http://doi.org/10.29227/IM-2021-02-18 Received: 02 Jun 2021, Accepted: 19 Aug 2021, Published: 10 Nov 2021

Geotechnical Properties of Soft Marine Soil at Chan May Port, Vietnam

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Abstract. Soft marine soil deposit is distributed under the sea with many special properties. This type of soil is rarely researched in Vietnam because of the difficult geotechnical investigation under the sea level. In this paper, the experimental laboratories were performed to investigate the geotechnical properties of soft marine soil at Chan May port, Vietnam. The field investigation results indicate that the thickness of soft soil varies from a few meters to more than ten meters. Soft soil has a high value of water content, void ratio, and compressibility and a low value of shear strength. The compression index has a good relationship with water content, liquid limit, and dry unit weight. The unit weight, shear strength, and pre-consolidation pressure increase with the increase of depth. These results show that the soil in the study area is unfavorable for construction activities.

Keywords: Geotechnical properties, Soft marine soil, Chan May port

1. Introduction

Chan May Port located in the Chan May embayment, Loc Vinh commune, Phu Loc district, Thua Thien Hue province, Viet Nam (Fig. 1). As reported, Chan May embayment has undergone some progradation stages. Between 6000 and 4000 years ago, the progradation rate is rather fast at around 2.3-2.7 m/year, but it is reduced in the range of 1.3-1.5 m/year from 4000 to 2000 years ago. In the past 2000 years, the rate of coastal progradation is slow at 0.6-0.7 m/year, and it now might be stopped [1]. The Chan May port project includes many items and can be faced with many challenges because the foundation is constructed under sea level [2]. The soft soil distributes at an elevation from -13.0 m, and the thickness of soft soil varies from few meters to more than ten meters. Therefore, it is necessary to research the properties of soft marine soil for construction works at Chan May Port.

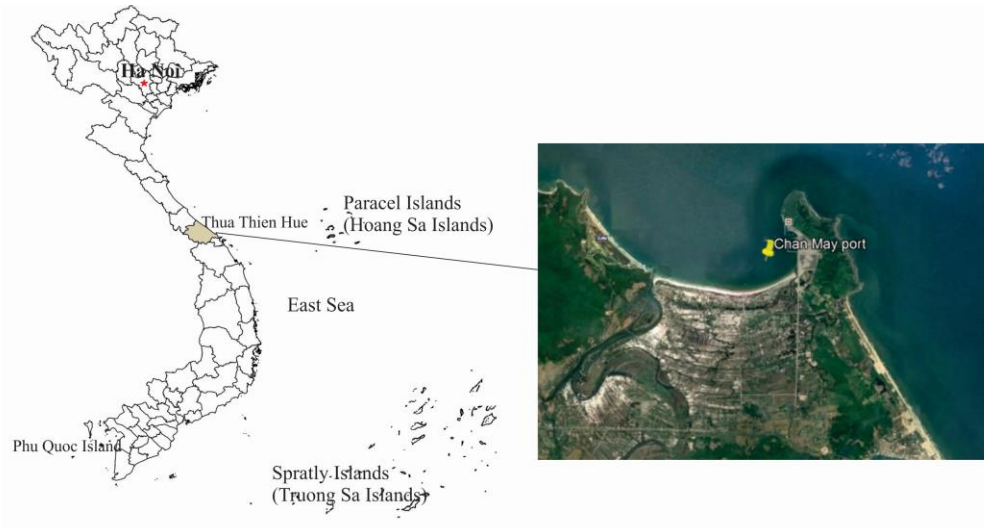

Fig. 1. The study location.

The mineral compositions of marine clays distributed in different areas have been investigated [3, 4, 5, 6, 7, 8, 9,10]. In general, these previous studies showed that the mineral compositions of marine clays depend on the location, the distribution depth, and the age of deposits. Besides mineral compositions, the geotechnical properties of soft marine soil have been studied by some researchers. Chu et al. [11] indicated that the vertical coefficient of consolidation of Singapore marine clay changed from 0.5 m^2/year to 2.0 m^2/year. The relationship between compression index and water content of marine clay in Northwestern Peninsular Malaysia has been studied by Oh et al. [12]. Mioa and Kavazanjian [13] showed that the ratio C_a/C_c of Jiangsu soft marine clay was constant. Ahmad and Harahap [14] investigated some properties of marine clays in Malaysia and indicated that the compression index varied from 0.177 to 0.797. The undrained shear strengths of marine clay in Singapore and the eastern coast of India were investigated by Arulrajah et al. [15] and Basack and Purkayastha[16], respectively.

