextiles and Geomembranes, **20** (5): 289-303.

Siamak, S., Ghader, B. and Hamid, S., 2015. Evaluation of permeability characteristic of polymer fibers-reinforced soil through laboratory test. Journal of Geological Society of India, **85**: 243-246.

Takashi, N., Haruo, M. and Masaaki, K., 2020. Application of vertical drains to increase the capacity of disposal pond for dredged marine clay. Geotechnics for sustainable infrastructure development: 677-683.

Wang, J., Geo, Z., Fu, H., Ding, G., Gai, Y., Geng, X. and Shi, C., 2019. Effect of surcharge loading rate and mobilized load ratio on the performance of vacuum preloading with PVDs. Geotextiles and Geomembranes, **47** (2): 121-127.

Zhang Z., Omine, K., and Flemmy, S.O., 2019. Effect of Solidification Agent Addition and Water Content on Improvement Effect of Reservoir Clay and Simple Dehydration method, Proc. of Technical Forum on Mitigation of Geo-disasters in Asia, 2019.

Abreu, A.E.S., Gandolfo, O.C.B. and Vilar, O.M., 2016. Characterizing a Brazilian sanitary landfill using geophysical seismic techniques. Waste Management, **53**: 116–127.

Anbazhagan, P. and Sitharam, T.G., 2006. Evaluation of dynamic properties and ground profiles using MASW: correlation between V_S and N_{60}. 13th Symposium on Earthquake Engineering, **13**: 8–18.

Anbazhagan, P., Parihar, A. and Rashmi, H.N., 2013. Seismic site classification and correlation between standard penetration test N value and shear wave velocity for Lucknow city in Indo-Gangetic Basin. Pure Applied Geophysics, **170**: 299-318.

Athanasopoulous, G.A., 1995. Empirical correlations Vs-N SPT for soils of Greece: A comparative study of reliability. Transactions on the Built Environment, **15**: 8─15.

Araffa, S.A.S., Atya, M.A., Mohamed, A.M.E., Gabala, M. and Zaher, M.A., 2014. Subsurface investigation on Quarter 27 of May 15th city, Cairo, Egypt using electrical resistivity tomography and shallow seismic refraction techniques. NRIAG journal of Astronomy and Geophysics, **3** (2): 170─183.

Banab, K.K. and Motazedian, D., 2010. On the efficiency of the multi-channel analysis of surface wave method for shallow and semideep loose soil layers. International Journal of Geophysics: 1─13.

Brown, L.T., Boore, D.M. and Stokoe, K.H., 2002. Comparison of shear-wave slowness profiles at 10 strong-motion sites from noninvasive SASW measurements and measurements made in boreholes. Bulletin of the Seismological Society of America, **92** (8): 3116─3133.

Xia, J., Miller, R. D., Park, C. B., Hunter, J. A. and Harris, J. B., 2000. Comparing shear-wave velocity profiles from MASW with borehole measurements in unconsolidated sediments, Fraser river delta, B.C., Canada. Journal of Environmental & Engineering Geophysics, **5** (3): 1─13.

Xia, J., Miller, R. D., Park, C. B., Hunter, J. A., Harris, J. B. and Ivanov, J., 2002. Comparing shear-wave velocity profiles inverted from multichannel surface wave with borehole measurements. Soil Dynamics and Earthquake Engineering, **22**: 181─190.

Yilmaz, O., Eser, M., Sandikkaya, A., Akkar, S., Bakir, S. and Yilmaz, T., 2008. Comparison of shear wave velocity depth profiles from downhole and surface seismic experiments. Proceedings of the 14th WCEE, Beijing, China.

Yokota, K., Imai, T. and Konno, M., 1991. Dynamic deformation characteristics of soils determined by laboratory tests. OYO Tec., **3**: 13–37.

Dikmen, U., 2009. Statistical correlations of shear wave velocity and penetration resistance for soil. Journal of Geophysics and Engineering, **6**: 61─72.

Do, L.V. and Vo, K.M., 2017. Borehole seismic report of residential development project in Thu Thiem villas area, District 2, HCM City report. South Vietnam Geological Mapping Division.

Do, L.V., Thai, Q., Ha, H.T., Lai, T.V., Duong, C.C., Le, D.A., Dong, P.B., Pham, T.T. and Vu, T.A., 2018. Characteristic of structure and modern activity of Sai Gon river fault and implication for the ground subsidence and flooding in Ho Chi Minh City area. GEOSEA XV, **15**: 57─65.

Eker, A.M., Akgun, H. and Kockar, M.K., 2012. Local site characterization and seismic zonation study by utilizing active and passive surface wave methods: A case study for the northern side of Ankara, Turkey. Engineering Geology, **151**: 64─82.

