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Undrained Shear Strength of Beaufort Peat: Behavioural Analysis

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ABSTRACT

Peat soil is a highly organic surface layer primarily derived from plant remains. Peat, on the other hand, is the subsurface of wetland systems and consists of unconsolidated superficial layers with a high content of non-crystalline colloid (humus). It is generally dark brown to black, has an organic odour, and a spongy consistency. Peat soil is commonly found in swamp areas and is a partly decomposed organic layer of soil generated from plant matter that accumulates under conditions of waterlogging, high acidity, oxygen scarcity, and nutritional deficiency. Peat soils typically have a low shear strength ranging from 5 to 20 kPa, high compressibility from 0.9 to 1.5, and a high moisture content exceeding 100%. Peat also exhibits significant deformation, varied magnitudes, and specific structures, with an organic matter content exceeding 75%. The investigation of peat soil involves Unconsolidated Undrained Triaxial Tests, where parameters are explored under varying Total Stress of 13kPa, 25kPa, 50kPa, and 100kPa, with samples taken from three different locations: Kpt-L1, Kpt-L2, and Kpt-L3. The findings suggest that different peat soil locations yield varying results due to differences in composition. The Triaxial Test Unconsolidated Undrained was used for the peat soil in Sabah. This was the first time this test was conducted by a researcher at Klias Peat Swamp Field Centre in Beaufort, Sabah. Unconsolidated Undrained and Consolidated Undrained tests are not significant since the moisture content of peat soil is high.

1. Introduction

Peat soils occur in all regions, they were more common in the Northern Hemisphere's temperate and frigid zones [1]. Table 1 shows the region covered by peatlands. North America has covered 117.8 M ha (million hectare) peat soils which was the largest among the other region and followed by Europe which was 75.0 M ha while 23.5 M ha in Asia and the Far East, 12.2 M ha peatlands in Africa, 7.4 M ha in Latin America, 4.1 M ha in Australia [2]. Latest research [3] found that 1,689,171 km2 was in the tropical peatland zones. 1.0 percent annual reduction in forest cover throughout insular

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Southeast Asia (including the Indonesian half of New Guinea), peat swamp forests clearly experienced the highest deforestation rates at an average annual rate of 2.2% with main change trajectories to secondary vegetation and plantations. Total land in Malaysia was covered by peat soil about 2.5 million ha (7.74%) [4]. About 30% of the peatland areas in Malaysia are in a Permanent Forest Reserve or Fully Protected Area [5].

Table 1
Region covered by Peatland

Regions	Area (ha)
Africa	12.2 M
Latin America	7.4 M
Asia and the Far east	23.5 M
Australia	4.1 M
North America	117.8 M
Europe	75.0 M
Total	240 M

The Triaxial Shear Test was commonly employed to assess the mechanical characteristics of various deformable solids, with a particular emphasis on materials such as soil (e.g., sand, clay), rock, and other granular substances or powders [6]. This testing method encompasses several variations, including Unconsolidated Undrained (UU), Consolidated Undrained (CU), and Consolidated Drained (CD) triaxial tests. For this research, it will only focus on conducting UU test due to the aim to obtain a result that resembles the on-site conditions in which the peat soil would be in an unconsolidated condition due to the depth of samples that would be taken hence consolidation would not occur and the undrained condition of peat as it tends to hold on to moisture due to its high organic content [7]. In addition, UU test was defined where loads were applied quickly, and the sample was not allowed to consolidate during the testing [8]. The sample was Totally stressed at a constant rate [9]. The objective of this study is to investigate the shear strength of Beaufort's Peat Soils using Triaxial Test Unconsolidated Undrained. Additionally, this study aims to generate a new dataset that can be utilized for future development, particularly in understanding Beaufort's Peat Soils. This testing and result of this study will be fulfilled the gap of research study, since there is no researcher have been used the Unconsolidated Undrained (UU) Triaxial test (Figure 1). This studies results will contribute to the industry and help the design engineer gain more information about dealing with peat soils in Beaufort. This information will significantly determine the suitability of the foundation, piling, and other infrastructure during the design stage.