From the literature review, the geotechnical properties of some soft marine soil types have been clarified. However, the marine soil distributed under the sea with many special properties needs to be further investigated. In Vietnam, some authors studied the geotechnical properties of soft soil [17-21]. In which, Oanh [21] investigated the undrained shear strength and consolidation yield stress of soft clay distributed in three sites along the coastal area of Vietnam. The research has indicated the suitable methods for the determination of the two parameters for soft soil improvement works. However, the properties of marine soil have not been widely investigated. Thus, this research will focus on soft soil's composition and some physicomechanical properties under the sea at Chan May port. Besides the relationship between physical properties and consolidation parameters, physical properties, and shear strength of soil, the change of soil properties with depth will be discussed.

2. Materials and Methods

In order to investigate the soil profiles, soil samples at different depths were taken from seven boreholes at Chan May port. Based on the soil description, the soft soil at this location is exposed on the seabed, which belongs to the Phu Vang formation. The thickness of the soft layer varies from 4.70 m to 11.6 m. Nineteen soft soil samples were collected from these boreholes to determine the physicomechanical properties. High-quality samples were taken using a thin-walled sampler at different depths (Fig. 2). The SPT values changed from 0 to 2 (blows). Thus, the soil is in a very soft state.

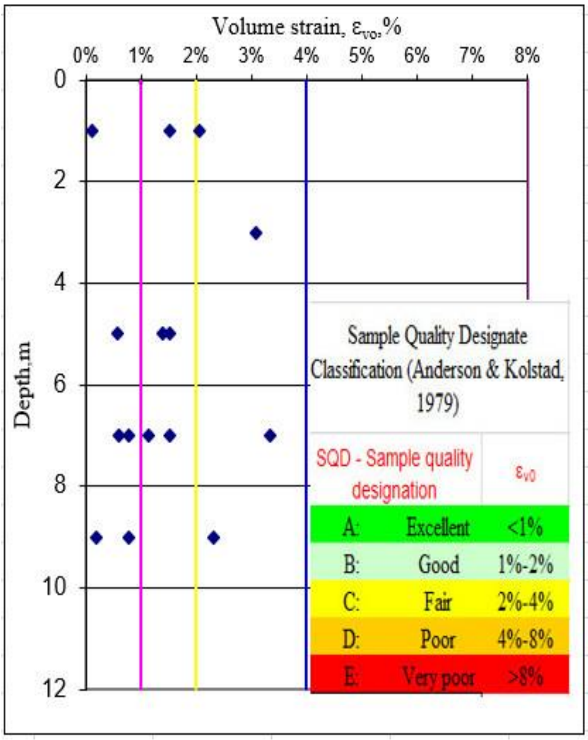

Fig. 2. The quality of the sample in this study.

In this study, particle size analysis and Atterberg limits of soil were determined according to *ASTM D7928 -16e and D6913-17, ASTM D4318-17*, respectively. The oedometer tests to determine the consolidation parameters were performed according to the ASTM *D2485-18* standard. The undrained unconsolidated triaxial compression test (*UU)* and unconfined compression test (Qu test) were used for determining the undrained cohesion force and undrained friction angle in accordance with *ASTM D2850-15, ASTM D 2166 -16* in respective. Finally, the undrained consolidated triaxial compression test (*CU*) was performed in accordance with *ASTM D4767-11* to determine the effective cohesion force and effective friction angle.

3. Results and discussions

3.1 Compositions and physical properties of soft marine soil

Fig. 3 shows the variation of particle size, salt content, organic matter, water content, wet unit weight, and void ratio with increasing depth from 0 to 11m. It can be seen that the salt content varies from 0.2% to 3.1%, with a mean value of 1.1%. The soft soil can be classified as low - saline to high - saline soil [17]. The organic matter content is smaller than 10% and changes from 0.2% to 8.0%, with an average value of 3.5%. As compared with the soft soil distributed in the coastal province of Mekong delta published in Nu et al. [17, 18, 19], the very soft soil in the study area contains a smaller organic matter content and higher salt content. The high salt content in soft soil at Chan May port can be caused by the distribution of soft soil. This very soft soil is distributed under the sea, and it will be affected by seawater.