Esfehanizadeh, M., Nabizadeh, F. and Yazarloo, R., 2014. Correlation between standard penetration (NSPT) and shear wave velocity (V_S) for young coastal sands of the Caspian Sea. Arabian Journal of Geoscience, **8**: 7333─7341.

Fabbrocino, S., Lanzano, G., Forte, G., Magistris, F.S. and Fabbrocino, G., 2015. SPT blow count vs. shear wave velocity relationship in the structurally complex formations of the Molise region (Italy). Engineering Geology, **187**: 84─97.

Fiore, V.D., Cavuoto, G., Tarallo, D., Punzo, M. and Evangelisa, L., 2015. Multichannel analysis of surface waves and down-hole tests in the archeological "Palatine Hill" area (Rome, Italy): Evaluation and influence of 2D effects on the shear wave velocity. Surveys in Geophysics, **37** (3): 625─642.

Fujiwara, T., 1972. Estimation of ground movements in actual destructive earthquakes. Proceedings of the Fourth European Symposium on Earthquake Engineering, London: 125─132.

Gautam, D., 2016. Empirical correlation between uncorrected standard penetration resistance (N) and shear wave velocity (V_S) for Kathmandu valley, Nepal, Geomatics. Natural Hazards and Risk Journal, **8**: 496─508.

Hanumantharao, C. and Ramana, G.V., 2008. Dynamic soil properties for microzonation of Delhi, India. Journal of Earth System Science, **117**: 719─730.

Hartantyo, E., Brotopuspito, K.K. and Waluyo, S., 2014. Comparison of 8 and 24 channels MASW data. Field performance: International Conference on Physics: 97─99.

Hasancebi, N. and Ulusay, R., 2007. Empirical correlations between shear wave velocity and penetration resistance for ground shaking assessments. Bulletin of Engineering Geology and the Environment, **66**: 203─213.

Haque, E.D.M., Kamal, M.A.S.M, Ullah, W.A.S.M. and Alam, B.Md., 2013. Comparison of shear wave velocity derived from PS logging and MASW - A case study of Mymensingh Pourashava, Bangladesh. Bangladesh Journal of Geology, **26**: 84─97.

Hunter, J.A., Benjumea, B., Harris, J.B., Miller, R.D., Pullan, S.E. and Good, R.L., 2002. Surface and downhole shear wave seismic methods for thick soil site investigations. Soil Dynamics and Earthquake Engineering, **22**: 931─941.

Imai, T. and Yoshimura, Y., 1970. Elastic wave velocity and soil properties in soft soil. Tsuchito-Kiso, **18**: 17─22.

Imai, T., Fumoto, H. and Yokota, K., 1975. The relation of mechanical properties of soil to P- and S-wave velocities in Japan. Proceedings of 4th Japan Earthquake Engineering Symposium: 89─96.

Imai, T., 1977. P and S wave velocities of the ground in Japan. Proceedings of IX International Conference on Soil Mechanics and Foundation Engineering, **2**: 127─132.

Imai, T. and Tonouchi, K., 1982, Correlation of N-value with S-wave velocity and shear modulus. Proceedings of the 2nd European Symposium of Penetration Testing, **2**: 57─72.

Jarari, M.K., Shafiee, A. and Razmkhah, A., 2002. Dynamic properties of fine grained soils in South of Tehran. Journal of Seismology and Earthquake Engineering, **4** (1): 25─35.

Kalteziotis, N., Sabatakakis, N. and Vassiliou, J., 1992. Evaluation of dynamic characteristics of Greek soil formations. Second Hellenic conference on Geotechnical Engineering: 92─100.

Kiku, H., et al., 2001. In-situ penetration tests and soil profiling in Adapazari. Proceedings of the ICSMGE/TC4 Satellite Conference on Lessons Learned From Recent Strong Earthquakes: 259─265.

Kirar, B., Maheshwari, B.K. and Muley, P., 2016. Correlation between shear wave velocity (V_S) and SPT resistance (N) for Roorkee region. International Journal of Geosynthetics and Ground Engineering, **1**: 1─11.

Lyisan, R., 1996. Correlations between shear wave velocity and in-situ penetration test results. Chamber of Civil Engineers of Turkey, **2**: 1187─1199.

Madun, A., Supa'at, M. E. A., Tajudin, S. A. S., Zainalabidin, M. H., Sani, S. and Yusof, M. F., 2016. Soil investigation using multichannel analysis of surface wave (MASW) and borehole. ARPN journal of engineering and applied sciences, **11**: 3759─3763.

