Undrained Shear Strength of Soft Soil in Some Areas of Vietnam's North Central Region

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ABSTRACT: The paper aims to investigate the undrained shear properties of soft soil distributed in some areas of Vietnam's North Central region. To study the undrained shear strength properties of soft soil, different test methods in the laboratory and in – situ at different sites were carried out. In the laboratory tests, the undrained shear strength of soft soil was determined by an undrained unconsolidated compressive test, unconfined compressive test, and consolidated undrained compression test. For the in-situ test, vane shear tests were performed at different depths in the borehole. The experimental results showed that there were various characteristics of undrained shear strength of soft soil in the study area. The undrained shear strength of soft soil depended on many factors, such as liquid limit, dry unit weight, void ratio, and plasticity index. The research results also showed that the correlations between the undrained shear strength of soft soil and physical properties have high determination coefficients.

KEYWORDS: Undrained shear strength, Qu test, UU test, CU test, Field vane shear test, Soft soil.

1. INTRODUCTION

The North Central region of Vietnam includes Thanh Hoa, Nghe An, Ha Tinh, Quang Binh, Quang Tri, Thua Thien Hue provinces which has been formed by the sedimentation of many rivers system. During the formation process, under the influence of the sea, therefore, many different sediment sources are formed. Soils are modern sediments, especially fine-grained deposits (Bui et al., 2020; Nu et al., 2021). Thus, the evaluation of the engineering properties of the Holocene clay layer has become an important issue for design and construction activities in coastal areas.

One of the main properties of the Holocene clay layer is the undrained shear strength which is the most important design parameter (Shogaki, 2006). The undrained shear strength can be used to determine the consistency and the ultimate bearing capacity of a clay layer (Ayadat, 2021). The shear strength of soil was affected by many factors, such as minerals composition, soil structure, humidity, draining condition, stress history, and loading rate (Sridharan et al., 1997). The in-situ shear strength was also affected by the mod of rupture, the anisotropy of soil, the deformation rate, and the stress history (Lunne et al., 2002). Al-Adhadh et al. (2021) reviewed the factors influencing the shear strength of clays and indicated that the most significant factors affecting the shear strength of clay are mineralogy, over-consolidation ratios (stress history) and drained versus undrained loading.

The shear strength of soil can be obtained from different methods. The laboratory tests to determine the undrained shear strength are unconsolidated undrained triaxial compression test (UU test), unconfined compression test (Qu test), and in-situ tests are the field vane shear test (FVT). The laboratory test to determine the undrained consolidated shear strength is consolidated undrained triaxial compression test (CU test). David et al. recommended that more than one technique should be used to determine the undrained shear strength. The undrained shear strength of soft soil depends on the testing methods. Thus, it is important to understand the relationships between the undrained shear strength determined by each test method and the reliability of these determinations (D'Ignazio et al., 2016). D'Ignazio et al. (2016) established the new correlation between undrained shear strength and the overconsolidation ratio (OCR), natural water content (w), liquid limit (LL), plasticity index (PI), liquidity index (LI), and sensitivity (St). Shimobe and Spagnoli (2020) observed that the interdependency among undrained shear strength, liquidity index, and water content is not unique due to the different physical and chemical characteristics of the clays.

In Vietnam, the properties and distribution of soft soil in some areas have been recently investigated (Suzuki and Oanh, 2011; Nguyen et al., 2020; Nu et al., 2019, 2020a, 2020b; Nu and Son, 2021).

In Vietnam's North Central region, the soft soil is widely distributed, especially along the coastal area, but there is limited study on the undrained shear strength of soft soil in this area. Thus, this paper aims to investigate the shear strength of soil at some typical coastal areas at Thanh Hoa, Nghe An, Ha Tinh in the North Central region; establish the relationship between undrained shear strength and other properties of soil.

2. MATERIALS AND METHODS

2.1. Materials

Undisturbed soil samples used in this study were collected from different boreholes (with the depth from 15 to 30 m) at Thanh Hoa, Nghe An, Ha Tinh in Vietnam's North Central region (Figure 1). Thin–walled sampler was used for obtaining high–quality samples at different depths. Firstly, the water content, Atterberg limits (liquid and plastic limits), and particle size were determined in accordance with the ASTM D2216 -19, ASTM D 4318-17, ASTM D7298-16e and ASTM D6193 -17, respectively.

