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Geotechnical characteristics of peat soil in OKI area, South Sumatra, Indonesia

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Abstract

Peat soil is characterized by a high-water table, significant compressibility, and low bearing capacity. Due to these characteristics, precise information about the physical, hydraulic, and mechanical properties of peat soil is required for the successful evaluation of suitability and improvement techniques in determining safe infrastructure through field and laboratory investigations. In this paper, soil properties, permeability, vane shear tests, and triaxial tests were conducted on peat soil at the locations of Kayu Agung, Pedamaran, Pedamaran Timur, and Ogan Komering Ilir (OKI), South Sumatra. Based on the samples obtained from the borings, the average thickness of peat soil was categorized as very deep, except for the location in Pedamaran, which was extremely deep. The moisture content in the OKI area ranged from 350% to 635%, with the largest in the Pedamaran Timur district. Furthermore, samples from OKI were classified as sapric peat soil, with ash content ranging from 19.71% to 39.24%, showing high ash and moderately acidic. The correlation of various geotechnical properties of peat soil was very close, and new equations were developed. Based on the results of the Vane Shear Test and Triaxial Unconsolidated Undrained test, the consistency of the soil at each location point was found to be very soft. These results provide valuable information for identifying appropriate design parameters and establishing correlations needed for evaluating peat soil.

Keywords: Peat soil, Physical properties, Vane shear test, Sapric peat

1. Introduction

Peat soil is characterized by a high-water table, significant compressibility, and low bearing capacity. The data from the Center for Agricultural Land Resources (BBSDLP), Ministry of Agriculture in 2019, shows that Ogan Komering Ilir (OKI) district has the largest peat soil area in South Sumatra province. The soil covers approximately an area of 647,766 Ha, (57.68%), followed by Musi Banyuasin and Banyuasin districts with 239,455 Ha (21.32%) and 147,880 Ha (13.17%), respectively [1]. Peat thickness is divided into several categories; shallow/D1 (50 - <100 cm), medium/D2 (100 - <200 cm), deep/D3 (200 - <300 cm), very deep/D4 (300 - <500 cm), extremely deep/D5 (500 - <700 cm), and extreme very deep/D6 (≥700 cm). From this area, the OKI region is dominated by the very deep category (D4) with a thickness of 300 to 500cm covering 381,406 Ha, and there is an extremely deep category (D5), ranging between 500 and 700cm, at 49,933 Ha.

The extensive distribution of peat soil, particularly in OKI, presents a challenge in planning infrastructure economically, safely, and comfortably. During planning, infrastructure that is safe against the stability of the soil fill should be included in the requirement. Generally, peat soil is characterized by a high-water table causing elevated compressibility and very low bearing capacity, passing through a unique process of organic matter decomposition that can lead to prolonged secondary consolidation. Therefore, the successful evaluation of soil suitability and improvement techniques in determining safe construction foundations requires precise information about the physical, hydraulic, and mechanical properties of peat soil through field and laboratory investigations.

The determination of soil physical properties includes soil volume unit weight (γ), moisture content (ω), Specific gravity (Gs), as well as organic, ash, and fiber contents. The hydraulic properties are also determined using various factors, including permeability, compressibility, or consolidation parameters. Meanwhile, the shear strength parameter of soil, which significantly affects the bearing capacity and safety of infrastructure, is carried out with the Triaxial test. In the field, it is carried out with the Vane Shear Test (VST), including the Standard Penetration Test (SPT), and Cone Penetration Test (CPT) tests, which are based on correlated values for determining soil parameters.

Several studies have been conducted to determine the evaluation of field and laboratory tests. For example, a study on the characteristics and engineering properties of peat soil in Southern Massachusetts addressed the requirement for constructing sheet piles, embankments, and levees on Cranberry bog soils, as well as retention ponds containing deep peat soil sediment [2]. Another study focused on compressible behavior and engineering properties of tropical peat soil in Malaysia, consisting of fabric (raw/young), hemic (semi-mature,) and sapric (mature/old) types with organic content of approximately 70 – 90% and their interpretation on the decline of constructions loaded for long periods [3]. Moreover, other studies include the Geotechnical exploration of peat soil in Sabah [4] and Parit Nipah [5] Malaysia, the Characteristics of fibrous peat soil in Palangkaraya [6], and the investigation of the physical properties of peat soil in the Western Province, Sri Lanka [7]. Studies on the disturbance of sampling on peat soil parameters were also investigated [8,9], including characteristics in South Sumatra, namely in Ogan Ilir [10] and Banyuasin [11]. This study presents the results of peat soil investigations in OKI, specifically Kayu Agung, Pedamaran, and Pedamaran Timur districts, which include the physical and mechanical properties of soil

2. Materials and methods

The determination of soil sampling points based on the distribution map obtained is shown in Figure 1, with coordinates presented in Table 1. Sampling at each location was carried out in different districts.

