International Journal of GEOMATE, April, 2024 Vol.26, Issue 116, pp.102-109
ISSN: 2186-2982 (P), 2186-2990 (O), Japan, DOI: https://doi.org/10.21660/2024.116.g13153
Geotechnique, Construction Materials and Environment

THE POTENTIAL USE OF FRUIT SCLEROMETER TO DETERMINE THE UNDRAINED SHEAR STRENGTH OF BANGKOK CLAY

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ABSTRACT: A fruit sclerometer is used to test the hardness of a fruit to evaluate its maturity by applying a pressure head press to fruits gradually and vertically, and it has a working principle similar to that of the pocket penetrometer used to estimate the undrained shear strength of cohesive soil. This study investigated the potential use of a fruit sclerometer to determine the undrained shear strength of fine-grained soils, especially Bangkok clay. A fruit sclerometer and an unconfined compression test were conducted in 82 undisturbed soil samples to measure the undrained shear strength, and the correlations of the undrained shear strength obtained from both methods were constructed to verify the potential use of fruit sclerometer in the determination of undrained shear strength for Bangkok clay. The results revealed that the undrained shear strength obtained from the fruit sclerometer was about two times greater than that obtained from the unconfined compression test. A reduction parameter was recommended for converting undrained shear strength from the fruit sclerometer test to the unconfined compression test. Nevertheless, further study is required to confirm this relationship for the other locations and the number of samples. It is essential to note that a fruit sclerometer is a primitive instrument subject to many errors. It should not replace laboratory testing and field analysis or be used to produce foundation design data.

Keywords: Fruit Sclerometer, Pocket Penetrometer, Undrained shear strength, Bangkok clay, Unconfined compression test

1. INTRODUCTION

Shear strength is widely used in engineering design and is particularly crucial for fine-grained soils. Shear strength determination is vital for ensuring the stability and safety of structures. Various techniques have been devised to measure the shear strength. Each method provides a different level of control over soil conditions during testing, which results in variations in the measured undrained shear strength. However, not all methods can accurately simulate soil conditions to match natural settings.

Stefanow and Dudziński [1] classified over 20 types of soil shear strength testing methods into two main groups: direct and indirect shear. Direct shear methods usually use instruments with rotational or translational shear kinematics. One of the laboratory's most common direct shear methods is the unconfined compression test [2,3].

Indirect methods are mainly based on soil compression and allow an estimation of soil shear strength. Soil shear strength based on the soil penetration method consists of a cone penetrometer, a pocket penetrometer, a ball penetrometer, and a T-bar penetrometer [4,5]. Among these methods, many researchers have used pocket penetrometers to determine fine-grained soil's undrained shear strength. The advantage of this method is that the pocket penetrometer is lightweight and portable. This tool provides a quick and user-friendly assessment, resulting in faster decisions in the field. Especially the trench stability evaluation that requires a primary assessment.

Yasun [5] used the pocket penetrometer to obtain the unconfined compressive strength of Baghdad clayey soil and later compared it with the unconfined compressive strength, which is the conventional test. The result showed that the average percentage of the difference between Penetrometer readings and unconfined compression test result values was less than 2%.

Mousavi et al. [6] studied the soil strength obtained from unconfined compressive strength and the pocket penetrometer test using a regression relationship in 45 large fine-grained soil samples. The results indicated that a pocket penetrometer can accurately predict the unconfined compressive strength of fine-grained soils with good accuracy and a minimal cost.

Tashin et al. [7] investigated the correlations of undrained shear strength among various laboratory tests of remolded samples, i.e., (i) pocket penetrometer test, (ii) unconfined compression test, (iii) fall cone test, (iv) laboratory vane test, and (v) unconsolidated-undrained using index test results such as liquidity index. The results show that the undrained shear strength obtained from pocket penetrometer test results is statistically compatible with other tests.