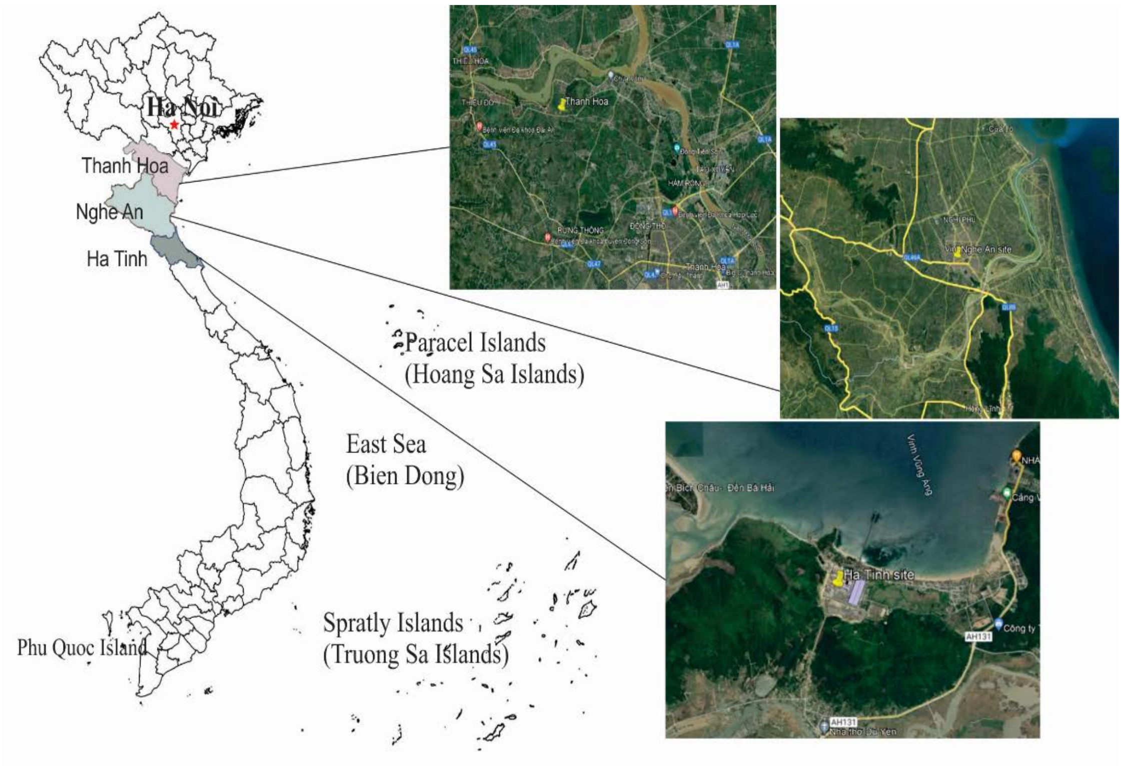
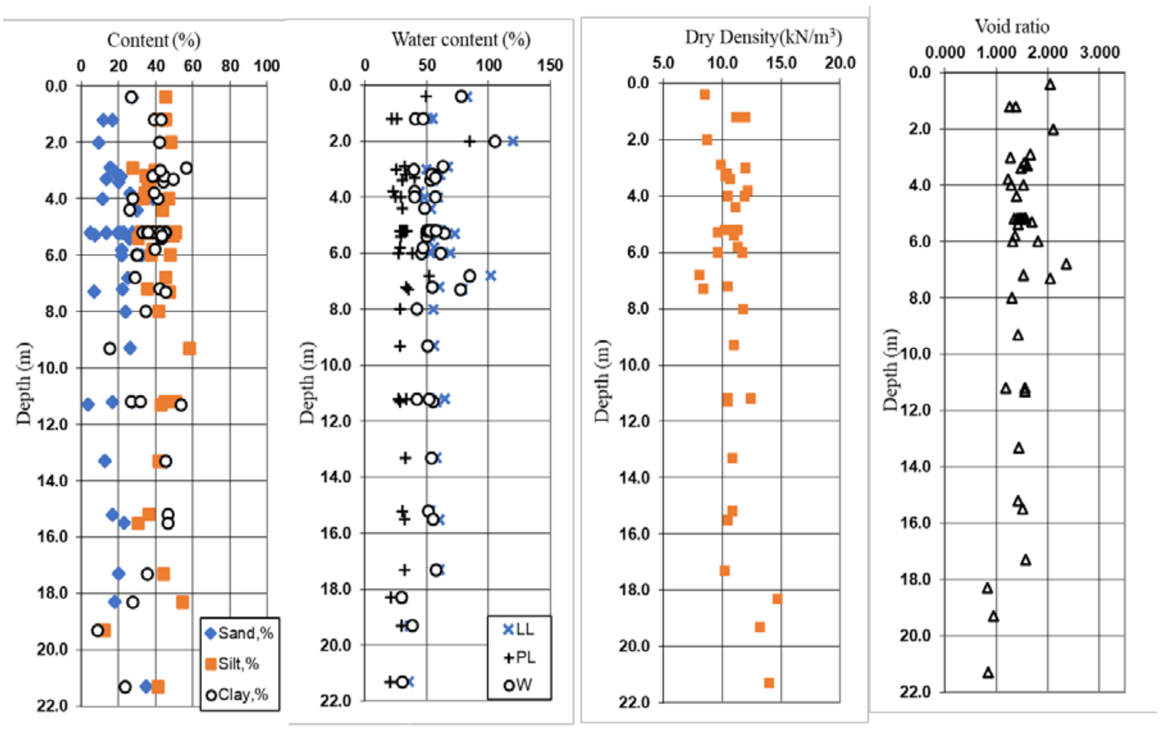


Figure 1 The study area in Vietnam's north central region

Figure 2 shows natural water content (w), liquid limit (LL), plastic limit (PL), particle size, void ratio, and dry density of soft soil at Thanh Hoa, Nghe An, and Ha Tinh provinces.