Figure 1 Location of testing and sampling points.

Table 1 Coordinates and location of each sampling location point.

Location	Coordinate		District
	Latitude	Longitude	
I	-3.399434	104.877389	Kayu Agung
II	-3.434889	104.897889	Pedamaran
III	-3.503472	104.955833	Pedamaran Timur

Before Undisturbed soil sampling, manual drilling was carried out to identify the soil layer and determine the depth of peat soil. The surrounding area was cleaned and dug to the depth of peat soil using manual drilling before sample collection. Subsequently, soil sample was taken using a cylindrical tube with a diameter of 10 inches and sampling was carried out at 2 adjacent points. A large diameter tube was used due to the presence of numerous fibers in peat soil, ensuring that the mechanical properties remained unchanged. Additionally, soil shear strength was determined by field VST following the ASTM D 2573-72 standard [12].

Soil samples were brought to the laboratory for testing several properties including Moisture Content (ASTM D-2216-19) [13], Sieve Analysis (ASTM D 421) [14], Organic Content, Ash Content (ASTM D: 2974-20) [15], Fiber Content (ASTM D: 1997-20) [16], and Degree of Acidity (ASTM D: 2976-22) [17]. Moreover, testing of soil hydraulic properties was carried out using the Permeability Test (ASTM D 5084) [18].

3. Results and Discussion

3.1 Field testing results

Based on the results of the manual drilling, the average thickness of peat soil was categorized as very deep, D4 (300 cm – 500 cm). However, location II in the Pedamaran district, with >900cm, was categorized as extremely very deep, D6 (>700 cm). As shown in Table 2, peat soil in the field was found to be very soft, with an average shear strength of < 15 kPa and below 10 kPa. The shear strength of the OKI peat soil was slightly lower compared to sapric in Johor Malaysia, which ranged from 13 to 22 kPa [19].

Table 2 Average manual drill and field vane shear test results at each location.

Location	Peat soil depth (m)	Field Soil Shear Strength	
		kPa	kg/cm^2
I	3.90	8.632	0.0880
II	9.00	7.636	0.0779
III	4.00	11.205	0.1143

3.2 Soil properties of peat

Initial identification of peat soil was performed based on the properties index, which included moisture content, soil density, fiber content, ash content, soil organic content, acidity, and soil dry density, as presented in Table 3. The soil classification was based on the degree of humification (von Post scale), ash content, fiber content, and acidity.

Table 3 Peat soil properties and hydraulic test results

Physical properties	Unit	Value		
		Location I	Location II	Location III
Moisture Content (w)	%	359.99	394.47	635.11
Density (ρ_b)	g/cm^3	1.223	1.127	1.243
Fiber Content	%	10.45	15.24	26.56
Ash Content	%	24.98	19.71	22.50
Organic Content	%	75.02	80.29	77.50
pH Soil	-	5	4	5
Dry Density (ρ_d)	kg/m^3	265.88	227.92	169.09
Soil Permeability	cm/s	4.357E-04	3.502E-04	2.244E-04
Classification (ASTM D4427) [20]	-	sapric peat	sapric peat	sapric peat
MacFarlane and Radforth Classification [21]	-	Amorphous peat	Amorphous peat	Fibrous peat

Table 3 shows the physical properties of three different peat soil samples collected from locations I to III. The results showed that the moisture content in the OKI area ranged from 350% - 635%, with the largest in location II, particularly in the Pedamaran Timur district. Peat soil density ranged from 1.12 g/cm^3 - 1.24 g/cm^3 and fiber content was 17.81% - 38.03%. Generally, fiber content of <33% is classified as sapric peat soil [20], [22] and according to the Alaska guide the soil degree humidity range is H7 - H10 [23]. Sapric peat soil was decomposed material, with the majority of the original plant fibers being lost, and very dark gray to black [24]. MacFarlane and Radforth [21] stated that peat soil with fiber content ≥ 20% was identified as Fibrous peat, while < 20% is Amorphous granular. From Table 3, peat soil in Kayu Agung and Pedamaran was classified as Amorphous granular peat, while Pedamaran Timur location consisted of Fibrous.