Madun, A., Tajuddin, S.A.A., Abdullah, M.E., Abidin, M.H.Z., Sani, S., Siang, A.J.L.M. and Yusof, M.F., 2016. Conversion shear wave velocity to standard penetration resistance. Materials Science and Engineering, **136**: 1─7.

Mhaske, S.Y. and Choudhury, D., 2011. Geospatial contour mapping of shear wave velocity for Mumbai city. Natural Hazards, **59**: 317─327.

Maheswari, R.U., Boominathan, A. and Dodagoudar, G.R., 2010. Use of surface waves in statistical correlations of shear wave velocity and penetration resistance of Chennai soils. Geotechnical and Geological Engineering, **28**: 119─137.

Nguyen, T. N., 2004. Analyzing of geophysics data in Ho Chi Minh City: PhD thesis, University of Science, Viet Nam National University Ho Chi Minh City.

Nguyen, T. N., Vu, T. T. and Dinh, Q. T., 2014. Borehole seismic project at German house report. South Vietnam Geological Mapping Division.

Nguyen, T. N. and Vo, Q. T. H., 2015. Borehole seismic project at Saigon High Tech Park, District 9, Ho Chi Minh City report. South Vietnam Geological Mapping Division.

Nguyen, N. N. K., Nguyen, T. N. and Dinh, T. Q, 2015. Determining trans-horizontal velocity V_S and elastic parameters of rock and soil by multichannel surface wave method. Journal of Geology, General Department of Geology and Minerals of Vietnam, **352─353**: 229─237.

Nguyen, H. K. and Phienwej, N., 2016. Practice and experience in deep excavations in soft soil of Ho Chi Minh City, Vietnam. Journal of Civil Engineering, **20** (6): 2221─2234.

Nguyen, B. T., Samsura, D. A. A., Kraben, E. and Le, D. A., 2016. Saigon-Ho Chi Minh City. Cities, **50**: 16─27.

Nguyen, T. N., Dinh, Q. T. and Vo, K. M., 2016. Borehole seismic project at Long Phu thermal power plant, Thanh Duc hamlet, Long Duc commune, Long Phu district, Soc Trang province report. South Vietnam Geological Mapping Division.

Ohsaki, Y. and Iwasaki, R., 1973. On dynamic shear moduli and Poisson's ratio of soil deposits. Soil Found, **13**: 61─73.

Ohta, Y. and Goto, N., 1978. Empirical shear wave velocity equations in terms of characteristic soil indexes. Earthquake engineering and structural dynamics, **6**: 167─187.

Pamuk, E., Ozdag, O. C., Ozyalin, S. and Akgun, M., 2017. Soil characterization of Tinaztepe region (Izmir/Turkey) using surface wave methods and Nakamura (HVSR) technique. Earthquake Engineering and Engineering Vibration, **16** (2): 447─458.

Park, C. B., Miller, R. D. and Xia, J., 1999. Multichannel analysis of surface waves. Geophysics, **64**: 800─808.

Park, C.B. and Ryden, N., 2007. Historical overview of the surface wave method. Symposium on the Application of Geophysics to Engineering and Environmental Problems: 897─909.

Pitilakis, K.D., Anastassiadis, A. and Raptakis, D., 1992. Field and laboratory determination of dynamic properties of natural soil deposits. The 10th Earthquake Engineering conference proceedings: 1275─1280.

Pitilakis, K., Raptakis, D., Lontzetidis, K., Tika-Vassilikou, Th. and Jongmans, D., 1999. Geotechnical and geophysical description of Euro-seistest, using field, laboratory tests and moderate strong motion recordings. Journal of Earthquake Engineering, **3** (3): 381─409.

Raef, A., Gad, S. and Tucker-Kulesza, S., 2015. Multichannel analysis of surface-waves and integration of downhole acoustic televiewer imaging, ultrasonic V_S and V_P, and vertical seismic profiling in an NEHRP-standard classification, South of Concordia, Kansas, USA. Journal of Applied Geophysics, **121**: 149─161.

Rahman, Md.Z., Siddiqua, S. and Kamal, A.S.M.M., 2016. Shear wave velocity estimation of the near-surface materials of Chittagong city, Bangladesh for seismic site characterization. Journal of Applied Geophysics, **134**: 210─225.

Rahman, Md.Z., Hossain, Md.S., Kamal, A.S.M.M., Siddiqua, S., Mustahid, F. and Farazi, A.H., 2017. Seismic site characterization for Moulvibazar town, Bangladesh. Bulletin of Engineering Geology and the Environment, **7** (77): 1451–1471.