A fruit sclerometer is an equipment invented to test a fruit's hardness to judge the fruit's maturity by applying the pressure head press to fruits slowly and vertically, a similar working principle to the pocket penetrometer that offers simplicity, high speed, and even the lowest cost in comparison to other soil penetration apparatus, especially pocket penetrometer. To the best of our knowledge, no researcher is using a fruit sclerometer to determine the shear strength of soil, leading to the investigation of the possibility of using a fruit hardness tester, which is typically used in agricultural settings [8-14], to determine the undrained shear strength of Bangkok clay.

The fruit sclerometer was used because of its ease of use, speed of operation, and cost-effectiveness. This study was motivated by the requirement to evaluate the dependability of nontraditional tools in soil science. The penetration test method, used in agricultural sciences to determine fruit biomechanics, such as their hardness and shear strength, utilizes a principle comparable to that of soil testing devices. By comparing the efficacy of the fruit hardness device with that of conventional soil strength tests, with a particular emphasis on Bangkok clay, this study contributed to the ongoing discussion regarding advancements in methodology and precision.

2. RESEARCH SIGNIFICANCE

This research presents a new way to use the fruit hardness tester, usually for checking fruit hardness, in figuring out the undrained shear strength of fine-grained soil like Bangkok clay. The unconfined compression test, one of the standard methods, was selected in the result comparison. his inventive approach offers a simpler, more cost-effective and could be an alternative tool for engineers in estimating the undrained shear strength of fine-grained soil.

3. MATERIALS

The fine-grained soil used in this study was collected from Chatuchak, Bangkok, Thailand. This area exhibits substantial geological changes, distinguished by a series of sediments deposited by rivers, streams, and deltas. Previously, the area was submerged under a shallow marine sea. During the Holocene period, Bangkok clay, a soft clay, formed in the area. Approximately 2,700 years ago, the water retreated, leaving behind a layer of worn soft clay [15-17]. The soil sampling location is presented in Fig.1.

The primary clay mineral in Bangkok clay is smectite, which has a large swelling capacity and considerably affects its geotechnical characteristics. This clay exhibits exceptional flexibility, characterized by a liquid limit range of 100%–140% and an activity range of 1.25–1.90. The chemical composition of water in this substance's pores exhibits lower chloride levels than saltwater, indicating that it originated from the ocean. The complex chemical composition of pyrite was demonstrated by its presence and fluctuations in pH at various depths [18].

Bangkok clay exhibits diverse properties throughout its profile from a geotechnical perspective. The Bangkok clay layer, located at depths from 3 to 12 m, exhibits very soft to soft consistency. Bangkok clay has an undrained shear strength of 10–30 kN/m^2 and a 60–105% natural water content. By contrast, the layer of clay, which is moderately to highly rigid, has a thickness of 15–35 m and exhibits greater values of undrained shear strength, typically from 26 to 160 kN/m^2. The variations in the observed characteristics result from the distinct depositional settings and the mechanical response of the clay under varying conditions [16].

Soil samples were obtained from seven boreholes. Each borehole was drilled to a depth of 15 m and located approximately 3 m apart (Fig.2). Undisturbed soil samples were collected every meter from each borehole by using a thin-wall tube to maintain the composition and structure of the soil to be the same as the natural conditions in the field. The thin-walled tube pushes slowly into the soil layer. After collecting the soil sample, wax was applied to avoid water evaporation in the soil mass.