Fig. 1. Triaxial Test – Unconsolidated Undrained set up

2. Methodology

According to ASTM D2850-23[10], the procedure can be broken down into five parts. Firstly, collect a representative sample of the peat soil via peat sampler (50mm diameter by 100mm height). Soil sampled via peat sampler would be called an undisturbed soil sample, and shear strength tests should be conducted on undisturbed soil samples as they would better reflect the soil structure at the site compared to remoulded soil samples [11]. Then, place the undisturbed soil sample into the triaxial chamber after wrapping it with a membrane and securing the O-rings in place. The chamber was a device that allows the application of confining pressure to the soil specimen. Thirdly, increase the total stress to the desired values (13kPa, 25kPa, 50kPa, and 100kPa) by applying cell pressure around the specimen in the triaxial cell, the selected values in this study are intended to simulate real-world scenarios, replicating the typical field conditions that soils might experience [12]. This approach ensures that the findings are applicable to practical geotechnical engineering contexts, where understanding soil behaviour under various stress conditions is crucial for designing stable and safe structures [13]. The drainage valve remains closed throughout the test, preventing the consolidation of the specimen. Once the confining pressure was applied, the specimen was subjected to shearing by applying a constant rate of undrained compression loading conditions (0.1mm/minute) [14]. During this stage, only the total stresses were controlled and recorded. The test runs for up to 3 hours for each total stress. Lastly, record the applied stresses, Axial Strain, and pore water pressure during the test. These measurements were used to determine the shear strength of the soil [15]

3. Results

In this section will discuss the comparison of results from three different sampling locations in the Klias Peat area, Beaufort, Sabah, labeled as Kpt-L1, Kpt-L2, and Kpt-L3. These locations represent distinct sampling points within the Klias Peat region. The study focuses on comparing the undrained shear strength, which is a measure of the soil's resistance to shear deformation without drainage, across the samples from these three locations. By analyzing the results from Kpt-L1, Kpt-L2, and Kpt-L3, the researchers aim to understand the variations in peat soil properties within the Klias Peat area. This comparison can help reveal the influence of local environmental factors on soil behavior, which is crucial for geotechnical engineering and land-use planning in the region [16].

3.1 Deviator Stress (kPa) vs Axial Strain (%)

The graph in Figure 3 shows the relationship between Deviator Stress (kPa) and Axial Strain (%), specifically at Kpt-L1. Overall, the graphs demonstrate an upward trend, with each graph having its own maximum failure limit in terms of Deviator Stress (kPa) against Axial Strain (%). The statement implies that an increase in Total Stress rate leads to a higher stress strain rate due to the associated stress-strain relationship. The 100kPa Total Stresses produced the highest Deviator Stress among the other loads, with a value of 374.62kPa and an Axial Strain of 20.70% - even though the graph shows it started at a lower value due to compression force during the sample preparation before testing [17]. The 50kPa Total Stresses was the second-highest Deviator Stress at 294.84kPa and an Axial Strain of 20.00%, followed by the 25kPa and 13kPa in the Kpt-L1 graph. The Deviator Stress of 100kPa Total Stress in Klias Beaufort, Sabah (Kpt-L1) was the highest when compared to the results of a previous study conducted in Bukau Api-Api, Sabah, which only recorded 92.03kPa [18]. According to the graph in Figure 3 it can be concluded that the Total Stress of 13kPa was the lowest in terms of Deviator Stress and Axial Strain in Kpt-L1.

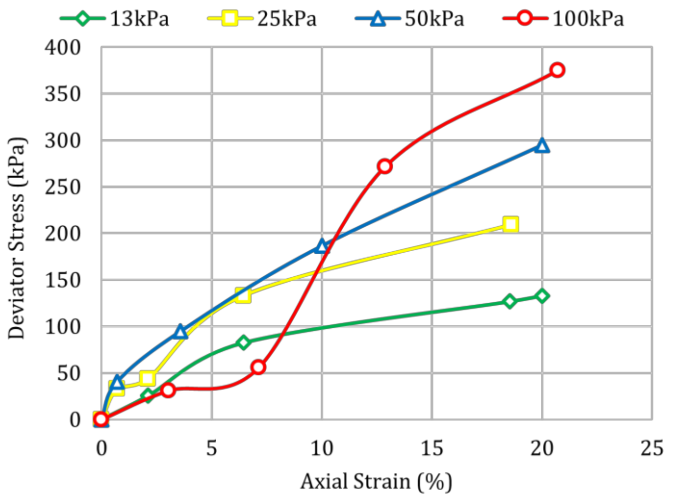

Fig. 3. The Kpt-L1 graph of Deviator Stress (kPa) to Axial Strain (%)

The graph presented in Figure 4 of the Kpt-L2 results between Deviator Stress (kPa) and Axial Strain (%) illustrates an upward trend. Each graph has its own maximum failure limit in terms of Deviator Stress (kPa) against Axial Strain (%). The 100kPa Total Stresses generated the highest deviator stress, with a value of 131.45kPa. However, for the Axial Strain (%), 13kPa Total Stress had the highest value, which was 20% compared to the others, which was 18.9% for 100kPa. Both 50kPa and 13kPa have 19.3% for Axial Strain (%), which can be viewed from the graph result for Kpt-L2. Notably, the shear strength of the sample Kpt-L2 degraded during the static load, which was evident from the increasing triaxial test under unconsolidated undrained by movement increasing at