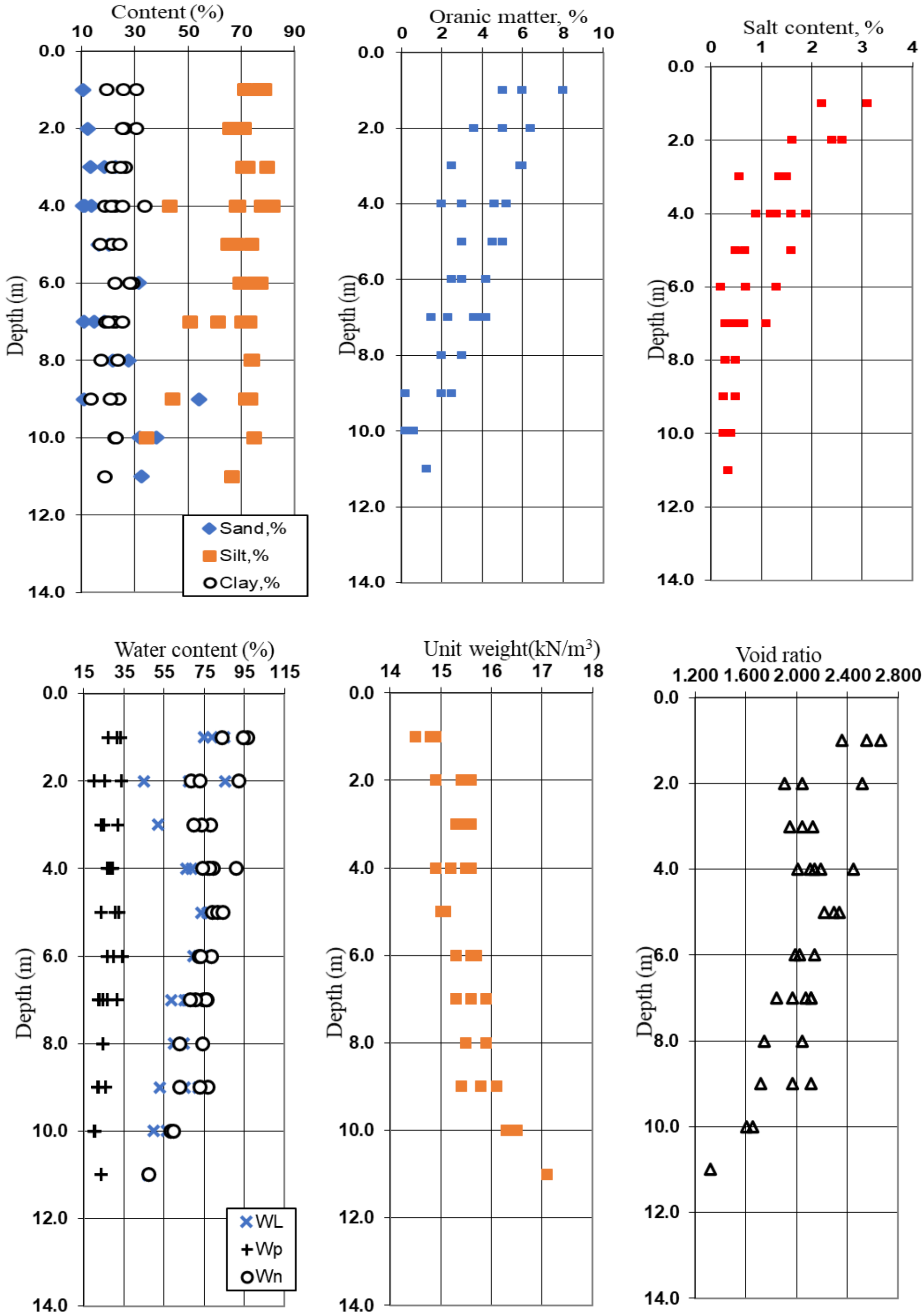

Fig. 3. The variation of soft marine soil properties with depth.

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As shown in Fig. 3, the particle size results show that the silt content is highest and varies from 34.3% to 81.7%. The clay content (<0.002 mm) is less than 40% and changes from 13.6% to 33.9%. The sand content significantly varies from 5.3% to 54.2%.