Fig.1 Soil sampling location

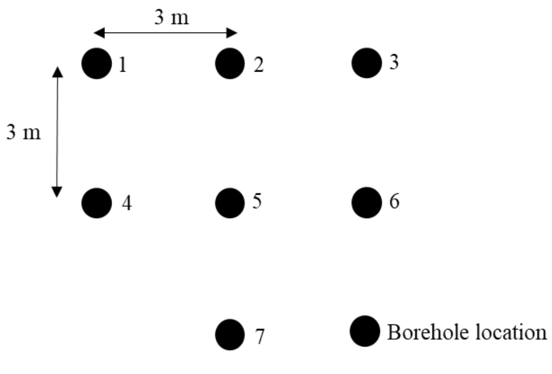


Fig.2 Borehole layout

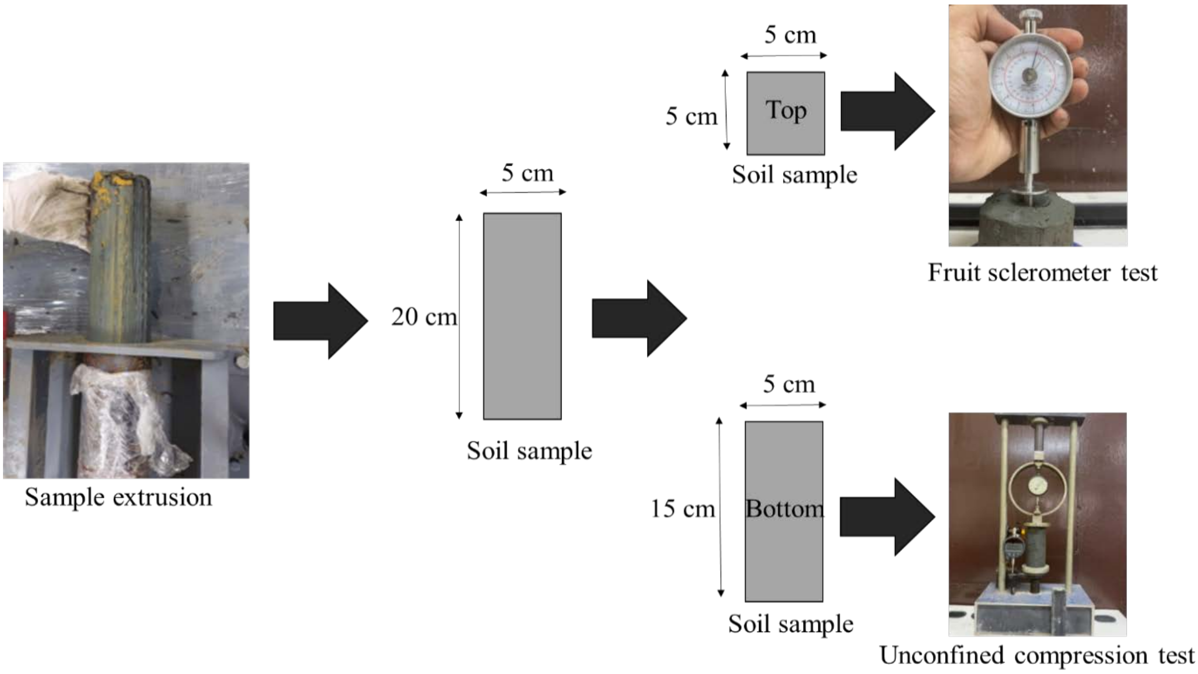


Fig.3 Sample preparation for the laboratory test

A total of 105 samples were collected from the field. Fourteen samples from the upper 2-m layer were not sent for laboratory testing because this layer was disturbed by human activity and can be classified as the filled layer. The other nine very soft samples could not be used in the unconfined compression test. Therefore, only 82 samples can be used in undrained shear strength determination from the unconfined compression and fruit sclerometer tests. The samples were sent to the laboratory for engineering properties testing following ASTM, including the natural water content, Atterberg's limits, total unit weight, and unconfined compression tests [19-21].