The ash content of peat soil ranged from from 19.71% - 24.98%, showing that the three locations were categorized as high because the value obtained was > 15%. Based on the acidity test, it was concluded that the peat was moderately acidic with a pH between 4 and 5. Subsequently, the permeability value of peat soil was in the range of 10^{-4} cm/s, showing that the water suction properties are significantly high.

3.3 Correlation between peat soil properties

Previous studies have established the correlations between soil properties by plotting experimental/testing values against calculated results. Dry density (ρ_d), specific gravity (Gs), and peat organic content (OC) have also been analyzed. In this study, Figure 2 illustrates the direct relationship between in-situ dry density (ρ_d) and in-situ moisture content (ω) for OKI peat. Based on this correlation, a lower soil moisture content, results in reduced dry density, with the equation (red line) $y_{(dry\ density)} = 19.652x_{(moisture\ content)}^{-0.739}$ or $\rho_d = 19.652\omega^{-0.739}$. This equation is compared with the curve formed (green line) from the empirical equation presented by Duraisamy et al. $\rho d = 22.422\omega^{-0.804}$ [3] and Zimar et al. [7] (blue line) for Malaysian and New Zealand peat which is $\rho_d = 0.872(\omega + 0.317)^{-0.982}$. The test results and calculations of the empirical equation showed a good fit, showing the application of the equation to estimate the dry density of peat soil in the OKI area.

The relationship between soil density (ρ_b) and OC is shown in Figure 3, as indicated by the red line, following the correlation equation $y_{(OC)} = 87.288x_{(density)}^{-1.62}$ or $OC = 87.288 \times \rho_b^{-1.62}$. The equation followed the relationship between organic content and peat soil density (blue line) proposed by Zimar et al. [7] for peat in West Malaysia, $OC = 59.836 \times \rho_b^{-4.64}$. Therefore, the equation formed from the test results is used to predict the organic content of peat in the OKI area.

3.4 Mechanical properties of peat soil

The mechanical properties were examined to obtain shear strength parameters, namely inner shear angle (ϕ) and cohesion (c). The evaluation of shear strength (τ) in soil samples included triaxial testing conducted under Unconsolidated Undrained (UU) conditions. Each sample was tested by applying different cell pressures and the strain rate used was 0.5 mm/min. The results of the triaxial UU (TUU) test were interpreted in the form of a stress circle called the Mohr-Coulomb circle, as shown in Figure 4.

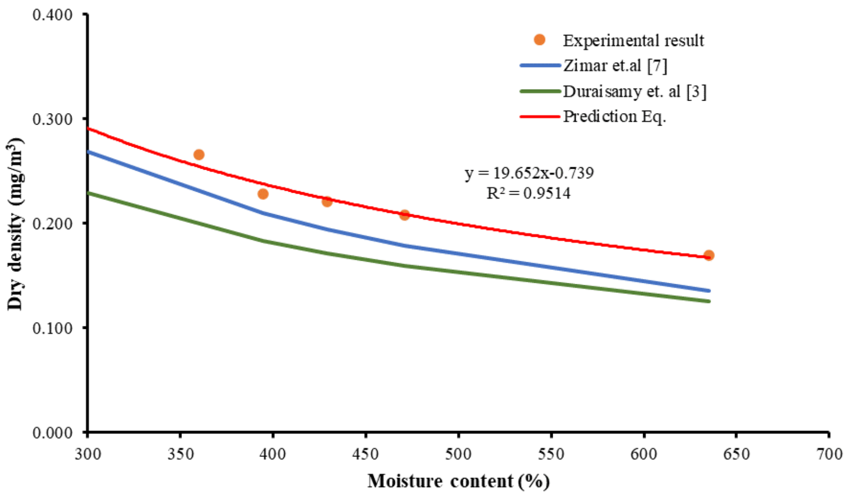

Figure 2 Relationship between soil dry density and moisture content.