As shown in Figure 2, the soft soil at Ha Tinh has the highest sand content and dry density, while the lowest values are observed at Thanh Hoa. The natural water content of soft soil at Thanh Hoa, Nghe An, and Ha Tinh varies from 29.8 % to 126.5%, 30.6% to 62.9%, and 16.5% to 70.1%, respectively. The void ratio of soft soil in Thanh Hoa, Nghe An, and Ha Tinh varies from 0.830 to 3.345, 0.848 to 1.773, and 0.502 to 1.891, respectively. As compared with the research of Nguyen et al. (2021) on Chan May soft soil (in the North Central province of Thua Thien Hue), the soft soils at Nghe An and Ha Tinh in this study have lower natural water content and void ratio, whereas the water content of Thanh Hoa soft clay is higher.



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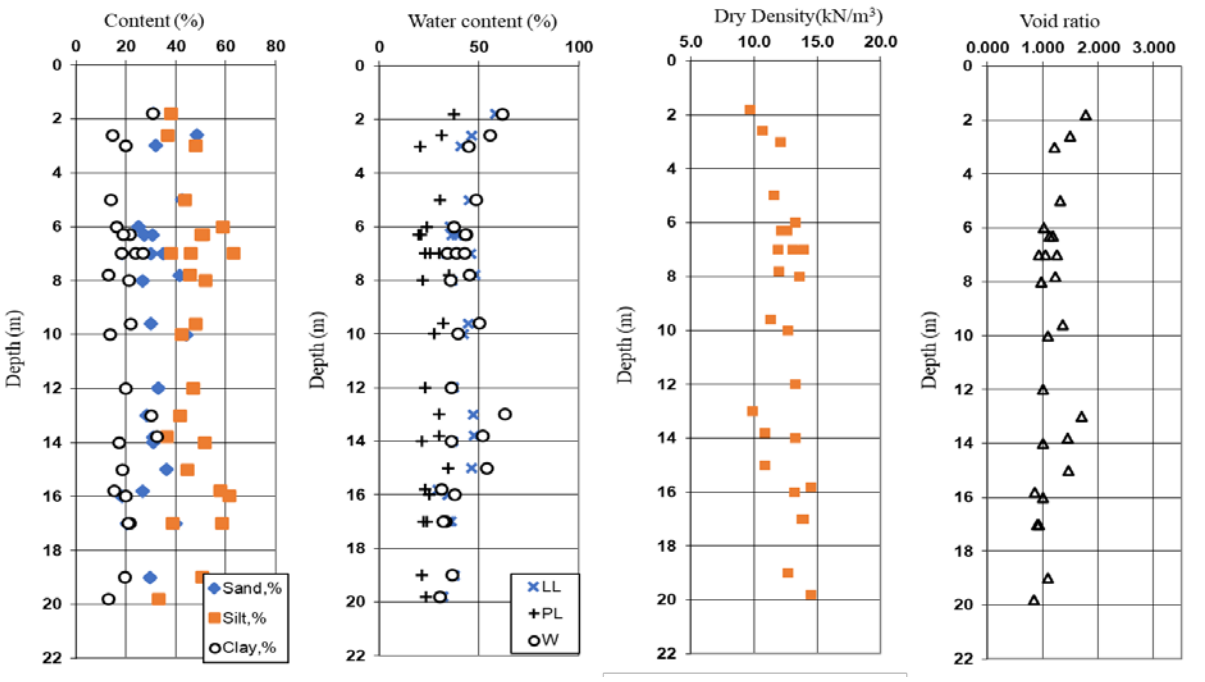

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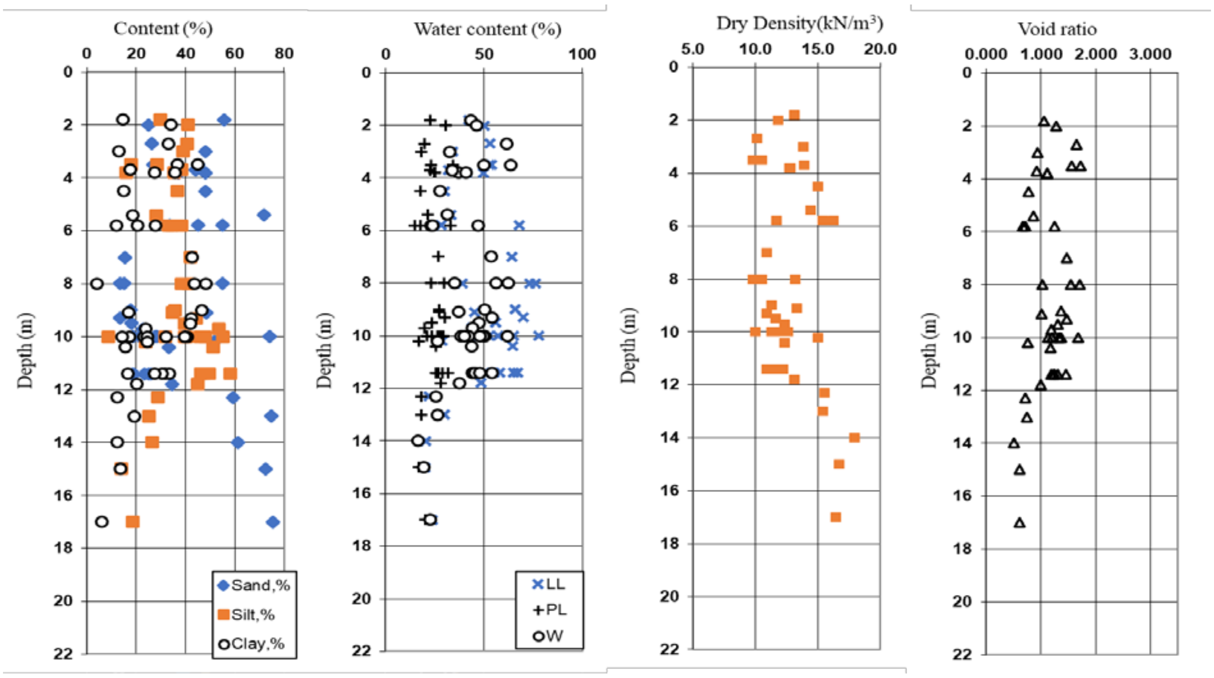