4. TESTING PROGRAM

Each sample was prepared to be at least 20 cm long and separated into two parts. The top 5 cm was prepared for the fruit sclerometer test, and the bottom 15 cm was prepared for the unconfined compression test with the natural water content, Atterberg's limits, and total unit weight. Fig.3 displays the sample preparation process. The testing program for the unconfined compression test and fruit sclerometer test are as follows:

4.1 Unconfined Compression Test (UC)

The unconfined compression test [19] is the standard test for obtaining the undrained shear strength of fine-grained soil. This test is fast and inexpensive. The undisturbed soil sample from the thin-wall sample was trimmed to 38 mm in diameter and 76 mm in height to obtain a height-to-diameter ratio of two. The force was applied to the soil sample in uniaxial compression mode without the confining pressure acting on the soil sample. The axial load was rapidly applied to the specimen until failure. The applied forces and displacements of the sample were recorded, and the relationship between stress and strain was detailed.

The unconfined compressive strength was the peak value of the axial load divined by the corrected area, and the undrained shear strength was assumed to equal one-half of the unconfined compressive strength, as presented in Eq. (1) to Eq. (4), respectively.

$$q_u = \frac{N}{A_c} \tag{1}$$

$$A_c = \frac{A_0}{(1-\varepsilon)} \tag{2}$$

$$\varepsilon = \frac{\Delta H}{H_0} \tag{3}$$

$$S_u = \frac{q_u}{2} \tag{4}$$

Where,

q_u is unconfined compressive strength
N is axial load
A_0 is the initial cross-sectional area

ε is the vertical strain
ΔH is the change in the height of the specimen
H_0 is the height of the specimen before loading
S_u the undrained shear strength

Undrained shear strength was used to classify cohesive soils into very soft, soft, medium, stiff, very stiff, and hard categories. Table 1 presents the classification of fine-grained soil based on undrained shear strength [22].

Table 1 Types of fine-grained soils based on undrained shear strength [22]

Consistency	S_u (kPa)
Very soft	<12.5
Soft	12.5–25
Medium	25–50
Stiff	50–100
Very stiff	100–200
Hard	>200

4.2 Fruit Sclerometer Test (FST)

A fruit sclerometer (Model GY-3 with a head size diameter of 11 mm., range 0.5–12 ksc) manufactured by HANDPI Company, China [23] was used to measure the unconfined compressive strength of soil. Table 2 presents three models of fruit sclerometer based on head size and scale value.

Table 2 Fruit sclerometer basic information [23]

Model	GY-1	GY-2	GY-3	
Scale value	2–15 ksc	0.5–4 ksc	1–24 ksc	0.5–12 ksc
Head diameter	3.5 mm	3.5 mm	8 mm	11 mm
Accuracy	±0.10	±0.02	±0.10	±0.10

The fruit sclerometer test can be conducted by pressing the pressure head 10 mm into the soil sample and then stopping. The pointer displayed the unconfined compressive strength of the soil. Measurements were conducted three times on each sample, and the average unconfined compressive strength was obtained. The unconfined compressive strength and undrained shear strength can be obtained from Eq. (5) and Eq. (6).

$$P = \frac{N}{A} \tag{5}$$

$$S_u = \frac{P}{2} \tag{6}$$

where,

S_u is the undrained shear strength (ksc)
P is the unconfined compressive strength (ksc)
N is the pressure of the dynamometer (kg)
A is the area of pressure (cm^2)