Fig. 3 also shows that the natural water content is higher than the liquid limit, and the soil is very soft. The natural water content varies from 47.2% to 96.4% and tends to decrease with increasing depth. Whereas the unit weight changes from 14.5 kN/m^3 to 17.1 kN/m^3 and increases with increasing depth. The void ratio is high and changes from 1.319 to 2.662. As compared with [13], the clay and silt contents, the natural water content, the liquid limit of soil in the study area are higher than those of Malaysia marine clays. However, these properties are smaller than those of some other marine clays [3, 22]

3.2 Consolidation properties of soft marine soil

Fifteen oedometer tests were performed to determine the consolidation properties of soft soil and are presented in Figs. 4-6. The soil samples were subjected to pressure levels of 12.5, 25, 50, 100, 200, and 400 kPa. From experimental results, it can be shown that the compression index changes from 0.404 to 0.754, the average value of *Cc* is 0.671. The swelling index varies from 0.05 to 0.139, with a mean value of 0.112. The compression and swelling indices are higher than those of some other marine clays [14]. The ratios of *Cs/Cc* range from 0.099 to 0.197. The pre-consolidation pressures (Pc) are determined by the Casagrande method and are plotted in Figure 6, with the values of Pc changing from 10 to 65 kPa. The over consolidation ratio (OCR) equals 1.0, and it can be seen that the soil belongs to normally consolidated soil.

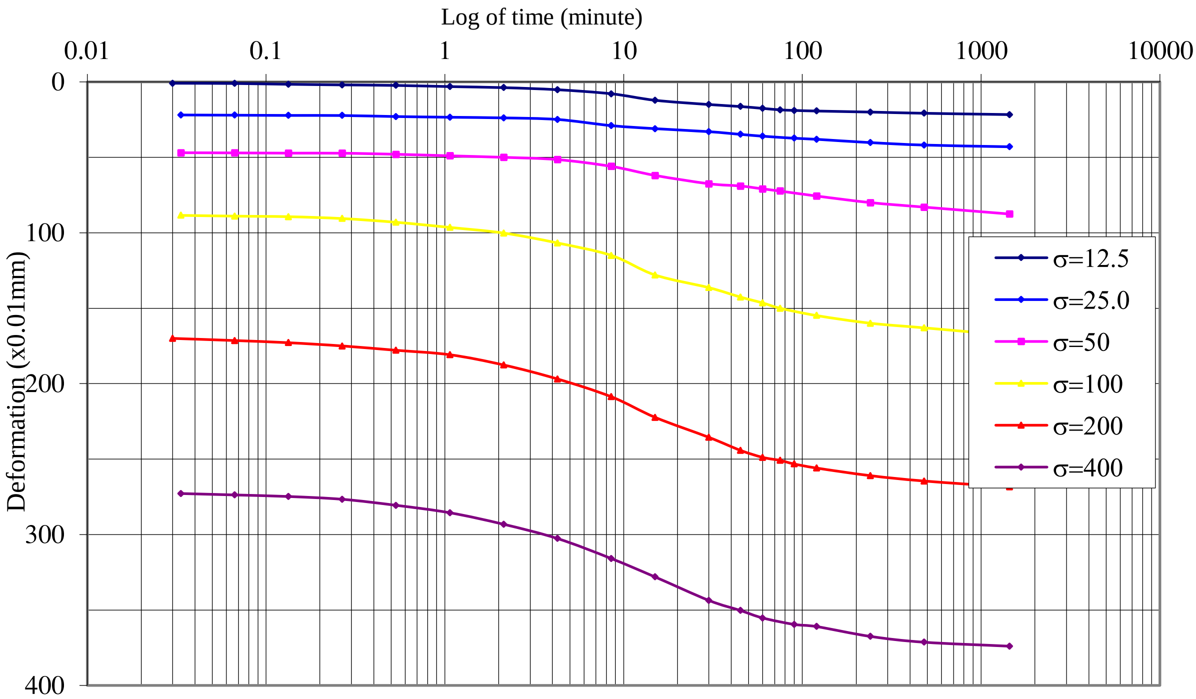

Fig. 4. S-log (t) curve.