0.01mm/minute. The percentage of Axial Strain (19.3%) with Total Stress 13kPa in Kpt-L2 was almost the same as Parit Nipah and Penor Axial Strain, which was 20% [19]. These results affirm that the higher Deviator Stress (kPa) does not necessarily give higher Axial Strain (%). Furthermore, the graph also indicates that Kpt-L1 and Kpt-L3 have lower initial tangents compared to Kpt-L2, likely due to differences in peat soil density. This could be because denser soils have particles packed more tightly, leading to greater interparticle friction and resistance to deformation. This observation is consistent with the behaviour seen during soil sampling.

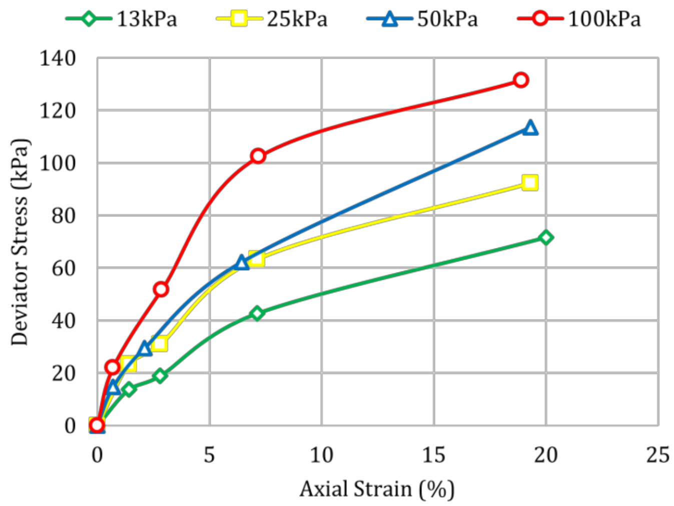

Fig. 4. The Kpt-L2 graph of Deviator Stress (kPa) to Axial Strain (%)

Based on Figure 5 Kpt-L3 analysis, it was found that Parit Nipah peat has varying Deviator Stress depending on the Total Stress and Axial Strain [20]. The Total Stress of 100kPa resulted in the highest deviator stress, while 13kPa Total Stress had the lowest Deviator Stress of approximately 106.8kPa and Axial Strain of 20%. Kpt-L3 results indicate that the Total Stress for 13kPa has a greater Deviator Stress of 106.8kPa compared to 100kPa Total Stress Parit Nipah peat's 90kPa [21]. The graph trend in Figure 5 showed an uptrend, indicating that each Total Stress reaches its maximum failure limit before changing direction downwards during testing. The composition of the peat plays a significant role in the Deviator Stress results, with Kpt-L3 peat being found to be more compact during sampling, due to the forecasted sunny day. Various factors, such as the magnitude of applied load, soil composition, past stress history, void ratio, and the way stress was applied, can influence the magnitude of strain in soil, as stated by Anggraini [22]. Higher moisture content and decomposition result in lower shear strength, while higher mineral content increases shear strength, according to [23]. The fibrous peat has an open structure, with the interstices filled with a secondary structural arrangement of fine non-woody fibrous elements [24]. Additionally, the depth of peat also plays a significant role in determining the shear strength of peat soil. It can be concluded that the Deviator Stress of peat soil differs depending on the area of study and condition of the soil.

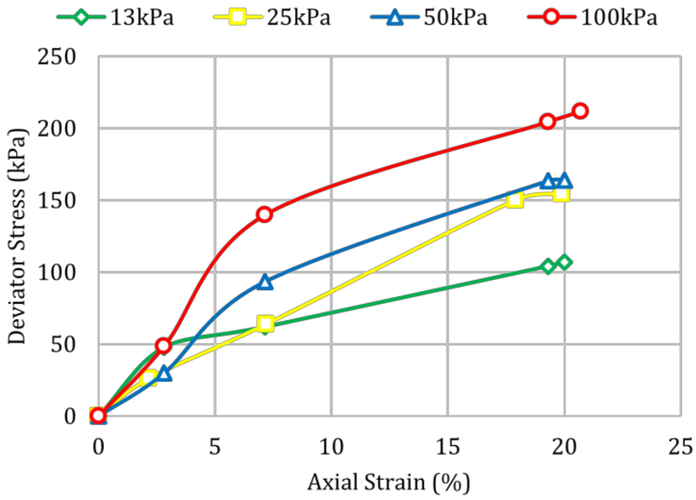

Fig. 5. The Kpt-L3 graph of Deviator Stress (kPa) to Axial Strain (%)