(c)

Figure 2 Some properties of soft soil at Thanh Hoa (a), Nghe An (b), Ha Tinh (c)

2.2. Methods

In this study, three laboratory shear tests (UU, CU, Qu tests) and the field vane shear test were carried out as follows:

2.2.1. Laboratory Tests

Unconfined compression test (Qu test): Undisturbed soil sample was trimmed to 38mm in diameter and 76mm in height. This size was the same as that for the undrained unconsolidated triaxial test (UU test) and the undrained consolidated triaxial test (CU test). The Qu test was conducted in accordance with ASTM D2166. The specimen was sheared with an axial strain rate of 1%/min until the load values decreased with increasing strain or until 15% strain is reached. Unconfined compressive strength, q_u, was determined at maximum value compressive stress or the compressive stress at 15% axial strain. The undrained shear strength S_u can be defined as half of the unconfined compressive strength, q_u.

Undrained unconsolidated triaxial test (UU test): Three specimens of soil samples were tested to determine undrained shear strength S_u according to ASTM D2850. The cell pressure was taken by ½ σ_{vo}, σ_{vo}, $2\sigma_{vo}$, where σ_{vo} is the total vertical field stress. A specimen was conducted with undrained compression of an axial strain rate of 1%/min until the load values decreased with increasing strain or up to an axial strain of 15%. The undrained shear strength S_u was defined as the haft of the maximum deviator stress. The shear strength parameters included the cohesion, c, and angle of shear resistance, φ were determined.

Undrained consolidated triaxial test (CU test): Three specimens of soil samples were consolidated isotopically under ½ σ_{vo}', σ_{vo}', $2\sigma_{vo}'$ in respective where σ_{vo}' is effective vertical field stress. After that, the undrained compression was conducted with an axial strain rate of 0.06mm/min up to an axial strain of 15% in accordance with BS 1377: Part 8: 1990. The undrained shear strength S_u was defined as haft of the maximum deviator stress. The shear strength parameters included the cohesion, c, and angle of shear resistance,φand the shear strength parameters in terms of effective stress, the cohesion, c' and angle of shear resistance, φ'.

2.2.2. The Field Vane Shear Test (FVT)

Field vane shear tests were carried out in the boreholes in the study area. The vane shear device with 50mm in diameter and 100mm in height was used. The vane's rate of rotating was 6^0 to 12^0 per minute according to ASTM D2573, and the torque was measured to estimate the undrained shear strength.

3. RESULTS AND DISCUSSION

Figure 3 shows the variation of undrained shear strength of soft soil at Thanh Hoa, Nghe An, and Ha Tinh in Vietnam's North Central Region with depth measured by various laboratory tests and field vane shear tests.