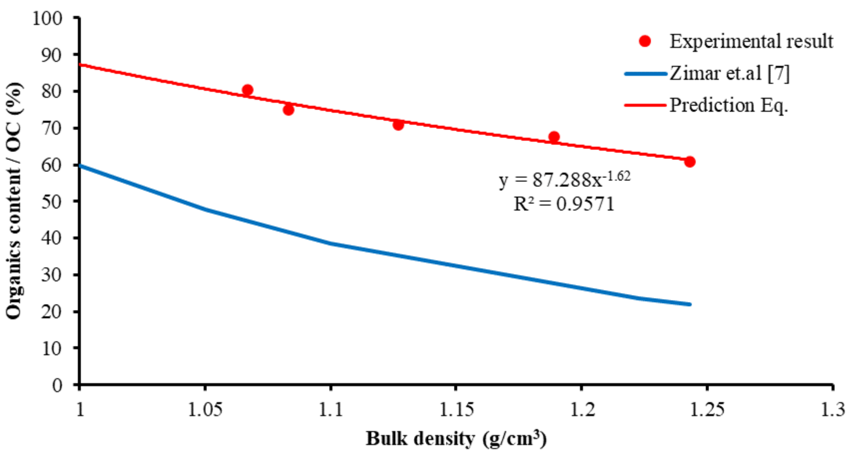

Figure 3 Relationship between organic content and soil density.

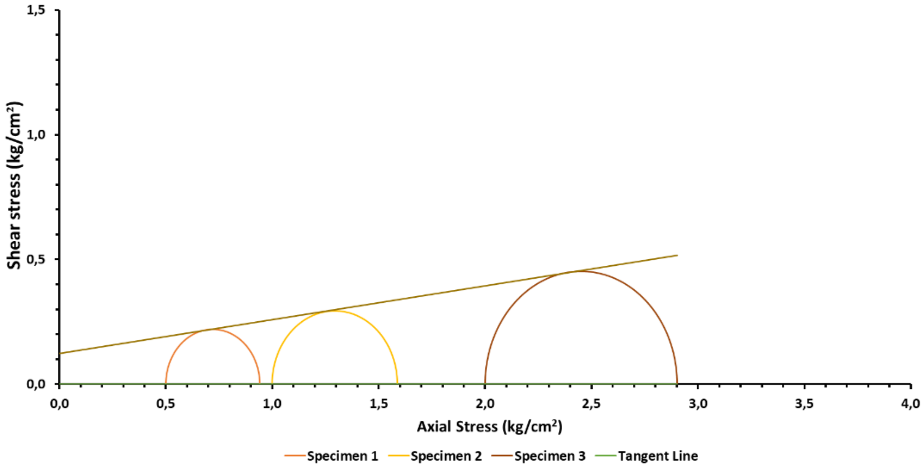

Figure 4 Mohr-Coulomb graph on one of the samples.

The results of the shear strength analysis on all soil samples are shown in Table 4.

Table 4 Soil Shear Strength Value in Triaxial UU Test.

Location	Point	Cohesion (c) (kg/cm^2)	Inner friction angle (ϕ) (deg)	Teg Normal (σ) (kg/cm^2)	Shear Strength (τ) (kg/cm^2)	Consistency
I	1	0.0711	6.3268	0.0856	0.0806	very soft
	2	0.0909	6.8426	0.0856	0.1012	
	Average	0.0810	6.5847	0.0856	0.0909	
II	1	0.0527	1.7427	0.1223	0.0564	very soft
	2	0.0817	0.6389	0.1223	0.0830	
	Average	0.0672	1.1908	0.1223	0.0697	
III	1	0.0922	6.7301	0.1243	0.1069	very soft
	2	0.1141	0.2361	0.1243	0.1146	
	Average	0.1032	3.4831	0.1243	0.1107	

The triaxial test results at each sample point showed that the soil consistency was very soft, with shear strength values ranging from 0.0697 kg/cm^2 - 0.1107 kg/cm^2 or 6.835 - 10.860 kPa. The mechanical properties of OKI peat soil are similar to tropical soil in Pekan District, Pahang, West Malaysia [25].

3.5 Correlation of field and laboratory shear strength test results

The results of the VST and TUU tests for each location point at the same depth are shown in Figure 5. Based on the figure, shear strength testing with the same specimen and various tools produced values that were not extremely different. The average triaxial shear strength value was slightly lower than the results of the VST. However, both tests were carried out without water flowing from and into the sample.