3.2 Mohr Circle of Deviator Stress (kPa) vs Axial Strain (%)

Table 2 presents the result of the Cohesion, C and Friction Angle, Ø and Figure 6 shows the typical Mohr Circle of Deviator Stress (kPa) to Normal Stress (kPa) for the results of Kpt-L1, Kpt-L2, and Kpt-L3 after undergoing a Triaxial Test - Unconsolidated Undrained, with varying Total stress levels applied. The table details the cohesion and friction angle for each test result. Based on the Mohr Circle, Kpt-L1 recorded a cohesion of 25kPa with a friction angle of 20.84˚. Kpt-L2 exhibited a cohesion of 12kPa and a friction angle of 11.68˚, the lowest values among the three samples. Kpt-L3 recorded a cohesion of 20kPa with a friction angle of 15.25˚. These results suggest variability in cohesion and friction angles due to differences in composition among the peat soil samples collected from three distinct areas. It can be concluded that peat soil generally has a higher friction angle compared to clay, which typically has a friction angle of about 5˚ [25]. This observation emphasizes the unique properties of peat soil and underscores the importance of considering composition variations in different regions when assessing cohesion and friction angle.

Table 2
Region covered by Peatland

	L1		L2		L3	
Cohesion, C	25kPa		12kPa		20kPa	
Friction angle, Ø	20.84		11.68		15.25	
	Failure Envelope					
Deviator Stress (kPa)	0	197	0	150	0	165
Normal Stress (kPa)	25	100	12	43	20	65

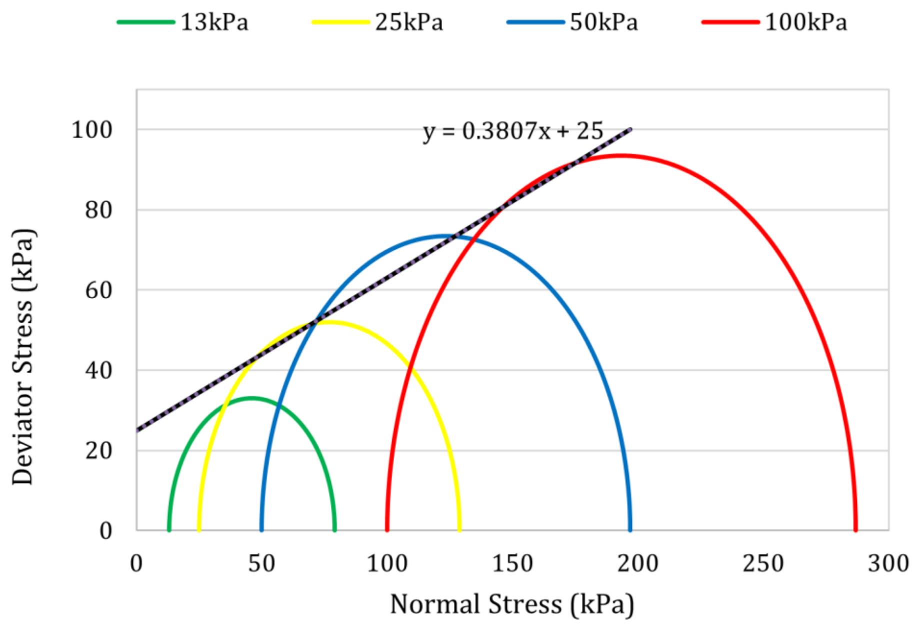

Fig. 6. The typical Mohr Circle of Deviator Stress (kPa) to Normal Stress (kPa)

4. Conclusions

The objective of this research has been successfully achieved through the conducted testing and the discussion of results. It can be concluded that different locations will produce different outcomes due to the varying composition of peat soils. Comparing the current results of the Triaxial testing of Unconsolidated Undrained with the past study of Consolidated Undrained, it can be concluded that there is no significant difference between the two tests, as the water content of the peat soil is high. Based on this research, the study successfully fills a significant gap in the existing literature. This achievement is attributed to the fact that the data collected for this study represents the first-ever dataset obtained from conducting these specific tests. This research marks the inaugural attempt by a researcher at the Klias Peat Swamp Field Centre in Beaufort, Sabah, to undertake such investigations that will contribute more to industry.

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