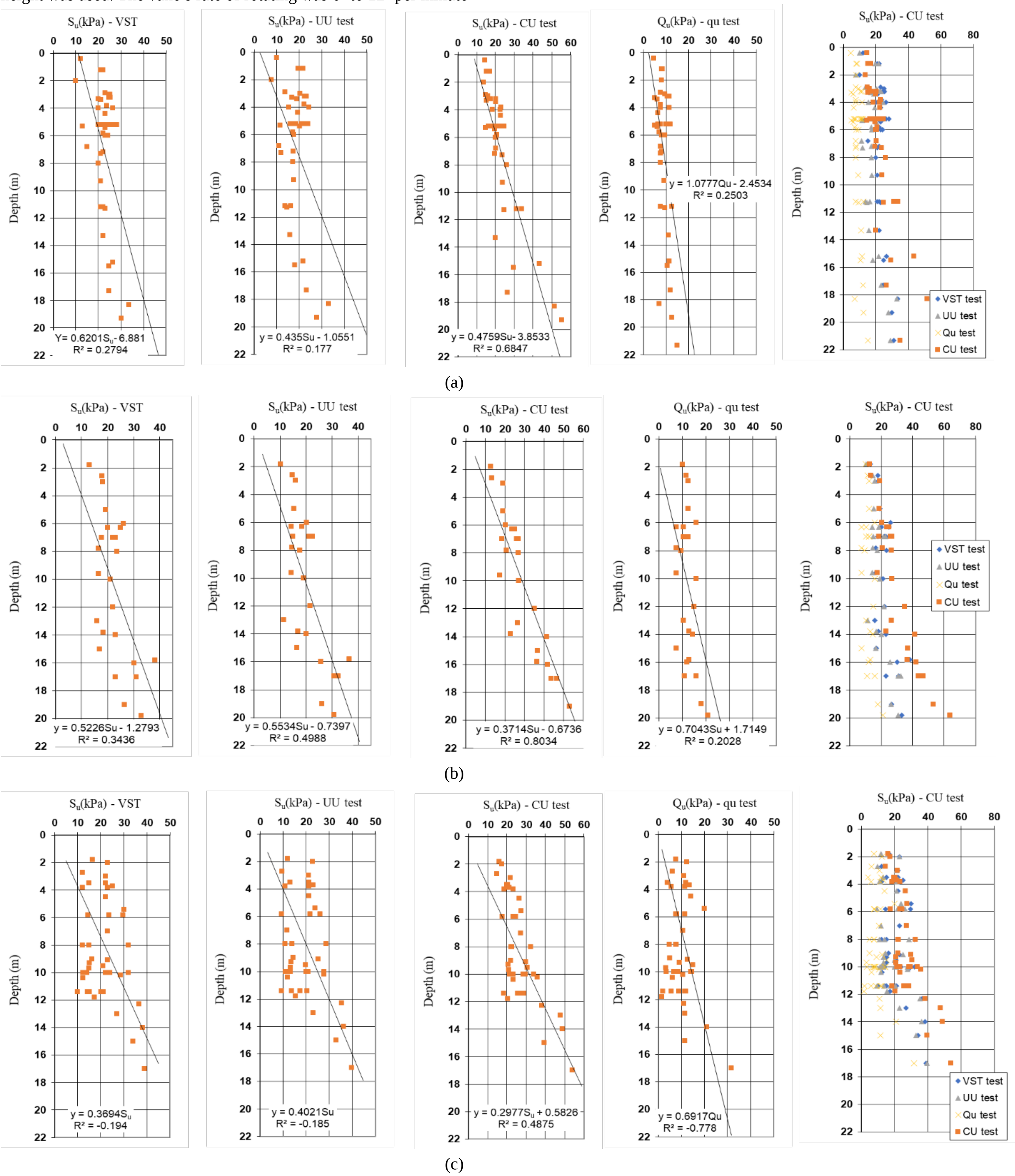


Figure 3 Undrained shear strength of soft soil at Thanh Hoa (a), Nghe An (b), Ha Tinh (c) in Vietnam's north central region

As shown in Figure 3, the undrained shear strength of soil in different sites varies in a wide range. The highest Su (UU test) is observed at Ha Tinh site and changes from 10 kPa to 39 kPa. The highest value of Su in Ha Tinh soil can be due to the fact that soils in this area contain a high content of sand in comparison with soils from other areas, as shown in Figure 2. Whereas the lowest Su (UU test) is found at Thanh Hoa site and varies from 7.6 kPa to 33.0 kPa. At Ha Tinh site, the Su (UU test) value varies from 10.3 to 36.6 kPa. In general, the values of Su are smaller than 40 kPa, and the soil can be classified as soft soil (Terzaghi et al., 1996).

From the field vane shear test (FVT) and Qu test (Figure 3), at Ha Tinh site, undrained shear strength changes from 13kPa to 38.3 kPa, 7.5 kPa to 21.0 kPa in respective. The smallest Su is found at Thanh Hoa site and changes from 10 kPa to 33.5 kPa, 4.5 kPa to 15 kPa, respectively. Whereas the highest Su is obtained from soil at Ha Tinh site and ranges from 10 kPa to 39 kPa (FVT) and from 1.6kPa to 31.7 kPa (Qu test).

For the CU test, a specimen was consolidated under the effective stress of up to 90%, so S_u values obtained from the CU test are larger than those obtained from UU, Qu, and FVT tests. At Thanh Hoa, Nghe An, and Ha Tinh sites, the Su values change from 13.7 kPa to 57.6 kPa, 12.6 kPa to 63.8 kPa, and 14.6 kPa to 54 kPa, respectively. (Ratananikom et al, 2017) also indicated that the highest Su of Bangkok clay was obtained from the CK0UC test (K0- consolidated undrained triaxial compression tests). It is consistent with Mayne et al. (2009), who indicated that the Su of Boston Blue Clay from the CIUC test is the highest.

As also shown in Figure 3, it can be clearly seen that the Su values from the FVT test are higher than those from the UU and Q_U tests. The Su value from the Q_U test is also smaller than that from the UU test. The result is similar to that of Mayne et al. (2009), who showed that the Su from Qu test is smaller than Su from UU test for Boston Blue Clay. Thus, the values of Su are in the order from highest to lowest as follows CU, FVT, UU, Qu tests. The lowest value of Su from Qu test with the lowest value of Su can be due to a reduction in the effective stress in the sample, which causes a reduction in a decrease in Su (Ladd and Lambe, 2011).