From the linear regression analysis graph, the equation of the relationship between the two shear strength values is $y_{(\text{triaxial shear strength})} = 0.77x_{(\text{vane shear strength})} + 1.4922$ or TUU = 0.77VST + 1.4922. Furthermore, the coefficient of determination, $R^2 = 0.8605$ or correlation coefficient R = 0.9276, shows that the correlation relationship between the two tests is acceptable.

A similar study that has been carried out produced a comparison of the shear strength values from field VST and Unconfined Compressive Strength (UCS) tests. The results obtained were that the undrained shear strength (Su) values from the field vane shear test were higher than the UCS test results which formed the equation Su(UCS) = 0.8254Su(FVST) + 0.0418 [26]. In this study, the shear strength value in the TUU test was 8% lower than the field VST. The difference in results could be attributed to several factors, including the varied disturbance experienced by each test sample, and changes in soil conditions in the field when brought to the laboratory, the ability of tools with several calibrations and capacities [27].

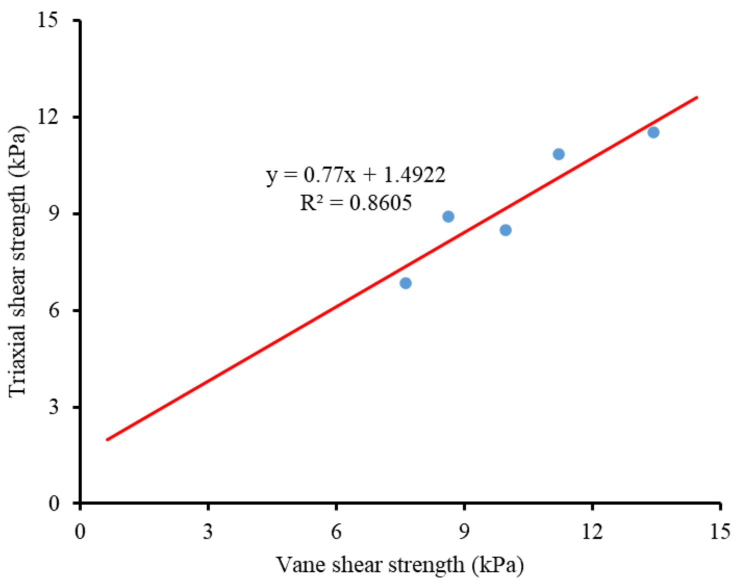

Figure 5 Relationship graph of shear strength values of Vane shear and Triaxial UU test results.

4. Conclusion

In conclusion, this study assessed the OKI peat soil to determine the geotechnical characteristics and evaluate their correlation. The moisture content of peat soils in the OKI area ranged from 350% - 635%, with Pedamaran Timur being the largest. OKI peat soil is classified as hemic and sapric peat, with Kayu Agung and Pedamaran Timur locations including Fibrous peat. The correlation between dry density (ρ_d) of the soil and moisture content (ω) was $\rho_d = 19.652\omega^{-0.739}$, while the correlation between OC and ρ_b was OC = $87.288\rho_b^{-1.62}$. The OKI peat soil consistency was found to be very soft.

5. Acknowledgment

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6. References

[1] Coordinator of the South Sumatra Regional Peat Restoration Team. Condition of the peat ecosystem of South Sumatra province. Palembang; 2021.

[2] Elsayed A, Paikowsky S, Kurup P. Characteristics and engineering properties of peaty soil underlying cranberry bogs. In: Geo-Frontiers 2011. Reston, VA: American Society of Civil Engineers; 2011. p. 2812–2821.

[3] Duraisamy Y, Huat BBK, Aziz AA. Engineering properties and compressibility behavior of tropical peat soil. Am J Appl Sci. 2007;4(10):768–773.

[4] Zainorabidin A, Musa H, Mohamad B. Engineering properties of integrated tropical peat soil in Malaysia. J Geotech Eng. 2017;22(2):457–466.

[5] Tong TI, Ling NL. Characteristics and correlation of the index properties peat soil : Parit Nipah. J Appl Sci Agric. 2015;10(105):19–23.