5. RESULTS AND DISCUSSION

5.1 Basic Engineering Properties

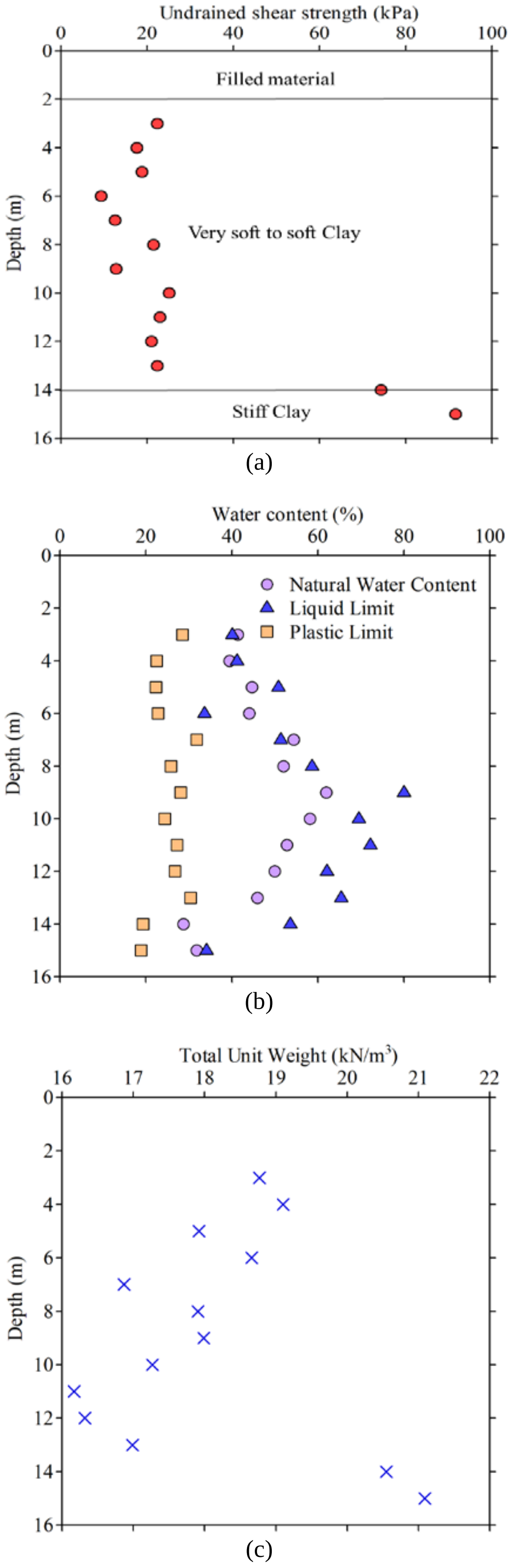
The subsurface condition of the sampling site can be classified into three layers based on the average unconfined compression test results of each meter depth from every borehole. The upper layer is a filled material layer with high disturbance from human activity; therefore, the samples from this layer will not be used in this study. The second layer is very soft to soft clay, and the last layer is stiff clay. The results are consistent with those in a previous study [17,18].

The soil at depths of 2–14 m and 14–15 m exhibited variations in the moisture content, liquid limit, and plastic limit. This phenomenon indicates that these soils exhibited various characteristics. Between depths of 2 to 14 m, a significant variation in the natural water content, ranging from 12.41% to 75.88%, was observed. The range for water content to remain in liquid form is from 26.33% to 88.10%. These findings indicate a combination of wetness levels and a notable inclination toward water retention observed in clayey soils. The plastic limit numbers vary considerably, indicating varying levels of soil flexibility.

At a depth of 14–15 m, the soil appeared to be uniform, mainly due to the varying water content of the surrounding environment, which ranged from 21.36% to 47.61%. Furthermore, the plastic limits in this area ranged between 15.42% and 26.79%. Significant variations were observed in the liquid limit rates, from 31.54% to 80.39%. The soil at this deeper level was likely more stable and exhibited fewer prominent clay properties than the upper layers. Fig.4 displays the soil layer, average undrained shear strength, natural water content, liquid limit, plastic limit, and total unit weight of each layer.

5.2 Undrained Shear Strength Results

Unconfined compression and fruit sclerometer tests were conducted in the laboratory to obtain the undrained shear strength. The undrained shear strength obtained from the unconfined compression test ranges from 4.95 to 158.13 kPa. The stress-strain relationship of soil samples from BH-5 at various depths is presented in Fig.5, as this borehole is located in the middle of the sampling site. According to [22], it can be classified as very soft to very stiff clay. Fig. 6 and Fig. 7 display undrained shear strength from the unconfined compression test and fruit sclerometer test plotted with depth are presented, respectively.