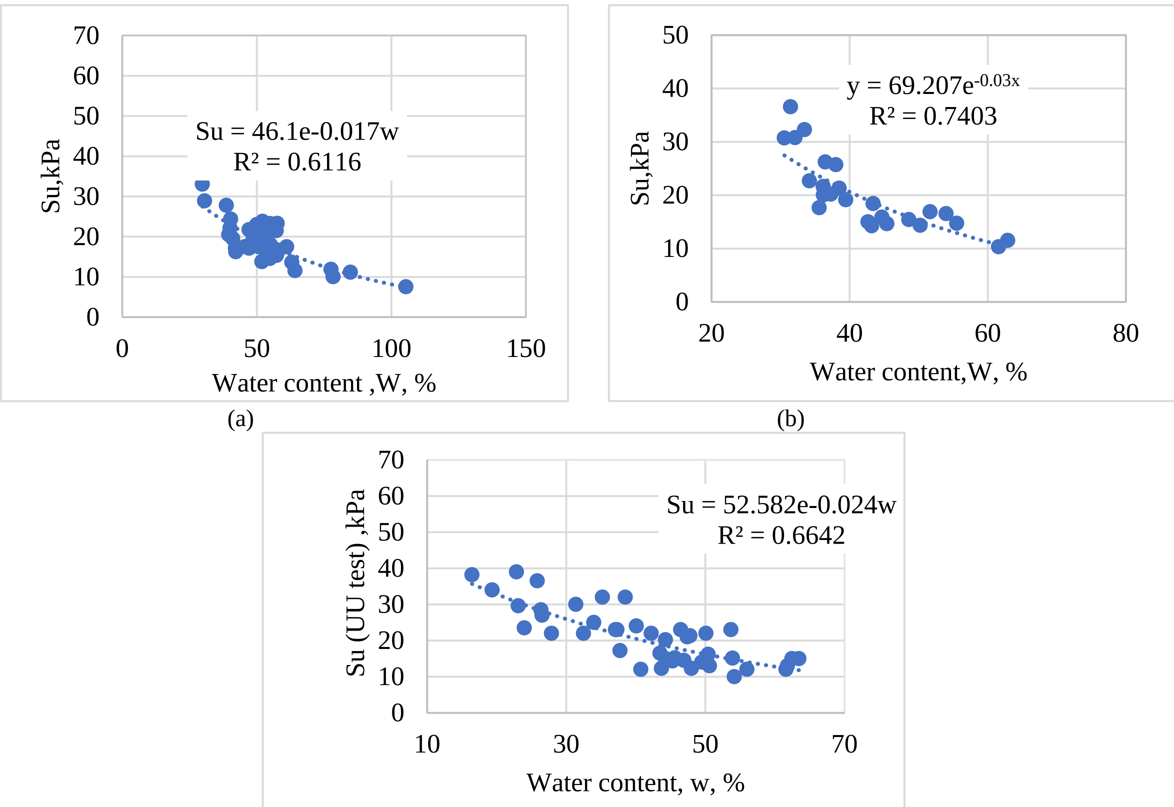
Based on the Su values from different tests, the relationship between them can be estimated as below:

$(Su)_{Qu} = 0.3584\ (Su)_{CU}$ ($R^2 = 0.9102$, Thanh Hoa site)
$(Su)_{UU} = 0.7488\ (Su)_{CU}$ ($R^2 = 0.917$, Thanh Hoa site)
$(Su)_{FVT} = 0.8853\ (Su)_{CU}$ ($R^2 = 0.919$, Thanh Hoa site)
$(Su)_{Qu} = 0.4004\ (Su)_{CU}$ ($R^2 = 0.9414$, Nghe An site
$(Su)_{UU} = 0.6203\ (Su)_{CU}$ ($R^2 = 0.9523$, Nghe An site)
$(Su)_{FVT} = 0.6771\ (Su)_{CU}$ ($R^2 = 0.9363$, Nghe An site)
$(Su)_{Qu} = 0.375\ (Su)_{CU}$ ($R^2 = 0.7578$, Ha Tinh site)
$(Su)_{UU} = 0.719\ (Su)_{CU}$ ($R^2 = 0.9389$, Ha Tinh site)
$(Su)_{FVT} = 0.7239\ (Su)_{CU}$ ($R^2 = 0.835$, Ha Tinh site)

From these relationships, it can be seen that the ratios of $(Su)_{Qu}$ to $(Su)_{CU}$ of soft clay in the study area are smaller than those of Bangkok clay, whereas the ratios of $(Su)_{UU}$ to $(Su)_{CU}$ of soft clay in the study area are higher than those of Bangkok clay (Ratananikom et al., 2017).

Figure 3 also shows that the Su tends to increase with increasing depth. Concerning the water content, void ratio, and dry density of soft soil in Figure 2, the Su value tends to decrease with the increasing of water content, liquid limit, void ratio, and decreasing of dry density. As shown in Figure 2, water content, void ratio, and liquid limit decrease with depth, and the dry density increases with depth. This is consistent with Lumb and Holt (1968), who indicated that the undrained shear strength of soft marine clay from Hong Kong increases linearly with depth.

In order to clarify the effect of the physical properties of the soil on undrained shear strength $(Su)_{UU}$, the relationship between them was established and shown in Figures 4 -7.