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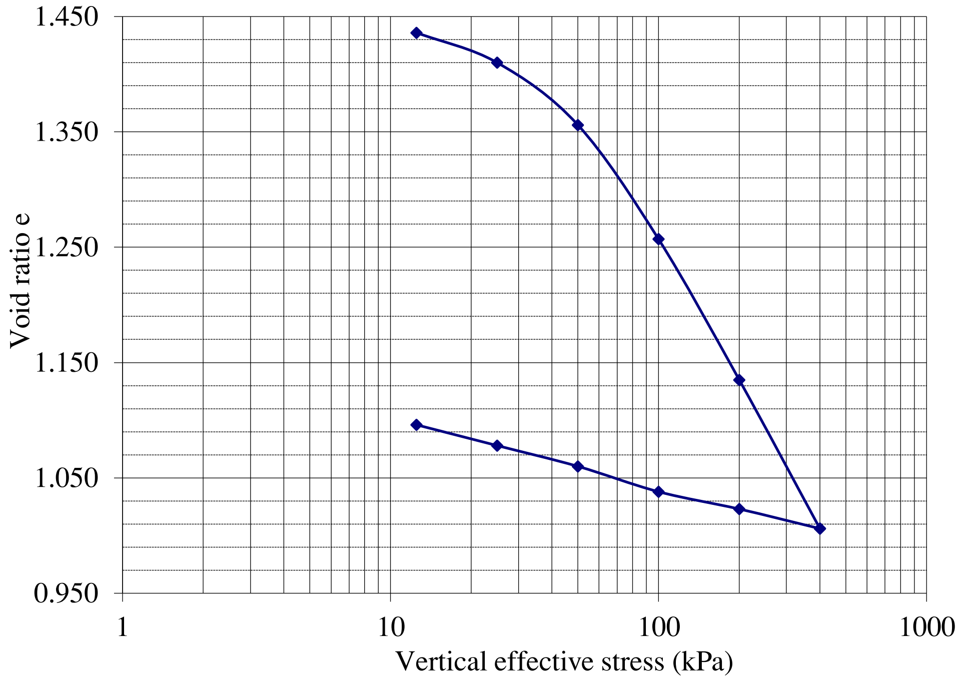

Fig. 5. Effective stress – Void ratio curve.

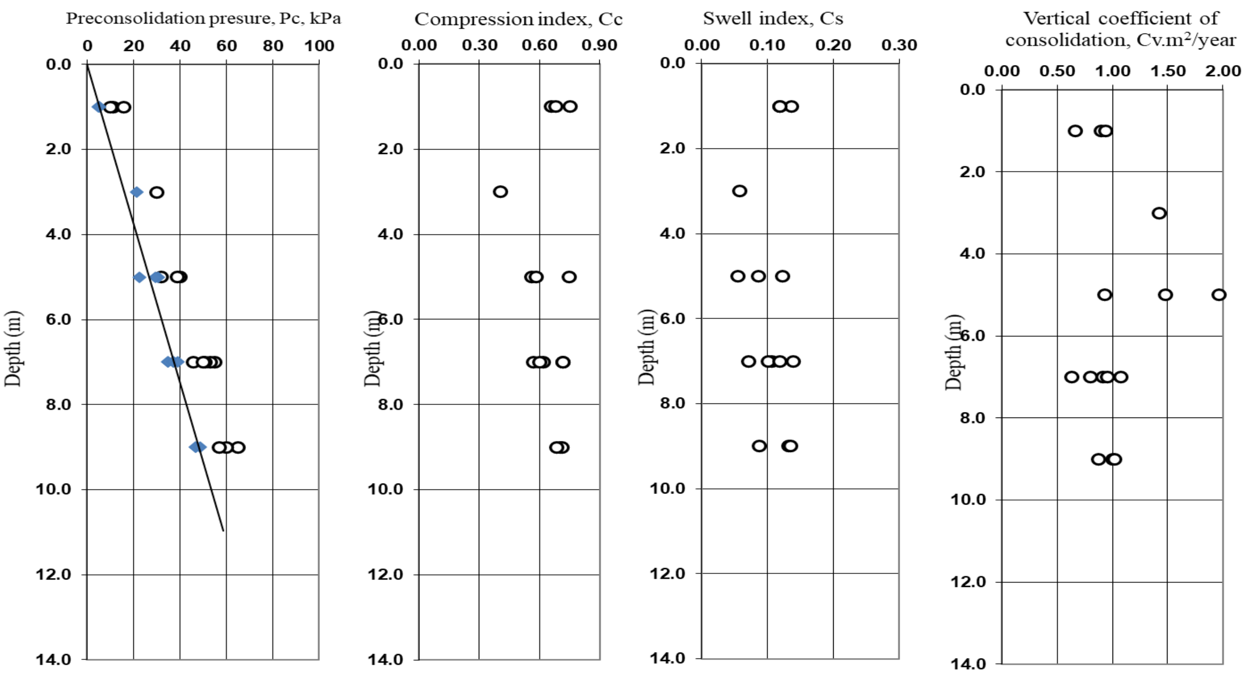

Fig. 6. The variation of consolidation properties of soft soil with depth.