(a)

(b)

(c)

Fig.4 Subsurface condition of the site (a) Undrained shear strength with depth, (b) Natural water content with depth, and (c) Total unit weight with depth

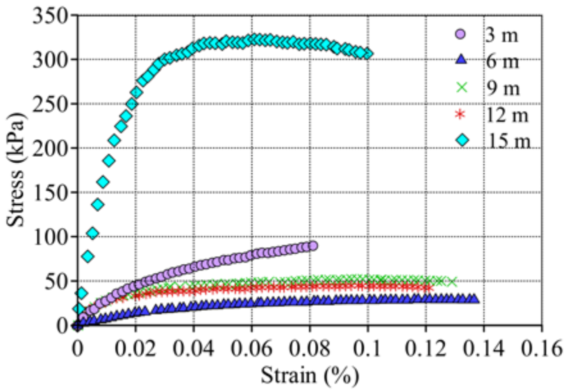


Fig.5 Stress-strain relationship from the unconfined compression test of samples from BH-5

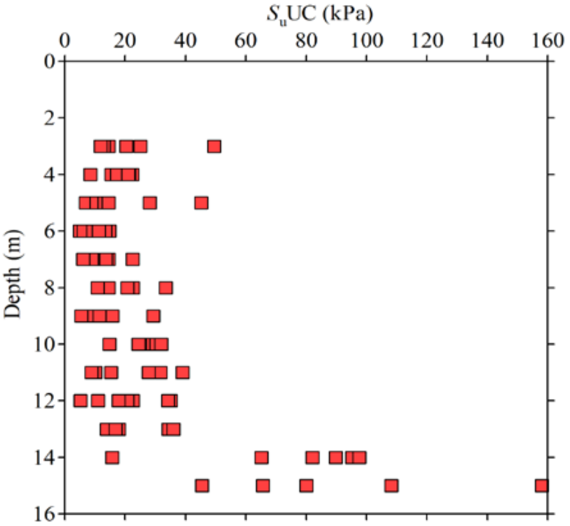


Fig.6 Unconfined compression test results

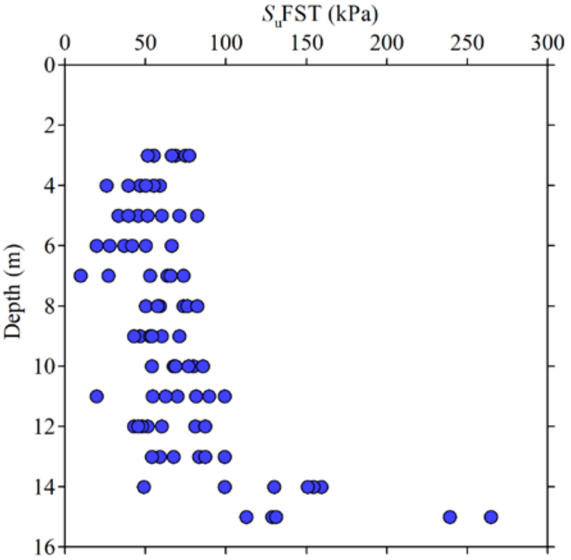


Fig.7 Fruit sclerometer test results

The undrained shear strength obtained from the fruit sclerometer ranges from 9.81 to 264.78 kPa. The test results from the fruit sclerometer exhibit a similar trend to those from the unconfined compression test.

This consistency across various tests demonstrates the potential usefulness of the fruit sclerometer in soil analysis. However, the fruit sclerometer test result revealed a greater value of undrained shear strength in all samples. Furthermore, this phenomenon confirmed the reliability of soil behavior at increasing depths.

5.3 Correlation Between the Fruit Sclerometer and Unconfined Compression Test

The undrained shear strength obtained from the fruit sclerometer was greater than that obtained from the unconfined compression test. Fig.8 displays the direct relationship between undrained shear strength obtained from the unconfined compression test and the fruit sclerometer test.