(a) (b) (c)

Figure 4 The relationship between undrained shear strength $(Su)_{UU}$ and water content (w) of soft soil at Thanh Hoa (a), Nghe An (b), Ha Tinh (c) in Vietnam's north central region

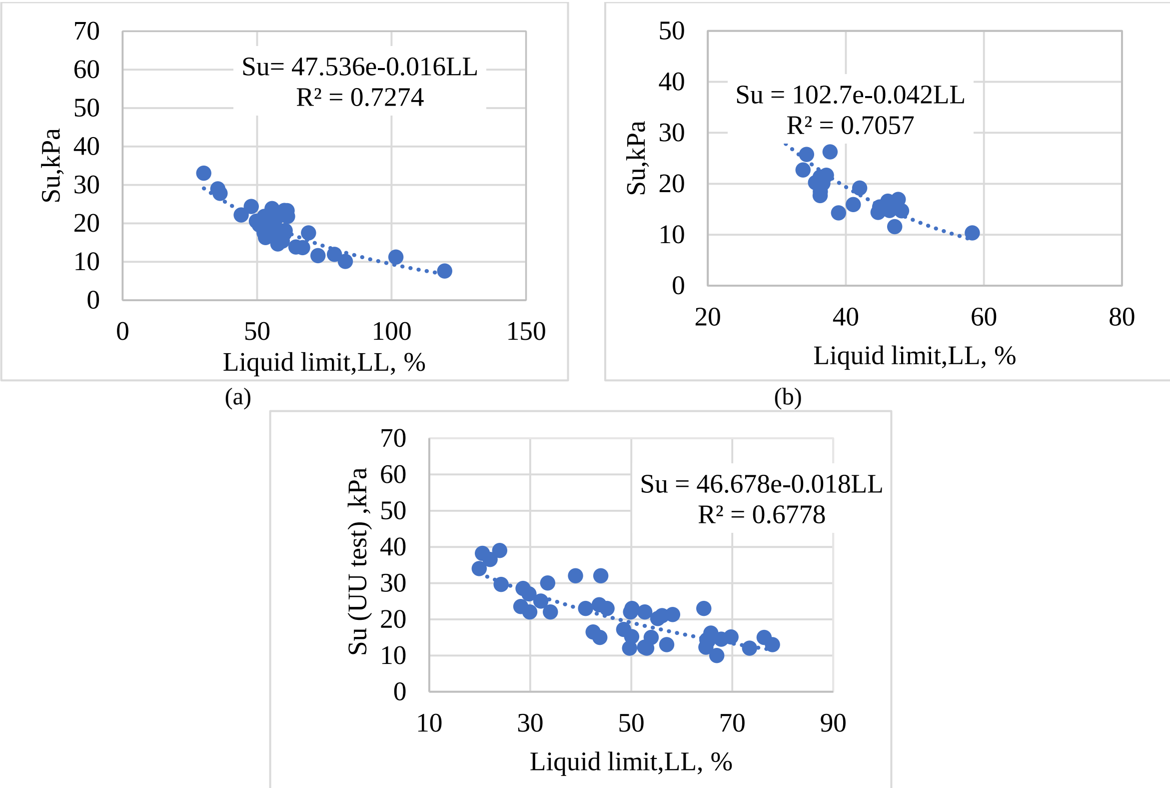


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Figure 5 The Relationship between undrained shear strength $(Su)_{UU}$ and liquid limit (LL) of soft soil at Thanh Hoa (a), Nghe An (b), Ha Tinh (c) in Vietnam's North Central region