Rahman, Md.Z., Kamal, A.S.M.M. and Siddiqua, S., 2018. Near-surface shear wave velocity estimation and $V_S{}^{30}$ mapping for Dhaka City, Bangladesh. Natural Hazards, **92** (3): 1687–1715.

Raptakis, D.G., Anastasiadis, A.J., Pititakis, K.D. and Lontzetidis, K.S., 1995. Shear wave velocities and damping of Greek natural soils. The 10th European Conference on Earthquake Engineering proceedings, **1**: 477–482.

Rehman, F., El-Hady, S., Atef, A.H. and Harbi, H.M., 2016. Multichannel analysis of surface waves (MASW) for s eismic site characterization using 2D genetic algorithm at Bahrah area, Wadi Fatima, Saudi Arabia. Arabian Journal of Geosciences, **9**: 519–532.

Seed, H.B. and Idriss, I.M., 1981. Evaluation of liquefaction potential sand deposits based on observation of performance in previous earthquakes. ASCE National Convention (MO): 481–544.

Stephenson, W. J., Louie, J. N., Pullammanappallil, R. A., Williams, J.K. and Odum, J. K., 2005. Blind shear-wave velocity comparison of ReMi and MASW results with boreholes to 200 m in Santa Clara valley: Implications for Earthquake Ground-Motion Assessment. Bulletin of the Seismological Society of America, **95** (6): 2506–2516.

Sun, C. G., Cho, C. S., Son, M. and Shin, J. S., 2013. Correlations between shear wave velocity and in-situ penetration test results for Korean soil deposits. Pure and Applied Geophysics, **170**: 271–281.

Thaker, T.P. and Rao, K.S., 2011. Development of statistical correlations between shear wave velocity and penetration resistance using MASW technique. Pan-Am CGS Geotechnical Conference.

Thitimakorn, T., 2010. Comparison of shear-wave velocity profiles of Bangkok subsoils from multi-channel analysis of surface wave and downhole seismic methods. Journal of Applied Sciences Research, **6**: 1953–1959.

Trupti, S., Srinivas, K.N.S.S.S., Kishore, P.P. and Seshunarayana, T., 2012. Site characterization studies along coastal Andhra Pradesh-India using multichannel analysis of surface waves. Journal of Applied Geophysics, **79**: 82–89.

Tsiambaos, G. and Sabatakakis, N., 2011. Empirical estimation of shear wave velocity from in situ tests on soil formations in Greece. Bulletin of Engineering Geology and the Environment, **7**: 291–297.

Vu, C. D. and Do, L. V., 2018. Primarily analyzing of DEM model to recognize active traces of river Sai Gon fault during late Pleistocen-Holocen Period in Ho Chi Minh City area. Journal of Science and Technology Development, **11**: 13–21.

Thaker, T.P. and Rao, K.S., 2011. Development of statistical correlations between shear wave velocity and penetration resistance using MASW technique. Pan-Am CGS Geotechnical Conference.

Thitimakorn, T., 2010. Comparison of shear-wave velocity profiles of Bangkok subsoils from multi-channel analysis of surface wave and downhole seismic methods. Journal of Applied Sciences Research, **6**: 1953–1959.

Trupti, S., Srinivas, K.N.S.S.S., Kishore, P.P. and Seshunarayana, T., 2012. Site characterization studies along coastal Andhra Pradesh-India using multichannel analysis of surface waves. Journal of Applied Geophysics, **79**: 82–89.

Tsiambaos, G. and Sabatakakis, N., 2011. Empirical estimation of shear wave velocity from in situ tests on soil formations in Greece. Bulletin of Engineering Geology and the Environment, **7**: 291–297.

Vu, C. D. and Do, L. V., 2018. Primarily analyzing of DEM model to recognize active traces of river Sai Gon fault during late Pleistocen-Holocen Period in Ho Chi Minh City area. Journal of Science and Technology Development, **11**: 13–21.

Xia, J., Miller, R. D., Park, C. B., Hunter, J. A. and Harris, J. B., 2000. Comparing shear-wave velocity profiles from MASW with borehole measurements in unconsolidated sediments, Fraser river delta, B.C., Canada. Journal of Environmental & Engineering Geophysics, **5** (3): 1–13.

Xia, J., Miller, R. D., Park, C. B., Hunter, J. A., Harris, J. B. and Ivanov, J., 2002. Comparing shear-wave velocity profiles inverted from multichannel surface wave with borehole measurements. Soil Dynamics and Earthquake Engineering, **22**: 181–190.

Symbols and abbreviations

m_s	Total weight of clay per dewatering day
m_w	Wet weight of clay per dewatering day
pF	Suction pressure
w_7	7 days average water content of dewatered clay
w_0	Initial water content of slurry clay
w	Average water content of the dewatered clay