The relationship between undrained shear strength from the unconfined compression test and the fruit sclerometer test is presented in the following equation:

$$S_uUC = 0.4352S_uFST \tag{7}$$

The undrained shear strength obtained from the fruit sclerometer was approximately two times greater than that obtained from the UC test. Therefore, a recommended reduction parameter of 0.4352 was required to convert undrained shear strength from the fruit sclerometer test to the unconfined compression test of Bangkok clay. Furthermore, Bangkok clay in this study was grouped into two groups based on consistency: the first group had 72 samples of soft Bangkok clay, and the second group had 10 samples of stiff Bangkok clay. The undrained shear strength acquired from the unconfined compression and fruit sclerometer tests was then compared for each group. Fig. 9 and Fig.10 present the relationship between the undrained shear strength obtained from the unconfined compression test and the fruit sclerometer test of soft and stiff clay, respectively.

The unsatisfactory correlation between undrained shear strength from the unconfined compression test and the fruit sclerometer test of soft Bangkok clay is presented in Eq. 8.

$$S_uUC = 0.3062S_uFST \tag{8}$$

The measuring range of a model GY-3 with a head size of 11 mm is 0.5 – 12 ksc, which can be converted to 49.033 – 1176.798 kPa. According to Table. 1, fine-grained soil with undrained shear strength below 50 kPa, the minimum measuring limit of fruit sclerometer, can be classified as very soft, soft, and medium clay. The poor relationship and the minimum measuring limit of the fruit sclerometer indicated that no model of the fruit sclerometer should be used in measuring the soft clay, especially in the Bangkok clay with a depth from 0 – 14 m.

A better relationship was observed in stiff Bangkok clay with an R-square of 0.839. The relationship between the undrained shear strength of stiff Bangkok clay is presented in Eq. (9) and Fig.10, respectively.

$$S_uUC = 0.5575S_uFST \tag{9}$$

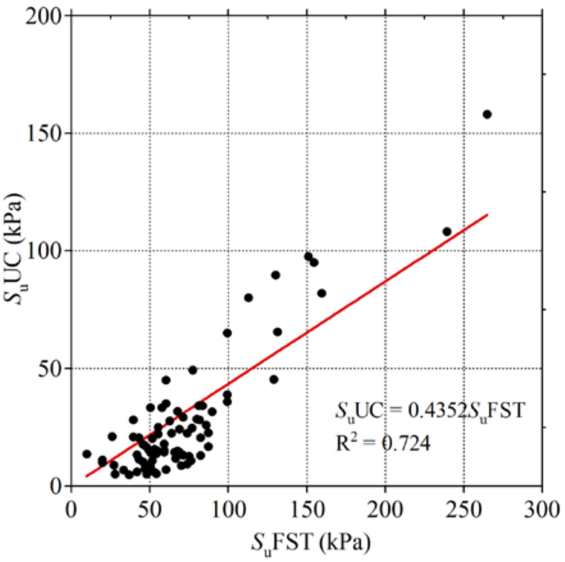


Fig.8 Relationship between S_u from FST and UC of Bangkok clay

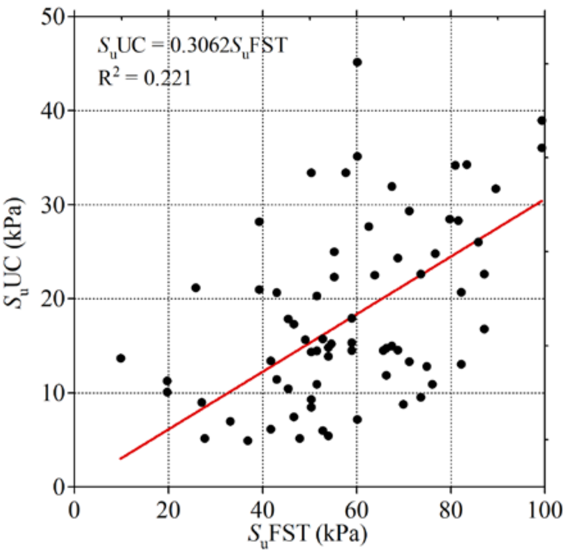


Fig.9 Unsatisfactory correlation between the Su of FST and UC of soft Bangkok clay