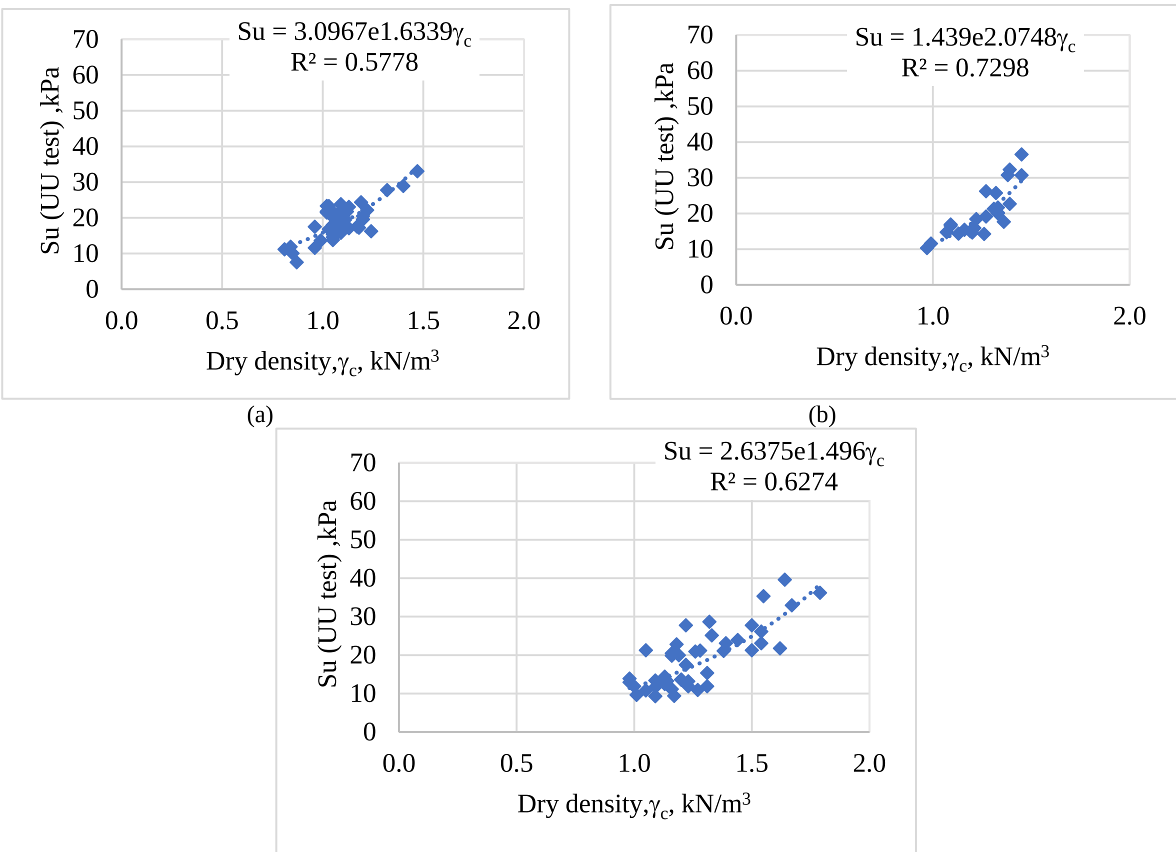

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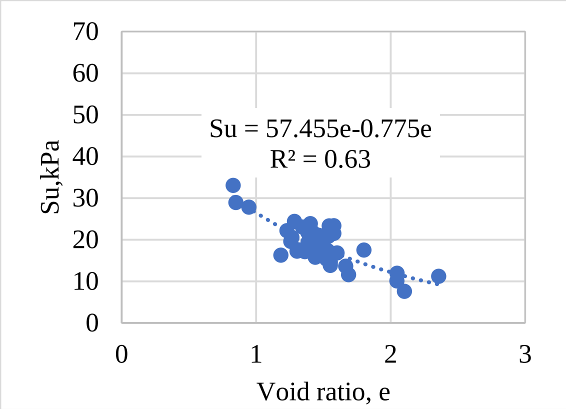
Figure 6 The relationship between undrained shear strength $(Su)_{UU}$ and dry density (γ_c) of soft soil at Thanh Hoa (a), Nghe An (b), Ha Tinh (c) in Vietnam's North Central region



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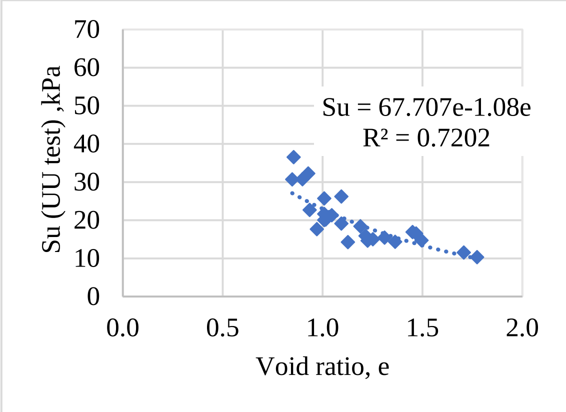

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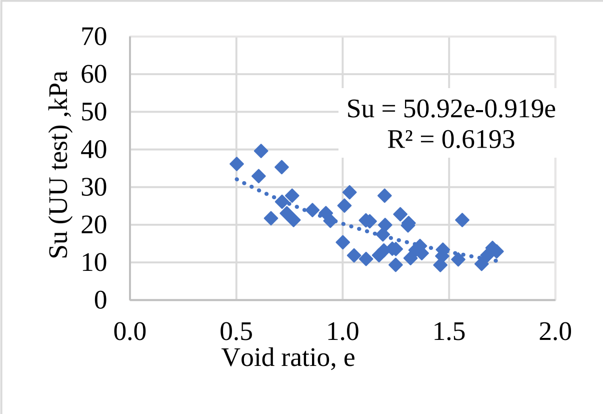

(c)

Figure 7 The relationship between undrained shear strength $(Su)_{UU}$ and void ratio (e) of soft soil at Thanh Hoa (a), Nghe An (b), Ha Tinh (c) in Vietnam's north central region

As shown in these figures, $(Su)_{uu}$ has a good relationship with liquid limit, water content, void ratio, and dry density with high correlation coefficients (R^2). Nguyen et al. (2021) indicated the equation S_u = -0.1859LL+17.797 (R^2 = 0.7257) for Chan May soft soil. It can be seen that the increase in liquid limit, water content, void ratio, and the decrease in dry density results in an increase in undrained shear strength. Similarly, Yin and Rui (2020) also proposed that the undrained shear strength and liquidity index has a good relationship. From the above discussion, it is clear that $(Su)_{uu}$ of soft soil at these sites has a good relationship with physical properties.

4. CONCLUSIONS

This paper has investigated the value of Su of soft soil in Vietnam's North Central region measured by laboratory tests, and in–situ test, i.e. (i) unconfined compression test – Qu test (ii) unconsolidated undrained triaxial compression test – UU test (iii) consolidated undrained triaxial compression test – CU test (iiii) Field vane shear test. Based on this investigation, the following observation and conclusions are made as follows:

The highest undrained shear strength is observed for soft soil at Ha Tinh site, and the smallest undrained shear strength of soft soil is found at Thanh Hoa site.

The undrained shear strength decreases with the increase in water content, liquid limit, and void ratio of soft soil. Besides, it also increases with the increase of dry density and depth. The research results showed that the undrained shear strength of soft soil in the study area has a good correlation with these physical properties of soil.

As compared with different test methods, the highest Su is obtained from the CU test, while the smallest one is obtained from the unconfined compression test (Qu test).

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