In order to clarify the effect of the physical properties of soft soil on the compression index, the relationship between them was established. These relationships are shown in Fig. 7. As shown, the compression index has a good relationship with water content, void ratio, liquid limit, and dry unit weight with high correlation coefficients (R^2). The increase in water content, void ratio, liquid limit, and decrease in dry unit weight result in an increase in a compression index. Regarding the correlation between Cc and LL of marine clay, Liu et al. [5] established the relationship between compression index and liquid limit of Lianyungang marine clay by equation Cc= 0.015 (LL-14). For soft clay in Vietnam, Luan et al. (2021) [20] indicated the equation Cc=1.6728LL-0.1888 for Ho Chi Minh soft clay. This indicated that the correlation between Cc and LL depends on each type of clay, and it cannot be generalized for all types of clay.

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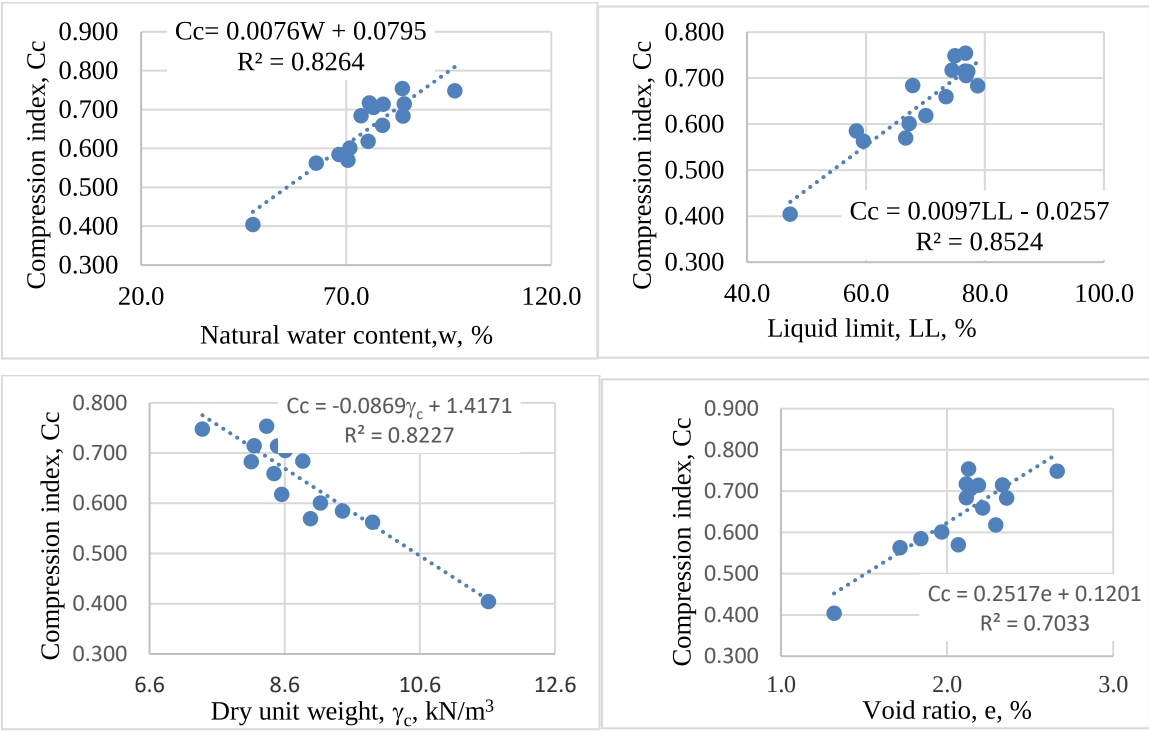

Fig. 7. The relationship between compression index and physical properties of soft marine soil.

3.3 Shear strength of soft marine soil

In this study, the unconfined compression test (Fig. 8a) and UU triaxial test (Fig. 8b) were conducted to determine the undrained shear strength. The test results show that the unconfined compression strength (q_u) is small and varies from 6.06 kPa to 13.76 kPa with the mean value of 8.49 kPa (Fig. 10a). The unconfined compression strength (q_u) increases with increasing depth. It is consistent with the change of physical properties of soil. With increasing depth, the dry unit weight increases, the natural water content decreases, and results in an increase in unconfined shear strength (q_u). Undrained shear strength of soft soil determined from the UU test changes from 3.01 kPa to 11.08 kPa with an average value of 5.16 kPa (Fig. 10b).