[6] Estu Yulianto F, Harwadi F, Rusdiansyahi. Characteristics of Palangkaraya fibrous peat. MATEC Web Conf. 2019;276:05008.

[7] Zimar AMZ, Nasvi MCM, Robert D, Jayakody S, Jayarathne JRRN, Smith J V. Experimental investigation on physical properties of peats in Western province, Sri Lanka. In: 10th Int Conf on Geotechnique, Construction Materials and Environment. Melbourne, Australia: Geomate; 2020. p. 1–7.

[8] Johari NN, Bakar I, Aziz MHA. Consolidation Parameters of Reconstituted Peat Soil: Oedometer Testing. Appl Mech Mater. 2015;773–774:1466–1470.

[9] Yamazoe N, Tanaka H, Ogino T, Nishimura S. Mechanism of sampling disturbance for peat ground and its influence on mechanical properties. Soils and Found. 2023;63(5):101361.

[10] Sutejoa Y, Dewi R, Hastuti Y, Rustam RK. Engineering properties of peat in Ogan Ilir regency. J Teknol. 2016;78(7–3):61-69.

[11] Sutejo Y, Saggaff A, Rahayu W, Hanafiah. hydraulic conductivity and compressibility characteristics of fibrous peat. IOP Conf Ser Mater Sci Eng. 2019;620(1):012053.

[12] ASTM D2573-08. Field vane shear test in cohesive soil. Annual Book of ASTM Standards. ASTM International; 2008. p. 1–8.

[13] ASTM D2216-19. Standard test methods for laboratory determination of water (moisture) Content of Soil and Rock by Mass. ASTM International; 2019. p. 1–7.

[14] ASTM D6913/D6913M − 17. Standard test methods for particle-size distribution (gradation) of soils using sieve analysis. Annual Book of ASTM Standards. ASTM International; 2017.

[15] ASTM D 2974-20. Standard test methods for moisture, ash, and organic matter of peat and other organic soils. ASTM International; 2020. p. 1–5.

[16] ASTM D1997-20. Standard test method for laboratory determination of the fiber content of peat. Annual Book of ASTM Standards. ASTM International; 2020. p. 1–4.

[17] ASTM D2976-22. Standard test method for pH of peat materials. ASTM International; 2022. p. 1–4.

[18] ASTM D5084. Standard test methods for measurement of hydraulic conductivity of saturated porous materials using a flexible wall permeameter. ASTM International; 2016. p. 1–24.

[19] Wahab N, Khaidir M, Talib A, Latifah N, Madun A, Pakir F. Comparative study of peat properties in Johore Malaysia. Asia Pac J Sci Technol. 2023;28(4):1–8.

[20] D 4427–92 (Reapproved 2002). Standard classification of peat samples by laboratory testing. Annual Book of ASTM Standards. ASTM International; 2002. p. 1–3.

[21] MacFarlane IC. Physical behaviour of peat derivatives under compression. Internal Report (National Research Council of Canada), NRC Publications; 1968.

[22] Zulkifley MTM, Ng TF, Raj JK, Hashim R, Ghani A, Shuib MK, et al. Definitions and engineering classifications of tropical lowland peats. Bull Eng Geol Environ. 2013;72(3–4):547–553.

[23] Alaska Department of Transportation and Public Facilities. Alaska Guide to Description and Classification of Peat and Organic Soil. Juneau: Alaska Department of Transportation and Public Facilities; 2007. p. 1–9.

[24] Huat BBK, Kazemian S, Prasad A, Barghchi M. A study of the compressibility behavior of peat stabilized by DMM: Lab model and FE analysis. Sci Res Essays. 2011;6(1):196–204.

[25] Wahab A, Hasan M, Kusin FM, Embong Z, Zaman QU, Babar ZU, et al. Physical properties of undisturbed tropical peat soil at Pekan district, Pahang, West Malaysia. Int J Integr Eng. 2022;14(4):403–414.

[26] Pandey S, Lamichhane A, Acharya I. P. Evaluating The Undrained Shear Strength of Kalimati Soil Using Field Vane And Unconfined Compression Test; A Study on Applicability of Bjerrum's Correction Factor. J Adv Coll Eng Manag. 2023;8(1):59–68.

[27] Ayadat T. Determination of the undrained shear strength of sensitive clay using some laboratory soil data. Stud Eng Technol. 2021;8(1):14.