The results indicated that the undrained shear strength obtained from the fruit sclerometer test was approximately twice that acquired from the unconfined compression test in stiff Bangkok clay. However, it is noted that the results from the study provide a preliminary relationship between undrained shear strength from fruit sclerometer and conventional unconfined compression test. There is only one sampling location in the central part of Bangkok and there are only 10 stiff Bangkok clay sample using the study. A more comprehensive study is required to confirm this relationship for the other locations, and a greater number of samples is required for further research.

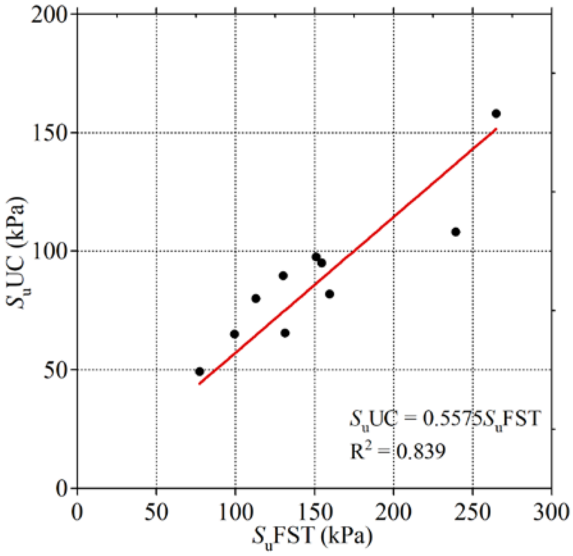


Fig.10 Relationship between the Su of FST and UC of stiff Bangkok clay

6. CONCLUSIONS

This study compared the undrained shear strength of Bangkok clay acquired by a fruit sclerometer and unconfined compression tests on 82 undisturbed Bangkok clay samples. The samples consist of 72 soft Bangkok clay samples, and the other 10 are stiff Bangkok clay samples. Three correlations of the undrained shear strength acquired from the unconfined compression and fruit sclerometer tests were constructed to verify the potential use of fruit sclerometer in the determination of undrained shear strength for Bangkok clay, soft Bangkok clay, and stiff Bangkok clay, respectively.

The minimum measuring limit of the fruit sclerometer is about 50 kPa, which is greater than that of the undrained shear strength of very soft, soft, and medium clay, resulting in the unsatisfactory correlation of undrained shear strength from FST and UC of soft Bangkok clay. Therefore, no model of the fruit sclerometer is recommended for measuring the soft clay, especially in the Bangkok clay with a depth from 0 – 14 m.

The undrained shear strength obtained from the fruit sclerometer was about two times greater than that obtained from the unconfined compression test, and The preliminary relationship with a reduction parameter of 0.5575 is recommended for the conversion of undrained shear strength from the FST to the UC in stiff Bangkok clay. The results prove the potential for using a fruit sclerometer to obtain the undrained shear strength of stiff Bangkok clay. Nevertheless, a more comprehensive study is required to confirm this relationship for the other locations, and a more significant number of samples is required for further research.

The direct reading scale in kilograms per square centimeter (ksc) of fruit sclerometer makes it ideal for quick and easy evaluations of undrained shear strength in construction projects. However, it is essential to note that a fruit sclerometer is a primitive instrument subject to many errors. It should not replace laboratory testing and field analysis or be used to produce foundation design data.

7. ACKNOWLEDGMENTS

Allowing soil sampling locations from The Research and Analysis division, the Civil Engineering department, and the State Railway of Thailand is highly appreciated.

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