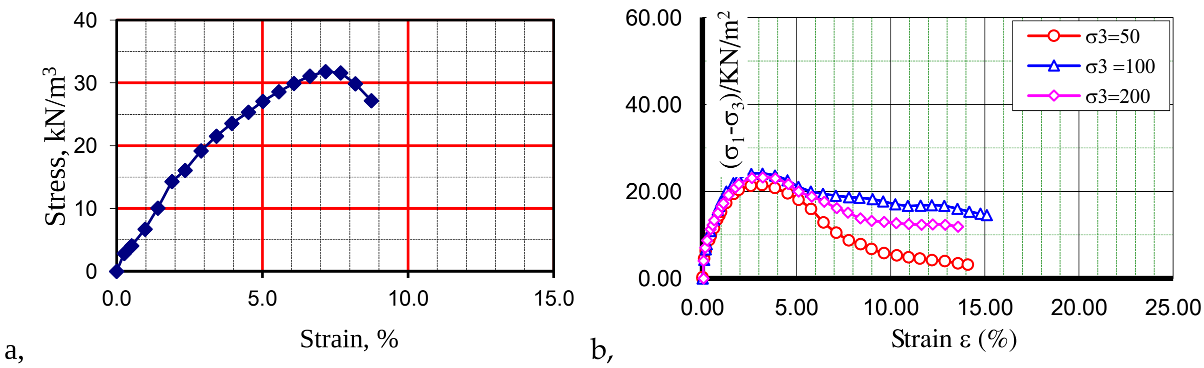

Fig. 8. The stress-strain curves from UCS test (a) and UU test (b).

From CU triaxial compression test (Fig. 9), the effective friction angle of soft marine clay varies from $18^0 50'$ to $24^0 38'$ with the mean value of $22^0 05'$, and effective cohesion changes from 3.44 kPa to 11.0 kPa with an average value of 7.8 kPa. The total cohesion (C_{cu}) and friction angle changes from 5.0 kPa to 15.2 kPa and from $4^0 04'$ to $15^0 08'$ with the average values of 10.30 kPa and $9^0 35'$, respectively. The experimental results indicated that the marine soil belongs to very soft soil and is unfavorable for construction activities such as dredging, excavation. As shown in Fig. 10c, the undrained shear strengths tend to increase with increasing depth. Lumb et al. [23] used vane shear tests, unconfined compression tests, and undrained triaxial tests to determine the undrained shear strength of soft marine clay from Hong Kong and also indicated that the undisturbed shear strength of the uniform clay increases linearly with depth.

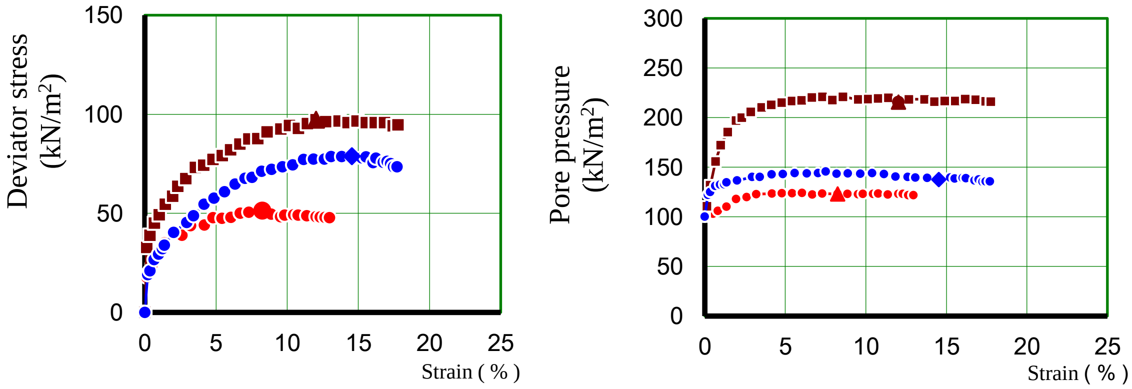

Fig. 9. The stress-strain and pore pressure-strain curves from the CU test.

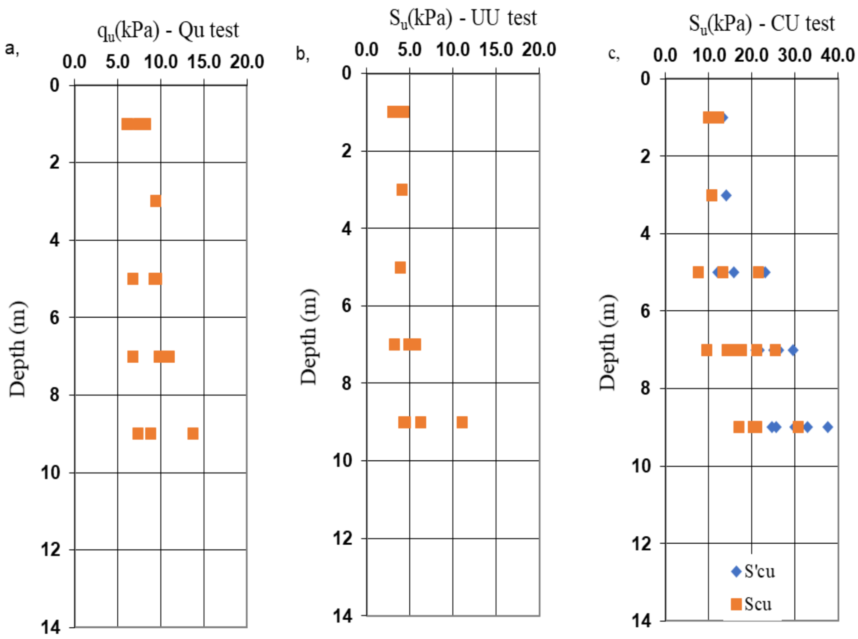

Fig. 10. The variation of unconfined compression strength (a), undrained shear strength – UU test (b), shear strength - CU test (c) of soft marine soil with depth.

Fig. 11 also shows that the relationship between undrained shear strength (Su) from the UU test and Liquid limit (LL). As shown, this relationship has a high correlation coefficient (R^2). The increase in liquid limit results in an increase in undrained shear strength (Su).

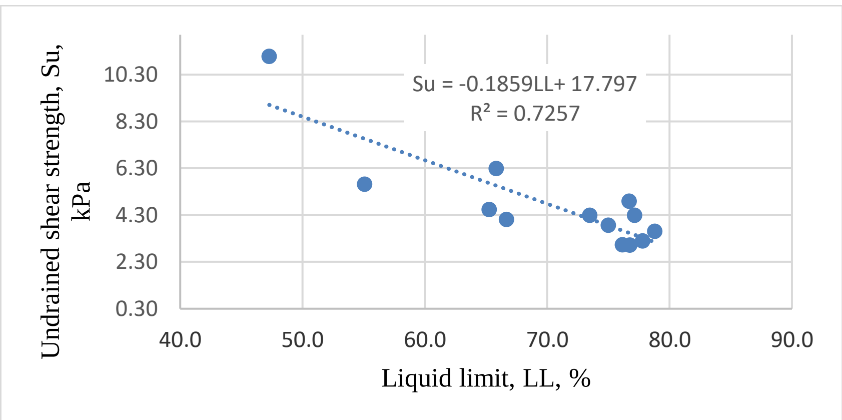

Fig. 11. The relationship between compression index and physical properties of soft marine soil.

4. Conclusions

Based on the experimental results, some conclusions can be made as follows:

- Soft marine soil has high water content, void ratio, and compressibility, and low shear strength.

- The compression index has a good relationship with water content, void ratio, liquid limit, and dry unit weight. The increase in water content, void ratio, liquid limit, and decrease in dry unit weight leads to an increase in a compression index.

- The undrained shear strength is also related to the liquid limit. The decrease in liquid limit results in increasing of undrained shear strength.

- The properties of soft soil change with increasing depth. Accordingly, the water content, void ratio, and liquid limit decrease while the dry unit weight, the undrained shear strength increase with the increasing of depth.

5. Acknowledgments

We would like to thank the Hanoi University of Mining and Geology for the provision of laboratory facilities used in this work.

The paper was presented during the 6th VIET - POL International Conference on Scientific-Research Cooperation between Vietnam and Poland, 10-14.11.2021, HUMG, Hanoi, Vietnam.

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http://doi.org/10.29227/IM-2021-02-18 Received: 02 Jun 2021, Accepted: 19 Aug 2021, Published: 10 Nov 2021